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Performance Evaluation and Application of Active Response Control Systems for Building Structures

（建築構造物における能動型制震（振）システムの性能評価とその応用に関する研究）

December 2000

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Preface

This treatise is composed of the systematic procedures for evaluating efficiencies of dynamic structural response control systems which are supported by the effectual applicability of active control techniques.

A lot of building structures have been constructed as the artificially designed products to satisfy human living demands. To promote those constructions of buildings, the traditional structural design procedures have been organized under the supports by the analyses of material-based structural elements. When the dynamic responses of those structural systems are evaluated as the expressions for the individualized behaviors into targeted constructions and additional controllers, a new turn on the structural designs may be taken into the structural control procedures to be organized on the active syntheses by utilizing replaceability of additional controllers. At the same time, those structural control techniques have produced the further progress as the intelligent technologies on the structural engineering field, namely, the future directions of syntheses for building constructions will not be only remained to the installations of passive type controllers but also approached to the applications of active type controllers.

Those controllers of active types may be always supposed as the assembled systems of three parts by observing, regulating and manipulating elements, and the artificial properties are generated on the structural systems under the independent energy systems by supports of computational applications. Namely, by introducing the controllers of active type, the concepts of structural response controls may be taken on a new meaning as that the dynamic behaviors of structural systems are regulated under the subjections by the additional controllers. At the same time, the response control syntheses as those regulations of structural behaviors may be systematically generalized under the traditional control theories. In a general sense, those traditional control theories are always concerned with the common meanings of the control manipulations which are expressed as the relations between inputs and outputs on any kinds of additional controllers. Namely, if only the transferring relations between inputs and outputs can be expressed to the same controlled rules, as a tacit understanding, the inherent behaviors of passive type controllers are regarded as to be theoretically equivalent to the consequent behaviors under the operations by active type controllers. Accordingly, the general sense of the control manipulations on the active control systems may be assessed as the generalized structural response control syntheses under the traditional control theories.

On the other hand, the dynamic structural response analyses have also participated to the significant part of structural designs under supports of the computational technologies, especially, installations of the digital-computations have enabled the systematic numerical analyses for the dynamic behaviors of various kinds of structural systems. At this point, developments of the digital-computing technologies can be also regarded as one of the most typical applications of active control techniques. Namely, the digital-computed processors are constructed in themselves as the intensive devices based on the active control technologies, and moreover, the digital-computing operations have prepared the complete functions which can emulate any kinds of active control manipulations on the digital-computed virtual world. When the digital-computed control emulators are interpreted under the traditional control theories, any kinds of control systems can be synthesized from the numerical approaches. And also, if only those numerical sub-systems can be analogized into the actual structural elements and the actual mechanical devices, those response control systems can be also evaluated from the experimental approaches. Accordingly, the general sense of control emulations for the active control systems may be assessed as the generalized structural response control analyses under the digital-computations.

Active control techniques may be functioned as the generalized control manipulators under the traditional control theories and as the generalized control emulators under the digital-computations. Under those substantial meanings of the active control, the generalized functions of active control techniques may be reached to the systematic applications for the evaluative researches on the practical designs of structural response control systems. At the same time, the generalized structural control design procedures can be effectually sheared to two kinds of the evaluative stages that the purposed properties are adequately composed by what kinds of controlled rules from the theoretical view point, and that those controlled rules are practically allocated by what kinds of control devices as passive or active controllers, or as hybrid type of those controllers from the mechanical view points.

To support those systematic structural response control syntheses, it may be significantly appeared that the generalized efficiencies by every control manipulations which is interpreted for various kinds of controlled rules should be prepared as the evaluative interfaces to be linked to the practical designs of structural control systems. Those evaluative interfaces may be provided practical meanings by relating to the benchmark evaluations, and also, the generalized functions of active control techniques may be participated to enable those benchmark evaluations for various kinds of structural response control systems. The concrete shapes of those evaluative interfaces are discussed through developments and installations of a standard evaluative testing apparatus for active structural response control systems. This standard testing apparatus is designed as to be provided accessibilities for both of numerical and experimental approaches, accordingly, the reliability of those evaluative interfaces can be confirmed by operating the mutual benchmark evaluations.

And also, as the further possibilities of those evaluative interfaces, various creations of response control systems as the 'knowledge-based' or the 'intuitive' approaches will be enabled and pioneered by the compensative accessibilities as the mutual benchmark evaluations.

The author wishes to close with his expectations that the present works can convey some of interesting aspects for the active response control technologies in the structural engineering field.

December 2000 Yoichi Mukai

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Yoichi Mukai

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1 Introduction

To ensure safety of building structures which are subjected to highly unpredictable earthquake ground motions, it is very important to realize non-stationary and non-resonant states of structural behaviors under those excitations. This is the starting point of the concept for the aseismic design of building constructions. Recently, progress on aseismic syntheses of building structures has been stood on the new stages which are supported by installations of 'response control' techniques. From the view points based on the structural controls, the aseismic design procedures have been operated under the systematic considerations, namely, the structural systems are explicitly evaluated as the two kinds of sub-systems which are classified into targeted constructions and additional controllers. Accordingly, on the process as that the aseismic designs for building constructions are newly organized under the introductions of response control techniques, progress of the structural designs are taken from the analyses and the tunings for latent structural properties based on the materials, into the syntheses and the controllings for apparent structural behaviors affected by the controllers. At the same time, the purposes of installations of those response controllers are widely and systematically discussed, namely, the structural control techniques have been introduced for various requests which are supposed as structural safeties and comfortableness and for various excitations which are supposed as earthquakes and strong winds.

On the procedures of structural control syntheses, the behaviors of those two kinds of the sub-systems which compose of the whole of structural systems are characterized as the transferring functions for the outputs to be resulted from the inputs by every sub-system. While inputs and outputs for the targeted constructions are corresponded to the excitations and the responses, respectively, inputs and outputs for the additional controllers are corresponded to the purposes and the manipulations, respectively. To connect those sub-systems, the outputs of targeted constructions are related to the differences from the input of additional controllers, and the outputs of additional controllers are superposed as the control action on the inputs of targeted constructions. Accordingly, the controlled behaviors on the whole of structural systems may be characterized by the mutual connections between those sub-systems as the targeted constructions and the additional controllers. At this point, the organic and the inorganic connections of those sub-systems can be considered, and those two kinds of connections may characterize an 'active' type and a 'passive' type of response control systems, respectively. Under the natural law, any structural systems may be provided two kinds of properties which are supposed as the pre-programed feed-forward function for any uncontrollable external inputs and which are supposed as the self-converged feedback function to their equilibrium states for the conservative energy systems. Accordingly, under the considerations for the inflow and the absorptions of physical energies, while the structural systems which are installed the controllers of passive type are classified as to be opened only for the external disturbances and the mechanical dampings, the actively controlled structural systems are subjected by the further inflows as the manipulated inputs under the independent energy systems. By the other word, while the sub-systems as the passive type controllers are affected as the structural elements to provide the behaviors which are subjected by the inherent properties under the law of natural world, the subsystems as the active type controllers are always composed by the three parts as observing, regulating and manipulating elements to generate the behaviors which are subjected by the artificial properties under the another energy systems. The actively controlled systems are constructed for connecting the additional controllers to the targeted constructions under the mediations by signals, accordingly, the additional controllers can produce the artificial structural properties as to be independent from the restrictions under the law of natural world.

The progress of motorizations or communications as applications of the energy engineering are not considered without the supports by active response control techniques, because, those artificial products are functioned as the artificial organic systems which are assigned the different properties from the natural governments. On the structural engineering field, control techniques for structural responses caused by earthquakes or strong winds have been also taken large interests, and developments of the required technologies to realize response controlled structures have been progressed steadily. However, when the response control syntheses for building constructions are considered, the passive response control techniques may be placed as the main currents, because, any purposes for the response controls of building constructions are pointed on the absorptions of vibration energy as to be converged to the inorganic static states under the natural law. Accordingly, while a lot of actual building structures which are installed passive control systems have been constructed in Japan in the most recent decades, the practical constructions of the active controlled building structures may be considered as to be late in getting the general installations.

By the way, those response controlled structures have created valuable opportunities to make the practical observations of earthquake-induced or wind-induced responses and to verify the effectiveness of response control techniques as the actual experiences. At the same time, the restrictions of the passive control systems have been also assured. When the realizations of structural constructions which will not suffer any large damage and can maintain their functions under the large earthquakes or the strong winds are considered as the final purposes of response control systems, it may be regarded that the more advanced progress of response control techniques for building constructions will be required. Since those requests for building constructions may be entered to the independent fields from the natural law, the possibilities on the active control systems will be also introduced to be approaching for those advanced purposes of structural constructions. The following discussions of this paper are started from the researches to evaluate for those possibilities of active control systems on the structural response control for building constructions.

1. 1 Contexts

In this paper, emphases are put on evaluating the effectual possibilities which are progressed by utilizing the active response control techniques for building constructions and put on investigating the systematic approaches to combine those possibilities into the practical syntheses of dynamically response-controlled structural systems. Those possibilities are pioneered under the applicable functions of active structural response control systems from two kinds of view points. The one of those functions is related to the efficiencies of active response controllers as an organic manipulator, and the installations of active response control techniques to building constructions may be able to actualize more intelligent regulations of structural vibrations as the release from the material-based restrictions on the passive response controllers. The another one of those functions is related to the characteristics of active response controllers as an automatic simulator, and the utilizations of active response control techniques to the dynamic response analyses may be able to produce the systematic evaluations of various kinds of structural response control systems as the applications of digital-computing procedures.

Those applicable functions of active structural response control techniques may be taken shapes in the following chapters under the developments of a standard evaluative testing apparatus for various kinds of structural response control systems. This standard testing system is introduced as 'evaluative interfaces' which are proposed as to benchmark the essential efficiencies which are characterized by every control operations for various kinds of response controllers, and those benchmarked effectiveness by every response control operations may be assessed as to be provided 'proportional replaceabilities'. Namely, the practical structural control syntheses may be systematically operated by estimating those replaceable effectiveness for various kinds of response controllers as the indicate to select the adequate controllers. At the same time, the significance to confirm the reliability of those evaluative interfaces are also considered. For this aim, this standard testing system is also designed as to operate the 'mutual benchmark evaluations' which are accessible from both of numerical and experimental approaches.

Accordingly, introductions to develop the standard testing system as the evaluative interfaces have been started from preparing the equivalent models for both of numerical simulations and experimental tests as the emulators of dynamic response control systems. Namely, the standard testing system is composed of numeric-based benchmark simulator and experiment-based benchmark emulator. Both parts of the standard testing system may be actualized under the supports by applications of active control techniques based on the digital-computations. When the numerical simulators for active response control systems are composed on the digital-computers, any control operations via the additional controllers can be interpreted to the manipulated input as control forces, so that, installations of any kinds of additional controllers can be supposed on this kind of numerical simulators if only the responsibilities of those additional controllers can be expressed as the equivalent control forces. And also, when this kind of numerical simulators which are interpreted on the digital-computers is analogized with the actual structural elements or the actual control devices, the experimental emulators for active response control systems can be constructed as the equivalent systems with those numerical simulators, so that, this kind of experimental emulators can imitate installations of any kinds of additional controllers if only any kinds of control forces can be adequately generated via the digital-computing manipulators.

Moreover, when the numerical simulators and experimental emulators which are supposed as the evaluative interfaces for structural response control systems can be confirmed as to be the equivalent systems, abilities to operate the mutual benchmark evaluations on this standard testing system may be also applied under the another meaning as the compensative participations for either numerical or experimental approaches, in addition to the meaning as confirming the reliability of evaluative interfaces. Any practical problems which are latent as the mechanical properties on the actual control systems may be appeared from the experimental approaches, the numerical models should be always introduced as the meaningful systems by considering and revising those actual items. For instance, the experiment-based benchmark emulators may enable the another approaches to start the evaluations for the structural response control systems on the cases that the numerical simulators are difficult to prepare as the theoretical models, and the numeric-based benchmark simulators may become accessible for composing of the equivalent numerical models from those experiment-based evaluations. And also, the numeric-based benchmark simulators by using those equivalent numerical models may enable any parametric evaluations, and the responsibilities on the experimental emulators can be sheared to charges of numerical procedures. Accordingly, this kind of compensative evaluating approaches may also enable the wide meanings of mutual benchmark evaluations for the various conditions as that the structural response control systems are exposed, if only the replaceabilities as the equivalent systems are confirmed between the numerical simulators and experimental emulators.

Those introductions of mutual benchmark evaluations which are proposed in this paper may be significantly supported by that the function of active response control techniques as the automatic simulator can be effectually applied under the supports of digital-computations. At the same time, since any kind of control manipulations can be evaluated under the operations of mutual benchmark evaluations based on the digital-computations by interpreting the functioned rules of additional controllers, it will be also considered that the another function of active response control techniques as the organic manipulator can be easily utilized for the creations of 'knowledge-based' or 'intuitive' response control systems. So that, preparations of evaluative interfaces as the mutual benchmark evaluations for active response control techniques may be regarded as to be also brought the possibilities as that the structural control techniques for building constructions will take a step forward as more intelligent technologies by the applications of active control techniques.

1. 2 Compositions of researches

This study is organized in six chapters. First of all, scopes and outlines on this paper are briefly introduced in the Chapter 1 which are concerned with the insight of dynamic response control systems for building constructions and concerned with the fundamental aspects by relating to the applicability of active control techniques.

In the Chapter 2, technical trends of dynamic response control systems for building structures are introduced as backgrounds for installations of active structural response control techniques. Various kinds of developments of control devices and control theories as those technical progress on the structural control fields are introduced and the fundamental efficiencies of those technological products are classified as both of mechanical categories and theoretical categories. And also, the advanced possibilities which are actualized by applicable installations of active structural response control techniques are considered from the practical view points. In the Chapter 3, concepts of evaluative interfaces for active structural response control systems are introduced and mutual benchmark evaluations as to be provided both of numerical and experimental procedures are proposed as the concrete shapes of those evaluative interfaces. As the first step for developments of a standard testing system to operate mutual benchmark evaluations, the experiment-based reproducibilities as the basic efficiencies of this testing system are investigated to consider the fundamental functions of active response control techniques as automatic simulators. And also, efficiencies of active brace systems as the standard evaluative components are examined under the preliminarily experimental operations on the shaking table and at the wind tunnel.

In the Chapter 4, aseismic active response control systems are considered as the one of applicable evaluations based on the mutual benchmark procedures. Those evaluative researches are executed to assure the possibilities for newly constructing control methods by applying the function of active response control techniques as organic manipulators. For this aim, a quasi-optimizing control method is proposed and evaluated through the mutual benchmark evaluations. The effectual applications of this new control method are investigated from various kinds of trials on the numeric-based simulators and polished as the knowledge-based organic active controller under the mutual benchmark procedures. In the Chapter 5, wind-resistant active control systems are adopted as to consider the another applicable function of active response control techniques as organic manipulators which are participated for newly developed control devices. Active fins are introduced as a new type of wind-resistant active response control devices, and active control systems by installing active fins are investigated through the mutual benchmark evaluations. The effective installations of this new type of control devices are evaluated from various kinds of trials on the experiment-based emulators and actualized as the intuitive organic active controller under the mutual benchmark procedures.

As the summaries of this study, concluding remarks and future aspects which have been and will be pioneered by the active response control techniques are pointed in the Chapter 6.

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2 Background of Active Response Control Systems

'Structural design' may be assessed on the point of view according to the physical relations or characteristics from the input to the output on the structural systems, whether targeted phenomena are in static conditions or in dynamic conditions. Concepts of 'response control' are concerned with all of building constructions in the common sense of structural designs. Namely, building constructions have been taken care for protecting the residential safeties and comfortableness from various kinds of external disturbances, and the structural designs for those building constructions should be always coordinated from the meanings as that the adequate structural responses can be actualized under the targeted external inputs.

Accordingly, it may be considered that the starting point of structural designs (which are assembled as 'human operations') are always taken a step as that "the response control are aimed to latent purpose under the memories or the expertisms (which are supported by the past experiences)". At the standpoint on the human engineering, the structural design may be interpreted as the meanings which are connected with 'control' in the global sense (in which, the word of 'control' is widely expanded to the human operations), however, it should be taken care for that this kind of interpretation for the control may not be directly assigned for the 'structural control'. Namely, while the global meanings of structural designs are explained as the controlled programmings on the human operations to promote the off-line 'procedures' of those structural designs, for any on-line 'behaviors' of artificial products which are designed by those procedures and which are practically constructed, the controlled structural systems (which are explicitly defined in the physical meanings) may not be always identified by the independence from the human actions.

At this point, to suppose those physical meanings of structural control, it may be significant to introduce the fundamental definitions of two words as 'control' and 'design'. General sense of the word of 'control' is explained as that 1) under a certain 'purpose' which are requested on the functions or efficiencies for a certain objective, 2) a certain 'manipulations' which can satisfy this specified purpose are operated 3) on any 'states' of this specified objectives. Similarly, general sense of the word of 'design' is explained as that 1) under a certain 'purpose' which are requested on the functions or efficiencies for a certain objective, 2) a certain 'materializations' can satisfy this specified purpose are constructed 3) as the actual 'substance' of this specified objective. By considering for the essential meanings of those words as 'control' and 'design', the item of the 'structural control design' may be explicitly explained from the following interpretation. Namely, the structural control may always request the explicit definitions as that the manipulations for the response control by on-line are automatically operated by the sub-systems which are included on the insides of the individualized systems of the artificial products, and accordingly, the structural control design are interpreted as the designs for those structural controlled systems by off-line. From the standpoint on the control engineering and the structural engineering, the structural control in the general sense are introduced by that the categories of the 'control' are restricted to the 'automatizations', and the human operations may be only concerned with the analyses and the syntheses of those structural control systems.

Under those considerations for the general meanings of the structural control, it may be emphasized that the traditional structural designs may be taken the advanced progress to the new field. Those progress may be introduced on the approaches as the structural control designs which are coordinated under the explicit definitions as that any structural systems are always assembled by the targeted constructions and the additional controllers. And also, those fundamental concepts of the structural control designs have been steadily produced the technological innovations on the structural engineering field. Namely, the traditional structural designs which are operated as the aseismic and the wind-resistant evaluations under the material-based restrictions in the past have been taken a advanced step to the structural response control designs for the building constructions under the supports by the developmental researches of the additional controllers which can produce any kinds of the mechanical and the theoretical applications as the structural response control technologies.

In the following two sections, the backgrounds and the technical trends as that those advanced progress on the structural designs have been established as the structural control designs on the structural engineering fields are introduced. Especially, by considering for those review of the structural control technologies, the significant meanings of the active structural response control techniques are suggested to assign the future directions of the structural control for the building constructions. At the same time, through the classifications of various kinds of the structural response control systems, the essential meanings of the structural response control are also discussed. And also, the fundamental efficiencies which characterize the active structural response control systems are investigated, and those possibilities to pioneer the more advanced structural response control designs are proposed.

2.1 Technical trends and classifications of response control systems for building structures

Substantial beginnings of the researches and activities on the structural response control for the building constructions may be traced to back in the 1960's. Those initiative arguments for the concepts of the structural response control systems have been introduced in Japan and in the United States for the almost same time. For instance, the fundamental concepts and theories for the 'earthquake control mechanism' may be suggested on the publications in 1960 by Kobori and Minai, the basic introductions and the experimental investigations for the 'earthquake isolation method' on the building constructions may be found out on the publications in 1964 by Kazuta, Mashizu and Uno, and the fundamental concepts for protecting the structural safeties under the 'structural control' techniques which are assembled by the control engineerings and the structural engineerings are also discussed on the publication in 1972 by Yao. Since those initiative discussions for the structural response control have been also walked along to the effectual progress which are produced on the computational technologies as to be introduced the digital-computing devices in the 1960's and are produced on the control engineerings as to be also organized the modern control theories in the 1960's, the remarkable activities as the developmental researches of the structural response control technologies have been continued and achieved as to be taken advantage of the opportunity.

The actual buildings which are installed the base-isolation systems have been constructed since the 1980's, and the practical constructions of the other kinds of the passively controlled building structures which are installed the inter-story damping devices or the dynamic tuned mass dampers have been also started. In 1989, the actual building constructions which are installed the active control system at the first time in the world have been constructed in Japan, and the advanced term points on the structural response control technologies have been reached in the 1990's. Namely, in this decade form 1989 to 1998, as shown in Table 2.1.1 (in this table, the abbreviations as AMD, HMD, AVS and AVD are mean the Active mass damper, the hybrid mass damper, the active variable stiffness and the active variable damping systems, respectively), 32 of the practical building constructions which are installed the active type of the response controllers have been constructed in Japan.

The academic movements in the structural engineering fields have been also actively produced as to be parallel with those technical progress of the structural response control technologies. As the first remarkable assemblies for the advanced technical researches for the structural response control systems on the 1970's and the 1980's, the special theme session which are specified as the 'seismic response control of structural systems' was proposed at the 9th World Conference on Earthquake Engineering (9WCEE) which are held at Kyoto and Tokyo in Japan, in 1988, and the active vibration control systems for the building constructions and the other civil engineering structures have attracted worldwide growing interests as the innovative technologies in the aseismic engineerings and also the wind-resistant engineerings. With this international research interchanges on the special theme session in the 9WCEE as the turning point, the arrangements for launching the organizations for the international collaborative researches have been started under the leaderships

Table 2.1.1 Practical active controlled building constructions in Japan.

Name of building	**Site**	**System**	**Year**
Kyobashi Seiwa Building	Tokyo	AMD	1989
Kajima Research Institute No.21 Building	Tokyo	AVS	1990
Sendagaya INTES	Tokyo	AMD	1991
Applause Tower	Osaka	HMD	1992
Kansai Airport Control Tower	Osaka	HMD	1992
Osaka ORC 200 Symbol Tower	Osaka	HMD	1992
Ando Nishikicho Building	Tokyo	HMD	1993
Yokohama MM21 Landmark Tower	Kanagawa	HMD	1993
Japan Long Term Credit Bank	Tokyo	HMD	1993
Porte Kanazawa	Ishikawa	HMD	1993
Shinjuku Park Tower	Tokyo	HMD	1994
Hikarigaoka J-City Tower Building	Tokyo	HMD	1994
Hiroshima Rihga Royal Hotel	Hiroshima	HMD	1994
Hamamatsu ACT City Building	Shizuoka	HMD	1994
MHI Yokohama Building	Kanagawa	HMD	1994
Riverside Sumida Building	Tokyo	AMD	1994
Osaka World Trade Center Building	Osaka	HMD	1994
Hotel Ocean 45 Building	Miyazaki	HMD	1994
Dowa Kasai Phoenix Tower	Osaka	HMD	1995
Hirobe Miyake Building	Tokyo	HMD	1995
Plaza Ichihara Building	Chiba	HMD	1995
Rinku Gate Tower North Building	Osaka	HMD	1996
HERBIS Osaka Building	Osaka	HMD	1997
Nisseki Yokohama Building	Kanagawa	HMD	1997
Itoyama Tower	Tokyo	HMD	1997
Nippon OTIS Elevator Test Tower	Chiba	HMD	1998
Odakyu Southern Tower Building	Tokyo	AMD	1998
Bunka Fashion College	Tokyo	HMD	1998
Daiichi Hotel Oita Oasis Plaza 21 Tower	Oita	HMD	1998
Kajima Shizuoka Building	Shizuoka	AVD	1998
Yamaguchi International General Center	Yamaguchi	HMD	1998
Shinagawa Intercity Building	Tokyo	HMD	1998

of the researchers in Japan and the United States. Those movements have been taken to the steady activities as the establishments of the Japan Panel on Structural response control which is organized as that Dr. T. Kobori, emeritus professor of Kyoto University is the Japanese representative and to establishments of the U. S. Panel on Structural Control research which is organized as that Dr. G. W. Housner, professor of California Institute of Technologies is the American representative, and the national symposiums and workshops which are coordinated to discuss for the active structural response control have been held in each country. Under the cooperative efforts of the Japan Panel, the U. S. Panel, the first international workshop to discuss for the future subjects on the structural response control was held at Hawaii in the United States in 1993. In 1994, the International Association for Structural Control (IASC) was established and the First World Conference on Structural Control (1WCSC) was hosted at Pasadena in the United States as the first official act of this newly formed IASC. The Second International Workshop on the Structural Control was also held in Hong Kong in 1996 under the hosts of the IASC, and the Second World Conference on Structural Control (2WCSC) which was promoted by IASC was held at Kyoto in Japan in 1998. The remarkable international communications and the technical interchanges have been achieved in this world conference and this successful meeting may be also produced under the cosponsoring associations as the Science Council of Japan (SCJ), the Architectural Institute of Japan (AIJ), the Japan Society of Civil Engineers (JSCE) and the Japan Society of Mechanical Engineers (JSME). As the most recent activity, in 2000, the Third International Workshop on the Structural Control was held at Paris in France, and the future promotions for the Third World Conference on Structural Control (3WCSC) under the host of the IASC has been steadily programed to hold at Como in Italy.

Those technical trends of the structural response control may be also evaluated as to be significantly related to the historical approaches on the aseismic and the wind-resistant structural design methods from the view points which are characterized as the mechanical classifications on the various kinds of the additional controllers. And, by reviewing and investigating those historical progress of the developmental researches for the additional controllers, it may be explicitly assigned what launch on the future directions of the structural control for the building constructions should be allocated. When the starting points of the substantial structural designs which are concerned with the dynamic response control are considered as the evaluative syntheses of the aseismic properties on the building constructions, the technical approaches of the structural syntheses in Japan from those traditional structural designs to the most recent structural control designs may be shown as Fig.2.1.1. Under the observable researches for the seismic damages of the building constructions on the San Francisco Earthquake at 1906 and the Kanto Earthquake at 1923, the fundamental frame works for the traditional structural designs of the building constructions have been suggested since the beginnings of the 20th century. And, in the 1920's, the aseismic structural design methods was introduced as the basic concept to construct the rigid structures which are coordinated under the strong resistant properties for the seismic excitations by evaluated as the static horizontal loads.

The first term point on those traditional aseismic structural designs was appeared on the observable researches for the seismic damages of the building constructions on the Fukui Earthquake at 1948, namely, the collapses of the building constructions which are synthesized under those traditional aseismic structural designs were occurred by this strong earthquake. In the 1950's, the significance of the dynamic verifications for the aseismic structural syntheses has been emphasized and the actual observations of the seismic excitations and the seismic structural behaviors have been also operated under the supports by the developments of the seismometers. In the 1960's, since the dynamic structural response analyses by using the practical strong motion records could be substantially operated under the popularizations of the digital-computers, the various kinds of the researches for the non-stationary structural behaviors have been actively investigated. Those investigations may be produced the substantial evaluations for the elasto-plastic behaviors and properties of the structural systems under the strong seismic excitations.

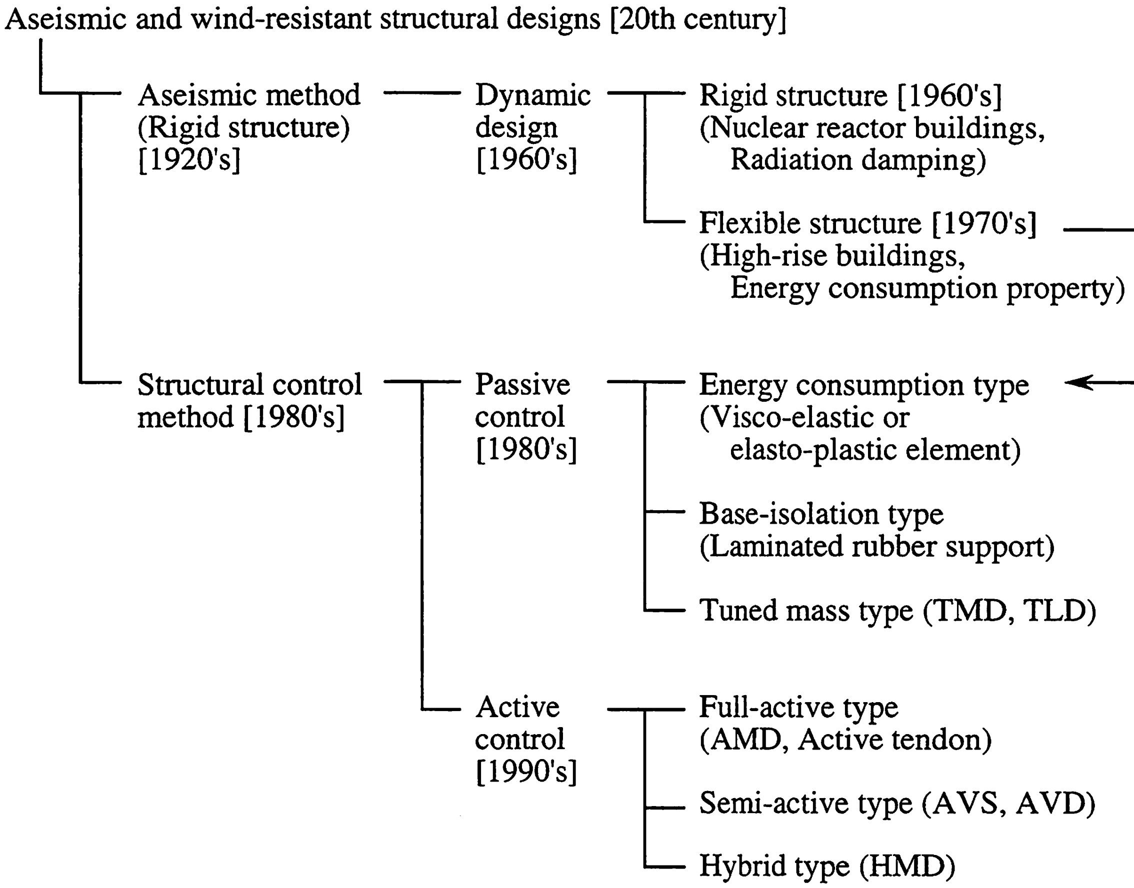

Fig. 2.1.1 Technical flow from aseismic structural design to structural response control design.

The structural designs for high-rise building constructions was also started in 1960's, the new stage of aseismic structural designs have been produced. Namely, although the kinds of approaches of structural designs as the syntheses of rigid structures and as the syntheses of flexible structures have been already discussed since the 1930's, practical applications for each adequateness with those concepts may be reached at the turns to be discussed by different cases according to the severally individualized configurations of targeted structural systems. As seen in Fig.2.1.1, those new outline of the aseismic structural designs have been explicitly polished as two kinds of typical flow as 1) the syntheses for the radiation damping of the structural systems which are evaluated for soil-structure interactions and which are represented on the structural designs for nuclear reactor building constructions, and as 2) the syntheses for the energy consumption properties of the structural systems which are represented on the structural designs for high-rise building constructions.

As introduced at the beginnings in this section, the substantial structural response control designs which are specified as the practical installations of the passive type of the response controllers on the building constructions have been achieved since 1980's, and those technical advances have been produced the second term point on the aseismic structural designs. As the drastic progress, it may be pointed that the fundamental meanings of the structural control design procedures are proposed as that the aseismic structural systems are explicitly designed as the syntheses of the individualized additional controllers for the targeted building constructions. And also, the continuing researches and developments on the structural response control engineerings may be taken a step to the new field on the structural engineerings which are closely connected with the mechanical engineerings and the control engineerings.

The passive type of the additional controllers have been popularized on the practical building constructions by the typical three kinds of the control devices which are classified from those mechanical characteristics. Namely, those passive type of the control devices are specified as 1) the base-isolation devices, 2) the energy consumption devices and 3) the tuned mass devices, and those three kinds of the classifications by the mechanical properties of the additional controllers may be also significantly connected to the several progressions on the three kinds of the flow of the structural designs. The structural control designs by introducing the base-isolation devices have been developed as the advanced approaches form the aseismic structural designs to construct the rigid structures. The base-isolation devices are produced as the mechanical control devices for that the first natural periods of the targeted structural constructions are generated as to be comparatively long. Namely, since the non-resonant properties of the comparative rigid structures with the dominant excited periods which are included on the seismic motions are aimed as the main purpose on the installations of the base-isolation devices, this kinds of the technical flow may be regarded as the complex approaches on the syntheses on rigid structures with the syntheses on flexible structures.

The second flow as the introductions of the passive type of the controllers which are specified by the developments of the energy consumption devices may be pointed as the reasonable progress which are appeared on the procedures as that the syntheses of the flexible structures have been systematically polished as the generalized structural control designs. Namely, the analytical researches for the energy consumption properties of the structural systems may be directly connected to the evaluations for the individualized damping efficiencies which are installed by the additional controllers. For this aim, the various kind of properties of the dampers have been developed and applied as the mechanical devices for the syntheses on the response control of the building constructions. At this point, those energy consumption devices may be roughly introduced as 1) the non-linear hysteretic type and 2) the visco-elastic type. The first type of the control devices are considered as that the remarkable products which are developed from the advanced procedures on the non-linear dynamic structural analyses, and those advances may be pointed on that the ductilities which are evaluated from the elasto-plastic behaviors of the structural systems are explicitly participated on the individualized properties of this type of the additional devices by separating from the material-based syntheses of the targeted constructions. The later type of the control devices may be considered for the intimate connections with the mechanical control systems which have been produced on the mechanical engineering fields, and those installations of the visco-elastic type of dampers may be also regarded as to produce the another remarkable approaches to apply for the design methods of the passive elements on the mechanical control technologies.

Similarly, the last flow of the installations of the control devices as the tuned mass type may be also introduced as the typical applications of the mechanical control devices which are proposed to passively reduce the vibrations on the mechanical systems. However, on the procedures to apply those mechanical systems to the mega-volumed building constructions, a lot of efforts to regain the mechanical capacities for the tuned mass type of the control devices have been also operated. Namely, those applications on the structural engineering fields for the control devices on the mechanical engineering fields have been proposed the new progress as the renewed developments of the control devices as the cooperative products with both fields as to be adequately agreed to the volumes of the building constructions. For instance, the support system of the tuned mass which are configured as the pendulum types and the multi-stage rubber bearings types are proposed and the utilizations as the ice storage-tanks or the fireproofing tanks are also considered as the substitute with the auxiliary mass.

In the 1990's, the third term point of the structural response control technologies have been introduced as the substantial developmental stage of the active structural response control systems for the building constructions under the technical assemblies as that the structural engineerings are intimately connected to the control engineerings and the mechanical engineerings. Those technical progress are produced by the supports of the modern control theories, and those actual installations of the active type of the additional controllers may be significantly related to the advanced approaches for applying the optimal regulators on the dynamic response control syntheses of the building constructions. The structural response control designs have been reached to the systematic syntheses as the regulations on the dynamic structural motions , namely as the designs of the generalized feedback systems by introducing active response control techniques in the theoretical meanings.

The active control systems are defined as the structural systems which are installed the active type of the control elements as the automatic manipulators on the additional controllers, and the active type of the control elements are interpreted as the generalized computational devices which are composed by the observing sub-system, the regulating sub-system and the actuating sub-system, and by the signal transferring connections to assemble those three kind elements. Accordingly, the active type of the control elements can always generate their control manipulations only under the supports by the additional energy system which are independently supposed to the targeted structural system, so that, those additional energy system may be only assessed to produce the sub-systems assembled by signal transferring connections. When those sub-systems are interpreted on the computational devices, the relations of any inputs and the outputs on those computational devices may construct the active control system. And also, when the any energy controls are programed under the automatic manipulations under those computational devices, those flow of the energies may be also composed the active control systems. On the active response control systems for the building constructions, those control manipulations by the active controllers may be generally evaluated as the additional control energies which are expanded to suppose the negative works. When the dynamic behaviors of the structural systems are interpreted to the equations of the motions, those effects on the controllers may be expressed as the additional control forces. Namely, the manipulations of the active control systems may be generalized as the operations of the response controls by supplying the control forces to suppress the structural response induced by disturbances.

On the other hand, from the mechanical view points, the active type of the response controllers can be classified to the three kinds of the control devices as 1) the semi-active type, 2) the hybrid type and 3) the full-active type (in which, although this type is generally called as the 'active type', this name is used in this study on the requested cases as to be distinguished with the semi-active type). Although those classifications are only appeared from the actual considerations for the whole of the mechanical configurations of the additional controllers which are separated from the targeted constructions, it may be also pointed the significant meanings on those classifications to evaluate for the practical sense of the applications of the active control systems. The semi-active type of the controllers may be introduced as the active switching systems of the passive type of the control elements. The mechanical configurations of the semi-active type of the control devices may be represented as the viscus dampers, the friction dampers or the inter-story braces which are attached the active controlled valves, namely, those mechanical properties of the semi-active type of the control devices which are specified as the dampings, the friction factors of the stiffness may become variable by on-line under the control manipulations of those active controlled valves. As the practical applications of the semi-active type of the control devices, the active variable damper system (AVD) and the active variable stiffness system (AVS) are developed and also installed to the actual building constructions as seen in Table 2.1.1.

The full-active type and the hybrid type of the control devices may be interpreted as the sub-systems of the additional controllers which are provided the active control force generators. While the full-active type of the control devices may be represented as that any additional control forces are supplied to the targeted constructions under the completely independent energy systems which are composed by the additional controllers, the hybrid type of the control devices may be introduced as the configurations as that the partial sub-systems which compose the additional controllers are separately installed as the passive type of the control elements, namely, the partial active and the partial passive control components are supposed as the hybrid type of the control system. As the typical materializations of those hybrid type of the control systems for the building constructions, the controllers which are composed as the parallel circuits or the series circuits by the active and the passive control devices, or the controllers as that the control operations by the active and the passive control device are switched under the manipulations of the bypass valves of the actuators by on-line have been proposed. On the installations of the hybrid type control devices, the significant meanings which are directly related to the practical problems to install the full-active system may be pointed. When the active structural response control for the mega-volumed building constructions, it may be often occurred the lack of the capacities of the actuators which are introduced as the active type of the controllers. Since those practical and mechanical restrictions may be more critical on the full-active system than the hybrid system, to overcome those problems, the hybrid type of the control system are considered as that the reductions of the responsibilities by the active controllers are aimed by the partial installations of the passive type of the control elements. Those hybrid control syntheses may be regarded as to be reasonable, since the generalized feedback controllers which are designed on the active control system can be partially replaced to the passive type of the control elements in the stages of the practical installations if only those specified partial sub-systems can be regarded as to be equivalent to the inherited properties of those passive type of the control devices. Accordingly, as seen in Table 2.1.1, while 26 of the actual building structures which are installed the hybrid type of the control devices (in this table, those buildings are specified as that the HMD system are installed) are constructed, it is assured that the full-active control systems are introduced on only 4 of the practical building constructions (in this table, those buildings are specified as that the AMD system are installed). From the other view points on Table 2.1.1, it may be assured that the auxiliary mass type of the control devices (which are represented as the active mass dampers (AMD) or the hybrid mass dampers (HMD)) are popularized on the whole of the building constructions which are practically installed the full-active type or the hybrid type of the control system. As the reason for this, it may be pointed that the most of those practical cases which are installed the active or the hybrid type co control systems were aimed to reduce the earthquake-induced of the wind-induced vibrations which are appeared as to be dominantly subjected to the first natural periods on the high-rise buildings, accordingly, the AMD or the HMD which can be easily attached to the top floors on those buildings may be regarded as one of the most adequate configurations of the additional control devices.

On the other hand, it may be considered that the more advanced aseismic or the wind-resistant response control by installing the active or the hybrid type of the control systems are actualized by the installations of the multi-mode response controllers, for this aim, the equipments of the multi devices on the multi-stories may be suggested as the significant discussions. However, from the view point of the designs on the configurations or the plannings of the building constructions, the installations of the auxiliary mass type of the control devices on the multi-stories may not be considered as the best solutions. From those meanings, various kinds of the mechanical configurations of the other type of the control devices have been also developed and investigated. A lot of researches to introduce those control devices have been already started as the developments of the non-auxiliary mass type of the active or the hybrid control systems, for instance, the active tendon or the active brace system, the active jointing member system, the active base-isolation system, the active air-bag system, the active fin system, and so on have been investigated for the future applications as the practical structural control designs.

At this point, those mechanical configurations of the various type of the control devices may be also evaluated under the classifications by the mechanisms to generate the additional control forces. As this kind of the classifications, 1) the type of the inertia forces and 2) the type of the restoring forces for the rigid or elastic support-structures, 3) the type of the changeable configurations to utilize the aerodynamic effects, and so on may be introduced as the typical examples. The considerations for those mechanisms to generate the additional control forces may be regarded as to be significantly connected to the designs of the configurations of the control devices, and also, according to those configurations and also those mechanical properties which are characterized by every types of the control devices, it will be requested to evaluate those merits or demerits as the preparative investigations for the practical syntheses for the future structural control systems. Namely, according to the various conditions or purposes for the design of the configurations or the plannings, it may be considered that various type of the mechanical configurations of the active or the hybrid types of the control devices will be introduced on the practical building constructions as the future possibilities.

As the further considerations which are related to the technical progress on the structural response controls, it may be pointed that the purposes of the structural control designs for the building constructions have been systematically expanded to the various kinds of the excitations and the various kinds of the residential criterions. Various kinds of the researches which are proposed as the applicable investigations of the active or passive type of the structural response control techniques have been targeted to the various purposed as the dynamic excitations to the structural system which are supposed as 1) the environmental vibrations (for instance, the mechanic vibrations, the traffic noise and so on), 2) the wind forces, and also 3) the seismic ground motions, and as the criterions of the structural response controls which are pointed on 1) the living comfortableness (which are aimed to decrease discomfort or uneasiness for people in the buildings or the civil engineering structures), 2) the maintaining performabilities (which are aimed to reform the functions of the buildings or the civil engineering structures for users), and 3) the structural safeties (which are aimed to keep up the human lives in the buildings or the civil engineering structures).

To satisfy those various demands for the structural responses under various excitations, the procedures of the structural response control designs have been also generalized to the following four mechanical categories as 1) cutting off the input energy from the disturbances (which are called as the insulation type), 2) isolating the natural frequencies of the structural systems from the predominant power components of the disturbances or installing the nonlinear structural characteristics for actualizing the non-stationary states and the non-resonant systems (which are called as the non-resonant type), 3) utilizing the energy absorption mechanisms on the internal structural system (which are called as the internal damping type), and 4) removing the vibration energies to the additional mass system which are provided the independent energy absorption mechanism (which are called as the spillage type). Those mechanical procedures of the reductions of the structural vibration energies may not be always actualized only by the passive type of the control elements, but also may not be produced until the supports by the active type of the control elements are considered. The most importance may be put on the item as that those four kinds of procedures of the structural response control designs are significantly related to the fundamental concepts of the structural response control as the response reductions. Accordingly, it should be emphasized as that any future directions of the structural response control technologies may be started and produced under the satisfactions for those fundamental meanings of the mechanical procedures.

2.2 General meanings of active structural response control systems

Through the discussions in the Section 2.1, the fundamental meanings of the structural response control designs are introduced as the actualizations of the mechanical procedures which are specified for the response control to reduce the structural vibration energies, and also, those concepts may be always placed as the most important item of the structural response control even if the response controllers are designed as the passive type or the active type of the control systems. At the same time, from the theoretical view points, the structural response control designs may be systematically introduced as the syntheses of the generalized feedback controllers by supposing the active structural response control techniques. At first, to consider the possibilities and the general meanings of the active control systems for the structural response control designs, it seems that the fundamental meanings of the feedback systems should be discussed.

Any natural products are participated to each function which is subjected to the fundamental law of the natural world even if they are belonged to the organic or inorganic substances. Those functions are determined as the 'behaviors' which are related to the transferring characteristics from the input to output. From the macroscopic view, either the organic or inorganic substances are composed as the sub-systems to be governed by the purposes of the natural world, it may be considered that those behaviors are synthesized under the fundamental law of the natural world. And also, from the microscopical meanings, every compositional elements of those substances as the materials such as solid or fluid are severally provided their inherent transfer functions as the 'material-based components' to organize those macroscopic sub-systems. At this point, it may be considered that the explicit border between those two kinds of substances which are classified as to be organic or inorganic are appeared on the existences of the another special functions which are constructed as the of the life-support system for the biological energy control. Namely, the physical behaviors of the organic substances may be subjected whether those life-support system are dead or alive, any functions on the organic substances may be changed to the governments as the inorganic substances by the suspensions of the biological energy control.

Under the activity of the life-support system as the special functions which are specified on the organic substances, the biological energies are functioned as the 'signal-based components' to characterize the behaviors of those organic sub-systems, and those behaviors may be always controlled by the life-support system as to be participated to the another purposes by the independence from the natural properties as the receptacles which are constructed by only the material-based components. By the other word, any organic sub-systems are effected for the protections of their lives and the 'sub-worlds' which are closed by every organic substances are actualized as the life activities under the closed-loop systems based on the biological energies controls. Accordingly, the behaviors of the organic substances are also characterized as the existences of the closed-loop controllers for the biological energies and those controllers as the life-support system are evaluated as to be composed the feedback systems.

Human beings have been constructed various kinds of the artificial products to satisfy various kinds of their purposes. Those artificial products are generally composed by the inorganic substances and the behaviors which are actualized by those artificial sub-systems are designed as to be provided the requested functions. At this point, when the human beings may design a certain 'automatizations' on those sub-systems in the artificial products (in which, those automatic operations may be generally actualized by the supports of the computational devices), the 'control systems' which are provided a certain 'resemblance' with the organic substances as the natural products can be recognized. In which, the words of the 'automatizations' may be interpreted as the automatic regulations, and those meanings may be essentially different from the 'automations' as the pre-programed process on the mechanisms as like the music boxes or the windup dolls. Accordingly, those artificial substances which are provided the automatizations may be regarded as the para-organic products which are designed by the human operations and controlled under the automatic operations, and also, a certain 'resemblance' with the natural products can be also recognized as the 'feedback systems' which are appeared on those artificial systems.

From those interpretations, it may be considered that the designs of the control systems are fundamentally operated as the procedures of the automatizations, and that the syntheses of the feedback systems are actualized by supposing the functions of those control systems. Accordingly, the substantial discussions of the structural control designs may not be generalized until directly connecting to the traditional control engineering theories, those generalized approaches may be actualized as the applications of the active control techniques which can generate the organic manipulations. When those generalized approaches of the structural control designs are systematically introduced on the structural engineering fields, various kinds of the control methods have been enabled to be investigated and applied to the syntheses of the control systems under the supports of the control engineering theories.

Those introductions of the control methods to synthesize the structural control systems have been started on the basic installations of the response feedback control theories, and the applications of the theories of the optimal regulators have been investigated for the more effectual structural response control designs under the supports of the modern control theories. And also, the syntheses of the feed-forward controllers and the observers have been introduced to improve the control performances of the structural response control systems for the various kinds of the structural properties and the various kinds of the external disturbances. As the current progress on the control engineering fields, the control syntheses for the 'adaptiveness' of the control systems which are significantly related to the organic properties of the controllers have been introduced, and the technological efforts to apply those advanced control methods on the structural engineering fields have been also operated on a lot of researches. For instance, as the advanced control methods, the model reference adaptive controls, the Fuzzy controls, the control methods based on the neural networks or the genetic algorithms, and so on have been appeared on the developmental procedures to be aimed to the practical installations on the structural engineering field. On those theoretical approaches, it may be emphasized that the active control techniques have been placed to the generalized emulators of those control methods to synthesize the effectual structural response control systems for the building constructions.

At last, the discussion may be reached to the consider for the future directions of the structural response control technologies which are significantly concerned with the applicable possibilities of the active response control techniques. By reviewing the technical trends of the structural control designs, the steady flow from the installations of the passive type of the control systems to the applications of the active type of the control systems may be confirmed. On those procedures of the technical progress, the active control techniques have been just reached to the stage as the compensative participations on the structural response control syntheses which are aimed to effectually improve the control performances on the passive control systems. Since the 'effectiveness' of the systems may be always subjected to the fundamental 'structures' of the systems, explicitly, the possibilities of the control systems may be expanded by introducing the control syntheses which are started from the structures of the active control systems instead of the control syntheses which are restricted to the structures of the passive control system. Accordingly, it may be suggested as the one of the future directions of the structural control designs as that the active control systems should be always placed to the main frames of the structural response control syntheses and the structural control systems may be designed and assembled in the structures of the active control systems whether the practical configurations of the control devices are designed by either the passive type or the active type of the control elements.

2.3 Concluding remarks

Through the considerations in this chapter, the technical trends of the structural response control technologies are introduced as the historical backgrounds, namely, the traditional aseismic structural designs have been approached to the most recent advances which are systematically established as the structural control designs. Those technical progress of the structural response control techniques are considered from the conceptual approaches on the structural control designs, and also, the classifications by the mechanical properties of the various kinds of the control devices are discussed by relating to those historical developmental approaches of the structural control designs. At the same time, the significant meanings of the syntheses of the generalized feedback systems are introduced and the importance to apply the active control techniques are pointed to support for those systematic approaches of the structural response control systems.

As the summary of the discussions in this chapter, it is pointed that the fundamental concepts of the structural response control designs may be placed as the following items.

(1) The developments of the various kinds of the mechanical control devices are intimately related to the technical trends which are supported by the progress of the structural control designs. Namely, by evaluating those mechanical properties by every control devices, the fundamental concepts and demands for the structural control designs have been explicitly classified and assembled.

(2) The fundamental mechanism on the structural controls for the building constructions are introduced as the actualizations of the mechanical procedures which are specified for the dynamic response control to reduce the structural vibration energies, and those procedures may be essentially introduced and interpreted as the syntheses of the generalized feedback systems.

(3) The effectual structural control designs may be established under the supports by the control engineering theories, and accordingly, the applicable possibilities of the active control techniques may be introduced in the meanings as the generalized emulators of those control theories.

Under those technical analyzations of the structural control designs, the general meanings of the active control systems are discussed, and the fundamental functions of the active control techniques are specified on the utilizations as the generalized emulators and as the organic manipulators. The further discussions in the following chapters, those applicable functions of the active control techniques will be investigated as the concrete shapes of the researches, and the more practical problems on the active control systems will be examined.

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3 Installation of Standard Evaluation for Active Response Control Systems

To actualize the dynamic response control systems for the building constructions, various kinds of the control devices as the mechanical elements of the additional controllers have been developed for providing the requested artificial properties and various kinds of the control methods as the theoretical installations of those controllers have been investigated for synthesizing the effective behaviors of the response controlled systems. The effectiveness of the response control operations as the general meanings may be evaluated from the differences of the structural behaviors of the targeted constructions which are supposed by whether the additional controllers are installed or not, namely, the comparative evaluations for those two kinds of the behaviors which are classified as the controlled responses and the non-controlled responses may characterize the essential efficiencies by every control operations. On the other side, since the purposes of the structural designs are pointed on the absolute restrictions as that the allowable boundaries for the structural behaviors as the fixed quantities are protected for the various kinds of the excitations, the syntheses of the response controlled systems on the structural designs may be considered as the practical tunings of those artificial efficiencies based on the installations of the additional controllers.

To support those technical progress of the dynamic response control systems, it may be significant to prepare the 'evaluative interfaces' which can link to the essential efficiencies by every control devices and link to the practical tunings of the artificial efficiencies as the structural designs, even if those additional controllers are supposed as the active type or the passive type of mechanical components. For this aim, those evaluative interfaces should be taken care to be introduced as that the benchmarked effectiveness by every response control operations are expressed under the generalized indicates and as that the responsibilities of those effectiveness are specified for the generalized behaviors on the targeted constructions. Namely, under the supports with those evaluative interfaces, the essential efficiencies by every control devices may be assessed as the replaceable effectiveness which are benchmarked under those generalized indicates. When a certain response control systems which are composed by the specified constructions and the typical type of the damping elements under the fixed quantities are supposed, and when a certain dynamic behaviors are practically designed as the original properties of the targeted constructions, the structural control syntheses to be satisfied for the allowable boundaries on the structural behaviors as the fixed quantities can be systematically operated as the tunings of the artificial structural properties by the replacements of the various kinds of the additional controllers. At this point, the most important item should be pointed on the reliabilities of those evaluative interfaces, and those reliabilities may not be substantiated until those replaceable effectiveness by every control devices can be confirmed under the 'mutual benchmark evaluations' through both of the numerical and the experimental procedures. Accordingly, the conditions of the evaluative interfaces should be also introduced as to be provided the accessibilities from both of the numerical and the experimental approaches.

At first, to consider for the condition of the evaluative interfaces as the numeric-based benchmark simulators, it may be found out the significant meanings which are assigned by the techniques of the dynamic response control analyses based on the digital-computations. Those procedures on the dynamic response control analyses are always subjected to the equations of motions of the whole of the structural systems, and those governmental equations are generally expressed as the balance between the responsible forces by the internal structural elements and the invaded forces by the external actions. Under the mechanical meanings, it may be considered that the passive type of controllers are directly functioned as a part of the internal structural elements, while the active type of controllers are always related to a part of the external actions. However, since the dynamic response control analyses based on the digital-computations are always concerned only with the relations between input and output, the responsible forces by the passive type of controllers can be also regarded as the equivalent invaded forces by the active type of controllers under the physical assumptions by that the active type of controllers can replace the behaviors of the passive type of controllers as the control forces. Accordingly, the active response controlled systems on the digital-computing procedures may be regarded as to be assembled by the sub-systems of the responsible forces which are allocated to the behaviors of the targeted constructions and the sub-systems of the invaded forces which are allocated to the behaviors of any kinds of the additional controllers and as the other external inputs. So that, the evaluative interfaces for any kinds of the response control operations which are accessed from the numerical approaches may be enabled under the applications of the active control techniques based on the digital-computations.

Secondly, to consider for the condition of the evaluative interfaces as the experiment-based benchmark emulators for any kinds of the response control operations which are evaluated by the numerical simulations, it may be requested that any sub-systems to be interpreted into the numerical models on the digital-computers are analogized as the actual structural elements or the actual control devices. Namely, it may be considered as to be significant that the targeted constructions are actually prepared as the experimental structural models which can adequately emulate the equivalent behaviors with the numerical structural models and that the additional controllers are actually produced as the mechanical control devices which can adequately generate any kinds of the control forces via the digital-computing manipulators. Accordingly, when the experimental testing systems which are composed by the mechanical elements are prepared as to be satisfied those conditions, the accessibilities of the evaluative interfaces for any kinds of the response control operations may be enabled from the experimental approaches. This function of the evaluative interfaces as the experiment-based benchmark emulators may be also considered to be supported by the applications of the active control techniques based on the digital-computations.

In this chapter, the preparative studies are operated to introduce the mutual benchmark evaluations for the various kinds of the structural response control systems. Through the developments of the standard testing apparatus as the evaluative interfaces for the syntheses of the structural response control systems, the concrete shapes of those evaluative interfaces which are provided both functions of the numerical simulators and the experimental emulators are considered in detail.

3. 1 Developments of compact testing apparatus for active response control systems

In this section, the standard testing systems as the concrete shape of the evaluative interfaces for the structural response control systems are proposed and the basic components to construct those standard testing systems are introduced and investigated as the preparations for the mutual benchmark evaluations in the following discussions. The fundamental conditions to develop the standard testing apparatus as the evaluative interfaces for the structural response control systems are pointed on the three items as follows :

Item-1) Various kinds of structural response controllers can be systematically evaluated through both of the numerical and the experimental procedures.

Item-2) The controlled efficiencies by every control operations can be explicitly observed by the evaluative tests and those control effects can be exactly confirmed as the individualized responsibilities by every additional controllers.

Item-3) The whole size of the experimental apparatus should be considered by the suitabilities for the environmental conditions which are restricted from the experimental facilities.

At first, to consider for the Item-1, the evaluating targeted models for the numerical simulations are supposed as the idealized lumped-mass type of the structural models, and accordingly, the experimental models are also designed as to be adequately emulated those numerical models. To evaluate the various kinds of structural response controllers, any control manipulations on the numerical procedures are allocated as the additional forces under the interpreted controlled rules. The part of the experimental control devices to emulate the various kinds of control operations are composed by the sensors, the digital-computers and the mechanical actuators. So that, those kinds of the experimental emulators which are charged to the part of the additional controllers are designed as the control force generators which can exactly manipulate the interpreted controlled rules on the digital-computers.

By considering for the Item-2, both of the observable responses of the evaluating targeted models and the observable manipulations of the additional controllers on the experimental apparatus are taken care for reproducing as the enlarged behaviors which can be directly evaluated the control effects from the scale of the human eyesight. Accordingly, the stiffness of the experimental structural models are designed to be as narrow as possible under the conditions as that the elastic deformations are allocated on the comparative large ranges. Moreover, to be definitely evaluated for the responsibilities of the additional control manipulations which are observed on the controlled responses of the structural models, the experimental structural models are also taken care for reducing the material-based dampings on the targeted models as far as possible.

As the considerations for the Item-3, to imitate the environmental conditions which are surrounding the targeted structural systems, the experimental facilities as like the shaking tables or the wind tunnels are required for those experimental tests. So that, the scales or the capacities of those experimental facilities which can be prepared in the practical or the economical sense should be significantly estimated to determine the allowable size of the targeted experimental structural models, as a matter of course. At the same time, to operate the control manipulations which are emulated on the targeted structural systems, the experimental equipments as like the sensors of the actuators have to be attached to the structural model. Accordingly, those experimental equipments should be also installed as to be provided the adequate scales or capacities for the size of the experimental structural models.

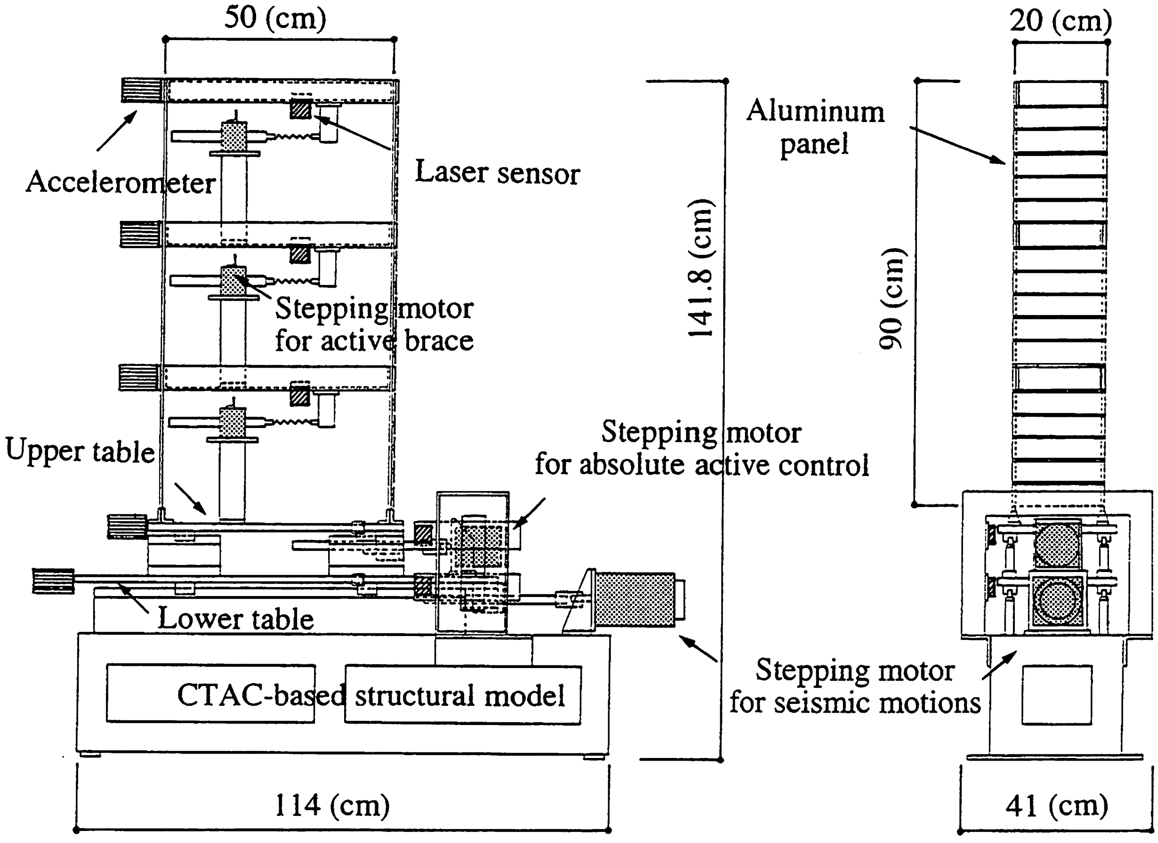
Under those preparative considerations, it may be appeared as the appropriate sequences to introduce the concrete shapes of the standard evaluative testing systems that the actual configurations of the experimental structural models are substantially determined under the practical environmental conditions as mentioned on the Item-3, if only the whole functions as the evaluative interfaces be designed as to be adequately satisfied for the Item-1 and the Item-2. On details for proposing the basic configurations of the experimental structural model, the reasonable environmental backgrounds which are significantly appended to the Item-3 have been existed as the practical situations on the authors' laboratory, namely, the actual configurations of the standard evaluative testing systems which are adopted on the author's laboratory may be proposed under the following three environmental conditions :

Situation-1) The authors have get the fortunate circumstances as to be able to handy use the wind tunnel which have been prepared as the existing facilities at the Faculty of Engineering in Osaka University.

Situation-2) The shaking table has been required to be newly introduced as the additional options for the developing procedures of the standard testing apparatus, however, those capacities may be restricted to the small-levels from the economical reasons.

Situation-3) The experimental equipments as the sensors and the actuators have been also required to be newly introduced for constructing the experiment-based evaluative systems, and those equipments should be selected from the considerations as to be on the markets as the actual products and as to keep a balance between their mechanical capacities and their physical size for adequately introducing on this experimental system.

Before to discuss how to be taken care for those environmental conditions on the author's laboratory, it may be convenient to introduce the actual designs for the configurations of the experimental structural model. The concrete outlook of the experimental structural model of the standard testing apparatus are designed as seen in Figs.3.1.1. Tentative specifications of this original design of the experimental structural model are shown in Table 3.1.1 (in which, the practically manufactured quantities of the experimental model as the final products are also specified in addition to this table). As seen in Figs.3.1.1, a three-degrees-of-freedoms of the lumped-mass type of the structural model are adopted as the targeted construction. The dominant vibrations on this structural model are restricted on the single-direction, namely, this structural model may be regarded as the almost idealized three-mass shear system that the structural responses of every mass are only appeared



(a) Front view, (b) Side view,

Fig. 3.1.1 Outlook of the experimental structural model of the standard testing system.

Table 3.1.1 Original designs and practical specifications of the experimental structural model.

Size of the experimental structural model (cm)	
Height	90.0
Width (Front)	50.0
Width (Side)	20.0

Structural properties		Original designs	Practical quantities
Mass (kgf)	1st	10.0	10.6
	2nd	10.0	10.6
	3rd	10.0	10.6
Stiffness (kgf/cm)	1st	3.0	3.05
	2nd	3.0	3.62
	3rd	3.0	3.96
Natural periods (s)	1st	0.823	0.80
	2nd	0.294	0.28
	3rd	0.203	0.19
Damping ratio	1st	-	0.5 (%)

on the single horizontal direction which are specified as the vibrational directions on Fig.3.1.1. This structural model are not targeted as the meanings of the practical three-stories of the building constructions, the concept to introduce to a three-degrees-of-freedoms of the system are put on the meanings as that the dynamic structural behaviors which are subjected by the dominant three modes of the natural periods on the multi-stories of the practical building constructions can be reproduced and evaluated on this structural model. At this point, those basic appearances of the experimental structural model are proposed as the one of the functions which are mainly requested by the Item-1 and the Item-2, accordingly, the further concrete properties of the structural model which are supposed as the size or the capacities may not be determined until the actual environmental conditions by appending to the Item-3 are considered.

To begin with the Situation-1, the size of the experimental structural model which are introduced for the following author's researches are determined under the practical capacities and the environmental conditions on this existing wind tunnel facility. Photo. 3.1.1 and Fig.3.1.2 show the outlook for the test sections and the plan for the whole facilities of the wind tunnel in Osaka University, respectively. Table 3.1.2 are specified the capacities and the scales of this wind tunnel. To operate the wind tunnel tests as that the wind-induced behaviors of the experimental structural model may adequately imitate, the projected area as the windward surface of the experimental structural model may be restricted as to be almost allocated within about 5 % for the whole area of the section of the wind tunnel under the considerations for the blockade effects. As seen in Table 3.1.1, since the openings of the test section of the wind tunnel are prepared as 180 (cm) of height and 180 (cm) of width, the size of the projected area for the windward surface on the experimental structural model (which are designed to be 90 (cm) height and 20 (cm) of the width as mentioned on Fig.3.1.1 (b) and Table 3.1.1) are determined as to be almost allocated to the upper limits for the allowable trials on the wind tunnel.

And also, when it is considered that the experimental structural models will be used for the evaluations through both of the shaking table and the wind tunnel tests on the following experimental researches, the further convenient ideas may be appeared as that those testing apparatus should be significantly taken care for the assemblies or the disassemblies, and the carriages or the establishments to replace the experimental facilities. For this aim, it may be reasonable that the portabilities of the experimental apparatus are also considered by composing the comparative small-scaled structural models. At the same time, it may be produced that the labor-saved operations may be enabled by those compactness of the experimental apparatus and that the maintenances of those testing apparatus may be also simplified in the handy or the economical meanings. Accordingly, every weights of the floorboards which are installed as the lumped-mass on each story of the experimental structural model are aimed for introducing as light as possible to be easily attached and replaced by human strength. As seen in Table 3.1.1, about 10 (kgf) of the tentative volumes as the weights of the floorboards are adopted and the total weights of the original design of the experimental structural model are introduced as about 30 (kgf). Under those volumes of the experimental structural model, when the assemblies and the disasemblies of this experimental structural model are requested as the preparatory procedures for the experimental operations, those works may be conveniently enabled

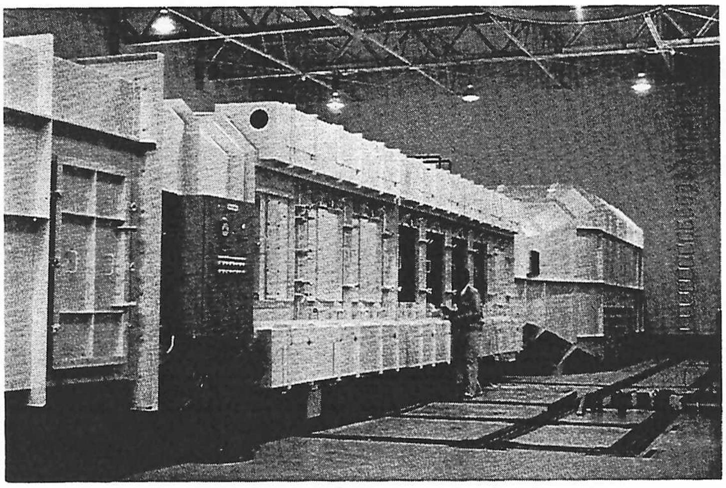


Photo. 3.1.1 Outlook of the test section of the wind tunnel †.

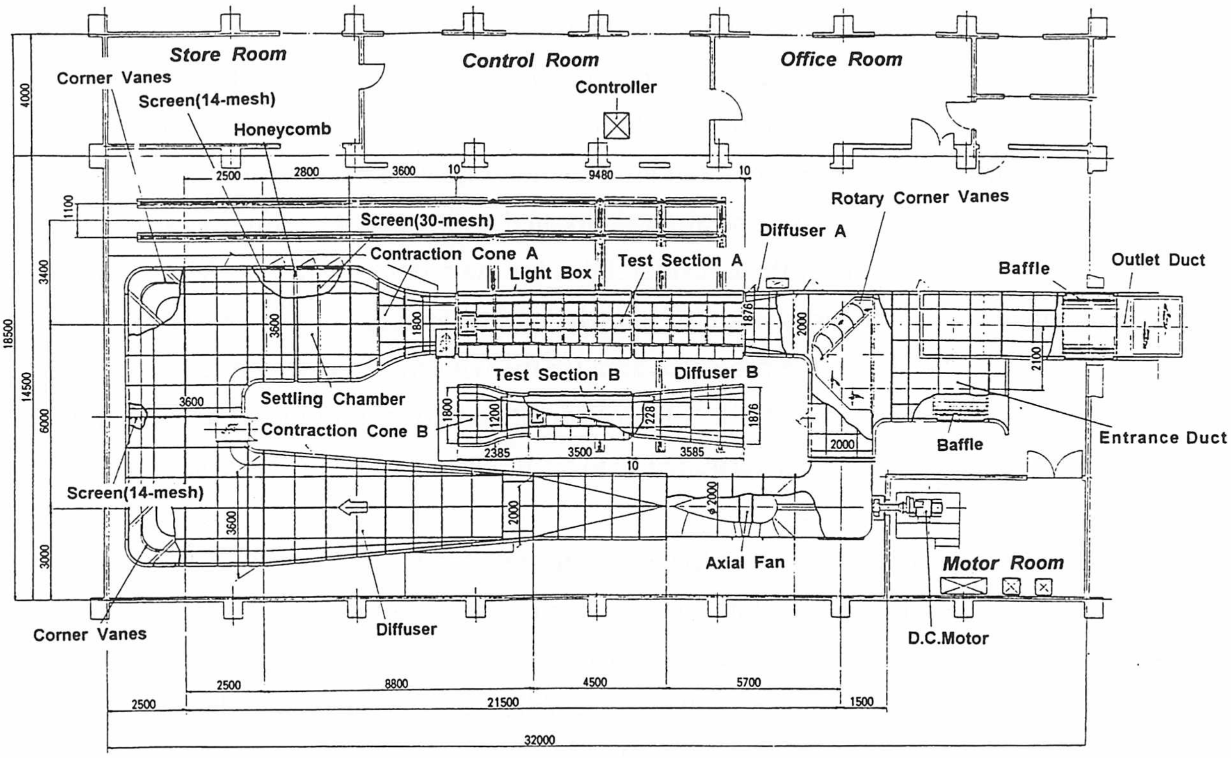


Fig. 3.1.2 Plane view of the whole facilities of the wind tunnel †.

Table 3.1.2 Specifications of the wind tunnel.

Capacities and size of the wind tunnel		
Dimension of test section	1.8 (height) × 1.8 (width)	(m)
Wind velocity	2.0 ~ 20	(m/s)
Maximum flow rate of fan	72	(m^3/s)
Speed range of drive motor	50 ~ 760	(rpm)

(† Reproducing those picture and drawing from the leaflet of the wind tunnel in Osaka University [3.26].)

the labor-saving as to be carried out by the handling of the single persons.

This tentative designs on the volumes of the experimental structural model may also produce the effective conveniences for the shaking table tests in the economical and the workable meanings as to be adequately related to the considerations for the Situation-2. Those compactness of the experimental structural model can enable to be lightened the load imposed on the actuators of the shaking tables, the experimental tests for the aseismic response control systems can be operated on the compact size of the shaking tables. As seen in Figs.3.1.1, the shaking table which are considered as to be provided the adequate capacities for those volumes for the experimental structural model is newly developed as the additional experimental facility for the standard experimental testing systems. This shaking table is designed as to be provided the double-decks of the configurations, the lower table are used for generating the earthquake excitations and the upper table are used for manipulating the active base-isolation controllers. At this point, this new functions which are specified as the installations of the upper tables may be also considered as the advanced efficiencies which have not been prepared on the shaking tables as the general existing products. Moreover, the whole size of this testing apparatus which are specified as the total system of the experimental structural model and the shaking table is mentioned as to be 142 (cm) height as seen in Figs.3.1.1. Accordingly, any maintenances which are supposed as to be attached or tuned the experimental equipments can be easily operated in the sense that the workabilities for the human heights can be enabled without any supports by the scaffolding devices.

Table 3.1.3 Capacities and the size of the equipments as components for the control devices.

Capacities and size of the laser displacement sensors		
Observable range	- 4.0 ~ + 4.0	(cm)
Sampling frequencies (± 3dB)	DC ~ 17	(Hz)
Dimension of size *	4.6 × 4.6 × 1.7	(cm)
Weight	0.165	(kg)

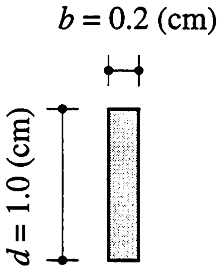
Capacities and size of the acceleration sensors		
Observable range	- 500 ~ + 500	(cm/s^2)
Sampling frequencies (± 3dB)	0.02 ~ 200	(Hz)
Dimension of size *	6.0 × 5.0 × 5.0	(cm)
Weight	0.380	(kg)

Capacities and size of the linear-motioned stepping motors		
Stroke	10	(cm)
Speed range	0 ~ 25	(cm/s^2)
Thrust	7	(kgf)
Dimension of size *	6.0 × 6.0 × 6.0	(cm)
Weight	1.9	(kg)

(* Dimension of size are mentioned by height × width × depth.)

To discuss the surplus considerations for the structural dynamic properties on the original designs of the structural model (which are significantly related to the Situation-3), the practical size and the capacities of the experimental equipments is introduced as shown in Table.3.1.3. Since the size of the openings of every inter-stories on the experimental structural model are limited to about 25 (cm) of height, 41 (cm) of width and 20 (cm) of depth as seen in Fig.3.1.1, the size of the sensors and the actuators which compose the additional control devices as to be directly attached to those inter-stories may be requested to be as small as possible. So that, those practical experimental equipments are at first adopted from those compactness, before that the structural dynamic properties of the experimental structures are determined. Accordingly, the surplus properties are designed as to be adequately allocated to the capacities of those experimental equipments which are introduced on Table.3.1.3.

As seen in this table, it may be pointed that the upper order of the sampling frequencies of the laser displacement sensors are restricted to about 18 (Hz). When the influences of the highest order of the natural periods of the experimental structural model can be observed under the adequate responsibilities of those laser displacement sensors, it may be reasonable that this highest order of the natural periods of the experimental structural model should be covered by about four time of samplings under this upper order of the sampling frequencies. Accordingly, the minimum quantities as the third order of the natural periods are supposed as about 0.2 (s). At this point, when the distributions of the mass and the stiffness of the three lumped-mass system of the experimental model are tentatively considered as the uniform type, the ratio of the natural periods of the third order for the first order can be evaluated as about four times. Under those considerations, to suppose about 0.8 (s) of the first natural periods on the experimental structural models, every mass and stiffness are uniformly allocated as 10 (kgf) and 3.0 (kgf/cm) (as seen in Table 3.1.1), respectively.



Number of columns : 4
Material : phosphor bronze
Yang's modulus : 1.224×10^{6} (kgf/cm^2)
Moment of inartia : 6.15×10^{-4} (cm^4)
Horizontal stiffness : 0.627 (kgf/cm)
Total stiffness : 2.51 (kgf/cm)

Fig. 3.1.3 Configurations and properties of the columns of the experimental structural model.

As the final designs of the original experimental structural model, the columns to support every floorboards are introduced as the concrete shapes. At this point, by considering for the mechanical conditions of the experimental structural model as that the dominant vibrations of the structural model are almost restricted to the single horizontal directions, proportions of each columns are introduces as shown in Fig.3.1.3. As seen in this figure, since the ratio of the moment of inertias between the orthogonal two directions are supposed as 25 times, the strong axis of the columns are regarded enough to be rigid for the narrow axis. As the material of those columns, the phosphor bronze is adopted by considering for the effectual abilities as the mechanical spring elements. Every floorboards are supported by four columns on every corners, and the total horizontal stiffness are calculated as about 2.51 (kgf/cm). The lacks on this value of the stiffness to the requested stiffness as 3 (kgf/cm) by mentioned in Table 3.1.1 are reserved by the attached spring elements on the additional control devices which are composed as the 'active braces' (in which, the details of the active brace systems will be introduced on the following discussions) as shown in Figs.3.1.1.

Through those discussions, the fundamental procedures to design the original configurations and the properties of the experimental structural models are explained. Those sequences to develop the concrete shapes of the standard testing systems are significantly subjected to the environmental conditions of the author's laboratory. Accordingly, various type of the configurations of the standard testing systems are proposed by various environmental conditions on every researchers. However, the developments of the standard testing systems are only the preparations of the common stage for operating the mutual benchmark evaluations, namely, the most importance may be put on the point as that following mutual benchmark evaluations are always operated on the same one of the standard evaluative testing systems. Namely, when various kinds of the structural response control systems can be comparatively evaluated on a certain standard testing systems, this specified standard testing systems may be at last assessed as the evaluative interfaces. From those meanings, when the fundamental conditions which are proposed in the beginnings of this section as the three items to develop the standard testing apparatus are discussed again, it may be considered that the Item-1 and the Item-2 are explained as the general concepts of the standard testing systems. And also, by considering the appropriateness of the Item-3, any kinds of the convenient ideas can be appended to the standard testing systems if only those general concepts are satisfied. By the other words, when the evaluative purposes by introducing any designs of the standard testing systems are always pointed on the preparative researches for investigating the replaceable efficiencies of the various kinds of the structural response control systems, it may be regarded that the fundamental meanings of the mutual benchmark evaluations are satisfied.

Finally, the actual experimental structural model is manufactured as to be almost satisfied the tentative structural properties which are determined under the considerations for the environmental conditions in the authors' laboratory as mentioned in Table 3.1.1. Those practical quantities are exactly measured on this actual experimental structural model. Accordingly, the numerical model which are belonging to the another side of the evaluative interfaces is also corrected to those quantities. By installing the digital-computing processors to this experimental structural model, the whole configurations of the standard testing apparatus which are named as the 'CTAC' system are completed as seen in Fig.3.1.4. The name of the CTAC are corresponded to the meanings as the 'Compact Testing apparatus for Active Control' in Osaka University. This flow of the CTAC system are also considered as the typical applications of the active control system under the digital-computing procedures.

As the control sequences to operating the experimental evaluations, at first, the relative displacements between each story and the absolute accelerations on each floor are measured by laser sensors and the accelerometers, respectively. Those signaled data are transferred to the digital-computers via A/D converters. According to those digitized data, the regulating commands under the interpreted control method are generated on the digital-computers, at the same time, the control pulse signals are generated at PC modules to transfer those commands to the digital-manipulator for driving the actuators. According to those pulse signals which are related to the control commands, the digital-manipulator are produce the analogized motions of the actuators. Those analogized motions of the actuators are affected as the control forces by the mechanical compositions of the control devices.

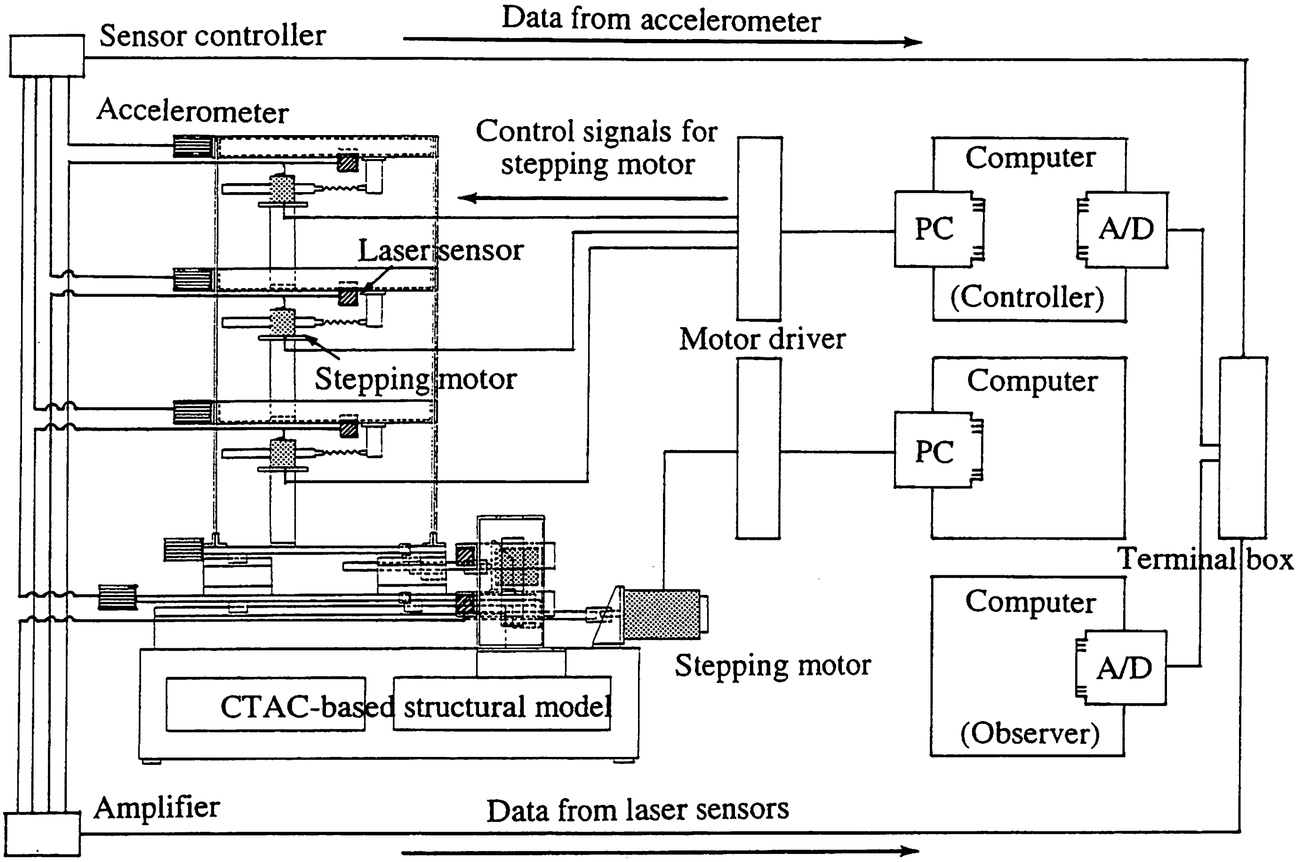


Fig. 3.1.4 Standard flow diagram of the whole of CTAC system.

At this point, as mentioned in Table 3.1.3, the stepping motors are introduced as the actual equipments which are corresponded to the actuators. While those equipments are adopted from their compactness as the basic considerations, as the further effectual specifications of the stepping motors, it may be also pointed that the exact positionings are enabled and that the control manipulations based on digital signals can be easily operated. As seen in Figs.3.1.1 and Fig.3.1.4, the active brace type of the control devices are illustrated as the basic equipments of the additional controllers on the CTAC system. By installing the stepping motors as the actuators, the other types of the control devices are also designed as the replaceable attachments as shown in Figs.3.1.5 (a), (c) and (d) (in which, the control device which is mentioned in Figs.3.1.5 (b) is composed by the air-actuators from the mechanical characteristics of the control systems). Four samples of the control devices are introduced in those figures, (a), (b), (c) and (d) are imitated the mechanical configurations of the active brace (or the active tendon), the active air-bag, the active mass driver and the active fin systems, respectively. As previously discussing for the basic configurations of the CTAC system, the active brace type of the control devices are proposed and adopted as the standard equipments for operating the general meanings of the CTAC-based evaluative experimental tests, and also, the dynamic properties of the structural models are designed under the prerequisites as that the spring elements of the active braces are always equipped. Those reasons as that the active braces are proposed as the standard equipments are mentioned as the following two points :

Point-1) Since the manipulated control forces are appeared as to be proportional to the displacements of the active braces, the control operations can be directly observed from the human eyesights.

Point-2) Since the stepping motors are good at the exact positionings, the most accurate control manipulations to generate the control forces can be actualized on the displacements controls as like the active brace systems.

When the mechanical and the theoretical properties of the various kinds of the structural response control systems can be interpreted to the numerical sub-systems on the digital-computers, the numerical procedures for the mutual benchmark evaluations can be systematically operated for those response control systems. And also, the experimental equipments as the control devices in the meanings of the experimental procedures for the mutual benchmark evaluations may be regarded as to be enough only to be able to emulate experimentally those numerically simulated control manipulations. Accordingly, while the active brace type of the control device for the CTAC systems are assigned as the special of meaning as the standard control force manipulators, in the another sense as the imitated model of the practical control devices, the mechanical characteristics of the active braces can be also evaluated as the comparisons with the other type of the control devices. On the Chapter 4 in this study, through the investigations of the newly proposed control methods, those two kinds of the meanings of the active brace systems for the CTAC systems will be actually discussed.

The other attachments of the control devices are also prepared as the optional equipments for the CTAC systems according to their individual requirements. The active air-bag type of the control device (as seen in Fig.3.1.5 (b)) are aimed to regain the demerits of the active brace system. The active air-bag type of the control device are different from the active brace type in the point as that the connections between the spring elements as the components of the control device and the targeted constructions are supported by the sliding mechanism under the support of the installations of the air-actuators, Accordingly, while both the active brace and the active air-bag are used the spring elements, those properties as the additional stiffness may not be superposed to the targeted structural model by introducing the active air-bag system. However, since the developments of the active air-bag system have been just started as the current researches on the author's laboratory, this type of the control device will be also introduced as the one of the main components for the CTAC system in the near futures. From the backgrounds as that the auxiliary mass type of control devices have been mostly popularized and adopted to the practical building constructions, the preparations of the active mass driver type of the control device (as seen in Fig.3.1.5 (c)) are aimed as that the control manipulations by installing those mechanical devices can be directly observed and investigated on the CTAC-based experimental tests. In which, to install the active mass type of the control devices, the additional mass are always requested. By those demerits (because, the structural properties of the targeted structural model are changed by equipping the additional mass and the general meanings of the individual responsibilities by installing the active mass driver control system may be regarded to difficult to evaluated), this type of control device are not adopted as the standard equipments of the CTAC system.

The active fin type of the control devices (as seen in Fig.3.1.5 (d)) are introduced to be proposed the new type of the wind-induced response control system. While the numerical simulations for aseismic response control systems may be regarded as to be comparatively easy to be operated, the wind-resistant response control systems may be generally considered as to be difficult to be simulated by the numerical approaches. Accordingly, the main participations for the mutual benchmark evaluations on the CTAC system are assigned to the experimental procedures when the control effects for the wind-induced structural vibrations are supposed as the evaluative purposes. On the Chapter 5 in this study, through the investigations of the newly developed active fin type of the control devices, those effectual meanings of the CTAC-based experimental evaluations for the wind-induced structural vibration control system will be actually discussed.

(a) Active brace type,

(b) Active air-bag type,

(c) Active mass driver type,

(d) Active fin type,

Fig. 3.1.5 Variations of the attachments of the control devices of the CTAC system.

Discussions may be reached to the starting point as that the mutual benchmark evaluations will be actually operated to investigate for the various kinds of the structural response control systems by using the CTAC system. Those mutual benchmark evaluations are always introduced as to be satisfied the fundamental conditions that the individualized control efficiencies by every control systems are expressed as the common meanings of the 'effectiveness' under the generalized indicates. For instance, when the responsibilities of various kinds of the structural response control systems are evaluated as the comparative investigations on the same targeted model of the CTAC system, the CTAC-based control effects which are specified as the relative merits for those evaluated structural response control systems may be assessed as the generalized effectiveness in the sense that the CTAC system is introduced as the standard evaluative testing apparatus. Namely, those generalized effectiveness by every response control systems may compose the 'evaluative interfaces' which are functioned to assess the relative relations for the variations of the response control systems. And also, the series of the CTAC-based control effects can be systematically transformed to the other targeted models, if only the responsibilities by introducing the representative one of the control systems are specified on both of those two kinds of targeted models and the transformable factors between those two kinds of the responsibilities are expressed as the 'compatible interfaces' which are functioned to assess the relative relations for the variations of the targeted models.

On the practical design procedures of the structural response controlled systems, it may be considered that the installations of the various kinds of response control systems for the various kinds of the targeted constructions are investigated and that the most adequate combinations will be adopted. As those sequences, firstly, the targeted constructions and the requested behaviors are specified as the fixed quantities, and then, the response control syntheses to satisfy the requested purposes are operated. Namely, the first stage on those sequences may be assigned as the preparations of the compatible interfaces as to propose the evaluative interfaces and those operations may be provided as the aspects which should be severally treated by every individual cases. On the other hand, the later stage may be assigned as the substantial utilizations of the evaluative interfaces and those operations may be produced as the systematic aspects under the supports of the evaluative interfaces. From those meanings, the essential meanings as the systematic syntheses of the structural response control systems may be put on the preparations of the evaluative interfaces. In the next section, to actually utilize the CTAC system as the evaluative interfaces for the structural response control systems, the basic capacities of the CTAC system to adequately operate the various kinds of the evaluative researches are assured through the preliminary check for the CTAC-based experimental apparatus.

As concluding remarks in this section, the fundamental concepts to introduce the standard evaluative testing apparatus for the structural response control systems are proposed. To introduce the concrete shapes of the standard evaluative testing systems, the essential meanings as the evaluative interfaces for the structural response control systems are discussed in detail. Under the considerations for the practical environmental conditions in the authors' laboratory, the configurations of the standard evaluative testing apparatus are designed as to be provided the appropriate compactness and the appropriate portabilities as the experimental testing apparatus. The CTAC system is proposed as the one of the configurations for the standard evaluative testing apparatus which are adequate to those conditions of the authors' laboratory.

3. 2 Preliminary tests for investigating standard testing apparatus

The basic configurations of the CTAC system are introduced as the one of the concrete shapes for the standard evaluative testing apparatus in the previous section. The main concept to propose those outlooks of the CTAC system is put on the compactness and portabilities as to be easily operated both the shaking table tests and the wind tunnel tests. Of course, the CTAC system are also designed as to satisfy the essential meanings as the evaluative interfaces by considering the significance to operate the mutual benchmark evaluations for enabling the systematic syntheses of the structural response control systems. Namely, the series of the following CTAC-based evaluative researches are assigned as the preparations of the evaluative interfaces for various kinds of the structural response control systems.

In this section, by executing the preliminary check for the CTAC-based experimental apparatus through the shaking table tests and the wind tunnel tests, the basic capacities and the adequate operative conditions of the CTAC system are investigated as the starting points to the following researches. As those preliminary check of the CTAC system, the case studies for the active control experimental tests by installing the multi-located active brace systems which are manipulated by the 'external para-damping control method' are introduced. Those experimental evaluations are operated as the three kinds of typical tests for controlling the structural behaviors on the free vibrations, the seismic-excited vibrations and the wind-induced vibrations.

At first, as the preparations for those preliminary check for the CTAC, the details of the control devices by supposed as the mechanism of the active brace system and the control algorithm by supposed as the external para-damping control method are introduced. The equations of motions of the CTAC-based experimental structural model which are introduced in the Section 3.1 may be expressed as follow,

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} = [W]\{w\} + [F]\{f\} \ , \tag{3.2.1}$$

in which, $\{\ddot{x}\}$, $\{\dot{x}\}$ and $\{x\}$ mean absolute acceleration, relative velocity and relative displacement vectors of the three-stories of the CTAC-based experimental structural model, respectively. $[M]$ and $[K]$ mean mass and stiffness matrices, respectively, and those structural properties are measured as the actual quantities as mentioned in Table 3.1.1 in the Section 3.1. The damping matrix $[C]$ is defined as the proportional type to stiffness matrix $[K]$ and 0.5 % of damping ratio for the first mode of the dominant frequency are supposed. $\{w\}$ and $\{f\}$ mean external input force vector (which is corresponding to externally excited force on each floor) and internal input force vector (which is corresponding to control force on each floor), respectively, and $[W]$ and $[F]$ are determined as the arrangement matrices which are related to those external and internal inputs for the system coordinate, respectively. In the following discussions, since those inputs $\{w\}$ and $\{f\}$ for the structural model are considered as to be related to the coordinate on the body forces which are lumped to each mass, both $[W]$ and $[F]$ are supposed as to be equal to the unit matrix $[I]$.

The basic configurations of the active brace system are shown in Fig. 3.2.1. The fundamental mechanism to generate the additional control forces by the active brace system are introduced as following conditions :

Condition-1) The horizontal stiffness (which are denoted as k_i ; $i = 1, 2, 3$) on every stories of the targeted structural system are assumed as to be composed by the two kinds of sub-systems, the first one is supposed as the inherent spring elements of the columns or the other aseismic elements (which are denoted as k_i^f ; $i = 1, 2, 3$) and the another one is supposed as the additional spring elements (which are denoted as k_i^b ; $i = 1, 2, 3$) which are installed the actuators on their connections to the targeted structural system.

Condition-2) When the targeted structural system is supposed as to be its static state and any horizontal resistant forces are not appeared on both sub-systems of the spring elements, this positionings of the actuators are regarded as the initial position. And also, when the actuators are allocated to the initial position and any horizontal resistant forces are appeared on both sub-systems of the spring elements according to the structural inter-story displacements, the additional control forces are regarded as to be zero.

Condition-3) When Δv_i^b are allocated as the positionings of the actuators, the deformations of the additional spring elements may be subjected by this value of Δv_i^b as the offset from the inter-story displacements on the i-th story (which are denoted as v_i ; $i = 1, 2, 3$). Namely, while the deformations of the inherent spring elements are always expressed by v_i , the deformations of the additional spring elements are manipulated as $v_i + \Delta v_i^b$ by the control operations of the actuators. Accordingly, since the inter-story restoring forces of the targeted structural system are supposed by $k_i \cdot v_i$, the additional control forces b_i which are introduced by the active brace system are regarded as to be $k_i^b \cdot \Delta v_i^b$.

So that, under the installations of the active brace system, in right side of Eq. (3.2.1), the term of control force vectors $\{f\}$ can be expressed by relating to the manipulated control forces supplied via active braces $\{\boldsymbol{b}\}$ as follows,

$$\{f\} = [\boldsymbol{P}]\{\boldsymbol{b}\}\ ,\ [\boldsymbol{P}] = \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ 0 & 0 & 1 \end{bmatrix}. \tag{3.2.2}$$

In which, $[\boldsymbol{P}]$ means the arrangement matrix which are related to those manipulated control forces via the active braces to the system coordinate.

As the next, the external para-damping control method are introduced as the one of the typical feedback controllers of the relative velocities between each mass and the basement. If this type of the additional controllers be installed as the passive type of the mechanical elements, the ground-connected visco-elastic dampers systems as that every mass of the targeted structural model are directly connected to the basement or to the rigid supports by standing on the basement may be supposed as the equivalent example. When each damping coefficient of those virtual visco-elastic dampers is denoted as c_i^e ($i = 1, 2, 3$), the additional control forces may be interpreted on the digital-computers as the following feedback relation between the control force vectors $\{f\}$ and the relative velocity vector $\{\dot{x}\}$,

$$\{f\} = [C^e]\{\dot{x}\}, \quad [C^e] = \begin{bmatrix} c_1^e & 0 & 0 \\ 0 & c_2^e & 0 \\ 0 & 0 & c_3^e \end{bmatrix}, \qquad (3.2.3)$$

in which, $[C^e]$ means the 'external para-damping' matrix, at the same time, this matrix is also corresponded to the feedback gain matrix to actively compose the external para-damping controllers. To operate those control manipulations by using the active braces $\{\boldsymbol{b}\}$, the following control forces via the active braces should be generated by considering Exp. (3.2.2).

$$\{\boldsymbol{b}\} = [P]^{-1}\{f\}, \quad [P]^{-1} = \begin{bmatrix} 1 & 1 & 1 \\ 0 & 1 & 1 \\ 0 & 0 & 1 \end{bmatrix}. \qquad (3.2.4)$$

Namely, the feedback relation between the manipulated control force vectors via the active braces $\{\boldsymbol{b}\}$ and the relative velocity vector $\{\dot{x}\}$ can be expressed as,

$$\{\boldsymbol{b}\} = [P]^{-1}[C^e]\{\dot{x}\} = \begin{bmatrix} c_1^e & c_2^e & c_3^e \\ 0 & c_2^e & c_3^e \\ 0 & 0 & c_3^e \end{bmatrix}\{\dot{x}\}. \qquad (3.2.5)$$

On the later half in this section, emphasis is put on the considerations how much levels of the external inputs should be supposed on the following CTAC-based experimental tests by every environmental conditions for the operations as the shaking table tests and the wind tunnel tests. Namely, it may be significant as that each adequate tuning of the external input level by every kinds of experimental tests are pre-provided as each standard input level by considering the observable capacities on the CTAC-based experimental system. From those meanings, as the preliminary checks of the CTAC system, the experimental case studies under two kinds of typical environmental conditions are executed by using the same experimental structural model, the same additional control device and the same control algorithm, and the one of the compatible interfaces to estimate the differences on those two kinds of environmental conditions for the CTAC-based experimental tests may be prepared. Those preliminary checks of the CTAC system are operated by the following sequences :

Step-1) At first, the reproducibilities of the seismic excitations which are generated by the shaking table are examined under the conditions as that the CTAC-based experimental structural model is equipped on the shaking table. By evaluating for the basic capacities of the CTAC system from both view points of the non-controlled responses of the structural model and the allowable efficiencies of the shaking table, the standard level of the seismic excitations on the CTAC-based experimental tests are determined.

Step-2) By operating the active control tests by installing the external para-damping control method under this standard level of the seismic excitations on this shaking table, the aseismic control effects are evaluated for variations on the external para-damping coefficients and the observableness for those control effects are examined. And, a certain one of the sets as the actual quantities of the external para-damping coefficients is selected for the next checks on the Step-3.

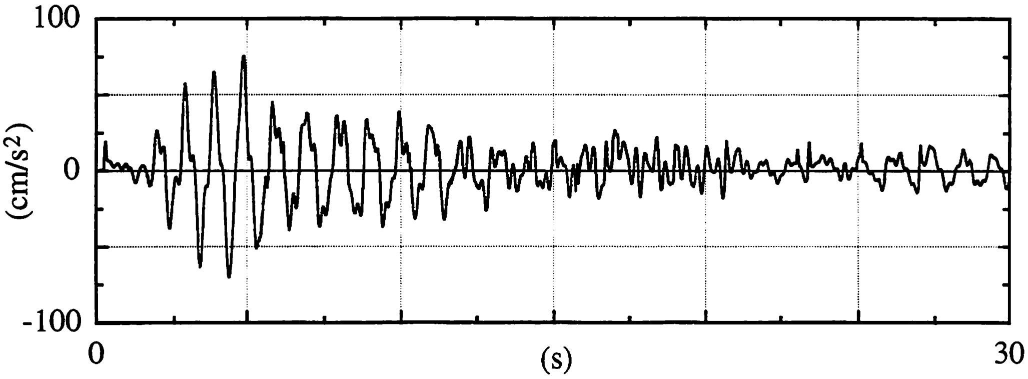
Step-3) By using the external para-damping control method under the same condition with the Step-2, the observableness of the control effects are checked for the cases which are supposed as the wind-induced vibrations of the structural model.

At this point, when the minimum resolutions of the sensors which are installed as the actual experimental equipments on the CTAC system are considered, the more accurate observations may be gained by that the control effects which are evaluated as the comparative considerations between the non-control responses and the controlled responses can be allocated to be as large as possible. And also, those enlarged differences between the non-controlled behaviors and the controlled behaviors on the CTAC-based experimental structural model may enable to confirm from the human eyesight. Accordingly, those observableness on the control effects may be evaluated from the enough conditions as to suitably satisfy those requirements for the CTAC-based experimental tests.

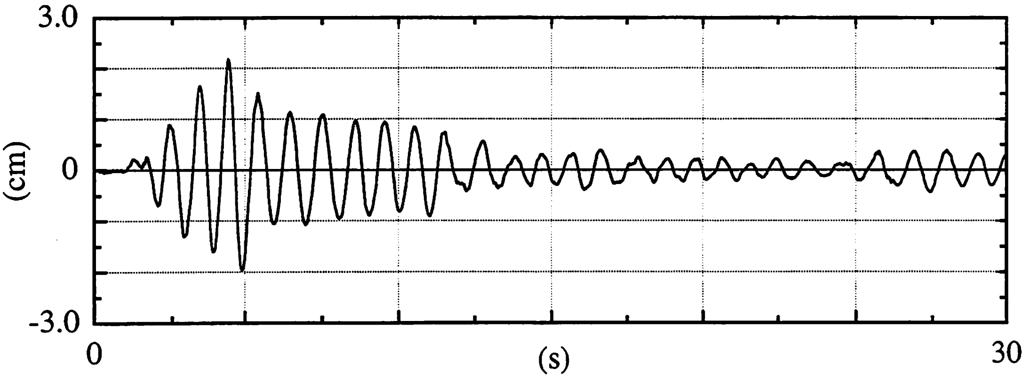
Study (3.2) - 1 :

As the first approach to the preliminary checks for the CTAC-based experimental operations, the item which is mentioned as the Step-1 is investigated by measuring the displacements of the upper table which are reproduced by the shaking table. El Centro (1940) NS and Taft (1952) EW are generated on the shaking table as the testing inputs of the seismic motions. Figs.3.2.1 (a), (b) and (c) show the accelerations and the displacements of the top floor of the structural model and the displacements of the upper table of the shaking table under the scaled-down input for El Centro NS as that the maximum velocity level is reduced to 3 (cm/s), respectively. Figs.3.2.2 (a), (b) and (c) show the accelerations and the displacements of the top floor of the structural model and the displacements of the upper table of the shaking table under the scaled-down input for Taft EW as that the maximum velocity level is reduced to 3 (cm/s), respectively. In Fig.3.2.1 (c) and Fig.3.2.2 (c), the solid lines are corresponded to the measured motions of the shaking tables and the broken lines are corresponded to the original input motions which are provided on the digital emulator for the shaking table system.

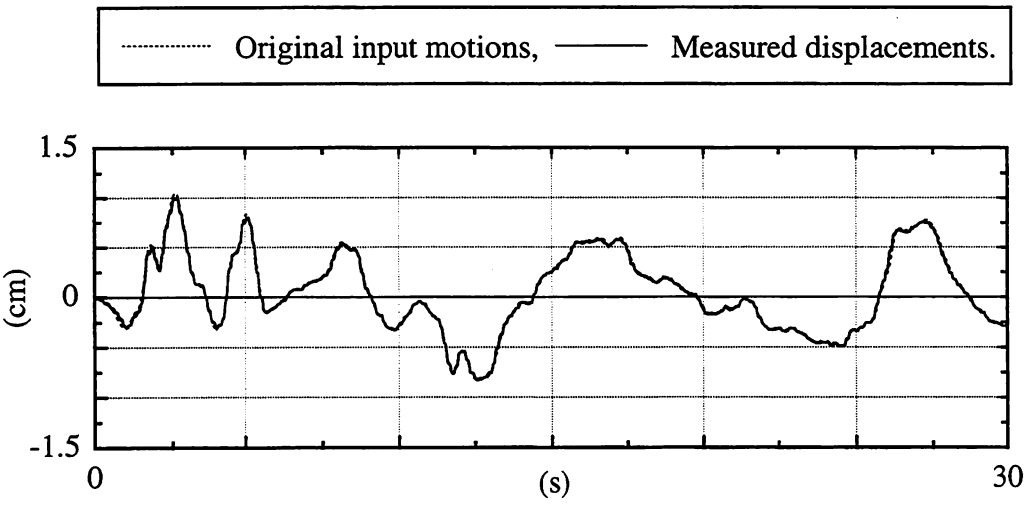
As seen in Fig.3.2.1 (c) and Fig.3.2.2 (c), the measured seismic displacements which are actually generated on the shaking table may be regarded as to be provided the enough exactness as the reproducibilities for the both of the original input motions on El Centro NS and Taft EW. When the mechanical properties of the stepping motors which are introduced as the actuator for this shaking table are considered, those exact positionings which are evaluated as the displacements of the shaking table can be adequately explained as to be produced by the advantage of the stepping motors. At this point, it may be also considered that the accelerations which are generated on this shaking table may not be so exactly reproduced as to be matched to the original input motions,



(a) Accelerations of the top floor of the structural model,

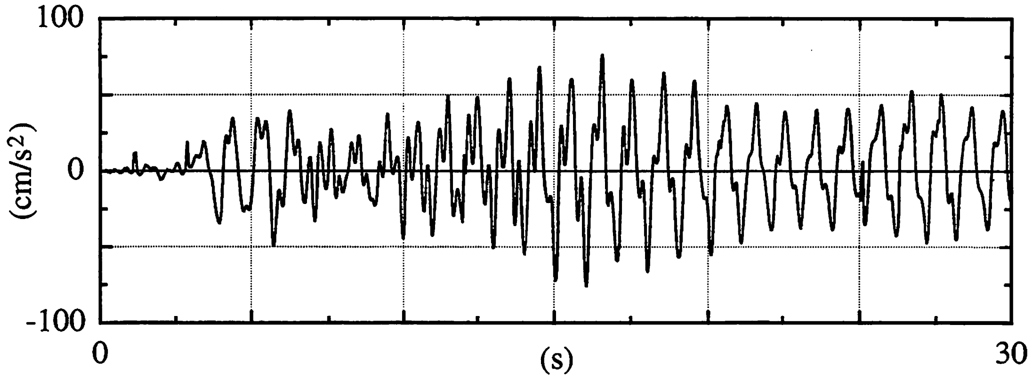


(b) Displacements of the top floor of the structural model,

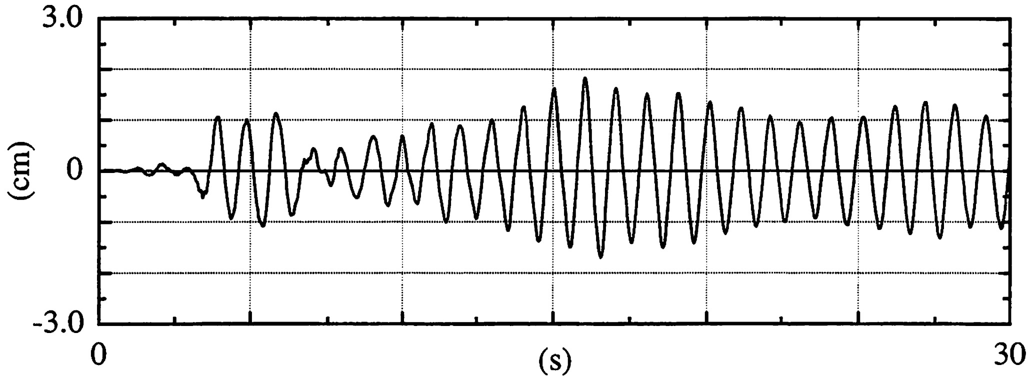


(c) Displacements of the upper table of the shaking table,

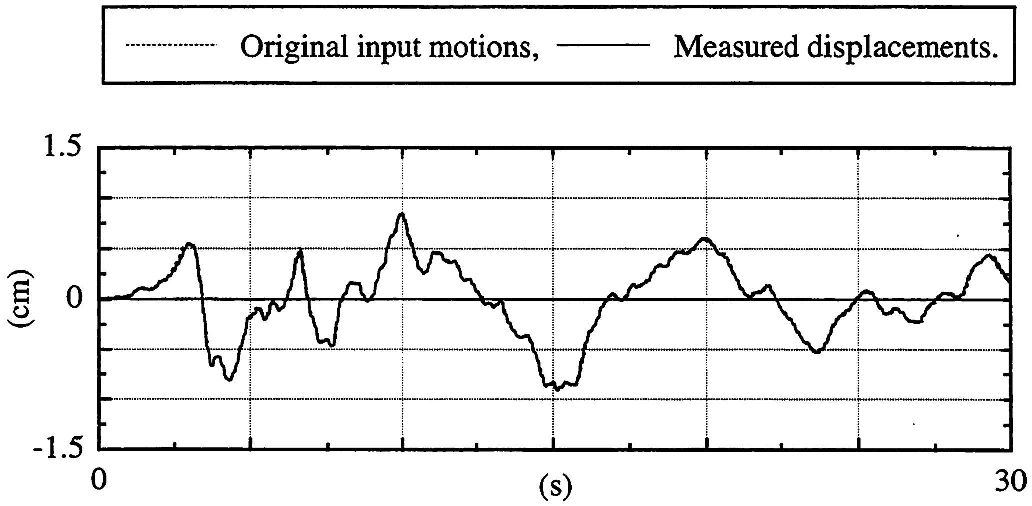
Fig. 3.2.1 Structural responses and reproducibilities of the shaking table (El Centro NS).



(a) Accelerations of the top floor of the structural model,



(b) Displacements of the top floor of the structural model,



(c) Displacements of the upper table of the shaking table,

Fig. 3.2.2 Structural responses and reproducibilities of the shaking table (Taft EW).

because the stepping motors are manipulated by the digital-sequencers for its positionings and those sequencers may be generally designed as to be concerned with only the signals for the differential angles and the rotating velocities by every discrete time intervals. Accordingly, it may be regarded that the reproducibilities of this shaking table which are introduced as the additional equipments for the CTAC system should be evaluated from the exactness for its displacements and also, it may be reasonable that the allowable capacities of the stepping motors should be judged from the maximum velocity level which is included on the reproduced seismic motion input data.

On the other side, when the larger motions than the allowable differential angles of the stepping motor by every discrete time intervals are considered, those over-positionings as exceeding the capacities of the stepping motors had to be delayed or rounded off in order to avoid the miss-steps of the stepping motors (in which, the miss-step means the phenomena as that any positionings of the stepping motor become to disable). Through those preliminary checks for the reproducibilities of this shaking table, it has been assured that the most of the seismic records (in which, El Centro (1940) NS and EW, Taft (1952) NS and EW, Hachinohe (1968) NS and EW, and JMA-Kobe (1995) NS and EW are examined for this aim) which are scaled down as not to be exceeded about 5 (cm/s) as the maximum velocity level can be exactly reproduced. When any seismic records which are exceeded about 5 (cm/s) as the maximum velocity level are tried on this shaking table, some parts on those reproduced displacements on the shaking table may be appeared as to be lost their exactness for the original input motions. Namely, the substantial allowances of this shaking tables may be evaluated about 5 (cm/s) as the maximum velocity which are included on the original input motions. When the eight kinds of the seismic records (which are mentioned above) are scaled down by 5 (cm/s) as the maximum velocity, the minimum value for the maximum acceleration is appeared as about 27 (cm/s^2) on Hachinohe EW, and the average value for the maximum accelerations of those scaled-down eight kinds of seismic records is evaluated about 42 (cm/s^2). Accordingly, when the standardizations of those eight kinds of the seismic records by the maximum acceleration are considered, it may be reasonable that the maximum acceleration level for those seismic motion records which is justified to about 30 (cm/s^2) is regarded as to be the upper limit for the standard input level in the following shaking table tests.

And also, as seen in Figs.3.2.1 (a) and (b), and Figs.3.2.2 (a) and (b), the maximum values of the non-controlled accelerations and displacements of the top floor of the structural model are observed about ± 80 (cm/s^2) and ± 2 (cm) for both of external inputs of El Centro NS and Taft EW which are scaled down to 3 (cm/s) as the maximum velocity level. In which, both of the maximum accelerations for those scaled-down external inputs of El Centro NS and Taft EW are calculated as about 31 (cm/s^2). When the maximum ranges for the laser displacement sensors and the accelerometers are considered, those values are specified as 12 (cm) and 500 (cm/s^2), respectively (in which, the maximum ranges for the top floor's displacement are supposed by the summations for the capacities of three laser sensors). Namely, both of the maximum values of those non-controlled responses are allocated to about 1/6 for the maximum ranges for each sensors, enough margins for the observable limits for those sensors may be confirmed. Since the most critical resolutions for those sensors are specified as to be 0.004 (cm) on the laser displacement sensors, the maximum vibrated ranges on the non-control displacements are also corresponded to about 1000 times, and the control effects which are evaluated as the comparative evaluations between the non-controlled responses and the controlled responses in the following researches may be enabled to be estimated by about 1/1000 of exactness. From those meanings, it may be also regarded as to be adequate that the standard input level on this shaking table are supposed as about 30 (cm/s^2).

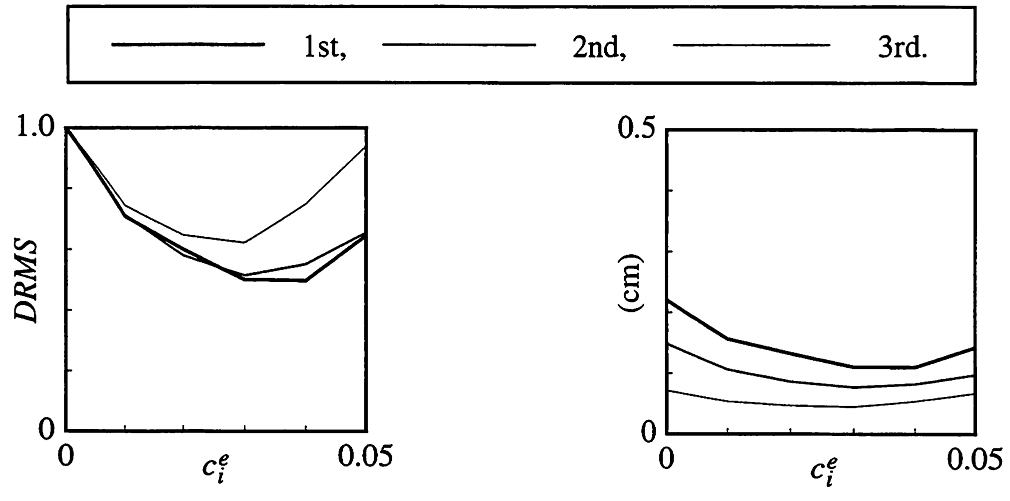
Study (3.2) - 2 :

As the next checks on the CTAC-based experimental operations by using the shaking table, the item which is mentioned as the Step-2 is investigated by operating the active control tests by using the external para-damping control method on the multi-located active brace system. To evaluate for the fluctuations of the control effects which are subjected by the differences of the quantities of the external para-damping coefficients c_i^e ($i = 1, 2, 3$), the parametric experimental tests are executed. The external para-damping coefficients c_i^e are supposed as to be equal values on every stories (namely, $c_1^e = c_2^e = c_3^e$), and the control effects by six kinds of cases which are supposed as $c_i^e = 0$ (namely, as corresponding to the case without control), 0.01, 0.02, 0.03, 0.04 and 0.05 (kgf·s/cm) are investigated. As the external seismic motions, El Centro NS and Taft EW as that the maximum acceleration level is reduced to 30 (cm/s^2) are adopted. The control effects are evaluated by the indicates which are expressed as the RMS (root mean square) displacements and as the displacements controlled factors.

The displacement controlled factors for the every inter-story's displacements $DRMS(v_i)$ are defined as the ratio of the controlled RMS responses on the i-th inter-story's displacements $v_{rms,\,i}$ with the non-controlled RMS response on the i-th inter-story's displacements $v'_{rms,\,i}$ during the ground motion inputs times (30 seconds), namely,

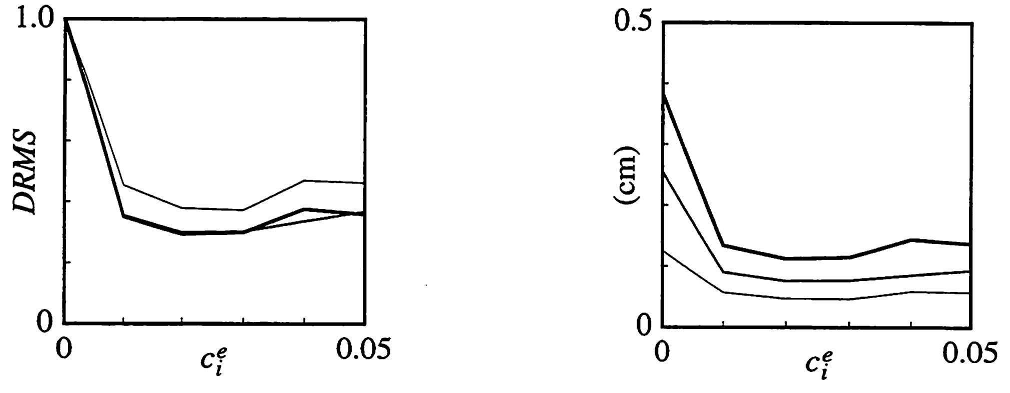
$$DRMS(v_i) = v_{rms,\,i} \,/\, v'_{rms,\,i}\;,\quad i = 1, 2, 3. \tag{3.2.6}$$

Figs.3.2.3 (a) and (b) show the fluctuations of the displacement controlled factors $DRMS(v_i)$ and the RMS displacements and $v_{rms,\,i}$ (cm) according to the differences for the external para-damping coefficients c_i^e for the cases which are supposed by the external input motions as El Centro NS, respectively. Figs.3.2.4 (a) and (b) show the fluctuations of the displacement controlled factors $DRMS(v_i)$ and the RMS displacement sand $v_{rms,\,i}$ according to the differences for the external para-damping coefficients c_i^e for the cases which are supposed by the external input motions as Taft EW, respectively. As seen in those figures, when the values of the external para-damping coefficients c_i^e are supposed as to be about 0.03 (kgf·s/cm), the most effective reductions of the displacements may be observed. When the values of the $DRMS(v_i)$ for the cases of El Centro NS and Taft EW are compared for those values of c_i^e (which are supposed as about 0.03 (kgf·s/cm)), it may be assured that those control effects for the two kinds of the external inputs which are evaluated as the ratio of the controlled RMS responses with the non-controlled RMS response are regarded as to be different. As the reason for this, it may be pointed that the disparity for the non-controlled RMS responses are appeared on those two kind of cases which are subjected by the different seismic motions. Namely, when the values of the displacement controlled factors are compared for the different kinds of the seismic motions, those evaluations should be considered as investigating for the compatible interfaces on the disparity among the difference of the seismic motions. Of course, when the values of the displacement controlled factors are utilized on the parametric comparisons on the responsibilities of the additional controllers for the same conditions of the external inputs, it may be regarded that those evaluations are adequately assigned as the meanings as the evaluative interfaces.



(a) displacement controlled factors, (b) RMS displacements,

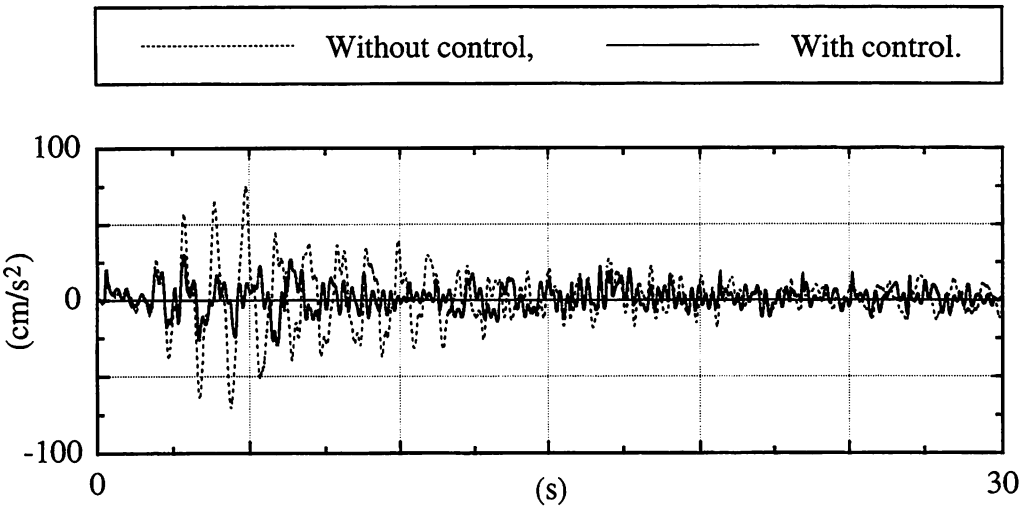
Fig. 3.2.3 Aseismic control effects (El Centro NS).



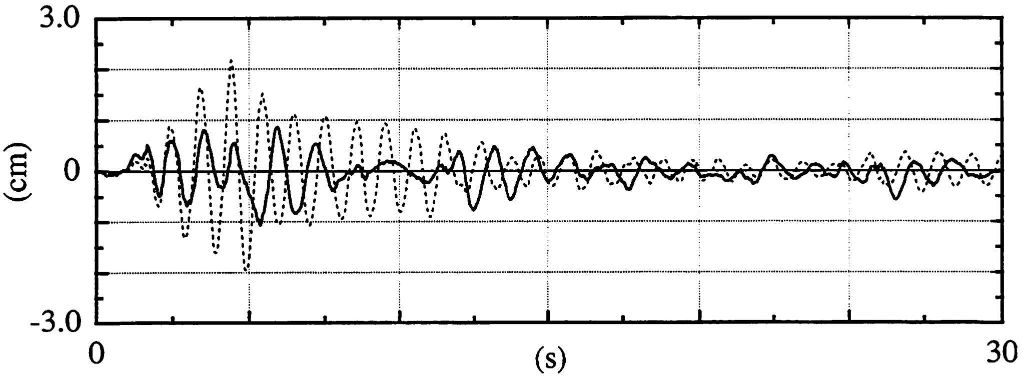
(a) displacement controlled factors, (b) RMS displacements,

Fig. 3.2.4 Aseismic control effects (Taft EW).

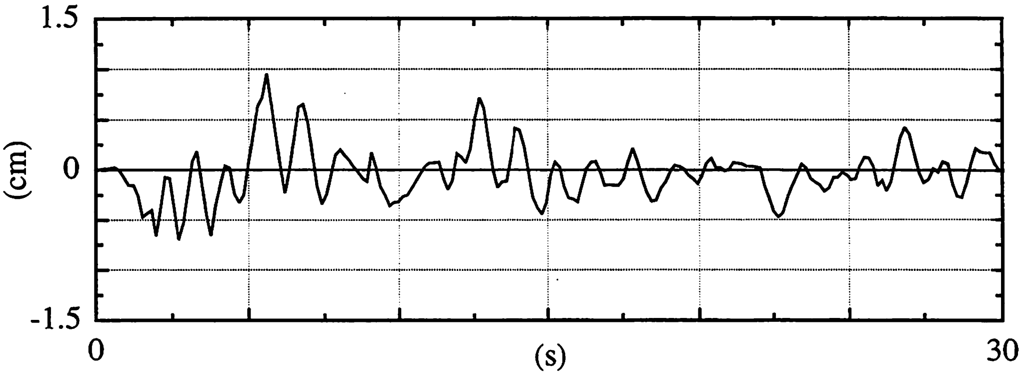
At this point, by comparing Fig.3.2.3 (b) and Fig.3.2.4 (b), it may be observed that the values of the $v_{rms,\,i}$ for both cases of El Centro NS and Taft EW are comparatively closed on those values of c_i^e (which are supposed as about 0.03 (kgf·s/cm)). It may be considered that the reductions of the responses by introducing the external para-damping control method are regulated to the almost same level by evaluated as the RMS controlled displacements for the two kinds of the different



(a) Accelerations of the top floor of the structural model,

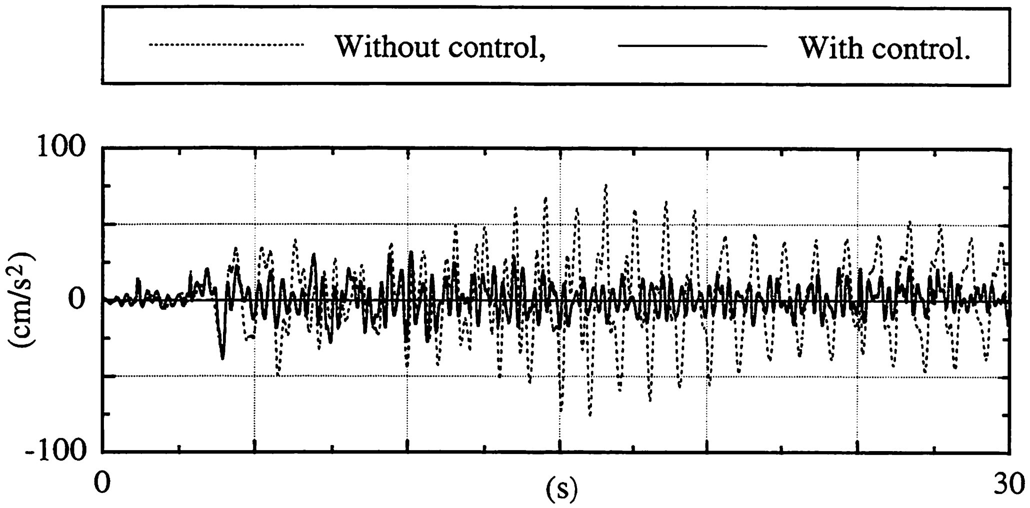


(b) Displacements of the top floor of the structural model,

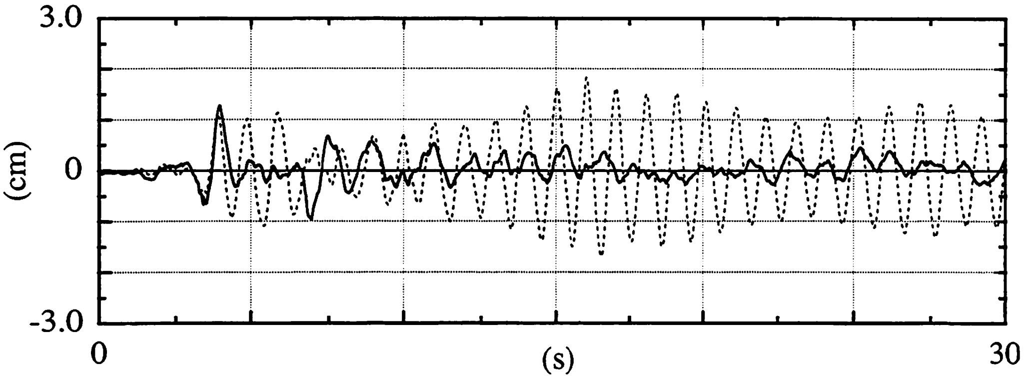


(c) Displacements of the active brace on the lowest story of the structural model,

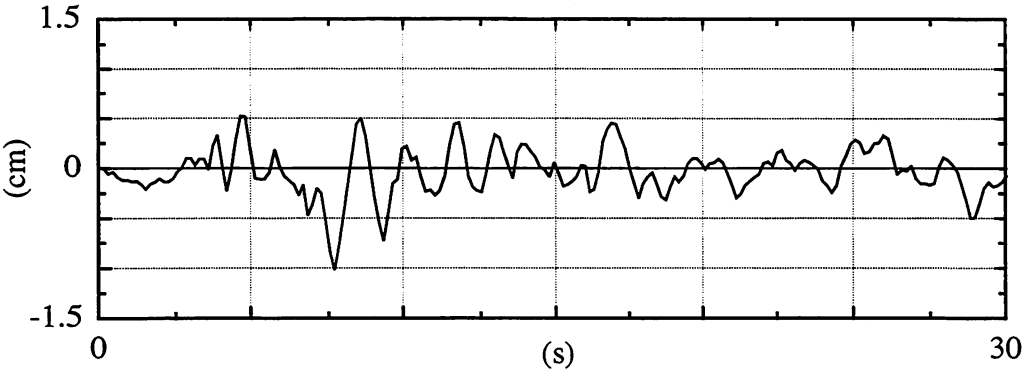
Fig. 3.2.5 Time histories under the aseismic response control (El Centro NS).



(a) Accelerations of the top floor of the structural model,



(b) Displacements of the top floor of the structural model,



(c) Displacements of the active brace on the lowest story of the structural model,

Fig. 3.2.6 Time histories under the aseismic response control (Taft EW).

seismic motions of El Centro NS and Taft EW. Those results may be also observed from the time histories of the controlled responses. Fig.3.2.5 (a), (b) and (c) show the time histories of the displacements and the accelerations of the top floor of the structural model and the additional displacements of the active brace on the lowest story for the cases under the external input of El Centro NS which is scaled down by 30 (cm/s^2) of the maximum acceleration, respectively. Fig.3.2.6 (a), (b) and (c) show the time histories of the displacements and the accelerations of the top floor of the structural model and the additional displacements of the active brace on the lowest story for the cases under the external input of Taft EW which is scaled down by 30 (cm/s^2) of the maximum acceleration, respectively. In those figures, the solid lines are corresponded to the controlled responses by using the external para-damping control method by $c_i^e = 0.03$ (kgf·s/cm), ($i = 1, 2, 3$) and the broken lines are corresponded to the non-controlled responses. As seen in those figures, the effective reductions of both of the accelerations and the displacements can be explicitly observed for both cases under the external input of El Centro NS and Taft EW. Although, the non controlled response on the later parts on the seismic-excited durations by the Taft EW are quite larger than the cases of El Centro, it may be assured that the controlled responses for both cases by those different seismic motions can be observed as to be comparatively similar behaviors. As seen in Fig.3.2.5 (c) and Fig.3.2.6 (c), it may be observed that the displacements of the active braces are also comparatively similar for both cases by El Centro NS and Taft EW. For both of those cases, the maximum additional displacements of the active brace are evaluated about ± 1 (cm). When the capacities of the stepping motors which are adopted to compose the active brace system are considered, this value is specified as ± 5 (cm). Namely, the maximum values of the manipulated displacements of the active braces is allocated to about 1/5 for the maximum stroke for each stepping motors, enough margins for the controllable limits for those actuators may be confirmed. And also, since the stiffness of the additional spring elements which are reserved to the active brace are allocated as to be 0.6 (kgf/cm), the maximum control forces which are loaded on the lowest story of the structural model can be estimated as to be about 0.6 (kgs), and this quantities are corresponded to only about 1.9 % for the total volume of the structural model (which is supposed as 31.8 (kgf)).

Moreover, through those preliminarily experimental checks in the Study (3.2)-2, those aseismic control effects which are compared with the differences between the non-controlled responses and the controlled responses as generating on the shaking table tests may have been also confirmed as to be provided the enough observableness from the human eyesights. From those meanings, it may be also confirmed again the adequateness as that the standard input level on this shaking table are supposed as about 30 (cm/s^2).

***Study (3.2) - 3* :**

As the last checks on the CTAC-based experimental operations, item which is mentioned as the Step-3 is investigated by operating the wind-resistant active control tests by using the external para-damping control method on the wind tunnel. The CTAC-based experimental structural model are equipped on the wind tunnel by that its vibrated directions are parallel to wind flow. At first, the non-controlled responses of the wind-induced structural model are measured by the sensors and also observed by the human eyesight. In which, since only semi-static deformations of the structural model to the leeward are dominantly appeared and the structural vibrations as the dynamic behaviors are observed as to be quite small under the laminar wind flow, the conditions of the wind flows are adopted as the semi-turbulent wind flow by inserting the grid lattices.

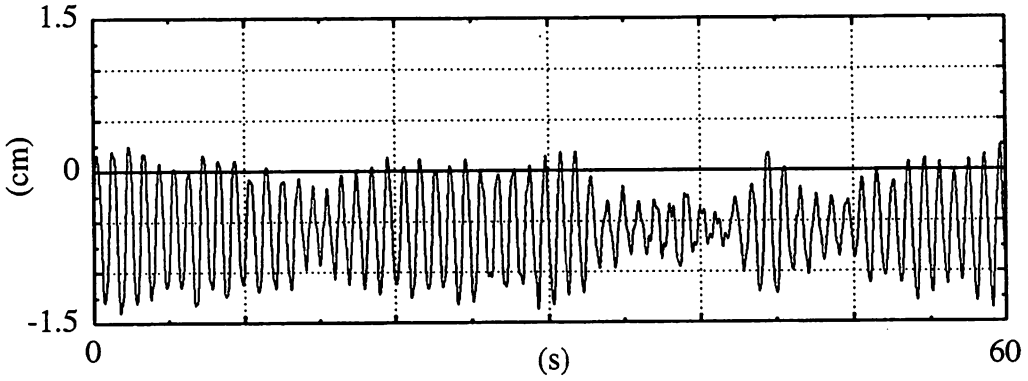


Fig. 3.2.7 Top floor's displacements (Without control, wind velocity : 8.0 (m/s)).

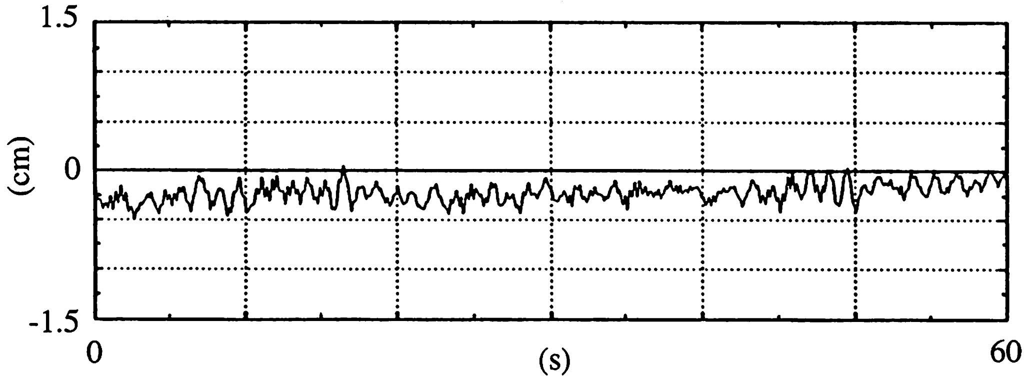


Fig. 3.2.8 Top floor's displacements (With control, wind velocity : 8.0 (m/s)).

Fig.3.2.7 show the non-controlled displacements of the top floor on the experimental structural model under about 8.0 (m/s) of the averaged wind velocity. As seen in this figure, the wind-induced structural dynamic behaviors may be observed as the superpositions by the semi-static deformations as subjected on the wind pressures and the vibrational movements as subjected on the dynamic turbulences of the wind flow. Namely, the non-controlled structural vibrations on the CTAC-based structural model may be evaluated as to be about ± 0.75 (cm) of the maximum amplitude at around to about 0.75 (cm) of the center of the vibrations under about 8.0 (m/s) of the semi-turbulent wind flow. In this case, the maximum displacement appeared as to be about 1.5 (cm) on the leeward side. Accordingly, when the allowable displacement of the structural model are allocated as to be almost equal level for the cases on the shaking table tests, it may be considered as that the maximum displacement which are supposed as the summations with the semi-static deformation and the maximum amplitude should be estimated as this allowable level for the wind tunnel tests.

Through those preliminary check for the wind-induced non-controlled responses on the wind tunnel, to allocate about 2 (cm) of the maximum displacement on the CTAC-based structural model, the adequate range of the averaged wind velocities of the semi-turbulent wind flow have been evaluated as from about 8.0 to about 10.0 (m/s). Accordingly, when the active control tests by using this CTAC-based structural model are executed on the wind tunnel, it may be reasonable the wind velocities which are justified to the range from about 8.0 to about 10.0 (m/s) are regarded as to be the upper limit for the standard input level by the tuning of the wind flow.

As the next, the wind-resistant active control tests are also examined under this tuning of the semi-turbulent wind flow which are supposed as to be about 8.0 (m/s) of the averaged wind velocity. As the active response controller, the external para-damping control method are also introduced on the multi-located active brace system. By evaluating the wind-resistant active control effects by the same conditions on the Study (3.2)-2, the external para-damping coefficient are introduced as $c_i^e = 0.03$ (kgf·s/cm), ($i = 1, 2, 3$). In which, those values of the external para-damping coefficients c_i^e are supposed as to be equal on every stories (namely, $c_1^e = c_2^e = c_3^e$). Fig.3.2.8 show the controlled displacements of the top floor on the experimental structural model. By comparing in this figure with Fig.3.2.7, it may be assured that the remarkable reductions of the responses can be observed as the wind-resistant response control effects by introducing the external para-damping control method. The RMS displacements (during 60 seconds) for the controlled and the non-controlled displacements of the top floors can be evaluated as to be about 0.147 and 0.308 (cm), respectively and it may be assured that the controlled responses can be reduced to about 48 % for the non-controlled-responses. And also, those wind-resistant control effects which are compared with the differences between the non-controlled responses and the controlled responses on the wind tunnel tests can be confirmed by the enough observableness from the human eyesights.

As concluding remarks in this section, the preliminary check of the CTAC system are operated for the two kinds of the typical environmental conditions for experimental studies (which are produced on the shaking table tests and the wind tunnel tests). Those preliminary examinations are introduced as the active control tests by using the external para-damping control method which is manipulated on the multi-located control devices of active brace type and the main purposes for those preliminary checks are put on the investigations of the adequate capacities of the CTAC system by every experimental conditions. For estimating those adequate capacities, the enough observableness from the human eyesights are also taken care as the significant items. Through those preliminary trials in this section, the procedures as the basic installations of the CTAC system may be regarded as to be completed and the following discussions in this study will be continued to the next stage which are approached to the applicative researches by utilizing CTAC system.

3. 3 Concluding remarks

Through the considerations in this chapter, the fundamental conditions which should be provided on the standard testing systems as the evaluative interfaces for the structural response control systems are discussed, and, under the conditions of experimental environments which are subjected to the authors' laboratory, the actual sequences to be practically developed the basic components of the CTAC system (which is proposed as the one of the concrete shapes of the standard evaluative testing apparatus) are introduced in detail.

In the Section 3.1, discussions are started from investigating for the fundamental concepts as that the standard evaluative testing systems can be essentially provided the actual accessibilities for the mutual benchmark evaluations and as that the explicit observableness of those evaluative tests can be reproduced on the standard evaluative testing systems. To practically consider for those concepts, the basic modelings of the targeted constructions are selected as the idealized lumped-mass type of the structural systems for the numerical simulations, and the experimental models are also designed as to be adequately emulated those numerical models. At the same time, the importance as that both of the observable responses of the targeted models and the observable manipulations of the additional controllers on the experimental apparatus can be explicitly and exactly evaluated, is pointed on the fundamental designs of the capacities of the standard evaluative testing systems. The further discussions as that the experimental facilities as like the shaking tables or the wind tunnels to imitate the environmental conditions (which are surrounding on the targeted structural systems are required as the additional components for standard evaluative testing systems) are also introduced. From those preparative considerations, the compactness and the portabilities of the CTAC system as that the experimental researches can be executed as the labor-saved operations are selected as the main developmental concepts, and the configurations and efficiencies of the CTAC system are concretely determined.

The preliminary checks of the CTAC system for the shaking table tests and the wind tunnel tests are executed in the Sections 3.2, and the adequate external input levels are examined by every two kinds of experimental tests. As the preliminarily installed active controllers for this aim, the external para-damping control method is introduced on the multi-located active brace type of the experimental attachments for the CTAC experimental system. Through the two kinds of the preliminarily experimental active control tests by using the same experimental structural model, the same additional control device and the same control algorithm, the standard external input levels by every typical environmental conditions for controlling the structural behaviors on the seismic-excited vibrations and the wind-induced vibrations are selected and prepared for the following experimental researches. Those actual quantities of the external input levels are determined from the view points as that both of the controlled and non-controlled behaviors (which are reproduced on the experimental structural model) can be explicitly and exactly observed on the CTAC system and as that those observableness (which are especially remarked as the control effects as to be specified by the differences between the controlled and non-controlled responses on the experimental structural model) can be also enable to be easily confirmed by the human eyesights.

As the summary of the discussions in this chapter, it is pointed that the basic developmental installations of the CTAC system may be taken a concrete shape by considering the following items.

(1) To actually operate the mutual benchmark evaluations, the standard evaluative testing systems are designed as to be satisfied the fundamental concepts as that both of the numerical and the experimental models are practically constructed as the equivalent systems and as that the experiment-based sub-systems are especially taken care for providing the enough reproducibilities and observableness to exactly evaluate for the control effects on the targeted structural control systems.

(2) As the further considerations for practically introducing the standard evaluative testing systems, it may be pointed that the enough discussions for the actual environmental conditions which are subjected by every researchers are requested, especially, the economical conditions by every researchers may be significantly affected to the decisions for the scale of the experimental apparatus for the standard evaluative testing system. In the common meanings as that the mutual benchmark evaluations can be actually operated, it seems that various scales of the standard evaluative testing systems may be enabled to produce. The CTAC system is produced as the one of the concrete shapes of the standard evaluative testing apparatus under the considerations for its compactness and its portability.

(3) The compactness and the portability of the CTAC system may be taken advantage to be able to operate the labor-saved experimental researches and to execute the human-scale maintenances for the testing apparatus. And the further merits, the CTAC-based experimental researches are produced under the considerations as that the observableness for the control effects on the targeted structural control systems can be explicitly confirmed from the human eyesights.

(4) By the preliminary checks of the CTAC system, when the shaking table tests are operated as the CTAC-based experimental evaluations, the allowable excitation levels are confirmed as to be limited to about 30 (cm/s^2) under the maximum capacities of this shaking table. By supposing this external input level, it may be confirmed that the control effects which are evaluated as the differences between the non-controlled responses and the controlled responses by using the external para-damping control method are explicitly observed by the human eyesights. In the following researches on the CTAC-based evaluations, this quantity of the external input levels are adopted as the standard ground acceleration for the aseismic active response control tests.

(5) By the preliminary checks of the CTAC system, when the wind tunnel tests are operated as the CTAC-based experimental evaluations, the wind velocities as that the non-controlled structural vibrations are effectually appeared for the observations the human eyesights are confirmed as to be allocated on about from 8.0 to 10.0 (m/s). Under those wind velocities, the control effects which are evaluated as the differences between the non-controlled responses and the controlled responses by using the external para-damping control method can be also explicitly observed by the human eyesights. In the following researches on the CTAC-based evaluations, those quantities

of the external input levels are adopted as the standard wind velocities for the wind-resistant active response control tests.

Under those preliminary discussions for developing the CTAC system, it seems that the basic installations to actually operate the mutual benchmark evaluations for the various kinds of the response control systems have been prepared. Namely, discussions may be reached to the starting point to operate the applicative researches by using the CTAC system. On the following two chapters, the investigations for the aseismic response control systems and the wind-resistant response control systems will be introduced and operated as the typical two kinds of the evaluative researches by applying the CTAC system. And also, the more effectual meanings of the mutual benchmark evaluations will be also discussed and assured on those actual utilizations of the CTAC system.

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4 Active Control on Structural Responses under Earthquake Disturbances

Most of optimal designs for aseismic active structural response control systems are synthesized as stabilized feedback controllers based on the solutions for regulator problems. The traditional optimal control method may be very attractive design technique for operating optimization of system performances which are supposed as both effects of response reductions and efforts of spending control forces by off-line. As a general installation, control performances of the controlled system are evaluated by introducing a linear quadratic index function in this method. In the mathematical meanings, those optimized systems may be warranted their stabilities under the assumptions that control devices for control manipulations can always supply the required control forces. However, from the practical view, unusual responses or manipulations may be allowed to organize those controlled systems, so that, ultimate structural deformations or unlimited device capacities are assumed in those considerations. Although there are a few practical buildings which are introduced active vibration control systems for earthquakes, the control devices installed on those buildings are almost designed as to stop their operations or as to supply saturated control forces under strong motions. Namely, as the one of the practical problems to be considered on constructions of aseismic response control systems, saturations of inputs or outputs for system behaviors may be pointed as the significant items when the strong seismic disturbances are supposed. This problem may be closely connected to the syntheses of the capacities of the control devices.

On the other hand, it seems that the most important notice for operating the aseismic response control is how to save structural deformations or accelerations evaluated as the maximum responses induced by earthquake disturbances during very short event time. In this sense, emphasis may be put on the importance that aseismic response control systems should be provided the efficiency to be able to cancel the future growth of structural vibrations caused by the present external inputs in addition to the efficiency to be able to reduce structural responses resulted from the past external disturbances. When the feed-forward controllers are supposed as to be able to cancel external disturbances without any spill-over, structural systems may be effectively isolated from the external inputs. However, the aseismic isolations may become possible only on the installations of the special equipments as like the base-isolators, because that the seismic motions acting on the basements of the structural systems may exist as the unavoidable and the uncontrollable resources of the external inputs. Namely, the general structural systems without the base-isolators may not be evadable from neither the subjections for the absolute displacements nor for the absolute accelerations of the basements caused by earthquakes. By considering those subjections, it may be appeared that the purpose for the installations of the aseismic response controllers is reached to the syntheses of the trade-off performances between the reductions of the inter-story displacements and the reductions of the absolute accelerations.

At this point, even if only the optimal feedback controllers are installed on the structural system, it may be considered to be explicitly attractive that the response controller can provide the efficiency as to cancel the influences from the external inputs, because that the external inputs may always disturb the effects of the actualized control forces produced via the optimal feedback controllers. Namely, the advantageous of the installations of the on-line evaluations for the external inputs may be appeared as the additional efficiency for the aseismic response controllers. However, as the practical importance when the limited capacities of the control devices are considered, it may be pointed that the installations of the additional feed-forward controllers as to be able to only cancel the external inputs may not be enough, because the earthquake disturbances may be regarded as to be unforecastable and the required control forces may not be actualized under the limitations of the device capacities. Accordingly, when the saturations of those additional feed-forward controllers are considered, the another kind of operations may be required as to be able to make the influences caused from the external disturbances 'remove adequately'. For this aim, the requirement of the expanded optimal controllers which can optimize the predicted responses of the system by on-line may be suggested.

In this chapter, from the considerations for those practical problems to be established on the aseismic response control system (possibilities of the strong ground motions may not be evaded in the essential sense of 'aseismic response control'), a 'quasi-optimizing control method' is proposed and evaluated as a new active control algorithm. As the fundamental instructions of the quasi-optimizing control method, sets of the discretized control forces are introduced as to be replaced to the continuous control forces based on the concept of feedback or feed-forward gains. Namely, since the pre-provided control forces for the quasi-optimizing control method are supposed as the limited number of the trials by discretizations of the control forces, predictions of the controlled structural responses can be easily installed on the digital computations. Moreover, the saturation problems of the control forces may be automatically avoided, because that the pre-provided control forces can be synthesized under considerations of device capacities. The fundamental compositions of the quasi-optimizing control method are described in the Section 4.1 and the stability problems for this new control method are also discussed in this section. The basic installations and applications of quasi-optimizing control method are investigated in the Section 4.2 and the Section 4.3. From those investigations, the three-stories of the CTAC standard structural model which is installed three inter-story active braces is used as the evaluative system. The estimations for the arrangements of the device capacities to operate effective control performances by introducing the quasi-optimizing control method are discussed in the Section 4.4. As the final step of those investigations for the quasi-optimizing control method, the effective syntheses of the discrete trial control forces are discussed in the Section 4.5.

Those evaluative studies are mainly executed through numerical simulations, because that this newly proposed control method are introduced as the digital computer-based control algorithm and that most of evaluations may be regarded as to be suitable to the parametric studies. To make sure evaluative results from those numerical simulations and to point out the practical problems for applications, experimental tests are also additionally executed. On those investigations in this chapter, the quasi-optimizing control method may be constructed and verified as to be able to provide the enough efficiencies as the practical programming algorithm for aseismic response control systems of building structures.

4. 1 Active control algorithm based on installation of discrete control forces

Occurrences of earthquakes can not be deterministically predicted for the future, so that, aseismic response controllers installed on building structures have to deal with the unforecastable external disturbances. Main purpose of response controls for building structures may be reached to regulator problems, namely, it may be placed as to attenuate structural vibrations (which was caused by the past external disturbances) into stabilized stational states efficiently. Any kinds of feedback controllers are synthesized as to provide 'optimal' damping effects which regulate dynamics of controlled systems without any excitations from any 'initial' conditions. In which, the word of 'optimal' damping effects may mean that efficiencies of some systems goes along with some purposes or penalties imposed by some engineering designers, the most suitably, and the word of 'initial' conditions may mean states of some systems at some time instance which were caused by any external inputs at the past. Each of those feedback controllers may be called as an 'optimal' controller (in the engineering meanings) from the point that the effects of those controllers can warrant the 'optimal' path on the prospected dynamics of the systems under assumptions that no external inputs will be invaded in the future.

However, from the view of the practical sense, it may be clear that external inputs by earthquakes cause some gaps from the 'optimal' path expected in those systems. Although this problem may be solved if feed-forward controller which can be provided with the efficiency to cancel external inputs completely is introduced along with 'optimal' feedback controllers, such kinds of controllers can not be synthesized for the unforcastable external disturbances. Because, capacities of control devices are limited in the practical sense and complete cancellations of the external inputs may not be warranted. Accordingly, when partial cancellations of the external inputs are operated by the additional feed-forward controllers, in order to estimate whether control performances of the whole systems will be improved or deteriorated by comparing with the original system (which is only installed the feedback controllers), it may be required that the future results of structural behaviors should be predicted by on-line. Because, the external inputs induced by seismic excitations (and also the feed-forward control forces which is established as to be subjected by those external inputs) are not forecastable and deterministic by off-line.

On the other hand, when modelings of structural systems can be expressed as comparatively exact accounts, structural responses which are caused by earthquake disturbances may be predicted for the short-ranged future as to be provided the enough precision in the sense of engineering strictness. By introducing numerical integrations which are supported on calculations by digital computers and which are based on observations of the external inputs via sensors, it may be considered that the structural behaviors in closed futures (which are resulted from some external inputs induced by earthquakes) can be estimated by on-line. At the same time, when some control forces based on some rules are pre-determined, the short-ranged future responses which are resulted from some internal inputs supplied by controllers may be also predicted. So that, it may be regarded that computer-based active structural response control systems can be constructed as to evaluate for the short-ranged future results from both external and internal inputs by considering those conditions. However, it may be remained as the practical problem what kinds of control forces should be selected. Although computer-based controllers can calculate every short-ranged future controlled responses for any kinds of internal inputs by numerical integrations and can also deal with the cases which can not solve analytically, it may not be practical to simulate unlimited cases of control inputs. So that, control inputs should be selected on some limited conditions which are pre-provided as some patterns of inputs based on some rules. To operate digital computer-based active control by estimating for the structural responses predicted by on-line, it may be reasonable that some set of limited discrete control forces are selected and that the finite numbers of the short-ranged future responses for those pre-provided patterns of the control inputs are simulated by the digital computer at every control time instances.

As the last considerations, it is pointed the importance how to estimate and determine the best pattern of control input among various patterns to practice the best one of the simulated short-ranged future responses. To solve this problem, it is required to introduce some penalty index function to compare or evaluate every predicted responses related to every patterns of control forces. So that, controlled responses or control performances may be synthesized and subjected by some indexes as going along with some purposes or penalties supposed by some engineering designers. From the reflections for those suggestions to construct practical aseismic response control systems, a basic framework of a new type of active response control method may be appeared. Conditions to be considered on this new aseismic active control method are enumerated as follows :

Condition-1) Structural responses and external inputs should be observable by sensors at any time instance as to be able to support the initial conditions on the on-line computations for the response predictions.

Condition-2) Internal models and explicit transitional descriptions which are expressed for the system states on the discrete time conditions should be provided to compute and simulate the short-ranged future responses of controlled systems by numerical integrations.

Condition-3) Limited numbers of discrete control forces by every control devices should be pre-provided to extract limited kinds of controlled futures of the systems which are predicted by computing on the indicated internal model.

Condition-4) To select the best one of the discrete control forces as the practical manipulation, a penalty index which can optimize and extract the most adequate future possibility among the choices of the future controlled performances (which are predicted on the internal model) should be synthesized.

By concretely assembling those conditions, the fundamental compositions of the new aseismic active control method are proposed. At first, as the introduction of this new type of the active control method, the Condition-1 and the Condition-2 mentioned above are considered and investigated. When an n degrees-of-freedom structural system equipped with r of control devices is supposed, equation of motion for this system is expressed as,

$$[M]\{\ddot{q}\} + [C]\{\dot{q}\} + [K]\{q\} = [W]\{w\} + [U]\{u\} \,, \tag{4.1.1}$$

in which, $\{q\}$ means a generalized parameter to define displacements of the system, $[M]$, $[C]$ and $[K]$ mean mass, damping and stiffness matrices, respectively, $\{w\}$ and $\{u\}$ mean external inputs (which are corresponding to external disturbances) and internal inputs (which are corresponding to control forces) , respectively, and $[W]$ and $[U]$ are determined as the arrangement matrices which are related to external and internal inputs for the system coordinate, respectively. When supposing the external inputs vector $\{w\}$ and the arrangement matrix of external inputs $[W]$ as corresponding to earthquake motions, those can be expressed by using the ground motion $\ddot{x}_0$ as,

$$\{w\} = \ddot{x}_0[M]\{\mathbf{1}\} \,,\ [W] = [I], \tag{4.1.2}$$

in which, $\{\mathbf{1}\}$ means a vector having unit quantities in all components and $[I]$ means an unit matrix. Let $\{X\}$ denote a state vector having $2 \times n$ components as,

$$\{X\} = \{q^T\, \dot{q}^T\}^T \,. \tag{4.1.3}$$

The equation of motion of this system can be described as a following expression by introducing the state vector.

$$\{\dot{X}\} = [A]\{X\} + [B]\{u\} + [D]\{w\} \,,$$

$$[A] = \begin{bmatrix} \mathbf{0} & \boldsymbol{I} \\ -\boldsymbol{M}^{-1}\boldsymbol{K} & -\boldsymbol{M}^{-1}\boldsymbol{C} \end{bmatrix},\ [B] = \begin{bmatrix} \mathbf{0} \\ \boldsymbol{M}^{-1}\boldsymbol{U} \end{bmatrix},\ [D] = \begin{bmatrix} \mathbf{0} \\ \boldsymbol{M}^{-1}\boldsymbol{W} \end{bmatrix}, \tag{4.1.4}$$

in which, $[A]$, $[B]$ and $[D]$ are state matrices defined from mass, damping and stiffness of the system, and arrangements of inputs. The difference equation of this system during discrete sampling time Δt_s from the time of $t_s = s\Delta t_s$ (where Δt_s means a discrete sampling time interval and s is an integer number) is expressed as follows,

$$\{X(t_{s+1})\} = [A^d]\{X(t_s)\} + [B^d]\{u(t_s)\} + [D^d]\{w(t_s)\} \,,$$

$$[A^d] = \boldsymbol{\Phi}(\Delta t_s) = \exp(A\Delta t_s) \,,$$

$$[B^d] = [A]^{-1}[\boldsymbol{\Phi}(\Delta t_s) - I][B] \,,\ [D^d] = [A]^{-1}[\boldsymbol{\Phi}(\Delta t_s) - I][D] \,, \tag{4.1.5}$$

in which, $\boldsymbol{\Phi}(\Delta t_s)$ means the transition matrix of the state of the system during discrete sampling time Δt_s . So that, the transition of the state of system from t_s to t_{s+1} can be expressed by using the state of the system and the external and the internal inputs as the initial states. For the formulation of Eqs. (4.1.5), it is assumed that the independent quantities for the state of the system (external and internal inputs) are held as the constant value during discrete sampling time Δt_s from the time instance of t_s . To operate prediction for the short-ranged future responses of the system by using digital computer, the transition matrix in Eqs. (4.1.5) should be approximately calculated as the numerical solution by using expansion of series. From the point of convenience for computer programming, it may be reasonable to introduce traditional numerical integration techniques (which may be provide the enough accuracy in engineering meanings) for computing transition of the state of the system. For this aim, *Newmark*'s β method is introduced as an approximate expression for the state transition of system in Eqs. (4.1.5). The state transition of the system is represented by using *Newmark*'s β method as follows,

$$\{\bar{\boldsymbol{X}}(t_{s+1})\} = [\bar{\boldsymbol{A}}]\{\boldsymbol{X}(t_s)\} + [\bar{\boldsymbol{B}}]\begin{Bmatrix} \boldsymbol{U}\,\boldsymbol{u}(t_{s+1}) \\ \boldsymbol{U}\,\boldsymbol{u}(t_s) \end{Bmatrix} + [\bar{\boldsymbol{D}}]\begin{Bmatrix} \boldsymbol{W}\,\boldsymbol{w}(t_{s+1}) \\ \boldsymbol{W}\,\boldsymbol{w}(t_s) \end{Bmatrix},$$

$$[\bar{\boldsymbol{A}}] = \begin{bmatrix} \bar{\boldsymbol{A}}_{11} & \bar{\boldsymbol{A}}_{12} \\ \bar{\boldsymbol{A}}_{21} & \bar{\boldsymbol{A}}_{22} \end{bmatrix},$$

$$\begin{aligned}
\bar{\boldsymbol{A}}_{11} &= \boldsymbol{\Omega}^{-1}\,[\boldsymbol{\Omega} - \{(\Delta t_s^2/2)\,\boldsymbol{M} + (1/4-\beta)\Delta t_s^3\,\boldsymbol{C}\}\boldsymbol{\Lambda}]\,,\\
\bar{\boldsymbol{A}}_{12} &= \boldsymbol{\Omega}^{-1}\,[\Delta t_s\,\boldsymbol{M} - \{(1/4-\beta)\,\Delta t_s^3\,\boldsymbol{C}\}\boldsymbol{\Gamma}]\,,\\
\bar{\boldsymbol{A}}_{21} &= -\boldsymbol{\Omega}^{-1}\,[\{\Delta t_s\,\boldsymbol{M} + (1/4-\beta)\,\Delta t_s^3\,\boldsymbol{K}\}\boldsymbol{\Lambda}]\,,\\
\bar{\boldsymbol{A}}_{22} &= \boldsymbol{\Omega}^{-1}\,[\boldsymbol{\Omega} - \{(\Delta t_s^2/2)\,\boldsymbol{M}\}\boldsymbol{\Lambda} - \{\Delta t_s\,\boldsymbol{M} - (1/4-\beta)\,\Delta t_s^3\,\boldsymbol{K}\}\boldsymbol{\Gamma}]\,,
\end{aligned}$$

$$[\bar{\boldsymbol{B}}] = [\bar{\boldsymbol{D}}] = \begin{bmatrix} -\,\beta\,\Delta t_s^2\,\boldsymbol{\Omega}^{-1} & -\boldsymbol{\Omega}^{-1}\,\{(1/2-\beta)\Delta t_s^2\,\boldsymbol{M} + (1/4-\beta)\Delta t_s^3\,\boldsymbol{C}\}\boldsymbol{M}^{-1} \\ -\,(\Delta t_s/2)\,\boldsymbol{\Omega}^{-1} & -\boldsymbol{\Omega}^{-1}\,\{(\Delta t_s/2)\,\boldsymbol{M} + (1/4-\beta)\Delta t_s^3\,\boldsymbol{C}\}\boldsymbol{M}^{-1} \end{bmatrix}, \quad (4.1.6)$$

in which,

$$\boldsymbol{\Omega} = \boldsymbol{M} + (\Delta t_s/2)\,\boldsymbol{C} + \beta\,\Delta t_s^2\,\boldsymbol{K}\,,\quad \boldsymbol{\Lambda} = \boldsymbol{M}^{-1}\boldsymbol{K}\,,\quad \boldsymbol{\Gamma} = \boldsymbol{M}^{-1}\boldsymbol{C}\,.$$

In Eqs. (4.1.6), notation over-bar ($\bar{\ }$) means approximate quantity. Sampling interval Δt_s is very short, so, it may not be hindered on assuming that $\boldsymbol{u}(t_{s+1})$ and $\boldsymbol{w}(t_{s+1})$ are equal to the initial condition $\boldsymbol{u}(t_s)$ and $\boldsymbol{w}(t_s)$, respectively, from the engineering view. When short-ranged future responses by every sampling interval Δt_s are computed on the internal model represented by Eqs. (4.1.6), predicted responses may include some numerical errors which is caused by approximations. However, those numerical errors may be negligible during very short time ranges. Because, by installing sensors which can measure the state of the system and external inputs at every sampling time steps and by renewing initial conditions of the internal model into exact values from observing in the external model at every sampling instances, those numerical errors may not be accumulated, also, if sampling interval Δt_s is enough small, numerical stabilities of solution for predicted response may be warranted.

As the next step based on the Condition-3, it is required to execute some trial control manipulations on the computer for proposing some meshed representatives among unlimited possibilities distributed in controlled future state space. For this aim, limited numbers of trial control forces by every control devices should be pre-provided. Trial control forces should be selected and synthesized carefully as to be able to pick up promising future possibilities. Let control forces of j-th device assume to be limited into N_j kinds of trial control forces. Those trial control forces can be expressed as 'set' to be provided for each control device, such as $<\hat{u}_j>$ for the

j-th device (where the notation $<\cdot>$ represents a set).

$$<\hat{u}_j> = <\hat{u}_{j,1}, \cdots, \hat{u}_{j,N_j}>, \quad (j = 1, 2, \cdots, r), \tag{4.1.7}$$

in which,

$$u_{min,j} \leq \hat{u}_{j,a_j} \leq u_{max,j}, \quad (a_j = 1, 2, \cdots, N_j).$$

$u_{min,j}$ and $u_{max,j}$ mean the minimum and the maximum values of trial control forces of the j-th device, so, when those values are synthesized as to be allocated within the capacity of each device, any spillover of control forces may not exist. Any one of trial control force vector $\{\hat{\boldsymbol{u}}\}$ can be composed by choosing one by one for each set of trial control forces as to cover every control devices. So that, let any one of the trial control force chosen for the j-th device denote $\hat{u}_j$, the set of trial control force vectors can be expressed as follow,

$$< \{\hat{\boldsymbol{u}}\} > = < \{\hat{u}_1, \cdots, \hat{u}_r\}^T >, \tag{4.1.8}$$

in which, all components of the set of trial control force vectors are consisted by all combinations from the sets of trial control forces to cover every control devices. So that, the total components included in the set of trial control force vectors are counted as,

$$S(r) = \prod_{j=1}^{r} N_j \ . \tag{4.1.9}$$

By computing those $S(r)$ kinds of trial manipulations of control on the internal model expressed in Exps. (4.1.6), the set of predicted responses $< \{\hat{\boldsymbol{X}}(t_{s+1}, \hat{\boldsymbol{u}})\} >$ (which also has $S(r)$ kinds of components) may be proposed as limited future possibilities, in which, $\{\hat{\boldsymbol{X}}(t_{s+1}, \hat{\boldsymbol{u}})\}$ means any one of state of the system predicted after sampling time interval Δt_s from the time of t_s.

As the last step based on the Condition-4, optimizing procedure should be operated for the predicted states of the system. The best one of the future possibility may be chosen by introducing the penalty index which is synthesized to improve performances of the controlled system. However, it is very difficult to provide systematically the penalty indexes as going along with some purposes or penalties supposed by some engineering designers. To solve this problem the concepts of quadratic index function indicated in the traditional optimal control method may supposed some clue. To introduce optimization of quadratic index function is very attractive on the point to be able estimate for state of system expressed in vector space by translating into scalar quantities, so that, the scales indicated by quadratic index function can be used systematically as a ruler to estimate for controlled system performances. So, as the penalty index at the sampling time instance t_s, the following expression is introduced.

$$\hat{J}(\{\hat{\boldsymbol{X}}(t_{s+1}, \hat{\boldsymbol{u}})\}) = \{\hat{\boldsymbol{X}}(t_{s+1}, \hat{\boldsymbol{u}})\}^T[\boldsymbol{Q}]\{\hat{\boldsymbol{X}}(t_{s+1}, \hat{\boldsymbol{u}})\} + \{\hat{\boldsymbol{u}}\}^T[\boldsymbol{R}]\{\hat{\boldsymbol{u}}\}, \tag{4.1.10}$$

in which, $\hat{J}(\{\hat{\boldsymbol{X}}(t_{s+1}, \hat{\boldsymbol{u}})\})$ means any one of penalty index which is corresponded to the one of the predicted response $\{\hat{\boldsymbol{X}}(t_{s+1}, \hat{\boldsymbol{u}})\}$. Since the penalty indexes are defined as a set of $S(r)$ kinds of discrete components, the set of those penalty indexes $<\hat{J}(\{\hat{\boldsymbol{X}}(t_{s+1}, \hat{\boldsymbol{u}})\})>$ are named a 'digital-index function'. In Eq. (4.1.10), $[\boldsymbol{Q}]$ and $[\boldsymbol{R}]$ mean the weight matrices concerning to the state of the system and control inputs, respectively, $[\boldsymbol{Q}]$ is defined as positive definite matrix, and $[\boldsymbol{R}]$ is defined as semi-positive definite matrix. Those constants may be tuned for synthesizing controlled performances of the system according to some purposes indicated by system engineers. Optimization procedures are operated by finding out the minimum value of penalty indexes for the digital-index function, namely,

$$\hat{J}^*(\{\hat{\boldsymbol{X}}^*(t_{s+1},\hat{\boldsymbol{u}}^*)\}) = Min \ < \hat{J}(\{\hat{\boldsymbol{X}}(t_{s+1},\hat{\boldsymbol{u}})\}) > , \tag{4.1.11}$$

in which, $\{\hat{\boldsymbol{X}}^*(t_{s+1},\hat{\boldsymbol{u}}^*)\}$ is resulted best one of the future state of the system, as the most adequate control force vector, $\{\hat{\boldsymbol{u}}^*\}$ is determined as the practical control force vector to supply on the external system. Those presented control procedures are named a 'quasi-optimizing control method' by means that the controlled future are selected from limited number of meshed representatives for future responses of the system. Through those consideration, this newly proposed quasi-optimizing method may be regarded very convenient for synthesizing practical system based on installation of digital computer.

As the further considerations, stability of the system should be discussed to warrant the reliability of controlled systems. When some conditions are satisfied at the basic stage of system syntheses, stability of the controlled system by installing quasi-optimizing control method can be warranted. Those conditions or assumptions are described as the following four items :

Assumption-1) Numerical errors included in the predicted responses which are computed by using internal model expressed as Exps. (4.1.6) have to be regarded as omissible and insignificant order, so that, those errors can be far smaller than the another latent errors which can not be avoided from limitations of the engineering accuracy mixed up on the practical system syntheses or constructions.

Assumption-2) Original system which is not installed quasi-optimizing controller is warranted its stability in the sense of *Lyapunov*. In which, some stabilized system which are controlled by the another controllers except the quasi-optimizing controller are included in the sense of the original system, in those cases, the quasi-optimizing controller may be placed as the additional sub-system of controllers.

Assumption-3) The sense of stability of the controlled system can be defined only under conditions which is supposed no external inputs in the future from some time instance, so that, when states of the system are disturbed by some external inputs at some time instance and are transferred to some state, stability of the controlled system are warranted for the infinite future without external inputs from beginning at this transferred states of the system as the initial states.

Assumption-4) Stability of quasi-optimizing controller can be warranted as the parasitic conditions which are borrowed from the original system satisfied the Assumption-2. For this aim, the one of the trial control force vector should be selected as zero vector to stabilize of quasi-optimizing controller.

Under those conditions or assumptions, stabilities of the system installed the quasi-optimizing control method can be explained as the parasitic stabilities in the sense of *Lyapunov*.

At first, let $\{\boldsymbol{X}(t_s)\}$ denote as the exact values of the state of the system at the time instance $t_s = s\Delta t_s$. $\{\boldsymbol{X}(t_s)\}$ can be gained as observed value by sensors, and those values are subjected by the following relations when the controlled system are expressed as Exps. (4.1.5).

$$\{\boldsymbol{X}(t_s)\} = [\boldsymbol{A}^d]\{\boldsymbol{X}(t_{s-1})\} + [\boldsymbol{B}^d]\{\boldsymbol{u}(t_{s-1})\} + [\boldsymbol{D}^d]\{\boldsymbol{w}(t_{s-1})\}\ . \tag{4.1.12}$$

So that, $\{\boldsymbol{X}(t_s)\}$ mean the hysteretic values which are resulted from the past states of the system, control inputs and external inputs subjected by the time instance t_s. When the control inputs at the time instance t_s are gained and no external inputs are exist after this instance, $\{\boldsymbol{X}(t_s)\}$ are enough information to predict future behavior of the system and can be used as initial conditions of the system. Future responses at the time of t_{s+1} which are computed by using internal model as Exps. (4.1.6) , under the consideration to the Assumption-3, can be expressed as follow,

$$\{\bar{\boldsymbol{X}}(t_{s+1})\} = [\bar{\boldsymbol{A}}]\{\boldsymbol{X}(t_s)\} + [\bar{\boldsymbol{B}}]\begin{Bmatrix} \boldsymbol{U}\,\boldsymbol{u}(t_{s+1}) \\ \boldsymbol{U}\,\boldsymbol{u}(t_s) \end{Bmatrix}, \tag{4.1.13}$$

Control inputs which are supplied at the time instance t_s are held as the same value until the next sampling time t_{s+1} and $\{\boldsymbol{u}(t_{s+1})\}$ are defined at the time instance t_{s+1}, so that, $\{\boldsymbol{u}(t_{s+1})\}$ can be regarded as equal to $\{\boldsymbol{u}(t_s)\}$ in Eq. (4.1.13). In which, by introducing the representation $\{\boldsymbol{X}(t_s)\} = \{\boldsymbol{X}(s)\}$ and $\{\boldsymbol{u}(t_s)\} = \{\boldsymbol{u}(s)\}$, Eq. (4.1.13) can be expressed as the function of s and $\{\boldsymbol{u}(s)\}$ as follows,

$$\{\bar{\boldsymbol{X}}(s+1, \boldsymbol{u}(s))\} = [\tilde{\boldsymbol{A}}]\ \{\boldsymbol{X}(s)\} + [\tilde{\boldsymbol{B}}]\ \{\boldsymbol{U}\,\boldsymbol{u}(s)\}\ ,$$

$$[\tilde{\boldsymbol{A}}] = [\bar{\boldsymbol{A}}]\ ,\quad [\tilde{\boldsymbol{B}}] = \begin{bmatrix} -\boldsymbol{\Omega}^{-1}\{\beta\,\Delta t_s^2\,\boldsymbol{I} + (1/2-\beta)\Delta t_s^2\,\boldsymbol{M} + (1/4-\beta)\Delta t_s^3\,\boldsymbol{C}\}\boldsymbol{M}^{-1} \\ -\boldsymbol{\Omega}^{-1}\{\,(\Delta t_s/2)\,\boldsymbol{I} + (\Delta t_s/2)\,\boldsymbol{M} + (1/4-\beta)\Delta t_s^3\,\boldsymbol{C}\}\boldsymbol{M}^{-1} \end{bmatrix}. \tag{4.1.14}$$

In Eqs. (4.1.14), $\{\boldsymbol{u}(s)\}$ is any one of the trial control force vector which is defined as Exp. (4.1.8). By using the Assumption-4, the one of the pre-provided trial control force vector should be equal to zero vector. When the zero vector is selected as the trial control force vector, namely, $\{\boldsymbol{u}(s)\} = \{\boldsymbol{0}\}$, one of the predicted response is expressed as follow,

$$\{\bar{\boldsymbol{X}}(s+1, \boldsymbol{0})\} = [\tilde{\boldsymbol{A}}]\ \{\boldsymbol{X}(s)\}\ . \tag{4.1.15}$$

On the other hand, the predicted response corresponding to the practical control force vector which is selected as the most adequate control force vector $\{\boldsymbol{u}^*(s)\}$ can be expressed as follow,

$$\{\bar{\boldsymbol{X}}(s+1, \boldsymbol{u}^*(s))\} = [\tilde{\boldsymbol{A}}]\ \{\boldsymbol{X}(s)\} + [\tilde{\boldsymbol{B}}]\ \{\boldsymbol{U}\,\boldsymbol{u}^*(s)\}\ . \tag{4.1.16}$$

The quasi-optimizing control method may warrant the following condition through optimization procedures by finding out the minimum value of penalty indexes for the digital-index function mentioned as Exp. (4.1.10) and Exp. (4.1.11).

$$\begin{aligned}
&\{\bar{\boldsymbol{X}}(s+1,\boldsymbol{u}^*(s))\}^T[\boldsymbol{Q}]\{\bar{\boldsymbol{X}}(s+1,\boldsymbol{u}^*(s))\}\\
&\qquad\le \{\bar{\boldsymbol{X}}(s+1,\boldsymbol{u}^*(s))\}^T[\boldsymbol{Q}]\{\bar{\boldsymbol{X}}(s+1,\boldsymbol{u}^*(s))\}+\{\boldsymbol{U}\boldsymbol{u}^*(s)\}^T[\boldsymbol{R}]\{\boldsymbol{U}\boldsymbol{u}^*(s)\}\\
&\qquad\le \{\bar{\boldsymbol{X}}(s+1,\boldsymbol{0})\}^T[\boldsymbol{Q}]\{\bar{\boldsymbol{X}}(s+1,\boldsymbol{0})\}\,. \qquad (4.1.17)
\end{aligned}$$

In which, let the following function $V(\bar{\boldsymbol{X}}(s+1,\boldsymbol{u}^*(s)))$ denote as possibility for the *Lyapunov* function.

$$V(\bar{\boldsymbol{X}}(s+1,\boldsymbol{u}^*(s)))=\{\bar{\boldsymbol{X}}(s+1,\boldsymbol{u}^*(s))\}^T[\boldsymbol{Q}]\{\bar{\boldsymbol{X}}(s+1,\boldsymbol{u}^*(s))\}\ \ge 0\,, \qquad (4.1.18)$$

in which, since $[\boldsymbol{Q}]$ is provided as the positive definite, $V(\bar{\boldsymbol{X}}(s+1,\boldsymbol{u}^*(s)))$ has non-negative values and $V(\bar{\boldsymbol{X}}(s+1,\boldsymbol{u}^*(s)))=0$ can be only existed when $\{\bar{\boldsymbol{X}}(s+1,\boldsymbol{u}^*(s))\}$ is equal to $\{\boldsymbol{0}\}$. The difference of $V(\bar{\boldsymbol{X}}(s+1,\boldsymbol{u}^*(s)))$ are defined as follow.

$$\Delta V(\bar{\boldsymbol{X}}(s+1,\boldsymbol{u}^*(s)))=V(\bar{\boldsymbol{X}}(s+1,\boldsymbol{u}^*(s)))-V(\bar{\boldsymbol{X}}(s,\boldsymbol{u}^*(s-1)))\,. \qquad (4.1.19)$$

By using Eq. (4.1.18), Eq. (4.1.19) can be rewritten as,

$$\begin{aligned}
\Delta V(\bar{\boldsymbol{X}}(s+1,\boldsymbol{u}^*(s)))&=\{\bar{\boldsymbol{X}}(s+1,\boldsymbol{u}^*(s))\}^T[\boldsymbol{Q}]\{\bar{\boldsymbol{X}}(s+1,\boldsymbol{u}^*(s))\}\\
&\quad-\{\bar{\boldsymbol{X}}(s,\boldsymbol{u}^*(s-1))\}^T[\boldsymbol{Q}]\{\bar{\boldsymbol{X}}(s,\boldsymbol{u}^*(s-1))\}\,. \qquad (4.1.20)
\end{aligned}$$

By comparing the first term of the right side in Eq. (4.1.20) with the Exp. (4.1.17), the following relations can be gained.

$$\begin{aligned}
\Delta V(\bar{\boldsymbol{X}}(s+1,\boldsymbol{u}^*(s)))&\le\{\bar{\boldsymbol{X}}(s+1,\boldsymbol{0})\}^T[\boldsymbol{Q}]\{\bar{\boldsymbol{X}}(s+1,\boldsymbol{0})\}\\
&\quad-\{\bar{\boldsymbol{X}}(s,\boldsymbol{u}^*(s-1))\}^T[\boldsymbol{Q}]\{\bar{\boldsymbol{X}}(s,\boldsymbol{u}^*(s-1))\}\,. \qquad (4.1.21)
\end{aligned}$$

From the consideration for the Assumption-1, $\{\bar{\boldsymbol{X}}(s,\boldsymbol{u}^*(s-1))\}$ which is appeared in the second term of the right side in Exp. (4.1.21) can be regarded as equal to $\{\boldsymbol{X}(s)\}$. Moreover, by comparing the first term of the right side in Exp. (4.1.21) with the Eq. (4.1.15), the following relations can be gained.

$$\begin{aligned}
\Delta V(\bar{\boldsymbol{X}}(s+1,\boldsymbol{u}^*(s)))&\le\{\boldsymbol{X}(s)\}^T[\tilde{\boldsymbol{A}}^T\boldsymbol{Q}\tilde{\boldsymbol{A}}]\{\boldsymbol{X}(s)\}-\{\boldsymbol{X}(s)\}^T[\boldsymbol{Q}]\{\boldsymbol{X}(s)\}\\
&=\{\boldsymbol{X}(s)\}^T[\tilde{\boldsymbol{A}}^T\boldsymbol{Q}\tilde{\boldsymbol{A}}-\boldsymbol{Q}]\{\boldsymbol{X}(s)\}\,. \qquad (4.1.22)
\end{aligned}$$

In which, let the matrix $[\boldsymbol{G}]$ denote as,

$$-\boldsymbol{G}=\tilde{\boldsymbol{A}}^T\boldsymbol{Q}\tilde{\boldsymbol{A}}-\boldsymbol{Q}\,. \qquad (4.1.23)$$

When the matrix $[\boldsymbol{G}]$ can be presented as the positive definite matrix, the following conditions can be satisfied.

$$\Delta V(\bar{\boldsymbol{X}}(s+1,\boldsymbol{u}^*(s)))\ \le\ 0. \qquad (4.1.24)$$

By explanations of the relation of Exp. (4.1.18) and Exp. (4.1.24), $V(\bar{X}(s+1, \boldsymbol{u}^*(s)))$ can be satisfied the condition as to be the *Lyapunov* function which can warrant the stability of the controlled system in the sense of *Lyapunov*. In which, it is very convenient that the conditions for the weight matrix of the control inputs [$\boldsymbol{R}$] is not appeared in the constraint for system syntheses to related for the matrix [$\boldsymbol{G}$] presented as Exp. (4.1.23), so that, when the zero vector is provided in the set of the trial control force vectors, the another components of the trial control force vectors can be selected as any kinds of control forces vectors, by only requiring that [$\boldsymbol{R}$] is provided as semi-positive definite matrix. However, this has only meaning for the discussions of the stability of the system, so, the another consideration for the syntheses of the weight matrix of the control inputs [$\boldsymbol{R}$] may be required to investigate control performances.

To obtain the relation of Exp. (4.1.24), the assumption which is described in the Assumption-3 is very important, because, when stability of the original system can not be warranted, the relation in Exp. (4.1.17) can not be obtained. All discussions mentioned for the stability of the quasi-optimizing controller may be worthful only when the quasi-optimizing controller is installed on the stabilized original system. So, the 'parasitic stability' may be proposed as the concepts instead of the word corresponding to 'stability' of controlled system and the 'rectification' may be proposed as the concepts instead of the word corresponding to 'stabilization' of system for the syntheses of the quasi-optimizing method, since definitions of the 'stability' or the 'stabilization' in those discussions are different from the general meaning of those words.

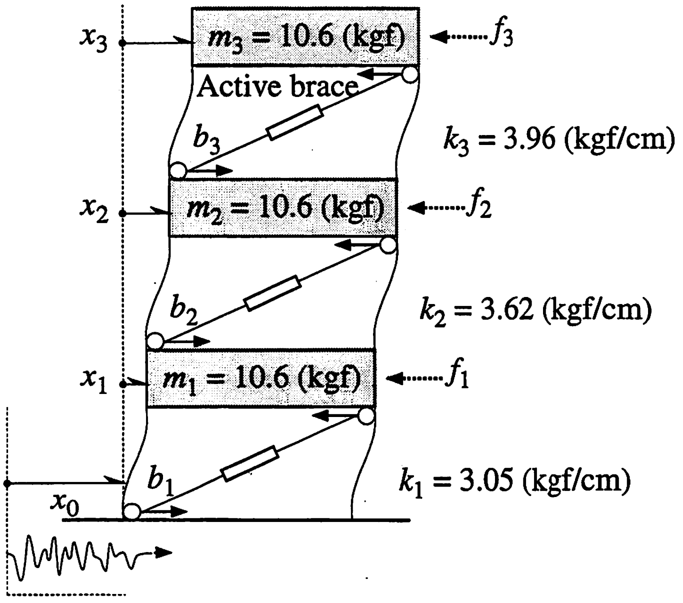
As concluding remarks of this section, concepts to introduce active control algorithm based on installation of discrete control force are discussed. The fundamental view of the quasi-optimizing control method is proposed as a new type of aseismic structural response control method. And also, general compositions and expressions of the quasi-optimizing control method are described. Moreover, to warrant the 'stability' of controlled system which is installed the quasi-optimizing controller, some important conditions are introduced. The syntheses for the quasi-optimizing control method are discussed to warrant the stability of the controlled system in the sense of *Lyapunov* by using proposed conditions and the new concepts of the 'parasitic stability'.

4. 2 Evaluated structural model and control installation of quasi-optimizing method

To assure the effectiveness of the quasi-optimizing control method as the aseismic active structural response control algorithm, numerical simulations and experimental tests are executed. A three degrees-of-freedom system which is installed three active brace devices in every stories is adopted (as shown in Fig. 4.2.1). Structural properties of this testing system are shown in this figure and those constants are approximately adjusted to the survey values of the experimental model of the CTAC which is proposed as the standard compact testing apparatus for active structural response control system (as described in the Chapter 3). Through the following studies, El Centro (1940) NS is used as the standard input of ground motions. As the standard input level according to the scale of the structural model, this wave record is scaled down to the maximum acceleration amplitude of 30 (cm/s^2) during the first part of 30 seconds. When it is required comparative studies for the another kind of ground motion, JMA-Kobe (1995) NS are also used by supplements.

Table 4.2.1 Dynamic properties of the structural model.

	Natural periods (s)	Damping ratio
1st	0.80	0.5 (%)
2nd	0.28	-
3rd	0.19	-



x_0 : Displacement (Basement),
x_i : Displacement,

b_i : Control force, (Inter-story force),
f_i : Control force, (Body force),

m_i : Mass,
k_i : Stiffness,

(i = 1, 2, 3).

Fig. 4.2.1 Structural model arranged the active braces.

Natural periods of the structural model are shown in Table 4.2.1. Those values are gained by the FFT (Fast *Fourier* Transform) analyses for exact structural responses of the experimental model. Also the same values are computed by the eigenvalue analyses for the numerical model. For numerical studies, the structural model is assured to the linear system which is subjected by the following equation of motions.

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} = [W]\{w\} + [F]\{f\} \ , \tag{4.2.1}$$

in which, $\{\ddot{x}\}$, $\{\dot{x}\}$ and $\{x\}$ mean the relative acceleration velocity and displacement vectors, respectively, $[M]$, $[C]$ and $[K]$ mean mass, damping and stiffness matrices, respectively, $\{w\}$ and $\{f\}$ mean external input force vector (which is corresponding to earthquake force on each floor) and internal input force vector (which is corresponding to control force on each floor), respectively, and $[W]$ and $[F]$ are determined as the arrangement matrices which are related to external and internal inputs for the system coordinate , respectively (in this case, both $[W]$ and $[F]$ are equal to the unit matrix $[I]$). In this numerical model, the damping matrix $[C]$ is defined as the proportional type to stiffness matrix $[K]$ and 0.5 % of damping ratio for the first mode of dominant frequency are supposed. Numerical simulations are executed by using *Newmark*'s β method and the sampling time Δt_s for numerical integrations is as to 0.01 (s). In left side of Eq. (4.2.1), when the structural responses are concerned with the coordinate of the inter-story responses, those quantities are expressed by $\{\ddot{v}\}$, $\{\dot{v}\}$ and $\{v\}$ which mean the inter-story acceleration, velocity and displacement vectors, respectively. Those vectors on the inter-story coordinate are transferred by the matrix $[V]$ from the vectors on the relative coordinate for the basements, namely, the inter-story displacement vector $\{v\}$ can be expressed as follow,

$$\{v\} = [V]\{x\}, \ [V] = \begin{bmatrix} 1 & 0 & 0 \\ -1 & 1 & 0 \\ 0 & -1 & 1 \end{bmatrix} . \tag{4.2.2}$$

And also, in right side of Eq. (4.2.1), the terms of external inputs and internal inputs can be expressed by relating to the ground acceleration $\ddot{x}_0$ and manipulated control forces supplied via active braces $\{b\}$ as follows,

$$\{f\} = [P]\{b\} \ , \ [P] = \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ 0 & 0 & 1 \end{bmatrix} , \tag{4.2.3}$$

$$\{w\} = -\ddot{x}_0[M]\{\mathbf{1}\} \ , \ \{\mathbf{1}\} = \{1, 1, 1\}^T . \tag{4.2.4}$$

At first, to install the quasi-optimizing control method, the set of trial control forces $< \hat{u}_i >$ for each control devices is selected the uniform division type as follows.

$$\hat{u}_{i,a_i} = (a_i - 1 - L_i) \cdot (u_{max,i} / L_i) = (a_i - 1 - L_i) \cdot u_{div,i} \ , \ a_i = 1, \cdots, N_i \ ,$$

$$< \hat{u}_i > = \ < \hat{u}_{i,1}, \cdots, \hat{u}_{i,N_i} > = < -u_{max,i}, \cdots, 0, \cdots, u_{max,i} > \ , \tag{4.2.5}$$

in which, $u_{max,\,i}$ and $u_{div,\,i}$ mean the maximum control force and the digit of control force of the i-th control device (i = 1, 2, 3), L_i is an integer number provided for i-th control device and those number mean the 'mesh level' for the arrangements of trial control forces and are related to the total number of trial control forces for i-th control device N_i by ($2 \cdot L_i + 1) = N_i$. In Exp. (4.2.5), the denotation $\hat{u}$ for trial control forces means the mediational variable which is used to make trial control forces relate to various kinds of control devices, for instance, when the active brace system or the active mass system are adopted as the control devices, the one of the trial control force vector $\{\hat{\boldsymbol{u}}^*\}$ which may be selected as the most adequate control force vector by the quasi-optimizing controller are related to $\{\boldsymbol{b}\}$ or $\{\boldsymbol{f}\}$, respectively. Any one of trial control force vector $\{\hat{\boldsymbol{u}}\}$ can be composed by any three components $\hat{\boldsymbol{u}}_1$, $\hat{\boldsymbol{u}}_2$ and $\hat{\boldsymbol{u}}_3$ chosen one by one for each set of trial control forces as to cover every control devices, the set of the trial control force vectors can be assembled by $S(3)$ kinds of components as follows,

$$< \{\hat{\boldsymbol{u}}\} > = < \{\hat{u}_1, \hat{u}_2, \hat{u}_3\}^T > \,, \quad S(3) = \prod_{i=1}^{3} N_i \,, \tag{4.2.6}$$

in which, all components of the set of trial control force vectors are consisted by all combinations from the sets of trial control forces to cover every control devices. On the installation of the fundamental quasi-optimizing control method which is proposed in the Section 4.1, $S(3)$ times of numerical integrations to simulate predicted responses for all components of trial control force vectors are required for this structural model adopted this section. At this point, it should be considered as a significant practical problem that the number of trial control force vectors will exist as the multiplication by the numbers of trial control forces for every control devices. So that, when the number of control devices is increased, CPU time by spending to optimization procedures may be multiplied drastically and it may be occurred the cases not to be allocated the sufficiently short control time interval as to warrant engineering accuracy of predicted responses. To solve this problem, additional operations in the continuing procedures of the quasi-optimizing control method are inserted, so that, the another kinds of optimization procedure which can reduce the number of times for numerical integrations are proposed.

To present the general instructions for this new optimization algorithm, discussions may be moved back again to the n degrees-of-freedom structural system equipped with r of control devices which is mentioned by Eq. (4.1.1) in the Section 4.1. For this aim, it should be considered the approximate searching method that "each component of the trial control force vectors $\{\hat{\boldsymbol{u}}\}$ is determined individually and sequentially". At first, let each control device have its number according to its priority for searching sequence, so that, the number of searching order of j-th control device is allocated as an integer $g(j)$. The correspondence from the number of control device j to the searching order $g(j)$ can be denoted as the permutation χ as follow,

$$\chi = \begin{pmatrix} 1 & \cdots & j & \cdots & r \\ g(1) & \cdots & g(j) & \cdots & g(r) \end{pmatrix}, \quad 1 \leq g(j) \leq r \,, \quad g(j) \neq g(i) \,. \tag{4.2.7}$$

The inverse permutation χ^{-1} means the correspondence from the number of the searching order g_j to the number of control device j. The permutation χ^{-1} can be expressed by sorting for those ascending powers of the upper components as follow,

$$\chi^{-1} = \begin{pmatrix} 1 & \cdots & j & \cdots & r \\ p(1) & \cdots & p(j) & \cdots & p(r) \end{pmatrix}, \quad 1 \leq p(j) \leq r \,, \quad p(j) \neq p(i) \,. \tag{4.2.8}$$

The series of the lower components of permutation χ^{-1} represents the searching sequence. This ordered series is expressed as follows,

$$\{p(j)\} = \{ p(1), \cdots, p(r) \}, \ j = 1, \cdots, r. \qquad (4.2.9)$$

Quasi-optimizing procedures are sequentially operated by dividing r times of searching stages. Those sequences can be described as the following flow :

Step-1) Set the incremental parameter for the order of the control device $j = 1$.

Step-2) Set the incremental parameter for the trial control forces of $p(j)$-th control device ap(j) =1.

Step-3) Select the one of the trial control force of $p(j)$-th control device $\hat{u}_{p(j), a_{p(j)}}$ from the set $< \hat{u}_{p(j)} >$, fix the control force of $p(i_1)$-th control device ($i_1 > j$) as to be equal to zero, fix the control force of $p(i_2)$-th control device ($i_2 < j$) as to be equal to the quasi-optimizing control force $\hat{u}^*_{p(i_2)}$ (when there is in the first stage, i.e. $j = 1$, any quasi-optimizing control force are not determined), and compose the one of the trial control force vector $\{\hat{u}\}^j_{a_{p(j)}}$.

Step-4) Compute the predicted response $\{\hat{X}^*(t_{s+1}, \hat{u}^j_{a_{p(j)}})\}$ corresponding to the control manipulation by selecting the trial control force vector $\{\hat{u}\}^j_{a_{p(j)}}$ which is gained at the Step-3.

Step-5) Increment the parameter $a_{p(j)}$. If $a_{p(j)} > N_{p(j)}$ then go to the Step-6, else then, go to the Step-3.

Step-6) Calculate the j-th stage of digital-index function which is defined the set of the penalty indexes as shown in Eq. (4.1.10) in the Section 4.1 for the all components of the set of predicted responses of the system $< \{\hat{X}^*(t_{s+1}, \hat{u}^j)\} >$.

Step-7) Execute j-th stage of optimization by using the operation as shown in Eq. (4.1.11) in the Section 4.1, and get the quasi-optimizing control force $\hat{u}^*_{p(j)}$ for $p(j)$-th control device.

Step-8) Increment the parameter j. If $j > r$ then go to the Step-2, else then go to the Step-9.

Step-9) Determine the quasi-optimizing control force vector $\{\hat{u}^*\}$.

In this flow, since the zero vectors are invariably evaluated as the one of the trial control force vectors regardless of the any kinds of searching sequence, the parasitic stability of the quasi-optimizing control method can be warranted. By introducing this searching algorithm, the number of the trial manipulation of control for simulating the predicted responses can be decreased to the following $S'(r)$ kinds.

$$S'(r) = \sum_{j=1}^{r} N_j \, . \qquad (4.2.10)$$

So that, the trial control force vectors are allocated to the r kinds of searching layers (the j-th layer includes N_j kinds of trial control force vectors) dynamically and only $S'(r)$ kinds of trial control force vectors by each control time instance may be selected as the partial set (components of this set is the counted as the summations by the number of trial control forces N_j in every devices) among the $S(r)$ kinds of total components of pre-provided trial control force vectors by the rule mentioned above. By the sense of those, this searching algorithm will be named as the 'multi-layer searching algorithm' and the previous searching algorithm which computes all operation of response prediction for the total components of the trial control force vector will be named as the 'universal searching algorithm'. In the installations of the multi-layer searching algorithm, by the order of priority of the control device, some trial manipulation may be omitted, so that, the j-th stage of trial manipulation will be operate only N_j kinds of trial control force vectors which has the difference in the j-th control forces and the another components have the fixed values, therefore, each component can be determined on-by one by operating to each searching layer. The trial manipulations in lower ordered searching layer will be always subjected to the quasi-optimizing control forces resulted from the trial manipulations in higher ordered searching layer by introducing the multi-layer searching algorithm. In this study, typical type of the multi-layer searching algorithm, the following two kinds of searching sequence may be investigated.

(i) *Step-up searching algorithm* :

In this case, the ordered series $\{p^U(j)\}$ is expressed as follows,

$$\{p^U(j)\} = \{\, 1\,, \cdots, j\,, \cdots, r\,\}\,, \tag{4.2.11}$$

in which, j means the location of the control devices and smaller number is assigned the lower locations. By introducing this type of the searching sequence, the quasi-optimizing control force will be fixed by going up to the upper stories at beginning from the control force of the control device located on the bottom story.

(ii) *Step-down searching algorithm* :

In this case, the ordered series $\{p^D(j)\}$ is expressed as follows,

$$\{p^D(j)\} = \{\, r\,, r-1\,,\ \cdots, j\,, \cdots, 1\,\}\,. \tag{4.2.12}$$

By introducing this type of the searching sequence, the quasi-optimizing control force will be fixed by going down to the lower stories at beginning from the control force of the control device located on the top story.

The multi-layer searching algorithm may be very attractive to omit close resemble trial manipulations included in the operations of the universal searching algorithm. When the each component of control force vector is un-interference to the system for each other, the solution by computing from the multi-layer searching algorithm may be agreed with the solution by computing from the universal searching algorithm, namely, the multi-layer searching algorithm can avoid the duplications of the trial manipulations and can operate the minimum numbers of trial manipulations under this condition. As the practical problem, in the cases that the complete un-interference among the multi-devices control system may not be difficult, the multi-layer searching will be effective approximations for the solution through the universal searching method, when the priority of the control devices are presented as the order of significance of the control devices suitably. In the structural systems which can be modelled as like to the system adopted in this section. The step-up or the step-down searching algorithm may be considered as the adequate approximate conformity with the universal searching algorithm.

The discussions will be come back to the CTAC model again. To investigate for installation of the quasi-optimizing control method, it is required to synthesize the penalty index for optimization procedure in the CTAC system. The following expression is adopted as the penalty index to execute the case studies in this section.

$$\hat{J}(\ \{\hat{\boldsymbol{Z}}(t_{\sigma+1},\hat{\boldsymbol{u}})\}\ ) = \{\hat{\boldsymbol{Z}}(t_{\sigma+1},\hat{\boldsymbol{u}})\}^T[\boldsymbol{Q}]\ \{\hat{\boldsymbol{Z}}(t_{\sigma+1},\hat{\boldsymbol{u}})\}\ ,$$

$$\{\hat{\boldsymbol{Z}}(t_{\sigma+1},\hat{\boldsymbol{u}})\} = \begin{Bmatrix} \hat{v}(t_{\sigma+1},\hat{\boldsymbol{u}}) \\ \hat{\dot{v}}(t_{\sigma+1},\hat{\boldsymbol{u}}) \end{Bmatrix} = [V]\begin{Bmatrix} \hat{x}(t_{\sigma+1},\hat{\boldsymbol{u}}) \\ \hat{\dot{x}}(t_{\sigma+1},\hat{\boldsymbol{u}}) \end{Bmatrix},\ [\boldsymbol{Q}] = \begin{bmatrix} \boldsymbol{Q}_1 & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{Q}_2 \end{bmatrix}, \tag{4.2.13}$$

in which, $\{\hat{\boldsymbol{Z}}(t_{\sigma+1},\hat{\boldsymbol{u}})\}$ means any one of the predicted state of the system corresponding to the inter-story displacements and the inter-story velocities for the time after control time interval Δt_c from the time of $t_\sigma = \sigma \cdot \Delta t_c$. The weight matrices $[\boldsymbol{Q}_1]$ and $[\boldsymbol{Q}_2]$ mean the inter-story displacements and the inter-story velocities, respectively, those quantities are proposed as the $[\boldsymbol{Q}_1] = 100\ [\boldsymbol{I}]$ and $[\boldsymbol{Q}_2] = [\boldsymbol{I}]$ and those values are synthesized as the ratio of the average stiffness with the total mass of the system, and the weight matrix of control forces $[\boldsymbol{R}]$ is adopted as the zero matrix (when the weight matrix of control forces is proposed as the semi-definite matrix, the parasitic stability is warranted). The optimization procedures of determining the quasi-optimizing control force vector may be described as follows.

When the universal searching algorithm is used for optimizations for the quasi-optimizing control method, the set of predicted responses $<\{\hat{\boldsymbol{Z}}(t_{\sigma+1},\hat{\boldsymbol{u}})\}>^U$ (which has the $S(3)$ kinds of components) is computed by simulating trial manipulation of control on the system expressed in Eq. (4.2.1). In this case, the digital index function $<\hat{J}(\{\hat{\boldsymbol{Z}}(t_{\sigma+1},\hat{\boldsymbol{u}})\})>^U$ will be denoted as the set of the penalty indexes which has the $S(3)$ kinds of components. The quasi-optimizing control force vector $\{\hat{\boldsymbol{u}}^*\}^U$ will be determined from the following conditions.

$$\hat{J}^*(\{\hat{\boldsymbol{Z}}^*(t_{s+1},\hat{\boldsymbol{u}}^*)\})^U = Min\ <\hat{J}(\{\hat{\boldsymbol{Z}}(t_{s+1},\hat{\boldsymbol{u}})\})>^U . \tag{4.2.14}$$

On the other hand, when the multi-layer searching algorithm is used for optimizations for the quasi-optimizing control method, the set of predicted responses $<\{\hat{\boldsymbol{Z}}(t_{\sigma+1},\hat{\boldsymbol{u}})\}>^M$ (which has the $S'(3)$ kinds of components) is computed by simulating trial manipulation of control on the system expressed in Eq. (4.2.1), in which, the number of trial manipulations $S'(3)$ can be counted as follow,

$$S'(3) = \sum_{i=1}^{3} N_i\ . \tag{4.2.15}$$

In this case, the digital index function $<\hat{J}(\{\hat{\boldsymbol{Z}}(t_{\sigma+1},\hat{\boldsymbol{u}})\})>^M$ will be denoted as the set of the penalty indexes which has the $S'(3)$ kinds of components. The quasi-optimizing control force vector $\{\hat{\boldsymbol{u}}^*\}^M$ will be satisfied for the following conditions.

$$\hat{J}^*(\{\hat{\boldsymbol{Z}}^*(t_{s+1},\hat{\boldsymbol{u}}^*)\})^M = Min\ <\hat{J}(\{\hat{\boldsymbol{Z}}(t_{s+1},\hat{\boldsymbol{u}})\})>^M . \tag{4.2.16}$$

By introducing the universal searching or the multi-layer searching algorithm, $\{\hat{\boldsymbol{u}}^*\}^U$ or $\{\hat{\boldsymbol{u}}^*\}^M$ which is selected as the most adequate control force vector on each case is determined as the practical control force vector to supply on the external system.

In the following discussions, the four kinds of indicates are introduced as the evaluative properties which is indexed to 'effectiveness'.

(i) *Displacements controlled factor* :

Let $DRMS(v_i)$ denote the ratio the controlled RMS (root mean square) response of the inter-story displacement on the i-th story $v_{rms,\,i}$ with the uncontrolled RMS response of the inter-story displacement on the i-th story $v\,'_{rms,\,i}$ during the ground motion inputs times (30 seconds), namely,

$$DRMS(v_i) = v_{rms,\,i}\ /v\,'_{rms,\,i}\ ,\ i = 1, 2, 3. \qquad (4.2.17a)$$

The average of the $DRMS(v_i)$ is denoted by $\overline{DRMS}$ as follow,

$$\overline{DRMS} = \{\sum_{i=1}^{3} DRMS\,(v_i)\}\ /\ 3\ . \qquad (4.2.17b)$$

(ii) *Velocities controlled factor* :

Let $VRMS(\dot{v}_i)$ denote the ratio the controlled RMS response of the inter-story velocity on the i-th story $\dot{v}_{rms,\,i}$ with the uncontrolled RMS response of the inter-story velocity on the i-th story $\dot{v}\,'_{rms,\,i}$ during the ground motion inputs times (30 seconds), namely,

$$VRMS(\dot{v}_i) = \dot{v}_{rms,\,i}\ /\dot{v}\,'_{rms,\,i}\ ,\ i = 1, 2, 3. \qquad (4.2.18a)$$

The average of the $VRMS(\dot{v}_i)$ is denoted by $\overline{VRMS}$ as follow,

$$\overline{VRMS} = \{\sum_{i=1}^{3} VRMS\,(\dot{v}_i)\}\ /\ 3\ . \qquad (4.2.18b)$$

(iii) *Accelerations controlled factor* :

Let $\ddot{\xi}_i$ represents the absolute acceleration on the i-the story and let $ARMS(\ddot{\xi}_i)$ denote the ratio the controlled RMS response of the absolute acceleration on the i-th story $\ddot{\xi}_{rms,\,i}$ with the uncontrolled RMS response of the absolute acceleration the i-th story $\ddot{\xi}\,'_{rms,\,i}$ during the ground motion inputs times (30 seconds), namely,

$$ARMS(\ddot{\xi}_i) = \ddot{\xi}_{rms,\,i}\ /\ddot{\xi}\,'_{rms,\,i}\ ,\ i = 1, 2, 3. \qquad (4.2.19a)$$

The average of the $ARMS(\ddot{\xi}_i)$ is denoted by $\overline{ARMS}$ as follow,

$$\overline{ARMS} = \{\sum_{i=1}^{3} ARMS\,(\ddot{\xi}_i)\}\ /\ 3\ . \qquad (4.2.19b)$$

(iv) *Control manipulation factor* :

Let $FRMS(u_i)$ denote the ratio the RMS value of the supplied control force via the control device located on the i-th story $u_{rms,\,i}$ (during 30 seconds of the ground motion inputs times) with the pair of required static force to occur the unit deformation (1 (cm)) only on the i-th story $(k_i \cdot 1)$, namely,

$$FRMS(u_i) = u_{rms,\,i} \ / \ (k_i \cdot 1) \ , \ i = 1, 2, 3, \tag{4.2.20a}$$

in which, k_i means the stiffness of the i-th story. The average of the $FRMS(u_i)$ is denoted by $\overline{FRMS}$ as follow,

$$\overline{FRMS} = \{ \sum_{i=1}^{3} FRMS\,(u_i) \} \ / \ 3 \ . \tag{4.2.20b}$$

To assure the effectiveness of the quasi-optimizing control method, numerical simulations and experimental tests are executed. In those studies, when numerical simulations are executed, control time interval Δt_c is adopted as 0.01 (s), and when experimental tests are executed, control time interval Δt_c is adopted as 0.1 (s) (this value are selected by considering the capacity for driving the practical actuator).

At first, to estimate for the adequate number of the trial control forces for the control devices and the suitable capacities of the trial control forces for the installation of the quasi-optimizing control method, two kinds of numerical investigations are operated under the input of El Centro (1940) NS which is scaled down to the maximum acceleration amplitude of 30 (cm/s^2). In those studies, the number of the trial control forces are selected the same number for the all control devices, namely, N_1, N_2 and N_3, are supposed as to be equal to N, the maximum values of the trial control forces are selected the same value for the all control devices, namely, $u_{max,\,1}$, $u_{max,\,2}$ and $u_{max,\,3}$, are supposed as to be equal to u_{max}, and the digits of the trial control forces are selected the same value for the all control devices, namely, $u_{div,\,1}$, $u_{div,\,2}$ and $u_{div,\,3}$ are supposed as to be equal to u_{div}.

***Study (4.2) - 1a* :**

In this study, three cases which are selected as the digits of the trial control forces of each control device u_{div} = 0.01, 0.03 and 0.05 (kgf) are investigated ($u_{div,\,1}$, $u_{div,\,2}$ and $u_{div,\,3}$ are equal to u_{div}). Those case studies are severally executed for the cases that are installed the universal searching, the step-up searching and the step-down searching algorithm. The maximum values of the trial control forces of each control device u_{max} are supposed as the parameters ($u_{max,\,1}$, $u_{max,\,2}$ and $u_{max,\,3}$ are equal to u_{max}), in which, the numbers of the trial control forces of each control device N are also defined as the variables depended on the u_{max}, namely, the number of control forces are supposed as $N = (\ u_{max} \ / \ u_{div}\ ) \times 2 + 1$ (N_1, N_2 and N_3 are equal to N).

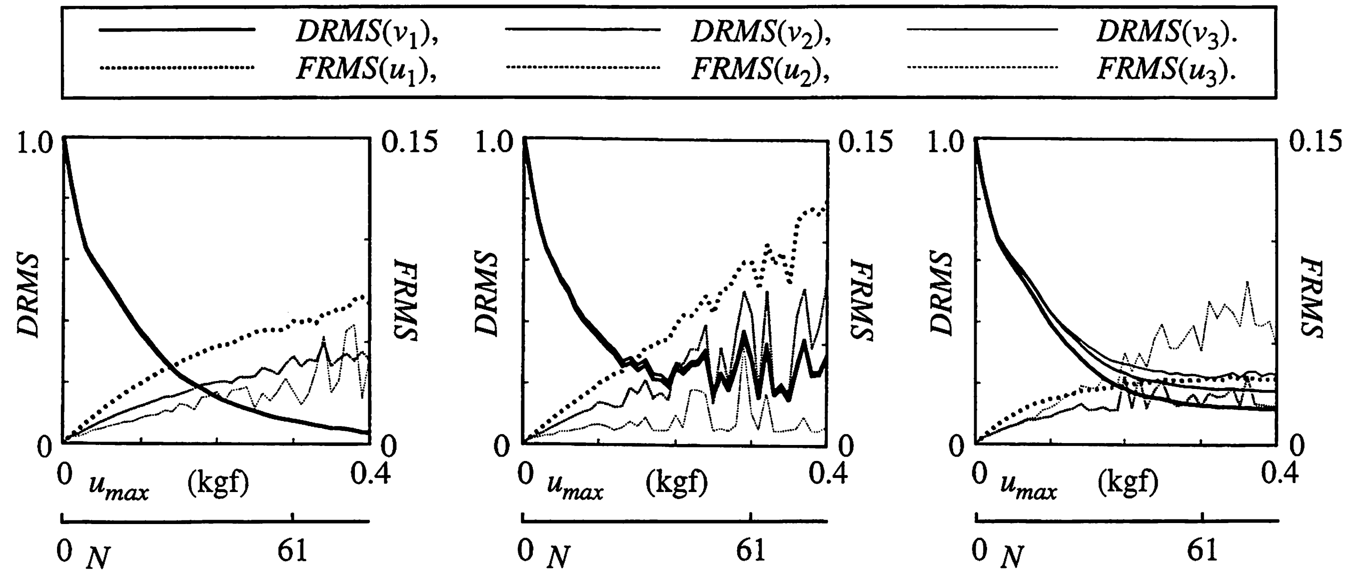
Figs. 4.2.2.1, 4.2.2.2 and 4.2.2.3 show the displacements controlled factors (*DRMS*) and the control manipulation factors (*FRMS*) for the three cases which are selected as the digits of the trial control forces u_{div} = 0.01, 0.03 and 0.05 (kgf), respectively. In those figures, (a), (b) and (c) show the cases that are installed the universal searching, the step-up searching and the step-down searching algorithm, respectively. The fluctuations of the *DRMS* and the *FRMS* are plotted in those figures according to the variations of the maximum trial control forces u_{max}.

By comparing (a), (b) and (c) with each other in those figures, the most effective reductions of responses are gained at the cases when the maximum trial control forces u_{max} are increased on the universal searching algorithm. By considering for the influences resulted from the difference of the digit of control forces on the cases by using the universal searching algorithm, it is assured that control effects evaluated as the *DRMS* have quite similar extents regardless of the difference of the number of trial control forces N when the same value is supposed as the maximum trial control forces u_{max} . When the digit of trial control forces are supposed as the small values, the disorders of the *FRMS* (those may be mainly existed in the control forces allocated at the upper stories) are seen by increasing the maximum trial control forces. As the reason of those, it may be considered that those behaviors are caused by influences with the discretization of control forces, and that the change of control forces be occurred frequently and sensitively when the small digit of trial control forces is supposed. So that, it may be regarded that the control performances evaluated as the *FRMS* are improved and smoothed by supposing the moderately large digit of trial control forces (as seen in Fig.4.2.2.3 (a)).

In the cases by using the step-up searching or the step-down searching algorithm, it may be observed that the larger control forces are supplied by the control devices which is ordered as the higher priorities, so that, when the step-up searching sequence is supposed, the lower control forced are enlarged than the upper ones, and when the step-down searching sequence is supposed, the upper control forced are enlarged than the lower ones. The control effects evaluated as the *DRMS* may be regarded as advantage in the cases by using the step-down searching algorithm to the cased by using the step-up searching algorithm. From this result, it may be considered that the step-down searching sequence can propose the more adequate order of the priority of the control devices for the system adopted in this section. In those cases, the disorders of the *FRMS* are also seen by increasing the maximum trial control forces, when the digit of trial control forces are supposed as the small values. Those behaviors are mainly existed in the control forces allocated at the upper stories for the both cases that the step-up searching and the step-down searching sequences are supposed. Those reasons may be considered as the same with the cases in the universal searching algorithm, namely, it may be regarded that those behaviors are caused by influences with the discretization of control forces. So that, in those cases by introducing the multi-layer searching algorithm, it may be also regarded that the control performances evaluated as the *FRMS* are improved and smoothed by supposing the moderately large digit of trial control forces (as seen in Fig.4.2.2.3 (b) and (c)).

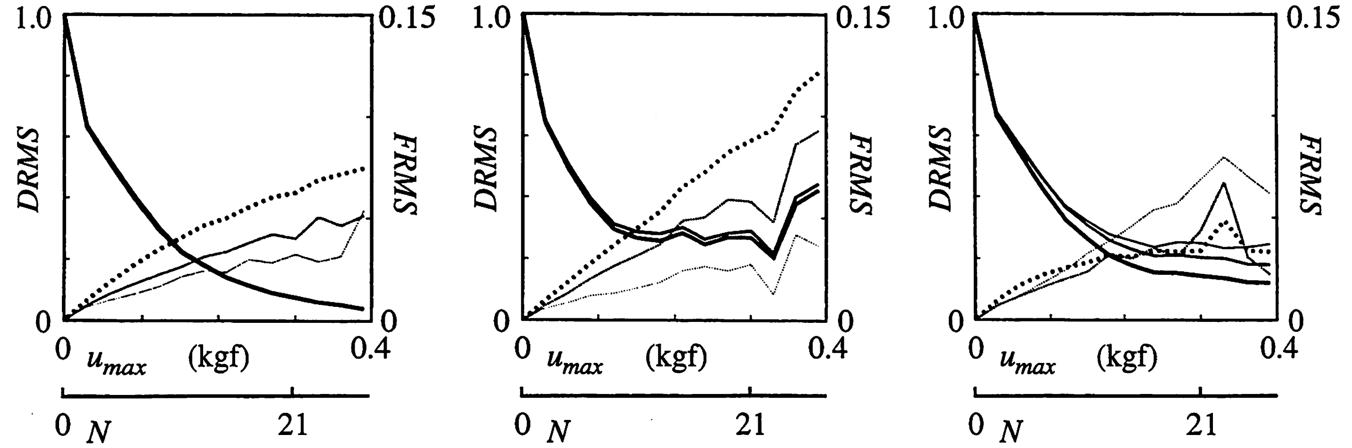
***Study (4.2) - 1b* :**

In this study, three cases which are selected as the numbers of the trial control forces of each control device $N = 3, 5$ and 7 are investigated (N_1 , N_2 and N_3 are equal to N). Those case studies are severally executed for the cases that are installed the universal searching, the step-up searching and the step-down searching algorithm. The maximum values of the trial control forces of each control device u_{max} are supposed as the parameters ($u_{max,1}$, $u_{max,2}$ and $u_{max,3}$, are equal to u_{max}), in which, the digits of the trial control forces of each control device u_{div} are also defined as the variables depended on the u_{max} namely, the digits of the trial control forces are supposed as $u_{div} = u_{max} \times 2 / (N - 1)$ ($u_{div,1}$, $u_{div,2}$ and $u_{div,3}$ are equal to u_{div}).



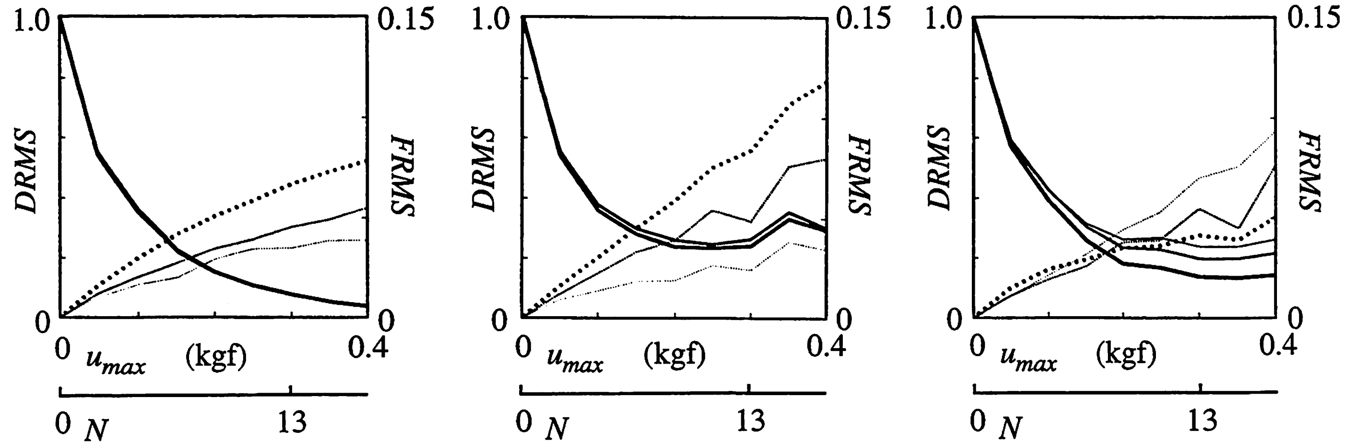
(a) Universal searching, (b) Step-up searching, (c) Step-down searching,

Fig. 4.2.2.1 Control performances (*DRMS* and *FRMS*) in the case of u_{div} = 0.01 (kgf).



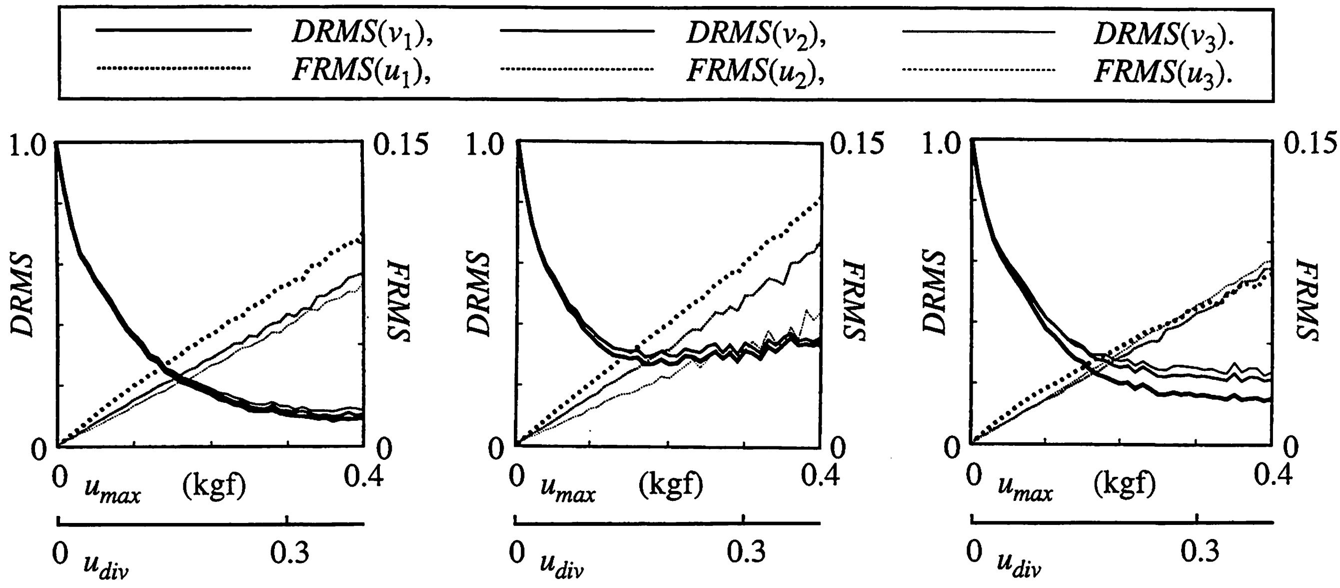
(a) Universal searching, (b) Step-up searching, (c) Step-down searching,

Fig. 4.2.2.2 Control performances (*DRMS* and *FRMS*) in the case of u_{div} = 0.03 (kgf).



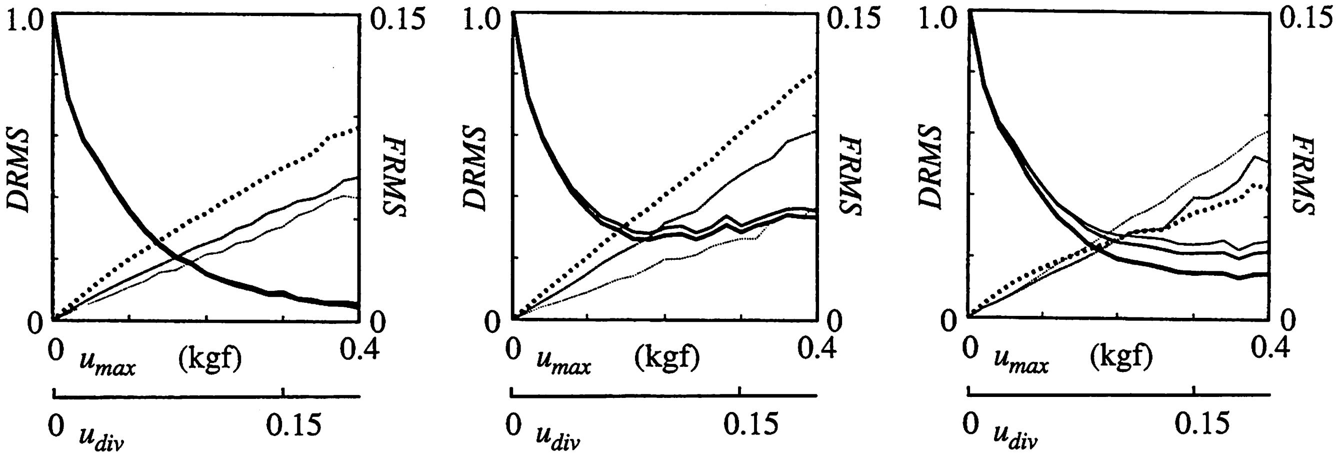
(a) Universal searching, (b) Step-up searching, (c) Step-down searching,

Fig. 4.2.2.3 Control performances (*DRMS* and *FRMS*) in the case of u_{div} = 0.05 (kgf).



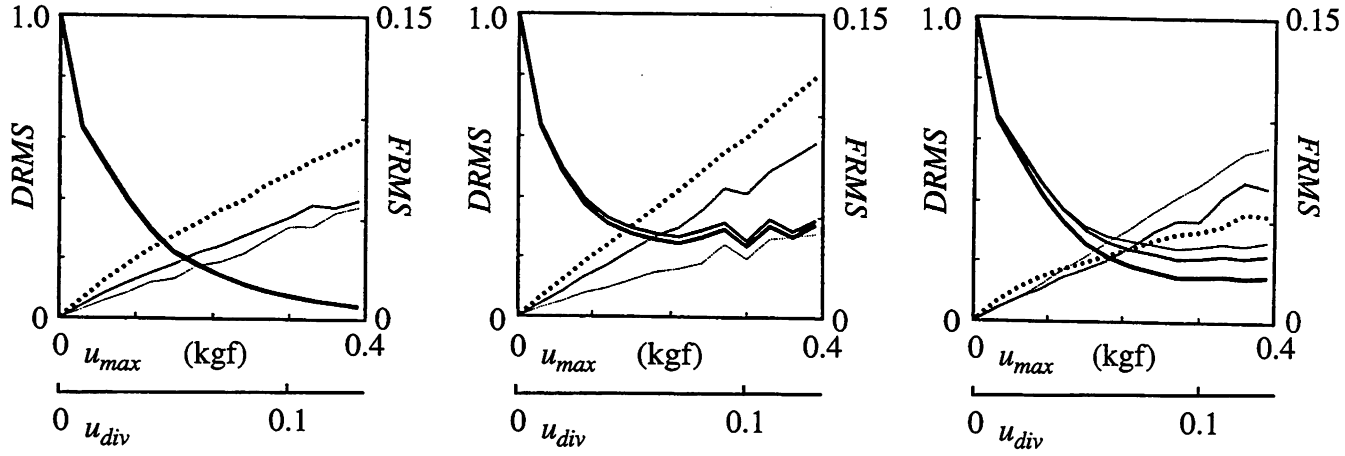
(a) Universal searching, (b) Step-up searching, (c) Step-down searching,

Fig. 4.2.3.1 Control performances (*DRMS* and *FRMS*) in the case of $N = 3$.



(a) Universal searching, (b) Step-up searching, (c) Step-down searching,

Fig. 4.2.3.2 Control performances (*DRMS* and *FRMS*) in the case of $N = 5$.



(a) Universal searching, (b) Step-up searching, (c) Step-down searching,

Fig. 4.2.3.3 Control performances (*DRMS* and *FRMS*) in the case of $N = 7$.

Figs. 4.2.3.1, 4.2.3.2 and 4.2.3.3 show the *DRMS* and the *FRMS* for the three cases which are selected as the number of the trial control forces $N = 3$, 5 and 7, respectively. In those figures, (a), (b) and (c) show the cases that are installed the universal searching, the step-up searching and the step-down searching algorithm, respectively. The fluctuations of the *DRMS* and the *FRMS* are plotted in those figures according to the variations of the maximum trial control forces u_{max}.

By considering to each case for installing the universal searching, the step-up searching or the step-down searching algorithm (those cases are corresponding to (a), (b) or (c) in those figures, respectively), it is assured that the quite similar control performances evaluated by the *DRMS* and the *FRMS* can be observed regardless of the difference of the number of the trial control forces N as the results from comparison for each case by introducing $N = 3$, 5 or 7 as the number of the trial control forces. So that, in any cases that any one of those three kinds of searching algorithms mentioned here is supposed, it may be regarded that the control performances are insensitive for the difference of the number of trial control forces N in the sense that the value of N is supposed as like that the digit of trial control forces u_{div} are not too small for the value of the maximum trial control forces u_{max}.

Study (4.2) - 2 :

As the last step for those investigations, comparative studies for the time histories of controlled behaviors resulted from the numerical simulations and the experimental tests are carried out. Experimental tests for the CTAC system by using the shaking table are executed under the input of El Centro (1940) NS which is scaled down to the maximum acceleration amplitude of 30 (cm/s^2). As the experimental structural model, three stories of the CTAC standard model which is surveyed as seen in the Fig.4.2.1 is used. Three active braces are equipped on every stories of this structural model. For the installations of the quasi-optimizing control method, the maximum trial control forces u_{max} of the every control devices are selected as 0.25 (kgf). Three cases which are supposed three kind of the number of the trial control forces, namely, $N = 3$, 5 and 7 are investigated for the three kinds of searching algorithms (Study (4.2)-2).

Figs. 4.2.4.1 and 4.2.4.2 show the displacements of the top floor and the accelerations of the top floor of the numerical or the experimental model corresponding to the case which is installed the universal searching algorithm, respectively. Figs. 4.2.5.1 and 4.2.5.2 show the displacements of the top floor and the accelerations of the top floor of the numerical or the experimental model corresponding to the case which is installed the step-up searching algorithm, respectively. Figs. 4.2.6.1 and 4.2.6.2 show the displacements of the top floor and the accelerations of the top floor of the numerical or the experimental model corresponding to the case which is installed the step-down searching algorithm, respectively. In those figures, (a), (b) and (c) show the experimental results for the cases that are selected as the number of the trial control forces $N = 3$, 5 and 7, respectively, and (d) shows the numerical results for the case that is selected as the number of the trial control forces $N = 5$.

In the cases by introducing the universal searching algorithm (as seen in Figs.4.2.4.1 and 4.2.4.2), the most effective reductions of responses may be observed in the case that is supposed N

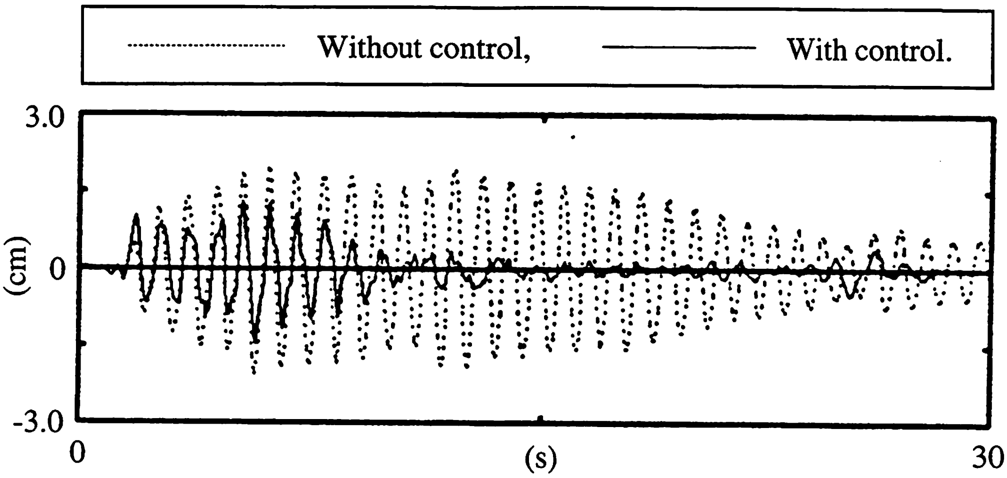
= 5 as the number of the trial control forces. When $N = 3$ is used as the number of the trial control force, the effectiveness for reductions of responses are decreased by comparing with in the case of $N = 5$. As the reason for this, it may be considered that the change of positive and negative control forces may be occurred frequently without complement for the neutral states. Moreover, when $N = 7$ is used as the number of the trial control force, the effectiveness for reductions of responses are also decreased by comparing with in the case of $N = 5$. As the reason for this, it may be considered that time durations spent in the optimization procedures may exceed the provided control time interval and the time delay of practical control operation may be occurred by the increase of the trial manipulation. By installing the universal searching algorithm, the number of the trial manipulation are multiplied as 27, 125 and 343 kinds for the cases of $N = 3$, 5 and 7.

The similar results can be suspected in the cases by introducing the step-down searching algorithm (as seen in Figs.4.2.6.1 and 4.2.6.2). In those cases, the most effective reductions of responses may be observed in the cases that is supposed $N = 5$ or 7 as the number of the trial control forces. When $N = 3$ is used as the number of the trial control force, the effectiveness for reductions of responses are decreased by comparing with in those cases. As reason for this, the same considerations may be discussed in the case by introducing the universal searching algorithm. By using the step-down searching algorithm (or using the multi-layer searching algorithm), since the number of the trial manipulation are decreased as 9, 15 and 21 kinds for the cases of $N = 3$, 5 and 7, time delay of practical control operation may not be occurred. So that, in the cases by introducing the step-down searching algorithm, it may be regarded that the effective reductions of responses can be also gained as much as the case of $N = 5$, when $N = 7$ is used as the number of the trial control force.

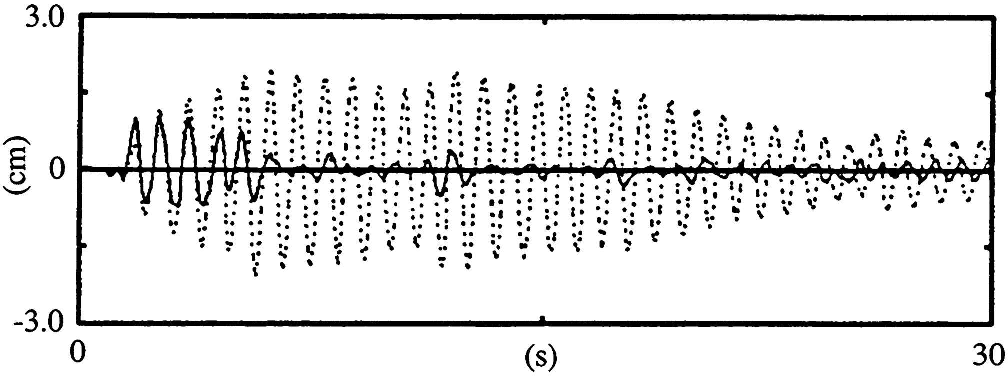
In the cases by introducing the step-up searching algorithm (as seen in Figs.4.2.5.1 and 4.2.5.2), the control effects for all cases which are supposed $N = 3$, 5 and 7 as the number of the trial control forces may be observed as to be quite similar. However, effectiveness for reductions of responses may be decreased by comparing the most effective cases for the universal searching algorithm ($N = 5$) and for the step-down searching algorithm ($N = 5$ or 7). From the sense of those, the control effects in the cased by introducing the step-up searching algorithm may be different from the results of the cases by introducing the other two algorithms. As the reason of this, by considering for the numerical results mentioned above, it may be regarded that the step-up searching sequence are unsuitable for the order of the priority of the control devices for the system adopted in this section.

By comparing those experimental results in the case of $N = 5$ (as seen in (b) of those figures) with the numerical results (as seen in (d) of those figures), the control effects which are observed by the experimental tests are less than those by the numerical simulations. As the one of reasons for those, it is regarded that those behaviors may be caused by the time delay of the practical control system. However, it seems that those control loss may be quite little and that any experimental results for the case of $N = 5$ have good accordance to the numerical results.

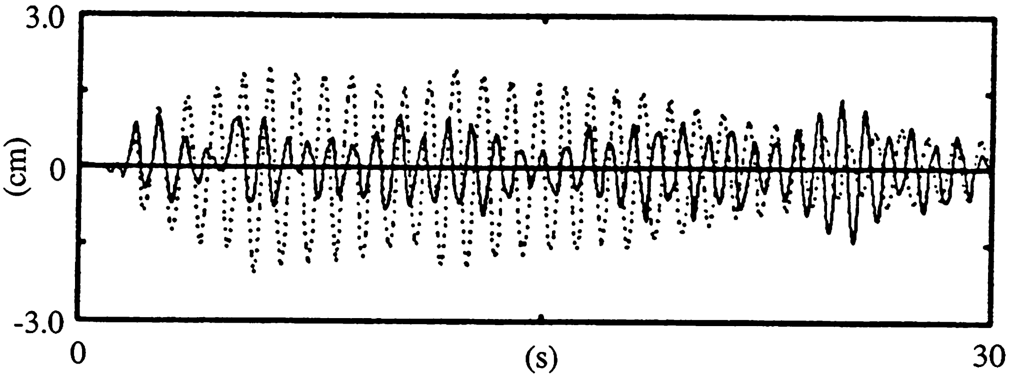
As concluding remarks of this section, installations of the quasi-optimizing control method on the CTAC system are presented to operate the numerical tests and the experimental simulations. The multi-layer searching algorithm for the optimization procedure on the quasi-optimizing controller is proposed to solve practical problem which is multiplied trial manipulations by increasing the control devices when the universal searching algorithm (which is introduced as the fundamental quasi-optimizing control method in the Section 4.1) is used. The step-up searching and the step-down searching algorithm as typical two kinds of multi-layer searching algorithms are investigated through the comparisons with the universal searching algorithm. Moreover, control performances with installations of those searching algorithm are estimated through comparative studies of the experimental tests and the numerical simulations.



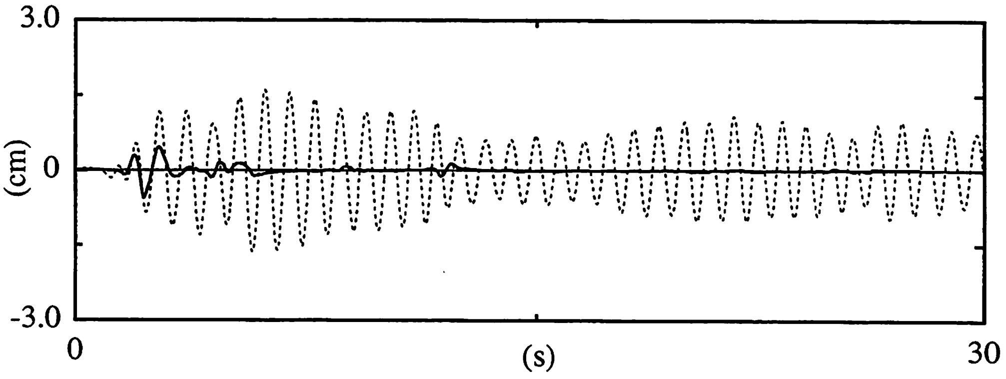
(a) Case of the number of the trial control forces $N = 3$ (Experimental results),



(b) Case of the number of the trial control forces $N = 5$ (Experimental results),

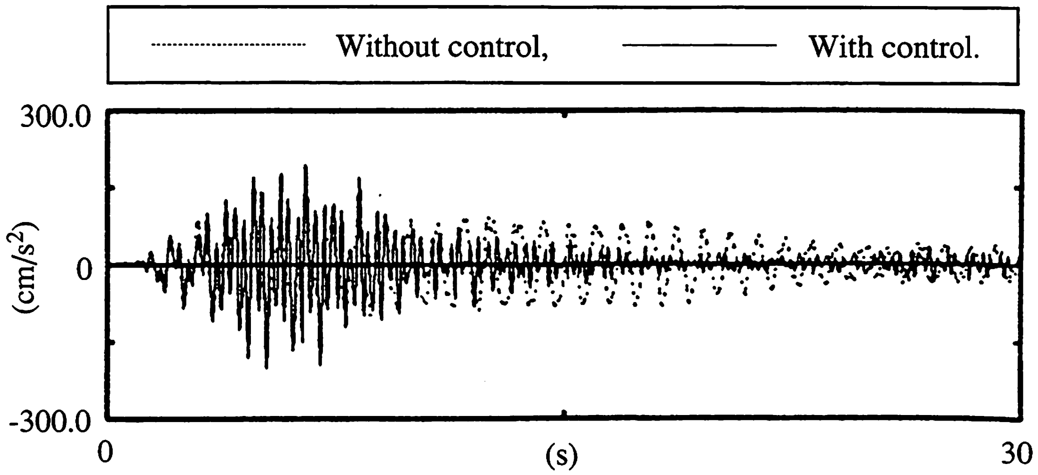


(c) Case of the number of the trial control forces $N = 7$ (Experimental results),

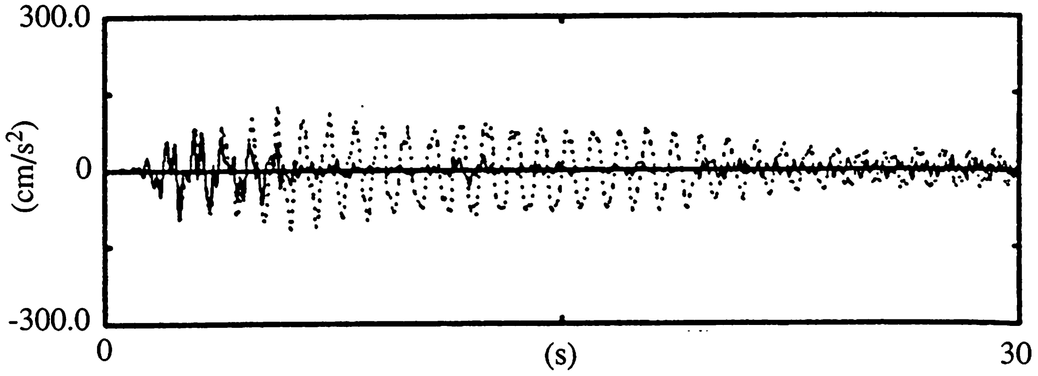


(d) Case of the number of the trial control forces $N = 5$ (Numerical results),

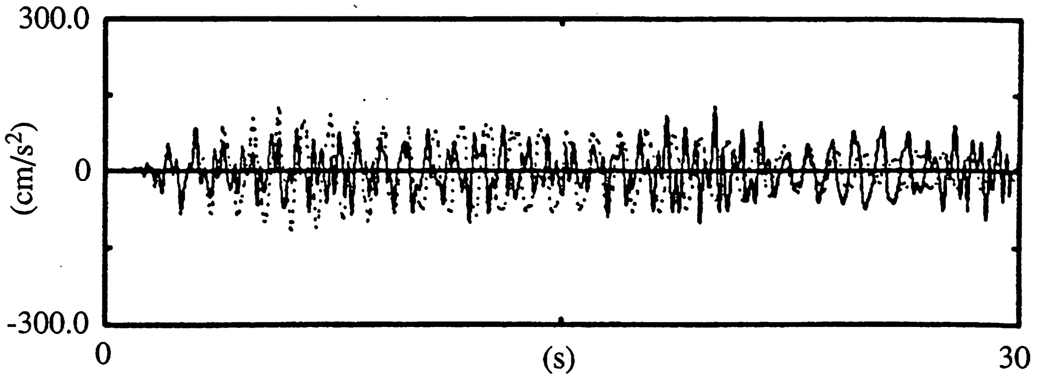
Fig. 4.2.4.1 Displacements of the top floor in the case of the universal searching algorithm.



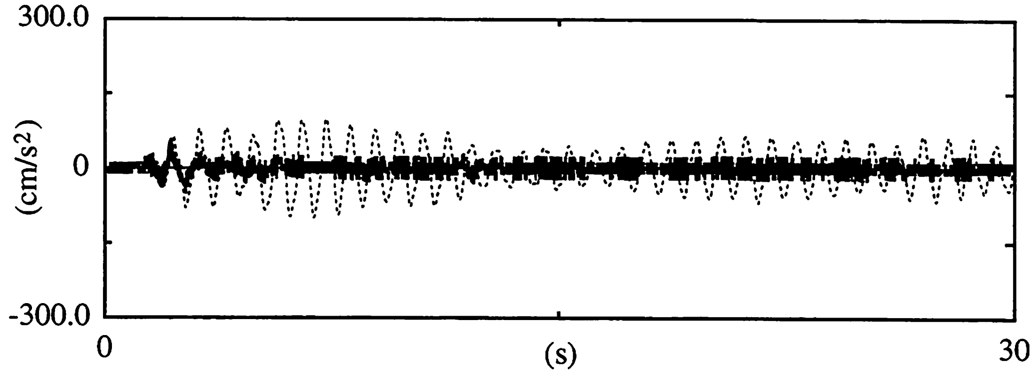
(a) Case of the number of the trial control forces $N = 3$ (Experimental results),



(b) Case of the number of the trial control forces $N = 5$ (Experimental results),

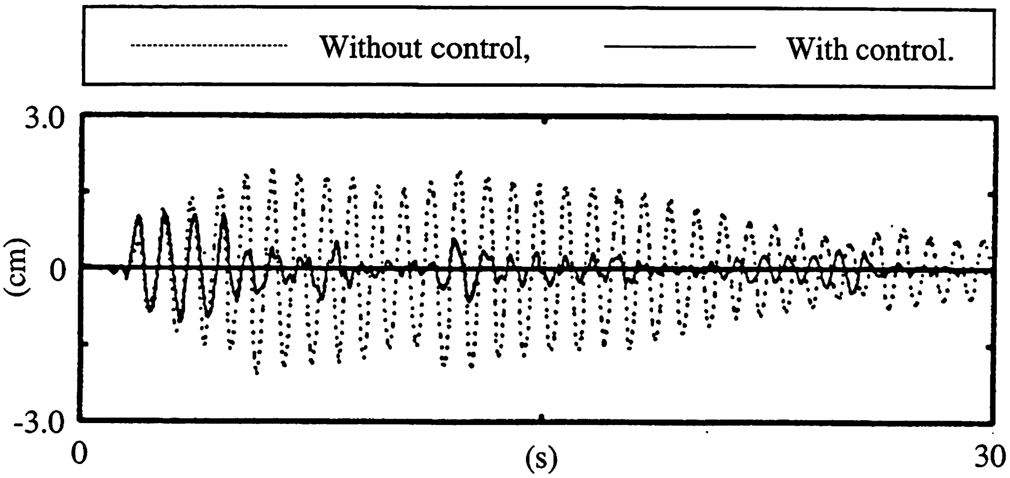


(c) Case of the number of the trial control forces $N = 7$ (Experimental results),

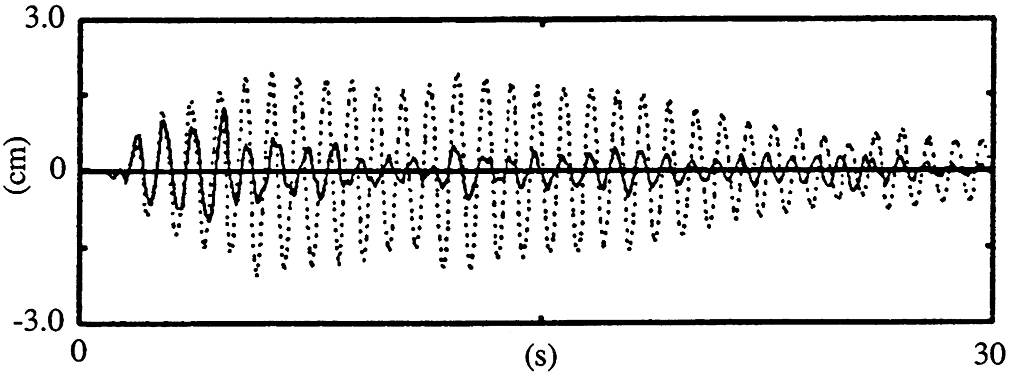


(d) Case of the number of the trial control forces $N = 5$ (Numerical results),

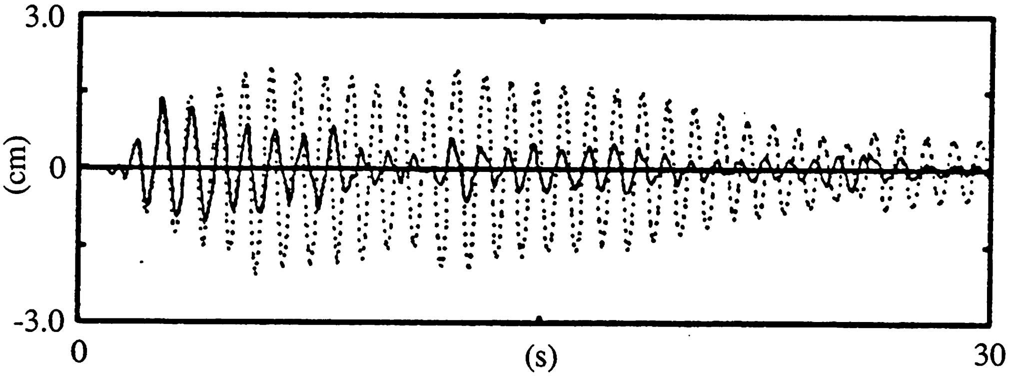
Fig. 4.2.4.2 Accelerations of the top floor in the case of the universal searching algorithm.



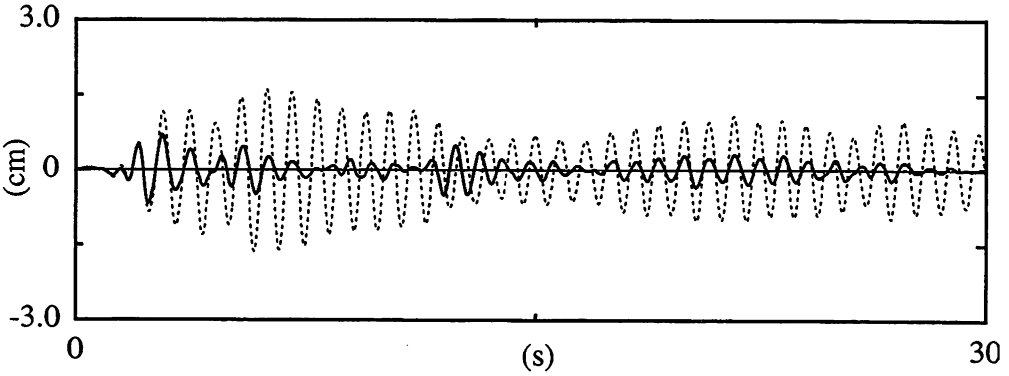
(a) Case of the number of the trial control forces $N = 3$ (Experimental results),



(b) Case of the number of the trial control forces $N = 5$ (Experimental results),

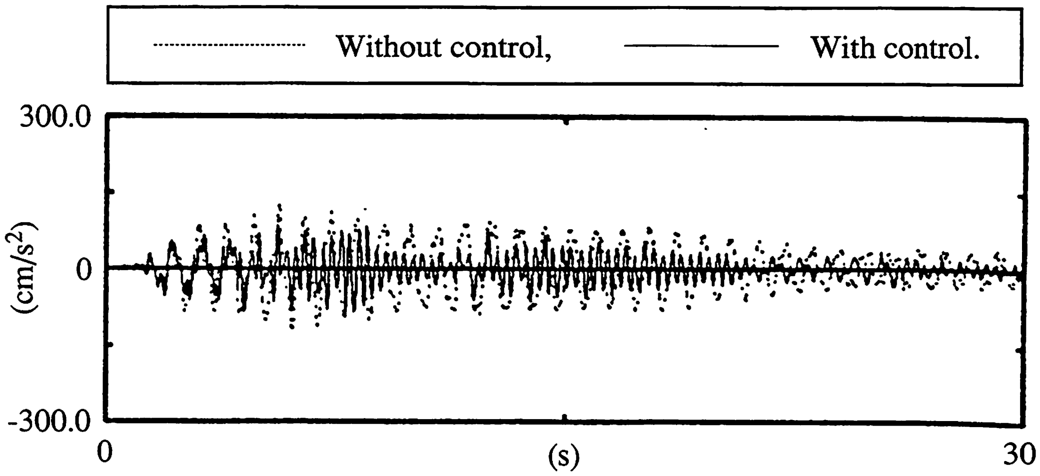


(c) Case of the number of the trial control forces $N = 7$ (Experimental results),

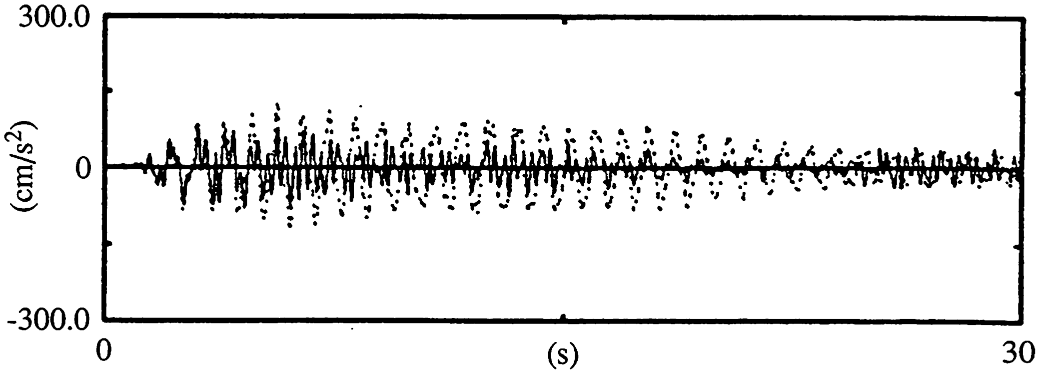


(d) Case of the number of the trial control forces $N = 5$ (Numerical results),

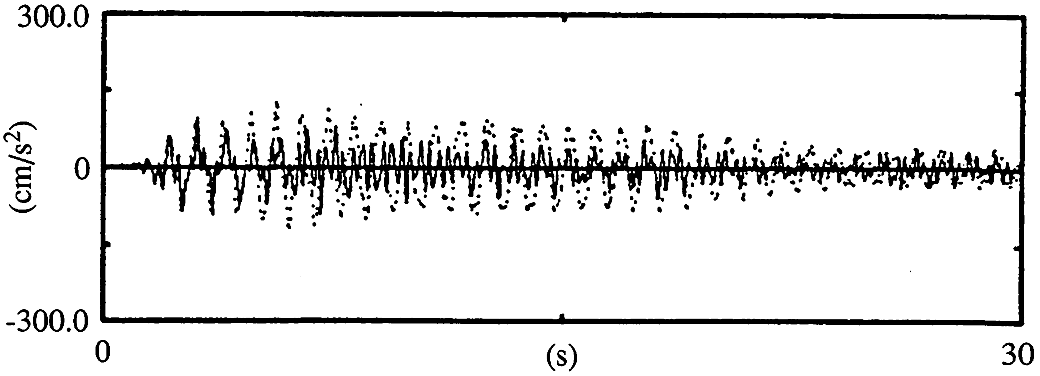
Fig. 4.2.5.1 Displacements of the top floor in the case of the step-up searching algorithm.



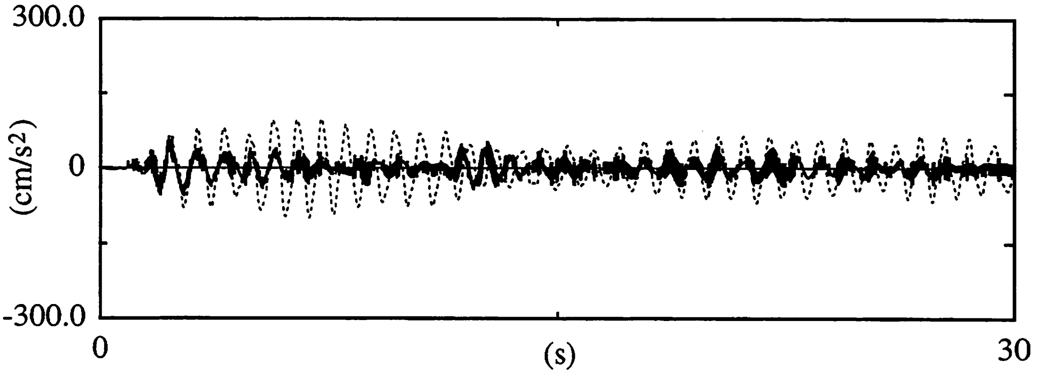
(a) Case of the number of the trial control forces $N = 3$ (Experimental results),



(b) Case of the number of the trial control forces $N = 5$ (Experimental results),

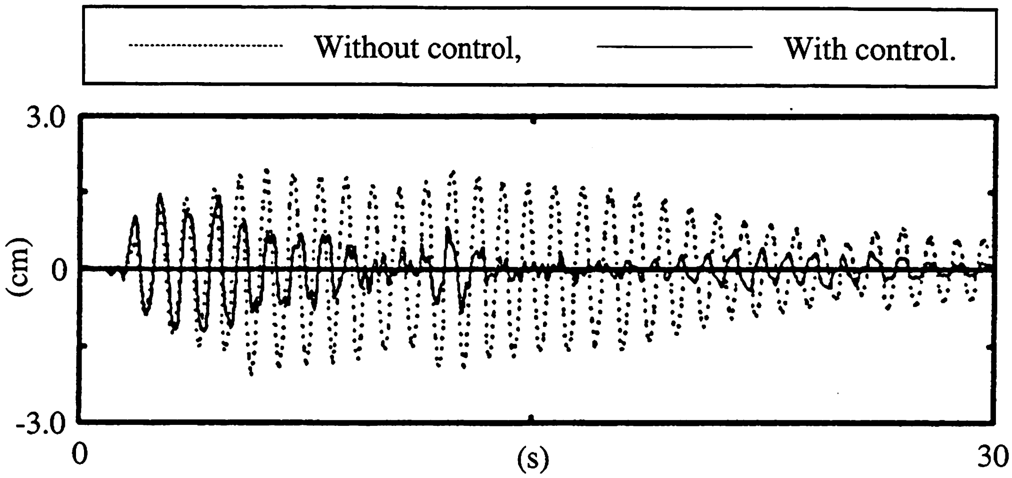


(c) Case of the number of the trial control forces $N = 7$ (Experimental results),

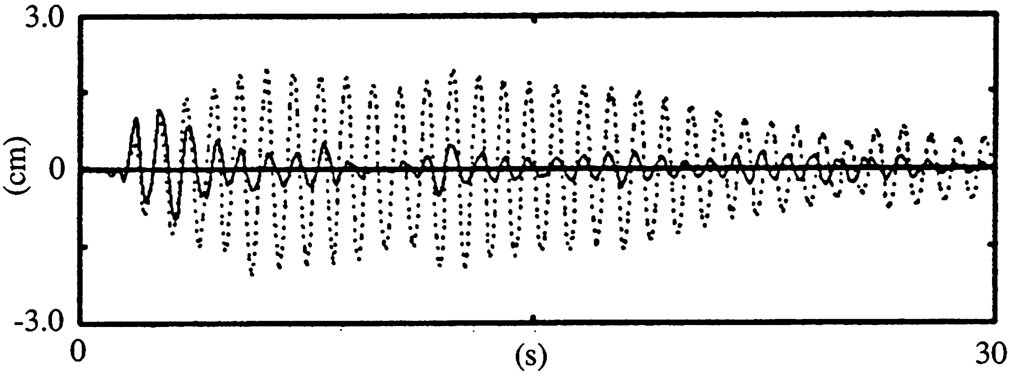


(d) Case of the number of the trial control forces $N = 5$ (Numerical results),

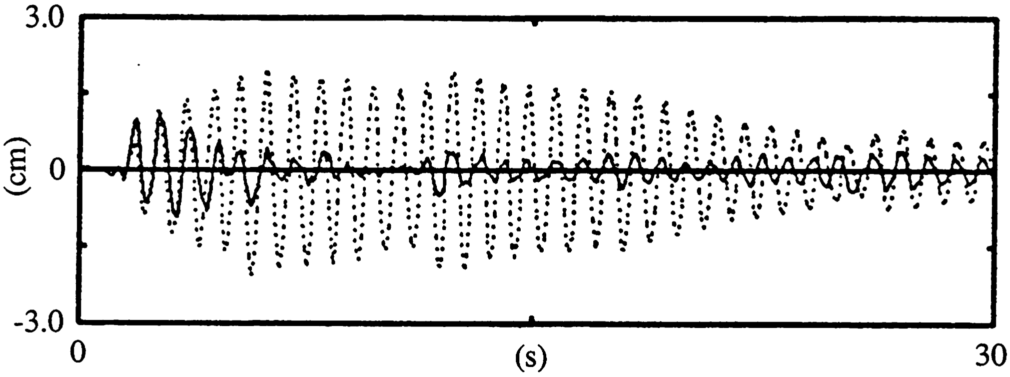
Fig. 4.2.5.2 Accelerations of the top floor in the case of the step-up searching algorithm.



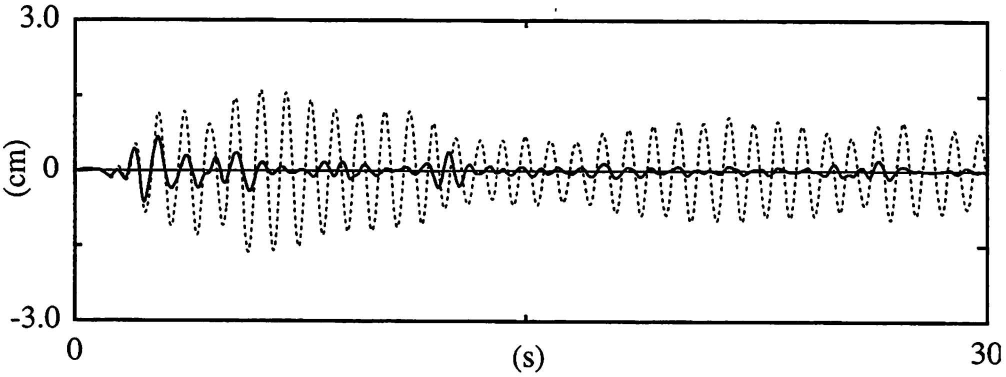
(a) Case of the number of the trial control forces $N = 3$ (Experimental results),



(b) Case of the number of the trial control forces $N = 5$ (Experimental results),

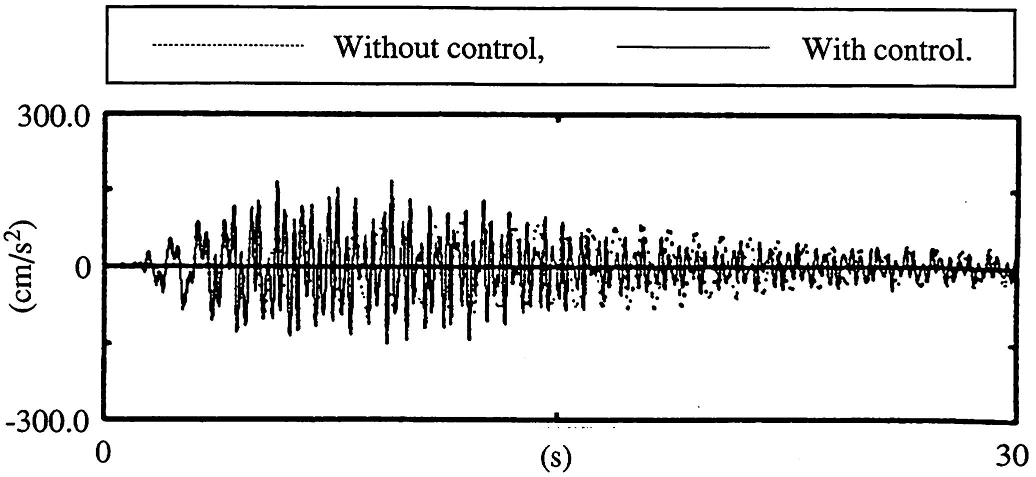


(c) Case of the number of the trial control forces $N = 7$ (Experimental results),

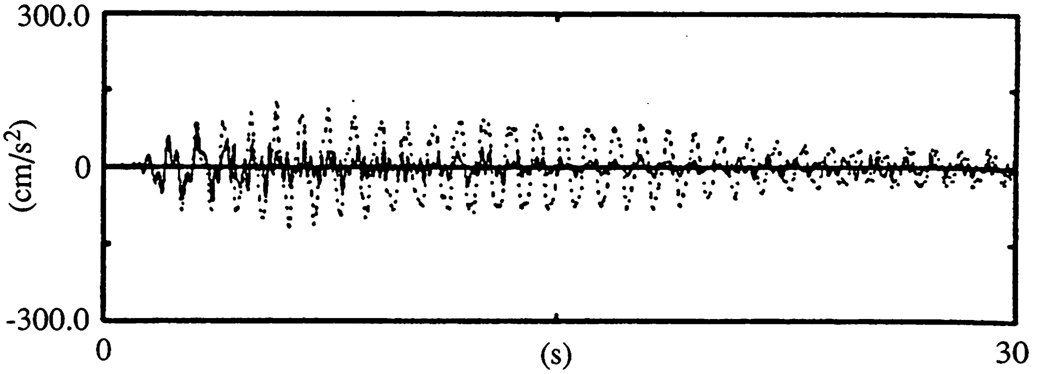


(d) Case of the number of the trial control forces $N = 5$ (Numerical results),

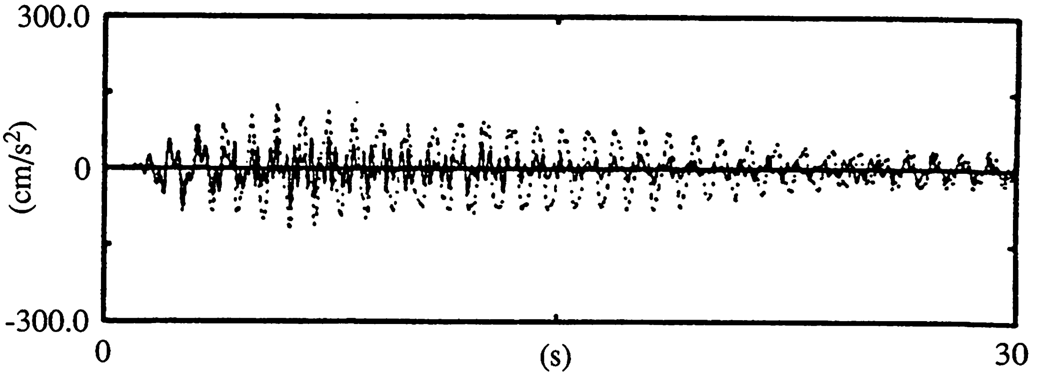
Fig. 4.2.6.1 Displacements of the top floor in the case of the step-down searching algorithm.



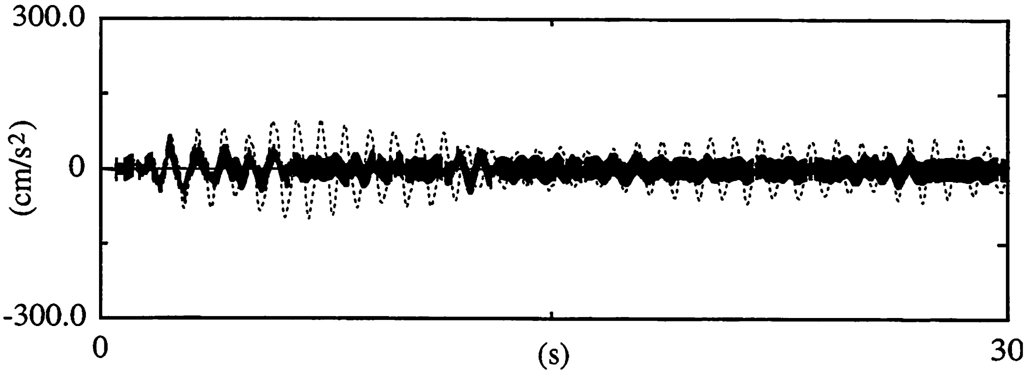
(a) Case of the number of the trial control forces $N = 3$ (Experimental results),



(b) Case of the number of the trial control forces $N = 5$ (Experimental results),



(c) Case of the number of the trial control forces $N = 7$ (Experimental results),



(d) Case of the number of the trial control forces $N = 5$ (Numerical results),

Fig. 4.2.6.2 Accelerations of the top floor in the case of the step-down searching algorithm.

4. 3 Arrangement of control forces on active control systems with multi-devices

The basic installation of the quasi-optimizing control method are described by introducing the three stories of the CTAC standard system in the Section 4.2. Active control system which is composed by three active brace located on every stories of the structural model is investigated through the experimental tests and the numerical simulations, and effectiveness of the quasi-optimizing control method are assured. Through those examinations, the multi-layer searching algorithms are proposed and estimated to consider to the practical placabilities for the multi-devices active control systems. To introduce those searching algorithms on the quasi-optimizing control method, the concepts of the priorities of the control devices are introduced. As the typical order of the priorities of the control devices, the step-up searching and the step-down searching sequence are supposed and evaluated. In the section 4.2, the word of 'priorities' of control devices is used only in the sense that those may instruct the searching sequence for optimization procedures on the quasi-optimizing control method, namely, the discussions may not be reached to the sense of the significance of control devices and may be operated only for the cases of the uniform distributions as the each control device capacity. In this section, the rates of the participation of each control device and the effective arrangements of control forces on each story are investigated. For this aim, numerical simulations are also executed by using the three stories of the CTAC standard system adopted in the section 4.2. The following studies are estimated for the controlled structural responses under the ground input of El Centro (1940) NS which is scaled down to the maximum acceleration amplitude of 30 (cm/s^2) during the first part of 30 seconds. Emphases are put on the following three items in those numerical studies :

Emphasis-1) To investigate the significance of the each layer which is supposed by using the multi-layer searching algorithm, control performances for the cases by using the single device are estimated. So that, by evaluating for control effects subjected to the difference of the location of single control device, the 'priority' of control devices in sense of the improvements of responses may be discussed through this study.

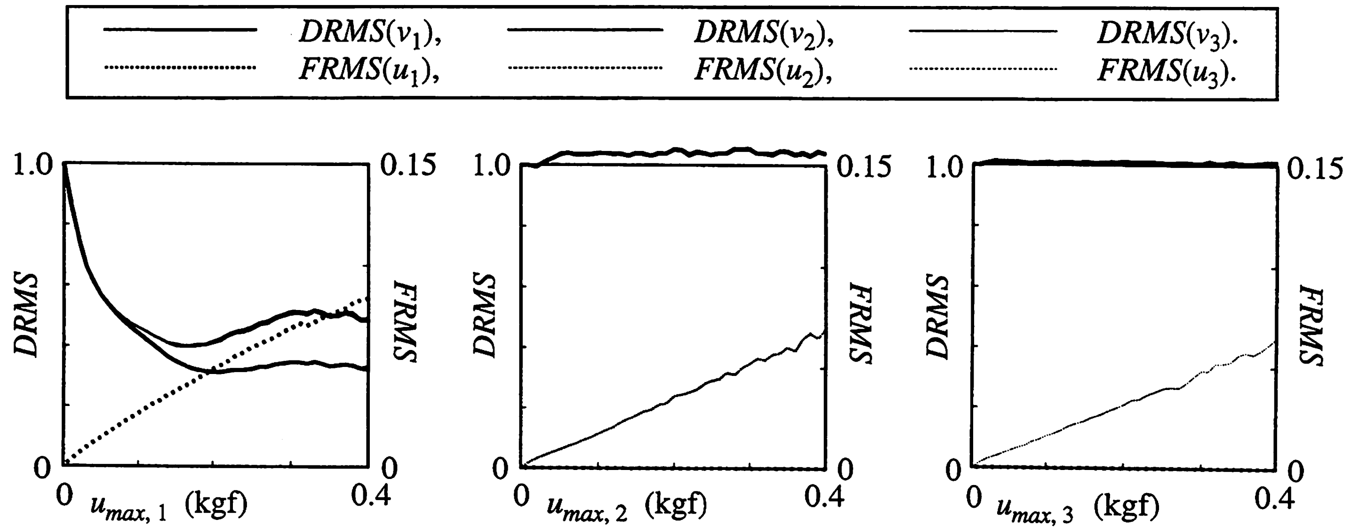
Emphasis-2) Significance of the control forces which are supplied by the control devices located on the lower stories are investigated on the multi-device active control system. So that, by considering to the partial responsibilities of the control forces supplied on the lower stories, the participation of those control forces are evaluated to the total sense of the control performances.

Emphasis-3) Significance of the control forces which are supplied by the control devices located on the upper stories are investigated on the multi-device active control system. So that, by considering to the partial responsibilities of the control forces supplied on the upper stories, the participation of those control forces are evaluated to the total sense of the control performances.

Through considerations for the those items, the adequate arrangements of control forces which are supposed as the partial responsibilities of control device may be discussed.

Study (4.3) - 1 :

At first, to investigate for the Emphasis-1, three kinds of case studies are executed. Those cases are supposed by using only any one of the control devices, namely, when the j-th control device is used, the control forces of the other control devises are always equal to zero. In those studies, the trial control forces of the j-th control device are proposed as Exp. (4.2.5) in the Section 4.2 (in which, as the number of trial control forces of j-th control device, $N_j = 5$ is adopted) and the other trial control forces of the i-th control device ($i \neq j$) are proposed as $<\hat{u}_i> = <0>$ (namely, the number of trial control forces of i-th control device $N_i = 1$ and the maximum trial control forces $u_{max,\,i} = 0$). Since the single-device is used in this study, only the single layer as the searching stage is supposed, namely, the same operation is produced by either optimization procedure based on the universal searching or the multi-layer searching algorithm (Study (4.3)-1).



(a) $u_{max,\,2} = 0,\ u_{max,\,3} = 0,$ (b) $u_{max,\,1} = 0,\ u_{max,\,3} = 0,$ (c) $u_{max,\,1} = 0\ ,\ u_{max,\,2} = 0,$

Fig. 4.3.1 Control performances in the cases by using the single control device.

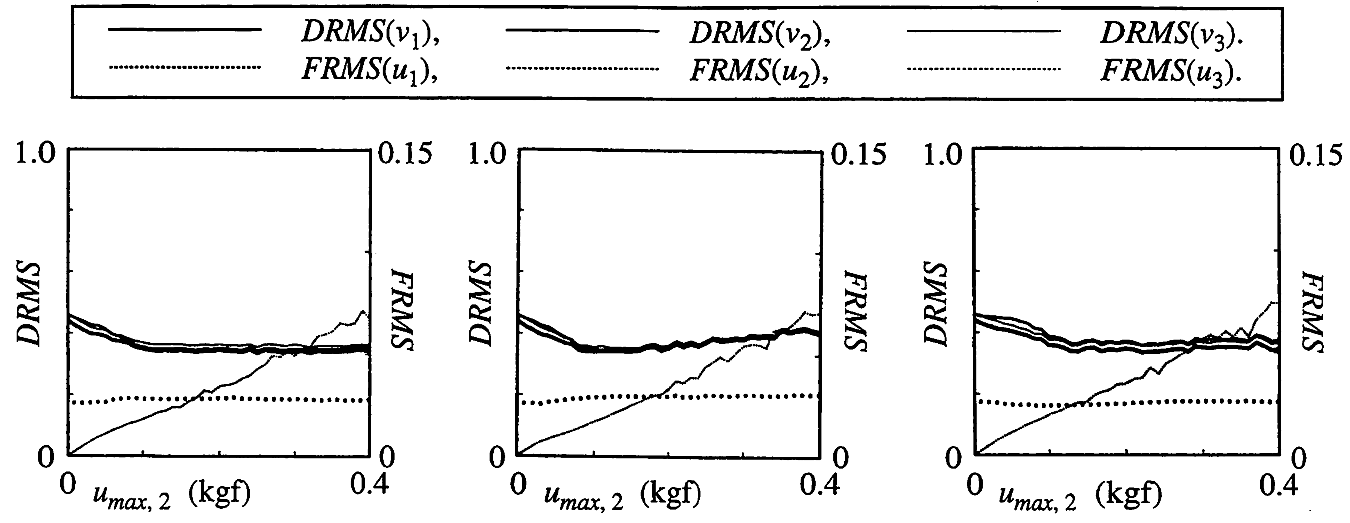
Figs. 4.3.1, show the displacements controlled factors (*DRMS*) and the control manipulation factors (*FRMS*) for the three cases which are used any one of the control devices. In those figures, (a), (b) and (c) are corresponding to the cases of j =1, 2 and 3 (in which, j means the selected single control device number to use actively), respectively. The fluctuations of the *DRMS* and the *FRMS* are plotted in those figures according to the variations of the maximum trial control forces $u_{max,\,j}$. By comparing those figures, the control effects in sense of reductions of responses can be observed only in the case which is used the control device located on the lowest story. In this case, control effects to reduce the *DRMS* may be improved by increasing the maximum trial control forces $u_{max,\,1}$, however, those control effects may be remained stagnant regardless of increase of the maximum trial control forces after reaching at the bottom state (as seen in Fig.4.3.1 (a)). As the reason of this, it may be regarded that the structural vibrations spilled out to the upper stories can not be controlled by this control device, although a certain amount of response reductions can be operated by only the control device located on the lowest story since the control forces allocated the lowest story have efficiency to isolate for the seismic disturbances. On the other cases which is used the control device located on the 2nd or the 3rd story, the *DRMS* may be adrift the closed state without control (as seen in Fig.4.3.1 (b) and (c)). So that, in those two cases, the control effects in sense of reductions of responses may not be gained. Through the investigations for the control effects evaluated by the *DRMS*, it is assured that the control forces which is located on the lowest story have predominant effects in sense of reductions of responses (those considerations may be supposed on the conditions for the control system which is adopted in this section).

On the other hand, the *FRMS* in all cases may be grown proportionally according to increasing the maximum trial control forces $u_{max,j}$. The very important instructions may be introduced from those results, namely, those results may assign to significant phenomena which are related to the 'parasitic stability' of the quasi-optimizing controller. Although all cases adopted here are supposed as the controller not to be warranted those controllabilities, the *DRMS* can be stayed within the finite nearly states for the uncontrolled responses or can be transferred to reduced states from the uncontrolled responses while the control inputs are supplied. As the conditions to warrant the parasitic stabilities related to the additional controllers, 'controllabilities' of those controllers are not required as long as the controller can select the one of manipulations as to stop the all control inputs at the any time instance (in which, the word of 'additional' is used in the meanings on the assumptions that stability of the original system without control is warranted or that the original system has been already stabilized by installations of the another kinds of controllers). So that, the results form this case study may be suggested the physical images for the concepts of the rectification of the system by installing the additional controller to be warranted its parasitic stability.

***Study (4.3) - 2a* :**

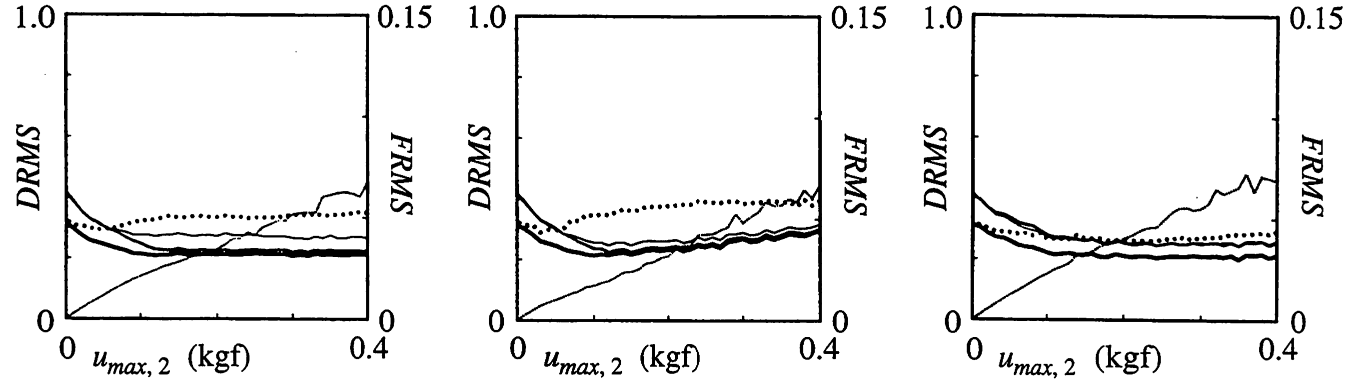
As the next step, to investigate for the Emphasis-2, the case studies for using two control devices which are located on the 1st and the 2nd stories are executed. In this study, three cases that the maximum control forces of the 1st story $u_{max,1}$ are supposed as $u_{max,1} = 0.1$, 0.2 and 0.4 (kgf) are evaluated. The maximum control forces of the 2nd story $u_{max,2}$ is evaluated as the parameter. In which, as the number of trial control forces of the 1st and the 2nd control devices, $N_1 = 5$ and $N_2 = 5$ is adopted. The sets of the trial control forces of those control devices are proposed as Exp. (4.2.5) in the Section 4.2. The trial control forces of the 3rd control device are proposed as $<\hat{u}_3> = <0>$ (namely, the number of trial control forces of 3rd control device $N_3 = 1$ and the maximum trial control forces $u_{max,3} = 0$). Those investigations are operated for the three cases by using the universal searching, the step-up searching and the step-down searching algorithms through the numerical simulations.

Figs. 4.3.2.1, 4.3.2.2 and 4.3.2.3 show the displacements controlled factors (*DRMS*) and the control manipulation factors (*FRMS*) when two control devices which are located on the 1st and the 2nd stories are used and are corresponding to the three cases which are selected as the maximum



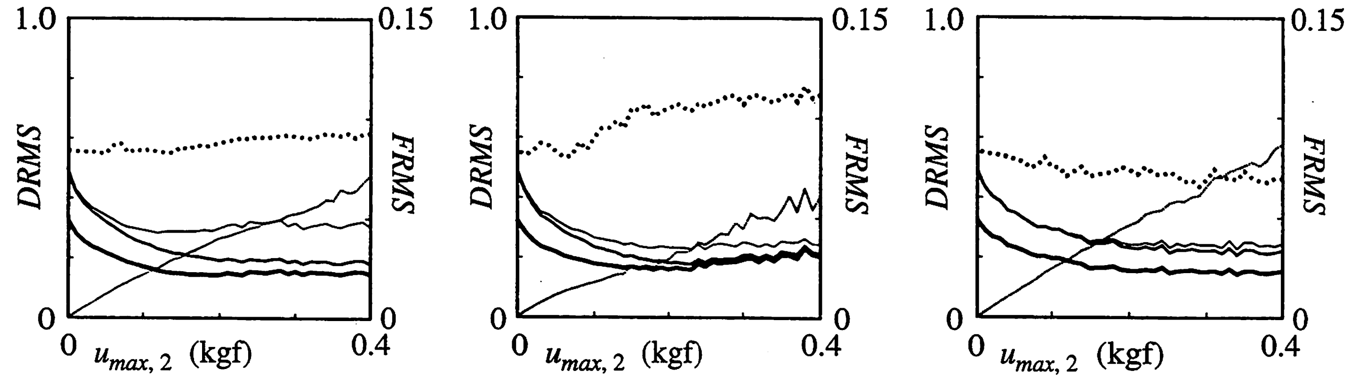
(a) Universal searching, (b) Step-up searching, (c) Step-down searching,

Fig. 4.3.2.1 Control performances by using two control devices ($u_{max,1} = 0.1$, $u_{max,3} = 0$).



(a) Universal searching, (b) Step-up searching, (c) Step-down searching,

Fig. 4.3.2.2 Control performances by using two control devices ($u_{max,1} = 0.2$, $u_{max,3} = 0$).



(a) Universal searching, (b) Step-up searching, (c) Step-down searching,

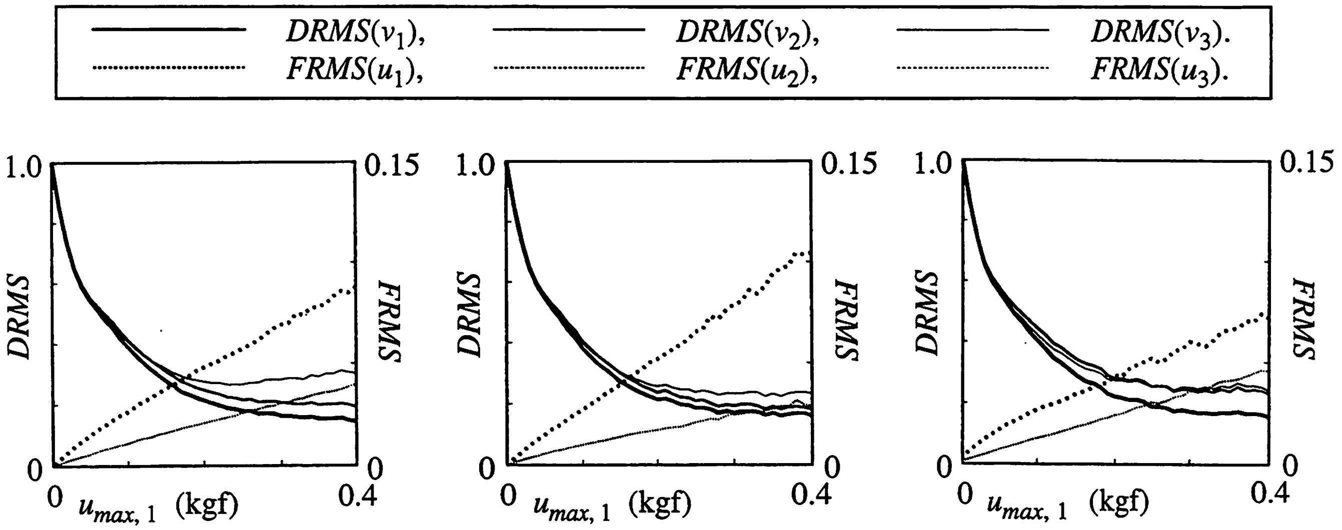
Fig. 4.3.2.3 Control performances by using two control devices ($u_{max,1} = 0.4$, $u_{max,3} = 0$).

control forces of the 1st story $u_{max,1} = 0.1, 0.2$ and 0.4 (kgf), respectively. In those figures, (a), (b) and (c) show the cases that are installed the universal searching, the step-up searching and the step-down searching algorithm, respectively. The fluctuations of the *DRMS* and the *FRMS* are plotted in those figures according to the variations of the maximum trial control forces of the 2nd control device $u_{max,2}$. By comparing (a), (b) and (c) with each other in those figures, it is assured that, as the common characteristics for each searching algorithms, control effects for the reduction of responses can be improved by increasing the maximum control forces of the 1st story $u_{max,1}$, and more effective reductions of responses can be gained by supplying the control forces of the 2nd stories than the cases of $u_{max,2} = 0$. From the considerations for those results, it may be regarded that the most effective reductions of responses can be gained by introducing about a half value of the maximum control force of the 1st control device $u_{max,1}$ as the minimum required control forces which is presented as $u_{max,2}$ by seeing in Figs.4.3.2.2 and 4.3.2.3. Although those values evaluated as the minimum required control forces of the 2nd control device may be enlarged in the case of $u_{max,1} = 0.1$ (as seen in Figs.4.3.2.1), as the reason of this, it may be considered that the supposed value of the maximum trial control forces $u_{max,1} = 0.1$ is not enough to reduce structural response effectively, namely, this value may be smaller than the value which is reached at the bottom state of the reductions of responses by increasing of the maximum trial control forces $u_{max,1}$ (as considerations in the previous case studies which is used the single device, namely, as seen in Fig.4.3.1 (a)).

Study (4.3) - 2b **:**

As the another consideration, by estimating for the cases by using the step-up searching algorithm (as seen in Figs. 4.3.2.1 (b), 4.3.2.2 (b) and 4.3.2.3 (b)), the most effective reductions of the responses may be gained by supplying the smaller value as $u_{max,2}$ than $u_{max,1}$. So that, it seems that control performances may be improved by introducing about a half value of $u_{max,1}$ as the maximum control force of the 2nd control device $u_{max,2}$. To assure those, the further case studies for using two control devices which are located on the 1st and the 2nd stories are executed. In this study, the maximum control forces of the 2nd story $u_{max,2}$ are supposed as a half value of $u_{max,1}$, namely, $u_{max,2} = u_{max,1} / 2$. In which, as the number of trial control forces of the 1st and the 2nd control devices, $N_1 = 5$ and $N_2 = 5$ is adopted. The sets of the trial control forces of those control devices are proposed as Exp. (4.2.5) in the Section 4.2. The trial control forces of the 3rd control device are proposed as $<\hat{u}_3> = <0>$. Numerical estimations are operated for the three cases by using the universal searching, the step-up searching and the step-down searching algorithms.

Figs. 4.3.3 show the displacements controlled factors (*DRMS*) and the control manipulation factors (*FRMS*) when two control devices which are located on the 1st and the 2nd stories are used (the maximum control forces supposed to those control devices are subjected by $u_{max,2} = u_{max,1} / 2$). In those figures, (a), (b) and (c) show the cases that are installed the universal searching, the step-up searching and the step-down searching algorithms, respectively. The fluctuations of the *DRMS* and the *FRMS* are plotted in those figures according to the variations of the maximum trial control forces $u_{max,1}$. By comparing those figures, the control effects evaluated by reductions of the *DRMS* can be observed as quite similar in the all cases which is installed the universal searching, the step-up searching and the step-down searching algorithms, also effective reductions of responses may be gained in all cases by increasing of the maximum trial control forces $u_{max,\,1}$ and $u_{max,\,2}$. In the case of the universal searching algorithm, it may be regarded that the *FRMS*(u_2) is close to a half value of the *FRMS*(u_1). When the step-up searching algorithm is supposed, it can be observed that the *FRMS*(u_2) may become larger than the value of *FRMS*(u_1) / 2, and when the step-up searching algorithm is supposed, it can be observed that the *FRMS*(u_2) may become smaller than the value of *FRMS*(u_1) / 2. At any rate, by introducing the adequate distributions of control forces for each story (in this case study, the distributions of control forces represented by $u_{max,\,2} = u_{max,\,1} / 2$ is supposed) , it is assured that effective control performances can be operated by using whichever searching algorithms of three kinds adopted here.



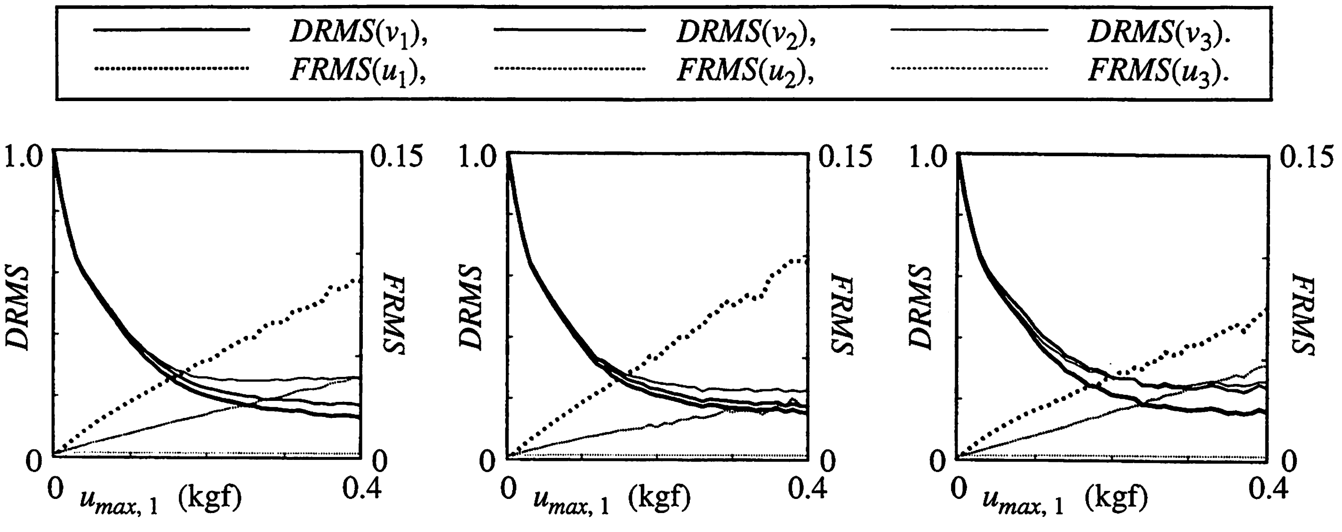
(a) Universal searching, (b) Step-up searching, (c) Step-down searching,

Fig. 4.3.3 Control performances (*DRMS* and *FRMS*) in the case of $u_{max,\,3} = 0$.

Study (4.3) - 3 :

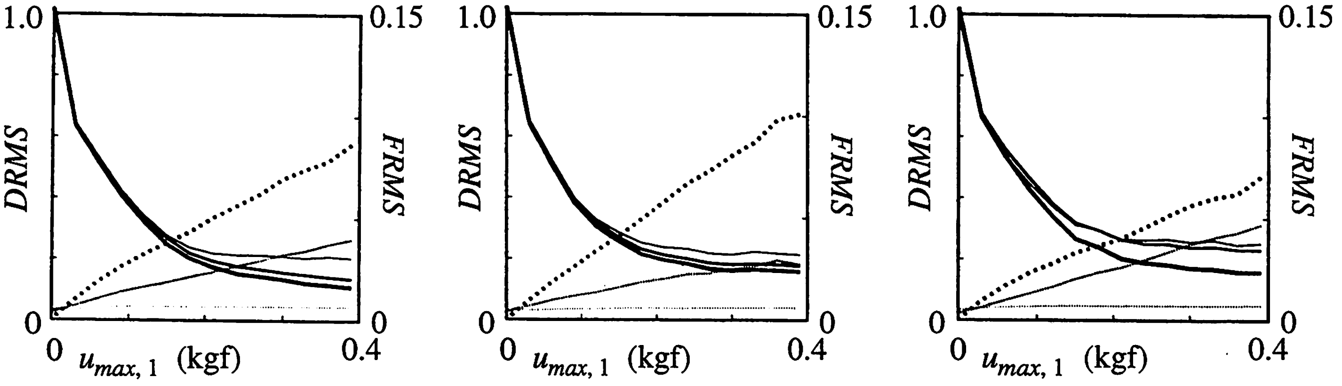
As the last step, to investigate for the Emphasis-3, the case studies for using all control devices are executed. In this study, three cases that the maximum control forces of the 3rd story $u_{max,\,3}$ are supposed as $u_{max,\,3} = 0.01$, 0.03 and 0.05 (kgf) are estimated. The maximum control forces of the 1st story $u_{max,\,1}$ is evaluated as the parameter and the maximum control forces of the 2nd story $u_{max,\,2}$ is supposed as the conditions which is $u_{max,\,2} = (u_{max,\,1} + u_{max,\,3}) / 2$. In which, as the number of trial control forces of every control devices are supposed as to be equal to 5. The sets of the trial control forces of those control devices are proposed as Exp. (4.2.5) in the Section 4.2. Those investigations are operated for the three cases by using the universal searching, the step-up searching and the step-down searching algorithms through the numerical simulations.

Figs. 4.3.4.1, 4.3.4.2 and 4.3.4.3 show the displacements controlled factors (*DRMS*) and the control manipulation factors (*FRMS*) when all control devices are used (the maximum control forces supposed to those control devices are subjected by $u_{max,\,2} = (u_{max,\,1} + u_{max,\,3}) / 2$) and are corresponding to the three cases which are selected as the maximum control forces of the 3rd story



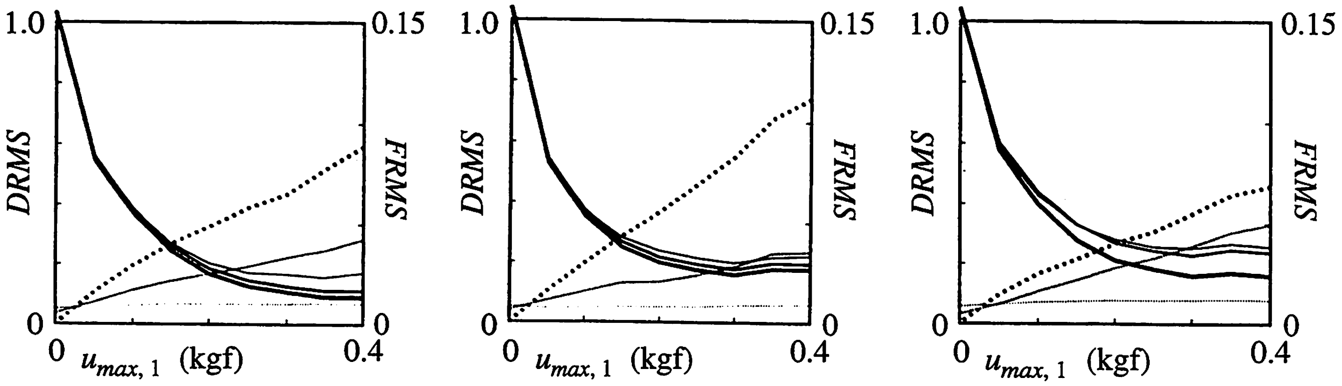
(a) Universal searching, (b) Step-up searching, (c) Step-down searching,

Fig. 4.3.4.1 Control performances (*DRMS* and *FRMS*) in the case of $u_{max,3} = 0.01$.



(a) Universal searching, (b) Step-up searching, (c) Step-down searching,

Fig. 4.3.4.2 Control performances (*DRMS* and *FRMS*) in the case of $u_{max,3} = 0.03$.



(a) Universal searching, (b) Step-up searching, (c) Step-down searching,

Fig. 4.3.4.3 Control performances (*DRMS* and *FRMS*) in the case of $u_{max,3} = 0.05$.

$u_{max,3}$ = 0.01, 0.03 and 0.05 (kgf), respectively. In those figures, (a), (b) and (c) show the cases that are installed the universal searching, the step-up searching and the step-down searching algorithm, respectively. The fluctuations of the *DRMS* and the *FRMS* are plotted in those figures according to the variations of the maximum trial control forces of the 1st control device $u_{max,1}$.

By comparing (a), (b) and (c) with each other in those figures, the control effects evaluated by reductions of the *DRMS* can be observed as quite similar in the all cases which is installed the universal searching, the step-up searching and the step-down searching algorithms, also effective reductions of responses may be gained in all cases by increasing of the maximum trial control forces $u_{max,1}$ and $u_{max,2}$. Moreover, the quite similar control effects can be observed regardless of the differences of the maximum trial control forces of the 3rd control device $u_{max,3}$ in all cases by using each searching algorithm. In which, the previous results which is assigned in the Figs. 4.3.3 are compared with the those results which are assigned in the Figs. 4.3.4.1, 4.3.4.2 and 4.3.4.3. The previous results are also corresponding to the case of $u_{max,3} = 0$ under the conditions which is $u_{max,2} = (u_{max,1} + u_{max,3}) / 2$. By observing (a), (b) and (c) with each other in all of those figures, it is assured that the quite similar control performances evaluated by the *DRMS* and the *FRMS* can be also operated regardless of the difference of the maximum trial control forces of the 3rd control device $u_{max,3}$. So that, by introducing the adequate distributions of control forces for each story (the distributions of control forces subjected by $u_{max,2} = (u_{max,1} + u_{max,3}) / 2$ is supposed in this case study), it may be resulted that effective control performances can be gained by using whichever searching algorithms of three kinds adopted here.

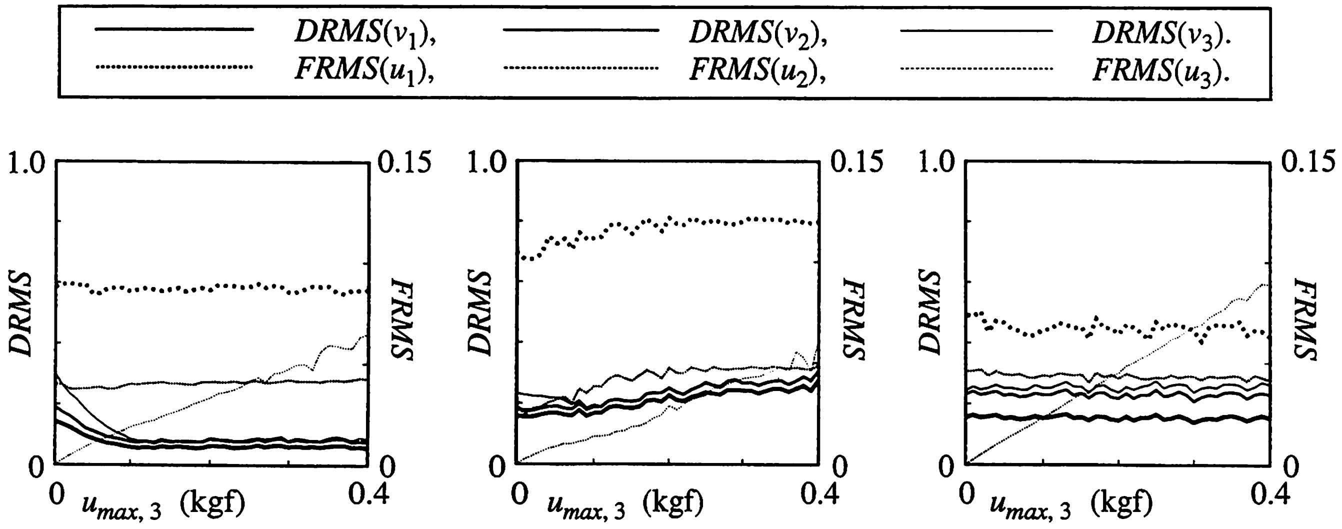
Study (4.3) - 4a :

As the another consideration for those results, by evaluating for the responsibilities of the 3rd control device, it seems that the rates of the participation and the significance of the 3rd control devices are comparatively smaller than the other control devices which are located lower stories. To assure those and to evaluate for the responsibilities of the 3rd control device, the further two kinds of case studies for using all control devices are executed under the following conditions.

As the first one, the maximum control forces of the 1st and the 2nd stories are supposed as $u_{max,1} = 0.4$ and $u_{max,2} = 0.2$ (kgf). The maximum control forces of the 3rd story $u_{max,3}$ is evaluated as the parameter (Study-1). In which, as the number of trial control forces of every control devices are supposed as to be equal to 5. The sets of the trial control forces of those control devices are proposed as Exp. (4.2.5) in the Section 4.2. Numerical estimations are operated for the three cases by using the universal searching, the step-up searching and the step-down searching algorithms.

Figs. 4.3.5 show the displacements controlled factors (*DRMS*) and the control manipulation factors (*FRMS*) when all control devices are used (the maximum control forces of the 1st and the 2nd story are supposed as $u_{max,1} = 0.4$ and $u_{max,2} = 0.2$). In those figures, (a), (b) and (c) show the cases that are installed the universal searching, the step-up searching and the step-down searching algorithms, respectively. The fluctuations of the *DRMS* and the *FRMS* are plotted in those figures according to the variations of the maximum trial control forces $u_{max,3}$.

By comparing those figures, the control effects evaluated by reductions of the *DRMS* can be improved by the increasing of the control forces of the 3rd control device $u_{max,3}$ only in the case which is installed the universal searching algorithm. When the step-up searching algorithm is supposed, the control effects may be deteriorated by increasing of the maximum trial control forces of the 3rd control device $u_{max,3}$ (as seen in Fig.4.3.5 (b)). When the step-down searching algorithm is supposed, the control effects may be almost unchanged by the difference of $u_{max,3}$ (as seen in Fig.4.3.5 (c)). In the case of the universal searching algorithm, about 0.1 (kgf) of the maximum trial control force of the 3rd control device $u_{max,3}$ may be regarded as the minimum required control forces of $u_{max,3}$ to operate the most effective improvements for the reductions of the responses as seen in Fig. 4.3.5 (a). It is regarded that this value may be satisfied the conditions for the responsibilities of control devices on the case which all devices are used , namely, $u_{max,2} = (u_{max,1} + u_{max,3}) / 2$. When the step-down searching or the step-down algorithm is supposed and this value (about 0.1 (kgf)) is supplied as $u_{max,3}$, the *DRMS* may not so different from the cases which is supposed the smaller values as $u_{max,3}$.



(a) Universal searching, (b) Step-up searching, (c) Step-down searching,

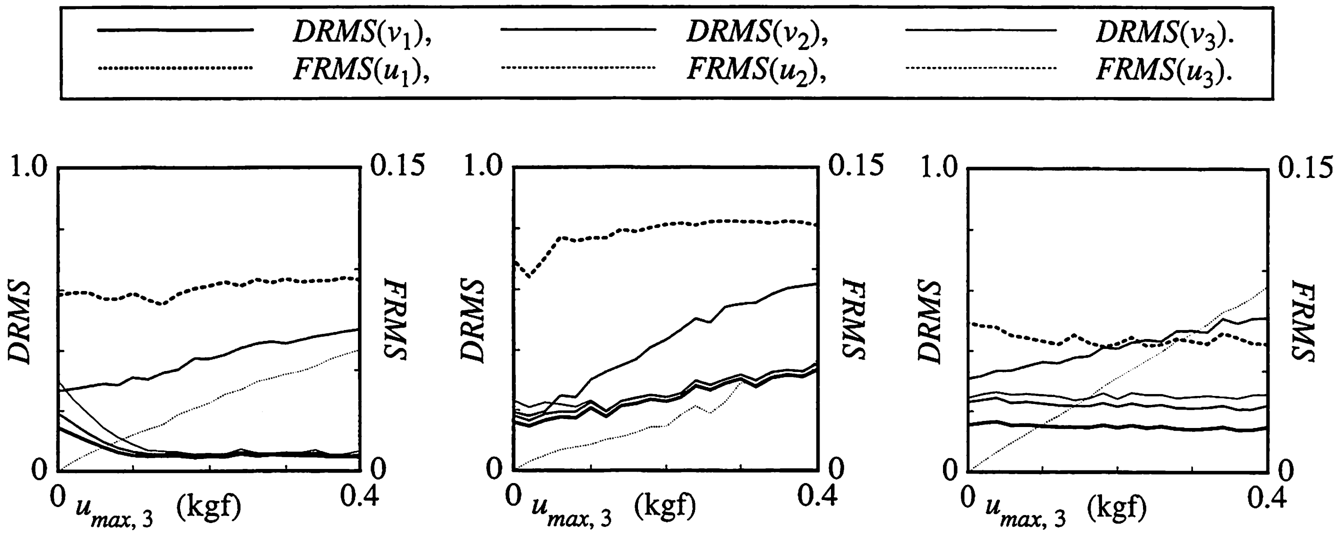
Fig. 4.3.5 Control performances in the case of $u_{max,1} = 0.4$ and $u_{max,2} = 0.2$.

Study (4.3) - 4b :

As the next one, the maximum control force of the 1st story is supposed as $u_{max,1} = 0.4$. The maximum control forces of the 3rd story $u_{max,3}$ is evaluated as the parameter. The maximum control force of the 2nd story is subjected as the arrangements of $u_{max,2} = (u_{max,1} + u_{max,3}) / 2$ (Study-2). In which, as the number of trial control forces of every control devices are supposed as to be equal to 5. The sets of the trial control forces of those control devices are proposed as Exp. (4.2.5) in the Section 4.2. Numerical estimations are operated for the three cases by using the universal searching, the step-up searching and the step-down searching algorithms.

Figs. 4.3.6 show the displacements controlled factors (*DRMS*) and the control manipulation factors (*FRMS*) when all control devices are used (the maximum control forces of the 1st and the 2nd story are supposed as $u_{max,1} = 0.4$ and $u_{max,2} = (u_{max,1} + u_{max,3}) / 2$). In those figures, (a), (b) and (c) show the cases that are installed the universal searching, the step-up searching and the step-down searching algorithms, respectively. The fluctuations of the *DRMS* and the *FRMS* are plotted in those figures according to the variations of the maximum trial control forces $u_{max,3}$.

By evaluating those figures and comparing those results with the ones of the Study-1, the quite similar results may be observed in all cases for the universal searching, the step-up searching and the step-down searching algorithm. In the Study-2, the arrangements of control forces are subjected as the condition $u_{max,2} = (u_{max,1} + u_{max,3}) / 2$. In this case, the control effects evaluated by reductions of the *DRMS* can be improved by supplying the values over about 0.12 (kgf) as the maximum trial control force of the 3rd control device $u_{max,3}$. When the step-down searching or the step-down algorithm is supposed and this value (about 0.12 (kgf)) is supplied as $u_{max,3}$, the *DRMS* may not so different from the cases which is supposed the smaller values as $u_{max,3}$. From those considerations, it may be appeared that the effective responsibilities of control devices of $u_{max,1}$: $u_{max,1}$: $u_{max,1}$ are evaluated as to about 3 : 2 : 1 when the condition $u_{max,2} = (u_{max,1} + u_{max,3}) / 2$ is supposed as the arrangements of control forces.



(a) Universal searching, (b) Step-up searching, (c) Step-down searching,

Fig. 4.3.6 Control performances in the case of $u_{max,1} = 0.4$ ($u_{max,2} = (u_{max,1} + u_{max,3}) / 2$).

Study (4.3) - 5 :

Those results are also evaluated by comparisons for the time histories of controlled behaviors of the system which are shown in Figs. 4.3.7.1, 4.3.7.2, 4.3.8.1 and 4.3.8.2. In those figures, (a), (b) and (c) show the cases that are installed the universal searching, the step-up searching and the step-down searching algorithms, respectively. Figs. 4.3.7.1 and 4.3.7.2 show the displacements of the first floor and the control forces of the first story, respectively, in this cases, the arrangements of the maximum trial control forces of each control devices are supposed as $u_{max,1} = 0.36$, $u_{max,2} = 0.36$ and $u_{max,3} = 0.36$ (kgf) (Case-1). Figs. 4.3.8.1 and 4.3.8.2 show the displacements of the first floor and the control forces of the first story, respectively, in this cases, the arrangements of the maximum trial control forces of each control devices are supposed as $u_{max,1} = 0.36$, $u_{max,2} = 0.24$ and $u_{max,3} =$

0.12 (kgf) (Case-2). In both of those cases, as the number of trial control forces of every control devices are supposed as to be equal to 5. El Centro (1940) NS which is scaled down to the maximum acceleration amplitude of 30 (cm/s^2) is used as the inputs of the ground motions. Table 4.3.1 show the *DRMS* which are corresponding to those two case studies, respectively. Table 4.3.2 show the *FRMS* which are corresponding to those two case studies, respectively.

Table 4.3.1 *DRMS* for the Case-1 and the Case-2 (%).

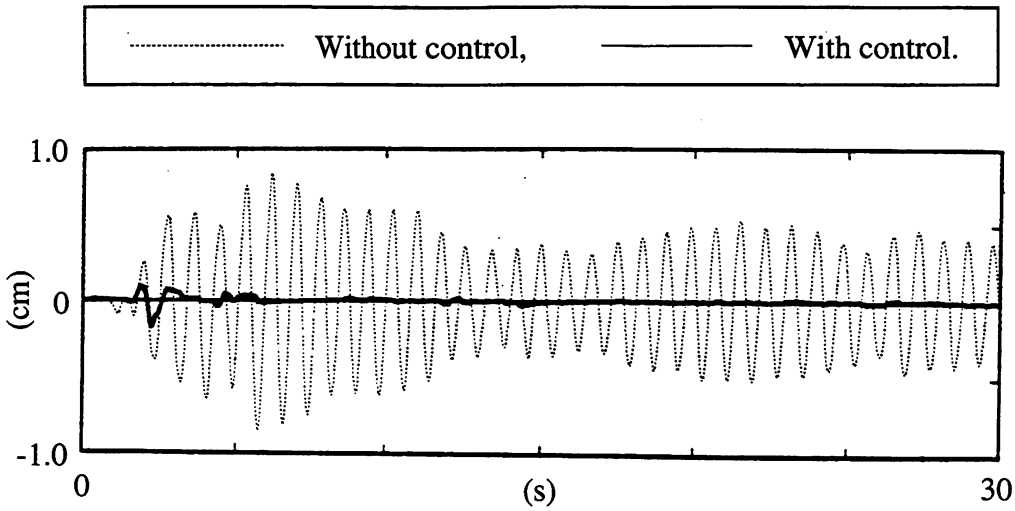
Case	Algorithm	$DRMS(v_1)$	$DRMS(v_2)$	$DRMS(v_3)$	$\overline{DRMS}$
Case-1	Universal	5.67	6.04	6.64	6.12
	Step-up	34.21	36.13	36.00	35.45
	Step-down	13.41	19.67	22.47	18.52
Case-2	Universal	5.84	6.53	7.47	6.61
	Step-up	20.63	22.39	22.40	21.81
	Step-down	15.68	22.30	26.04	21.34

Table 4.3.2 *FRMS* for the Case-1 and the Case-2 (%).

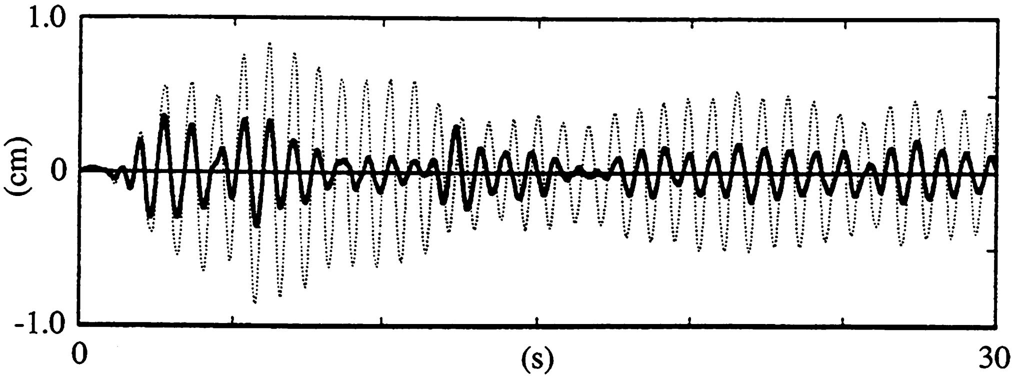
Case	Algorithm	$FRMS(u_1)$	$FRMS(u_2)$	$FRMS(u_3)$	$\overline{FRMS}$
Case-1	Universal	8.98	6.33	5.89	7.07
	Step-up	11.07	8.72	5.05	8.28
	Step-down	5.81	6.78	8.24	6.94
Case-2	Universal	7.91	4.46	1.95	4.77
	Step-up	10.54	4.86	1.54	5.65
	Step-down	6.24	5.20	2.80	4.75

By evaluating for Figs. 4.3.7.1 and 4.3.8.1, the most effective reductions of responses can be observed in both the Case-1 and the Case-2 when the universal searching algorithm is supposed. As the reason of those, it may be suggested that control forces on the lower stories in the cases by using the step-up searching algorithm are supplied more than the cases by using the universal searching algorithm and that control forces on the lower stories in the cases by using the step-down searching algorithm are supplied less than the cases by using the universal searching algorithm. Those considerations may be also assured by observing the behaviors of control forces as seen in Figs. 4.3.7.2 and 4.3.8.2 or the values of the *FRMS* as assigned in Table 4.3.2. Through the comparisons of Figs. 4.3.7.1 and 4.3.8.1, when the universal searching algorithm is supposed, the quite similar control effects may be observed both the Case-1 and the Case-2. When the step-down searching algorithm is supposed, the quite similar control effects may be also observed both the Case-1 and the Case-2. On the other hand, when the step-down searching algorithm is supposed, control effects in the Case-2 may be gained the more improvements for reductions of responses, the reductions of responses evaluated as the *DRMS* may be almost the same as the case of the step-down searching algorithm. So that, it is assured that the difference of the control effects in the case by introducing the step-up searching algorithm from the cases by introducing the other two algorithms (those are discussed in the Section 4.2) can be avoided when the Case-2 is supposed as the arrangements of the maximum trial control forces of each control devices.

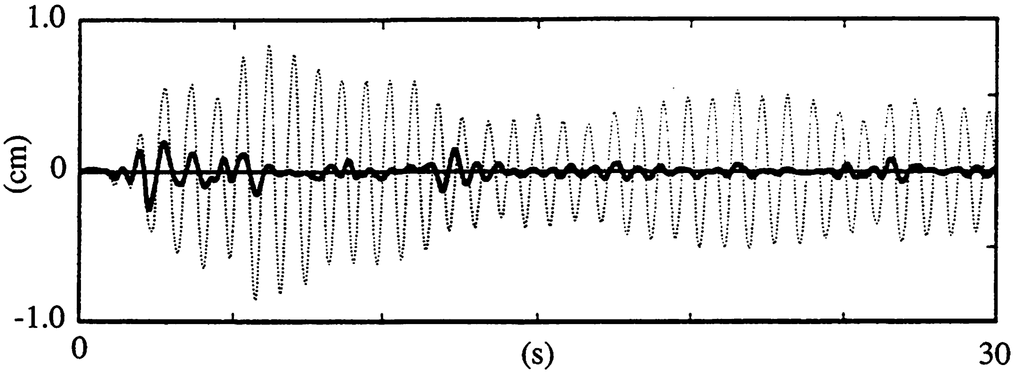
As concluding remarks of this section, the rates of the participation of each control device are evaluated through numerical investigations. By investigating for the 'priority' of control devices in the sense of the improvements of control effects for the reductions of responses, the effective arrangements of control forces (which are supposed as the partial responsibilities of control device) are proposed.



(a) Universal searching,

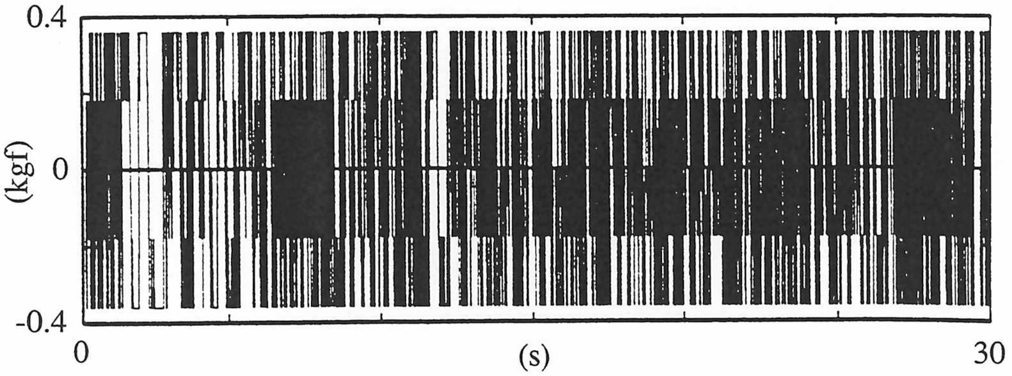


(b) Step-up searching,

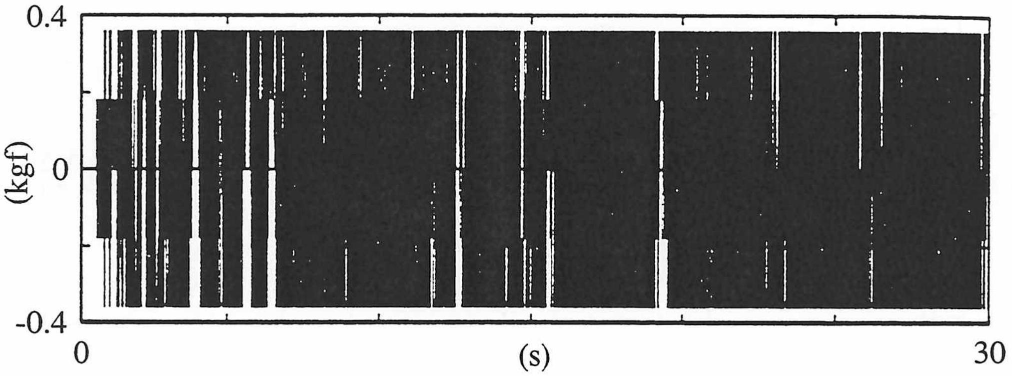


(c) Step-down searching,

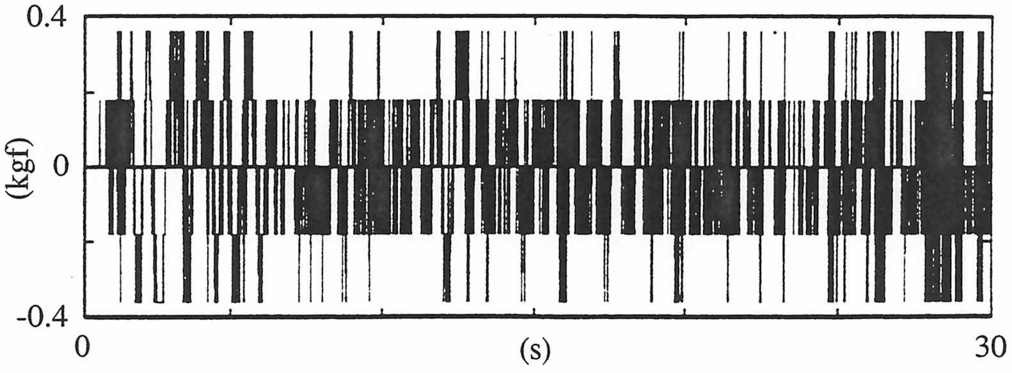
Fig. 4.3.7.1 Displacements of the first floor for El Centro NS ($u_{max,1} = 0.36$, $u_{max,2} = 0.36$ and $u_{max,3} = 0.36$ (kgf) : Case-1).



(a) Universal searching,

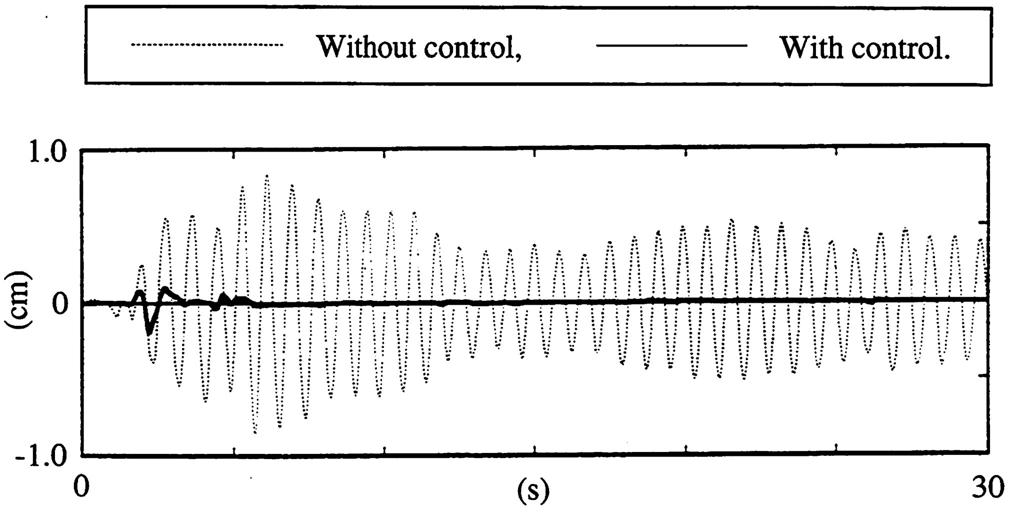


(b) Step-up searching,

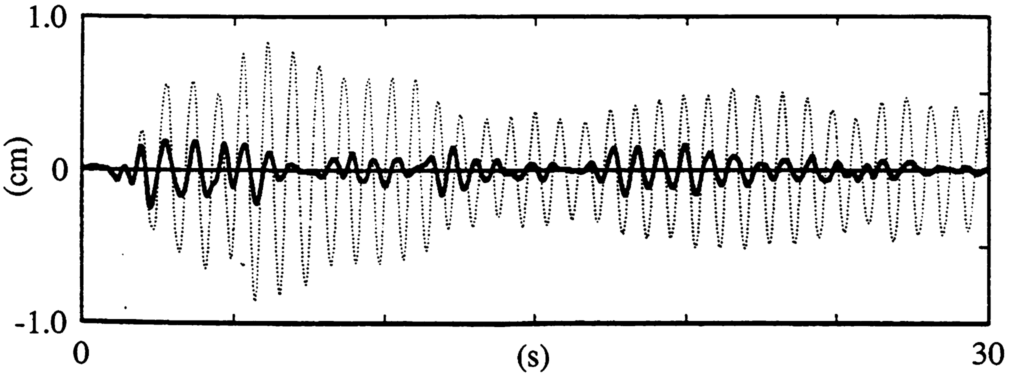


(c) Step-down searching,

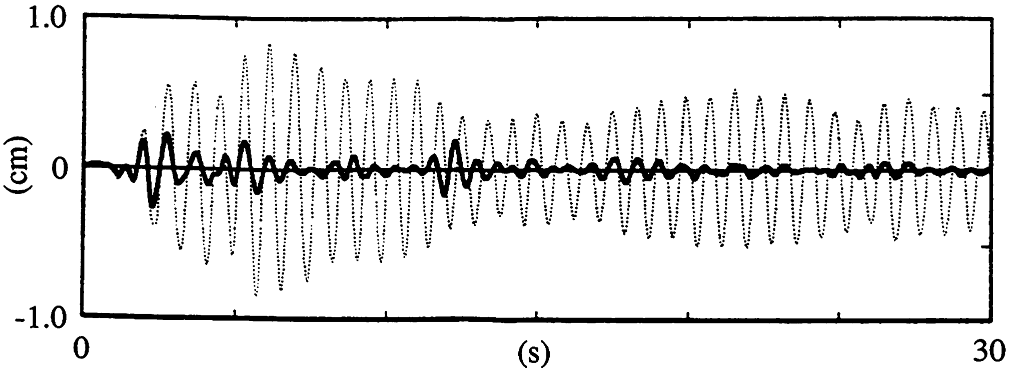
Fig. 4.3.7.2 Control forces of the first story for El Centro NS ($u_{max,1} = 0.36$, $u_{max,2} = 0.36$ and $u_{max,3} = 0.36$ (kgf) : Case-1).



(a) Universal searching,

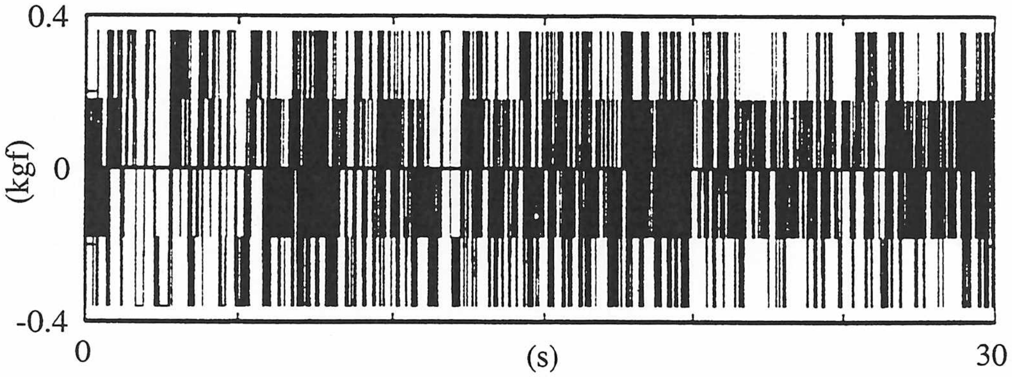


(b) Step-up searching,

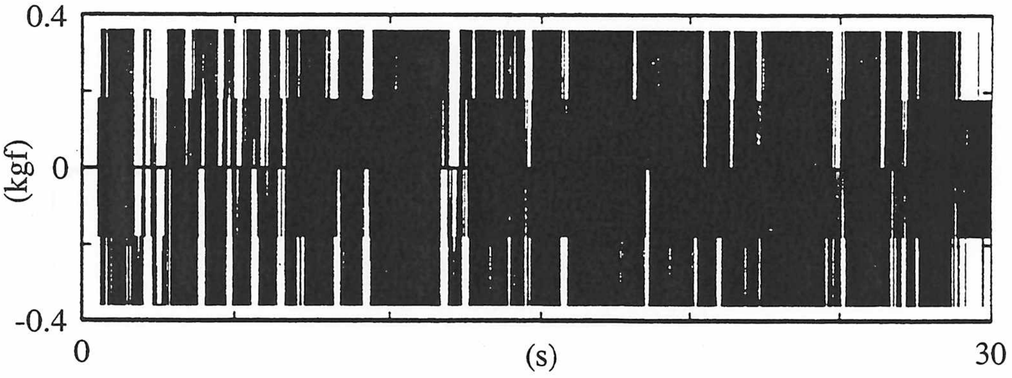


(c) Step-down searching,

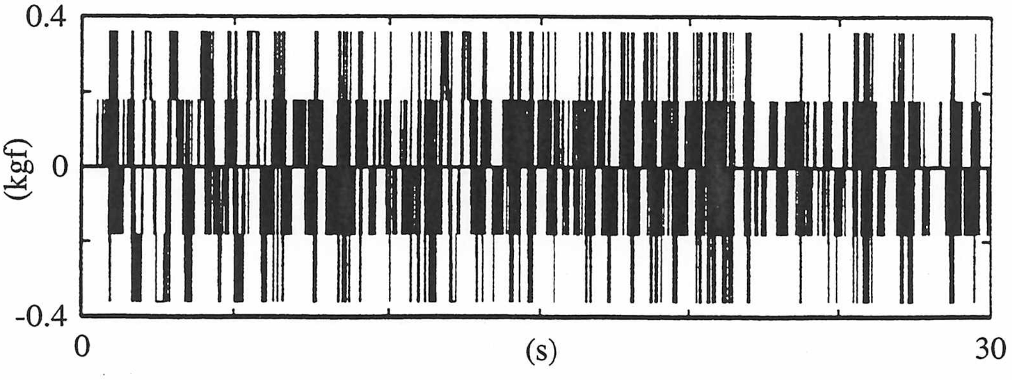
Fig. 4.3.8.1 Displacements of the first floor for El Centro NS ($u_{max,1} = 0.36$, $u_{max,2} = 0.24$ and $u_{max,3} = 0.12$ (kgf) : Case-2).



(a) Universal searching,



(b) Step-up searching,



(c) Step-down searching,

Fig. 4.3.8.2 Control forces of the first story for El Centro NS ($u_{max,\,1} = 0.36$, $u_{max,\,2} = 0.24$ and $u_{max,\,3} = 0.12$ (kgf) : Case-2).

4. 4 Evaluation of control force system generated by multi-devices

The responsibilities of the control devices are discussed in the Section 4.3. Since the quasi-optimizing control force vectors are directly related to the manipulated control force vectors supplied via active braces in the previous studies, the effective arrangements of the capacities of each control device (those are evaluated and supposed as the partial responsibility of each control device) may be subjected the characteristics of the 'control force system' which are provided as the inter-story forces. In such a sense, it may be interested to investigate that "the trial control force vectors can be related to the other coordinates of the control force systems which can be indirectly produced as the 'para-systems' of control forces". So that, discussions for the responsibilities of the 'control devices' may be extended for the arrangements of the acting points of the 'control forces', apparently.

At first, the actualization of the para-systems of control forces are considered for the multi-devices active control system. For this aim, by using the three stories of the CTAC standard system adopted in the Section 4.2 (as seen in Fig. 4.2.1), compositions of the para-systems of control forces via active braces installed on every stories are discussed. The equation of motions of this structural model is expressed as Eq. (4.2.1). As the denotation in the Section 4.2, $\{\boldsymbol{b}\}$ means the manipulated control force vector which is directly supplied to the structural model via the active braces and the coordinate of the trial control force vectors is supposed as $\{\boldsymbol{u}\}$. In which, the coordinate of the trial control force vectors are provided the meanings of the mediational variable which is used to make trial control forces relate to various kinds of control force systems which are subjected by the difference of the mechanical characteristics of control devices or the locations of control devices. For instance, in the previous investigations in the Sections 4.2 and 4.3, when the quasi-optimizing control force vectors $\{\hat{\boldsymbol{u}}^*\}$ (which is selected as the most adequate control force vector by the quasi-optimizing controller from the set of trial control force vectors $<\{\hat{\boldsymbol{u}}\}>$) is determined in the mediational coordinate $\{\boldsymbol{u}\}$, $\{\boldsymbol{u}\}$ is directory related to the inter-story forces as the manipulated control force vector $\{\boldsymbol{b}\}$ via the mediational transformation matrix $[\hat{\boldsymbol{P}}]$ which is supposed as $[\hat{\boldsymbol{P}}] = [\boldsymbol{I}]$. The mediation matrix $[\hat{\boldsymbol{P}}]$ may be utilized to introduce the para-systems of control forces for the quasi-optimizing control method when the $[\hat{\boldsymbol{P}}]$ is supposed as the invertible matrix. So that, the existence of both $[\hat{\boldsymbol{P}}]$ and $[\hat{\boldsymbol{P}}]^{-1}$ is required for the actualization of the para-systems of control forces as follows,

$$\{\boldsymbol{u}\} = [\hat{\boldsymbol{P}}]\,\{\boldsymbol{b}\}, \tag{4.4.1a}$$

$$\{\boldsymbol{b}\} = [\hat{\boldsymbol{P}}]^{-1}\,\{\boldsymbol{u}\}. \tag{4.4.1b}$$

Namely, $[\hat{\boldsymbol{P}}]$ means the transformation of the coordinate from $\{\boldsymbol{b}\}$ to $\{\boldsymbol{u}\}$ and $[\hat{\boldsymbol{P}}]^{-1}$ means the transformation of the coordinate from $\{\boldsymbol{u}\}$ to $\{\boldsymbol{b}\}$. In which, the significant notice should be considered as the practical problem. So that, the maximum trial control forces which is related to the coordinate $\{\boldsymbol{u}\}$ should be synthesized under the limitations that the manipulated control force vectors $\{\boldsymbol{b}\}$ supposed by Exp. (4.4.1b) are not be supplied exceed the capacities of control devices.

In this sections, as the one of the para-systems of control forces produced by using active braces, the coordinate of the body force vector $\{f\}$ acting on the each mass is adopted and evaluated, through the comparisons with the control force system which is supposed as the coordinate of the inter-story force vector $\{\boldsymbol{b}\}$ (as investigated in the previous studies). Those two kinds of control force systems can be represented as follows.

(i) *Linked-path control force system* (System-1) :

When the mediational coordinate $\{\boldsymbol{u}\}$ is adopted as to be related to the coordinate of the inter-story forces, the following mediational transformation matrix $[\hat{\boldsymbol{P}}_1]$ is supposed to represent the manipulated control forces via the active braces $\{\boldsymbol{b}\}$.

$$\{\boldsymbol{u}\} = [\hat{\boldsymbol{P}}_1]\,\{\boldsymbol{b}\},\ [\hat{\boldsymbol{P}}_1] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} = [\boldsymbol{I}], \tag{4.4.2a}$$

$$\{\boldsymbol{b}\} = [\hat{\boldsymbol{P}}_1]^{-1}\,\{\boldsymbol{u}\}. \tag{4.4.2b}$$

In this case, the actualized control force vectors $\{f\}$ in Eq. (4.2.1) may be subjected as the conditions of the additional shear forces acting on each story of the structural model via the mediational coordinate $\{\boldsymbol{u}\}$, namely,

$$\{f\} = [\hat{\boldsymbol{F}}_1]\ \{\boldsymbol{u}\},\ [\hat{\boldsymbol{F}}_1] = \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ 0 & 0 & 1 \end{bmatrix}, \tag{4.4.3a}$$

$$\{\boldsymbol{u}\} = [\hat{\boldsymbol{F}}_1]^{-1}\ \{f\},\ [\hat{\boldsymbol{F}}_1]^{-1} = \begin{bmatrix} 1 & 1 & 1 \\ 0 & 1 & 1 \\ 0 & 0 & 1 \end{bmatrix}. \tag{4.4.3b}$$

The control force system which is composed by the actualizing transformation matrix $[\hat{\boldsymbol{F}}_1]$ is supposed as the permeation with the shear forces flow, so that, each component of trial control force vectors $\{\hat{\boldsymbol{u}}\}$ which are selected on the quasi-optimizing control method is interfered with some components of the actualized control force vectors. In this control force system, when $u_{max,\,i}$ ($i = 1, 2, 3$) is supposed as the maximum value of each element of the trial control force vector, the minimum capacities for each control device $b_{lim,\,i}$ should be synthesized the following conditions by referring the Exp. (4.4.2b).

$$b_{lim,\,i} = u_{max,\,i}\,. \tag{4.4.4}$$

For instance, in the case of $u_{max,\,i} = u_{max}$ ($i = 1, 2, 3$) supposed as the maximum trial control forces, the ratio of the minimum capacities for each control device $b_{lim,\,i}$ should be synthesized as $b_{lim,\,1} : b_{lim,\,2} : b_{lim,\,3} = 1 : 1 : 1$.

(ii) *Lumped-node control force system* (System-2) :

When the mediational coordinate $\{\boldsymbol{u}\}$ is adopted as to be related to the coordinate of the body forces, the following mediational transformation matrix $[\hat{\boldsymbol{P}}_2]$ is supposed to represent the manipulated control forces via the active braces $\{\boldsymbol{b}\}$.

$$\{\boldsymbol{u}\} = [\hat{\boldsymbol{P}}_2]\,\{\boldsymbol{b}\},\ [\hat{\boldsymbol{P}}_2] = \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ 0 & 0 & 1 \end{bmatrix}, \tag{4.4.5a}$$

$$\{\boldsymbol{b}\} = [\hat{\boldsymbol{P}}_2]^{-1}\,\{\boldsymbol{u}\},\ [\hat{\boldsymbol{P}}_2]^{-1} = \begin{bmatrix} 1 & 1 & 1 \\ 0 & 1 & 1 \\ 0 & 0 & 1 \end{bmatrix}. \tag{4.4.5b}$$

In this case, the actualized control force vectors $\{f\}$ in Eq. (4.2.1) may be subjected as the conditions of the additional body forces acting on each mass of the structural model via the mediational coordinate $\{\boldsymbol{u}\}$, namely,

$$\{f\} = [\hat{\boldsymbol{F}}_2]\ \{\boldsymbol{u}\},\ [\hat{\boldsymbol{F}}_2] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} = [I], \tag{4.4.6a}$$

$$\{\boldsymbol{u}\} = [\hat{\boldsymbol{F}}_2]^{-1}\ \{f\}. \tag{4.4.6b}$$

The para-system of control forces which is composed by the actualizing transformation matrix $[\hat{\boldsymbol{F}}_2]$ is supposed as the body forces, so that, each component of trial control force vectors $\{\hat{\boldsymbol{u}}\}$ which are selected on the quasi-optimizing control method is directly represented as each component of the actualized control force vectors. In this control force system, when $u_{max,\,i}$ (i = 1, 2, 3) is supposed as the maximum value of each element of the trial control force vector, the minimum capacities for each control device $b_{lim,\,i}$ may be subjected the following conditions by referring the Exp. (4.4.5b).

$$b_{lim,\,i} = \sum_{j=i}^{3} u_{max,\,j}\ . \tag{4.4.7}$$

For instance, in the case of $u_{max,\,i} = u_{max}$ (i = 1, 2, 3) supposed as the maximum trial control forces, the ratio of the minimum capacities for each control device $b_{lim,\,i}$ should be synthesized as $b_{lim,\,1} : b_{lim,\,2} : b_{lim,\,3} = 3 : 2 : 1$.

The control forces supposed by the lumped-node control force system (System-2) are generated as the mimetic control forces, when the active braces are installed on every inter-stories. In this case the manipulated control forces of each control device are always subjected additional works because of the constrained conditions for the actualized control forces, namely, to produce the mimetic control force acting on the j-th floor, the same shear forces via active braces located on the j-th and the lower stories may be allocated. On the other hand, those control forces of the System-2 may be regarded as the directly supplied body forces, when it is assured that active control devices are installed as like to be able to actualize the independent body forces on every floors, for instance, those kinds of active control devices may be considered as that the active mass dampers are located on every floors or that the base-connected active braces are equipped on every floors. At this point, in the following discussions, control performances by introducing the lumped-node control force system (System-2) are evaluated from the two kind of view points.

Viewpoint-1) The lumped-node control force system (System-2) is regarded the para-system of control forces produced by using the active braces are installed on every inter-stories.

Viewpoint-2) The lumped-node control force system (System-2) is regarded the directly actualized control force system produced by using the active mass dampers located on every floors or the base-connected active braces equipped on every floors.

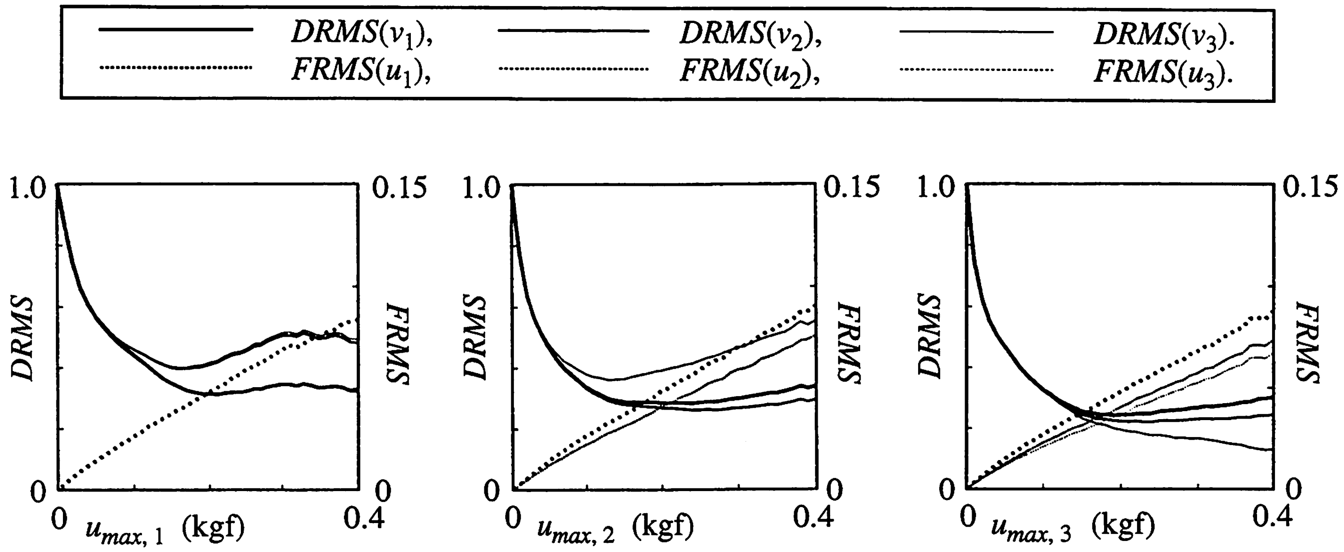
Study (4.4) - 1 :

At first, the responsibilities of the each component of mediational control force vector which is supposed by using the lumped-node control force system (System-2) are evaluated. Those studies are supposed by using only any one component of the mediational control force vector in the System-2, namely, when the j-th component is used, the other components are always equal to zero. The trial control forces of the j-th component are proposed as Exp. (4.2.5) in the Section 4.2 (in which, as the number of trial control forces of j-th control device, $N_j = 5$ is adopted) and the other trial control forces of the i-th control device ($i \neq j$) are proposed as $< \hat{u}_i > = < 0 >$ (namely, the number of trial control forces of i-th control device $N_i = 1$ and the maximum trial control forces $u_{max,\,i} = 0$). Since the single component of the mediational control force vector is used in this study, only the single layer as the searching stage is supposed, so that, the same operation is produced by either optimization procedure based on the universal searching or the multi-layer searching algorithm. Numerical simulations are executed under the ground input of El Centro (1940) NS which is scaled down to the maximum acceleration amplitude of 30 (cm/s^2) during the first part of 30 seconds.

Figs. 4.4.1, show the displacements controlled factors (*DRMS*) and the control manipulation factors (*FRMS*) for the three cases which are used any one component of the mediational control force vector in the System-2. In those figures, (a), (b) and (c) are corresponding to the cases of j =1, 2 and 3 (in which, j means the selected single component number to use actively), respectively. The fluctuations of the *DRMS* and the *FRMS* are plotted in those figures according to the variations of the maximum trial control forces $u_{max,\,j}$.

By comparing those figures, the control effects in sense of reductions of responses can be observed in the all cases which is used any one component of the mediational control force vector in the System-2 and the *FRMS* in all cases may be grown proportionally according to increasing the maximum trial control forces $u_{max,\,j}$. The most effective reductions of responses may be operated by using the 3rd component of the mediational control force vector in the System-2.

In which, by considering those results from the Viewpoint-1, the mimetic control forces which are produced by using only j-th component of the mediational control force vector in the System-2 may subject as to suppose the same shear forces via active braces located on the j-th and the lower stories. Namely, when the supplied control forces are evaluated as the manipulated control forces, the total required control forces via active braces located on the inter-stories may be increased to about j times for the required control forces of the case by using only 1st component of the mediational control force vector in the System-2 (this case is corresponding to the case for using the single active brace located the bottom story). However, it may be unsuitable to evaluate control performance of the active braces located on the every inter-stories from those results because that para-systems of control forces in this study are constrained as to produce the any one of body force among the System-2.



(a) $u_{max,2} = 0, u_{max,3} = 0,$ (b) $u_{max,1} = 0, u_{max,3} = 0,$ (c) $u_{max,1} = 0 , u_{max,2} = 0,$

Fig. 4.4.1 Control performances by using the single component of control forces in System-2.

At this point, by considering those results from the Viewpoint-2, the actualized control forces which are produced by using only j-th component of the mediational control force vector in the System-2 may be regarded as the independent body forces which are directly supposed by the control system as like that the single active mass damper is located on the j-th floor or that the single active brace is equipped between the j-th floor and the basement. By considering for the control effects evaluated for the *DRMS* in Figs. 4.4.1 as the results from operation by the single active mass damper or the single base-connected active brace and by also considering the previous results as seen in Figs.4.3.1 in the Section 4.3 (those studied are investigated for the cases which are supposed by using only any one of the active braces located on the inter-stories), very significant consequence may be assigned. To reduce structural responses by using single control device, the actualized control forces should be supposed as the one of the body force acting on any mass, independently. Namely the single active mass damper or the single base-connected active brace may be provided the control efficiency that the *DRMS* can be transferred to reduced states from the uncontrolled responses while the control inputs are supplied. Moreover, it may be regarded that the responsibilities of the body forces acting on the top mass are the most significant to reduce structural responses effectively (as seen in Figs. 4.4.1).

In the following studies, to investigate for control performances by introducing the lumped-node control force system (System-2) under the conditions which can use actively all components of the mediational control force vector in the quasi-optimizing control method, comparative numerical studies with the cases for introducing the linked-path control force system (System-1) are executed. By considering control performances by introducing those two kinds of control force system, effective arrangements of control forces for the multi-devices aseismic active control system may be discussed.

Study (4.4) - 2a :

As the first step, as the considerations from the Viewpoint-1, control performances of the System-1 and the System-2 are comparatively evaluated by using actively all components of the mediational control force vector in those control force systems. Namely, the estimations are operated under the conditions as to be the para-systems of control forces which is supposed by installing the multi-located active braces on every inter-stories. In those studies, the following three cases are supposed:

Case-1) The linked-path control force system (System-1) is supposed as the para-system of control forces for the quasi-optimizing control method, namely, the mediational control force vectors are subjected to the conditions of the additional shear forces acting on each story as that are directly actualized via the inter-story active braces. In the Case-1, the maximum trial control forces $u_{max,\,i}$ ($i = 1, 2, 3$) are supposed as the same value, so that, $u_{max,\,1} : u_{max,\,2} : u_{max,\,3} = 1 : 1 : 1$. The quantity $b_{lim,\,i}$ which is synthesized as the minimum capacities for each control device is supposed as Eq. (4.4.4), so that, the ratio of the minimum capacities for each control device $b_{lim,\,i}$ is supposed as $b_{lim,\,1} : b_{lim,\,2} : b_{lim,\,3} = 1 : 1 : 1$. The total capacities of all control devices (the inter-story active braces) $\Sigma\, b_{lim}$ is related to the $b_{lim,\,2}$ by $\Sigma\, b_{lim} = 3 \times b_{lim,\,2}$.

Case-2) The linked-path control force system (System-1) is supposed as the para-system of control forces for the quasi-optimizing control method, namely, the mediational control force vectors are subjected to the conditions of the additional shear forces acting on each story as that are directly actualized via the inter-story active braces. In the Case-2, the ratio of the maximum trial control forces $u_{max,\,i}$ ($i = 1, 2, 3$) is supposed as $u_{max,\,1} : u_{max,\,2} : u_{max,\,3} = 3 : 2 : 1$. The quantity $b_{lim,\,i}$ which is synthesized as the minimum capacities for each control device is supposed as Eq. (4.4.4), so that, the ratio of the minimum capacities for each control device $b_{lim,\,i}$ is supposed as $b_{lim,\,1} : b_{lim,\,2} : b_{lim,\,3} = 3 : 2 : 1$. The total capacities of all control devices (the inter-story active braces) $\Sigma\, b_{lim}$ is related to the $b_{lim,\,2}$ by $\Sigma\, b_{lim} = 3 \times b_{lim,\,2}$.

Case-3) The lumped-node control force system (System-2) is supposed as the para-system of control forces for the quasi-optimizing control method, namely, the mediational control force vectors are subjected to the conditions of the additional body forces acting on each mass. In the Case-3, the maximum trial control forces $u_{max,\,i}$ ($i = 1, 2, 3$) are supposed as the same value, so that, $u_{max,\,1} : u_{max,\,2} : u_{max,\,3} = 1 : 1 : 1$. The quantity $b_{lim,\,i}$ which is synthesized as the minimum capacities for each control device is supposed as Eq. (4.4.7), so that, the ratio of the minimum capacities for each control device $b_{lim,\,i}$ is supposed as $b_{lim,\,1} : b_{lim,\,2} : b_{lim,\,3} = 3 : 2 : 1$. The total capacities of all control devices (the inter-story active braces) $\Sigma\, b_{lim}$ is related to the $b_{lim,\,2}$ by $\Sigma\, b_{lim} = 3 \times b_{lim,\,2}$.

In those three cases, Both the Case-2 and the Case-3 are supposed to $b_{lim,\,1} : b_{lim,\,2} : b_{lim,\,3} = 3 : 2 : 1$ as the arrangements of capacities of the inter-story active braces, while the Case-1 is supposed as the uniform arrangements of capacities of the inter-story active braces which have the same capacities ($b_{lim,\,1} : b_{lim,\,2} : b_{lim,\,3} = 1 : 1 : 1$). To investigate for control performances of the System-1 and the System-2 comparatively, it may be explicit that the total capacities of all control devices (the inter-story active braces) $\Sigma\ b_{lim}$ are used as the evaluative indicate which is indexed to control manipulations. In all of those cases, as the number of trial control forces of every control devices are supposed as to be equal to 5. Those case studies are operated for the three cases by using the universal searching, the step-up searching and the step-down searching algorithms.

Figs. 4.4.2.1, 4.4.2.2 and 4.4.2.3 show the displacements controlled factors (*DRMS*) and the control manipulation factors (*FRMS*) in the cases that are installed the universal searching, the step-up searching and the step-down searching algorithm, respectively. Figs. 4.4.2.4 show the average of displacements controlled factors $\overline{DRMS}$ and the average of the control manipulation factors $\overline{FRMS}$ for each searching algorithm with together. In those figures, both (a) and (b) show the results for the Case-1 and (c) and (d) show the results for the Case-2 and the Case-3, respectively. The fluctuations of the *DRMS* and the *FRMS* plotted in those figures can be referred according to the variations of the maximum trial control forces of the 3rd control device $u_{max,\,3}$, the capacity of the minimum capacities for the 2nd control device $b_{lim,\,2}$ and the total capacities of all control devices (the inter-story active braces) $\Sigma\ b_{lim}$. The horizontal axes of (a) of those figures are adjusted as to make the scale of the $u_{max,\,3}$ equal to (c) and (d) of those figures and the horizontal axes of (b) of those figures are adjusted as to make the scales of the $b_{lim,\,2}$ and the $\Sigma\ b_{lim}$ equal to (c) and (d) of those figures.

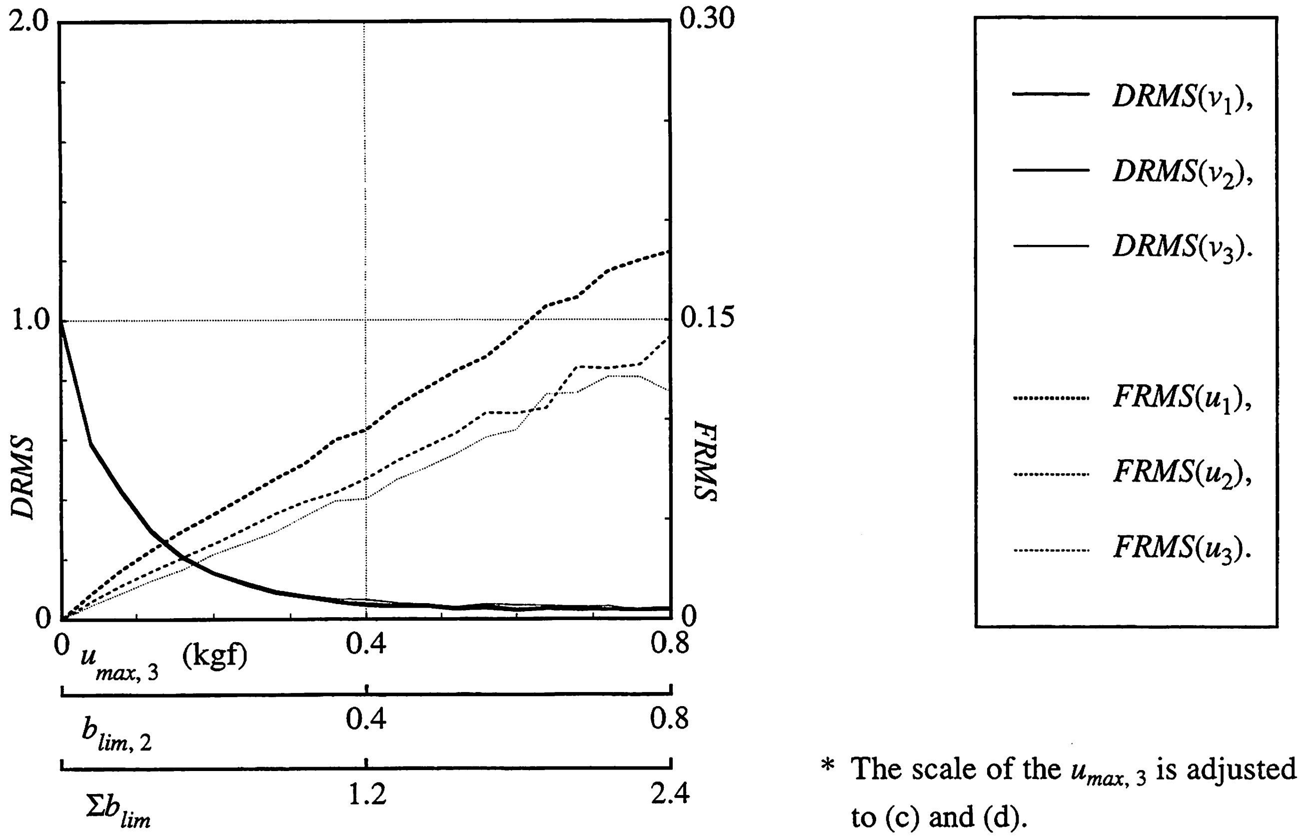
By seeing Figs. 4.4.2.1, when the universal searching algorithm is supposed, the quite similar response reductions which are observed for the *DRMS* may be observed in the Case-2 and the Case-3. In those case, the supplied control forces which are evaluated by the *FRMS* may be reduced in the Case-3 in comparison with the Case-2 (as comparisons of Figs. 4.4.2.1 (c) and (d)), while the same capacities are allocated severally for each inter-story active brace in those two cases. So that, it assured that the control performances which are evaluated from both the *DRMS* and the *FRMS* may be improved by introducing the lumped-node control force system (System-2). As the another considerations, the *DRMS* may be reduced more effectively in the Case-2 and the Case-3 in comparison with the Case-1, namely, in sense of the effect to reduce structural responses, the Case-2 may suppose as the more effective arrangements of capacities of the inter-story active braces for the linked-path control force system (System-1) than the Case-1. One of reasons of this may be clear by considering that the arrangement of capacities of the inter-story active braces in the Case-2 is adjusted to the distributions of the partial responsibilities for the story shear forces, in the physical meanings. Moreover, in the case by introducing the universal searching algorithm, it may be considered that the manipulated control forces resulted from the Case-2 are approximately actualized quite similar control forces which are resulted from the Case-3.

By seeing Figs. 4.4.2.2, when the step-up searching algorithm is supposed, it may be explicitly assured that the most effective reductions of responses may be gained in the Case-3, while the supplied control forces which are evaluated by the *FRMS* in the Case-3 may be quite smaller than those of the Case-1 and the Case-2. In the Case-1 and the Case-2 (the linked-path control force system (System-1) is introduced to those two cases), control effects to reduce the *DRMS* may be improved by increasing the total capacities of all control devices $\Sigma\, b_{lim}$, however, those control effects may be deteriorated by increasing of the $\Sigma\, b_{lim}$ after reaching at the bottom state. The Case-2 may operate more reduction of the *DRMS* than the Case-1, the *FRMS* of the Case-2 may be increased in comparison with the Case-1. By considering those results, and also, by considering the previous results for the step-up searching algorithm mentioned in the Section 4.2 and 4.3, it may be regarded that the step-up searching algorithm are unsuitable as the searching sequence for the linked-path control force system (System-1). However, when the lumped-node control force system (System-2) is introduced as the para-system of control forces, it is assured that control performances by introducing the step-up searching algorithm are improved effectively.

By seeing Figs. 4.4.2.3, when the step-down searching algorithm is supposed, the most effective reductions of responses may be observed in the Case-3, and also the supplied control forces which are evaluated by the *FRMS* in the Case-3 may be observed as the smallest in those cases. In the Case-1 and the Case-2, the control performances which are evaluated from both the *DRMS* and the *FRMS* may be regarded as to be quite similar. In those two case, control effects to reduce the *DRMS* may be improved by increasing the total capacities of all control devices $\Sigma\, b_{lim}$, however, those control effects may be remained stagnant regardless of increase of the $\Sigma\, b_{lim}$ after reaching at the bottom state. As the difference of those two cases, it may be pointed that the *FRMS* of the top story in the Case-2 are observed as to be smaller than those of the Case-1, although the total supplied control forces in those cases may be almost even. As a reason of this, it may be considered that the arrangement of capacities of the inter-story active braces in the Case-2 make the partial responsibility of the top story decrease. By considering those results, and also, by considering the previous results for the step-down searching algorithm mentioned in the Section 4.2 and 4.3, it may be assured that control effects of the step-down searching algorithm for the linked-path control force system (System-1) may not be affected much for the difference of the arrangement of capacities of the inter-story active braces in the Case-1 and the Case-2. However, when the lumped-node control force system (System-2) is introduced as the para-system of control forces, it is assured that control performances by introducing the step-down searching algorithm are improved effectively.

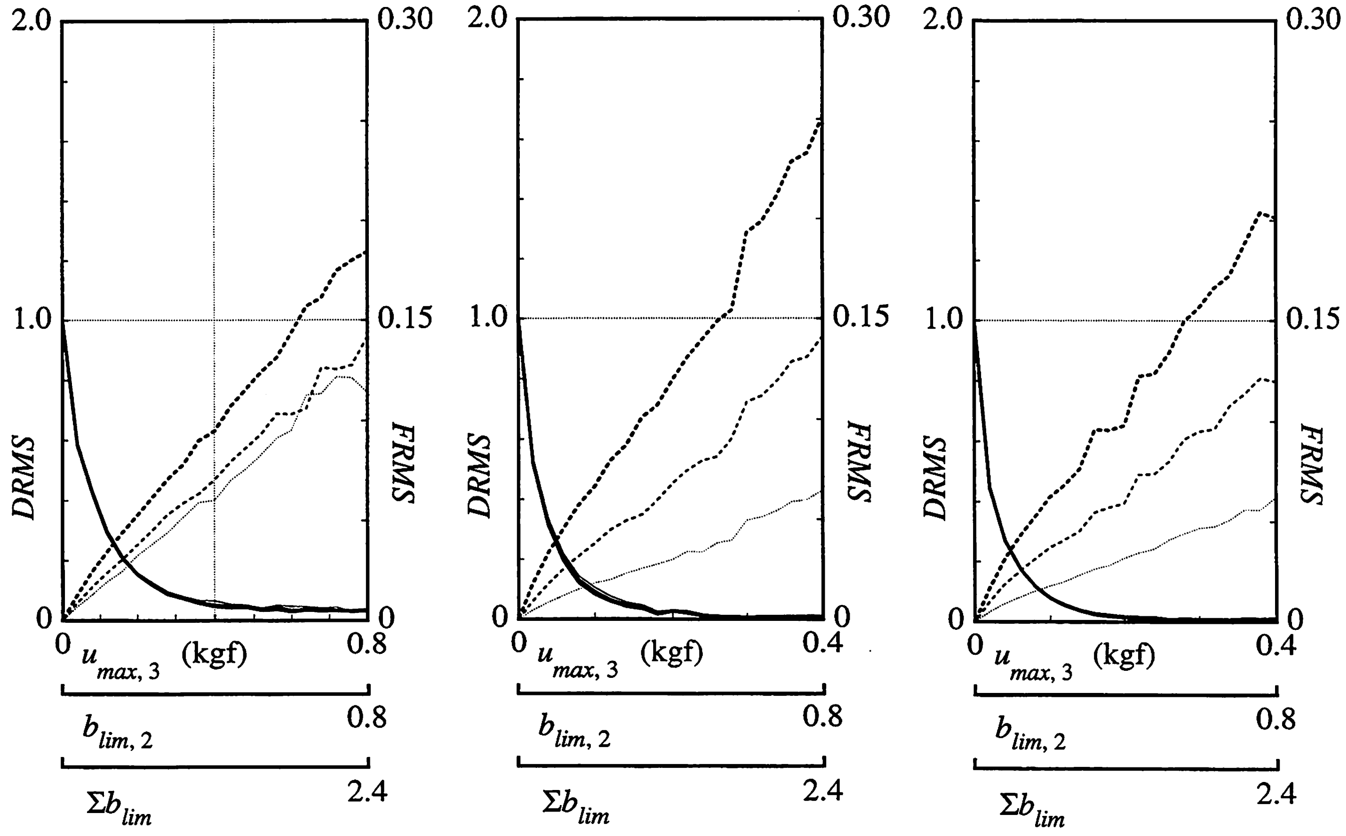
By seeing Figs. 4.4.2.4, when the universal searching algorithm is supposed, the most effective reductions of responses may be observed in all cases, and also the supplied control forces which are evaluated by the *FRMS* in the Case-3 may be observed as the smallest in those cases. In the Case-3, the quite similar reductions of responses can be observed in the cases by introducing two kinds of the multi-layer searching algorithms as much as the cases by introducing the universal searching algorithm, while the supplied control forces which are evaluated by the *FRMS* in the multi-layer searching algorithms may be considerably reduced in comparison with the universal searching algorithm.

Through those considerations in the Study (4.4)-2a, it is assured that when the lumped-node control force system (System-2) is introduced as the para-system of control forces which is supposed



* The scale of the $u_{max,3}$ is adjusted to (c) and (d).

(a) Case-1 *,

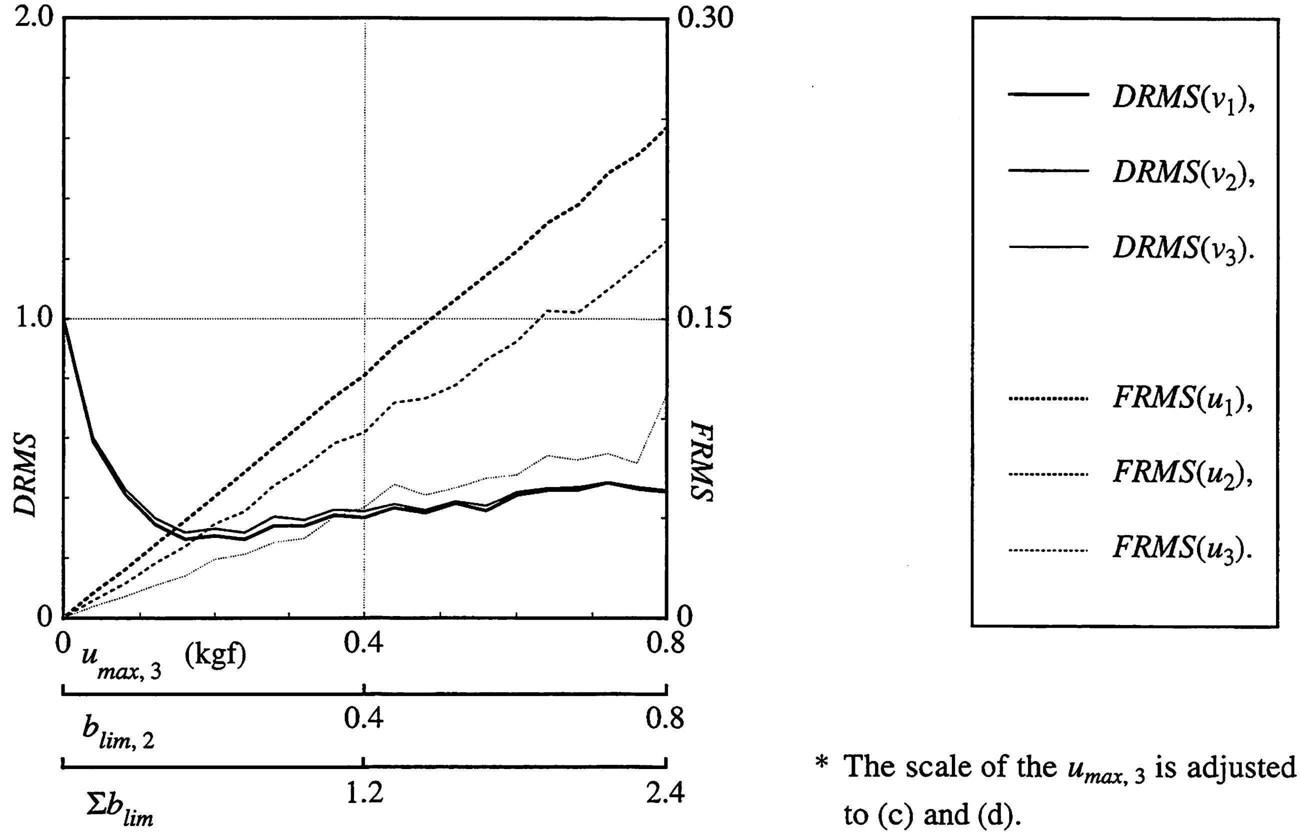


(b) Case-1,

(c) Case-2,

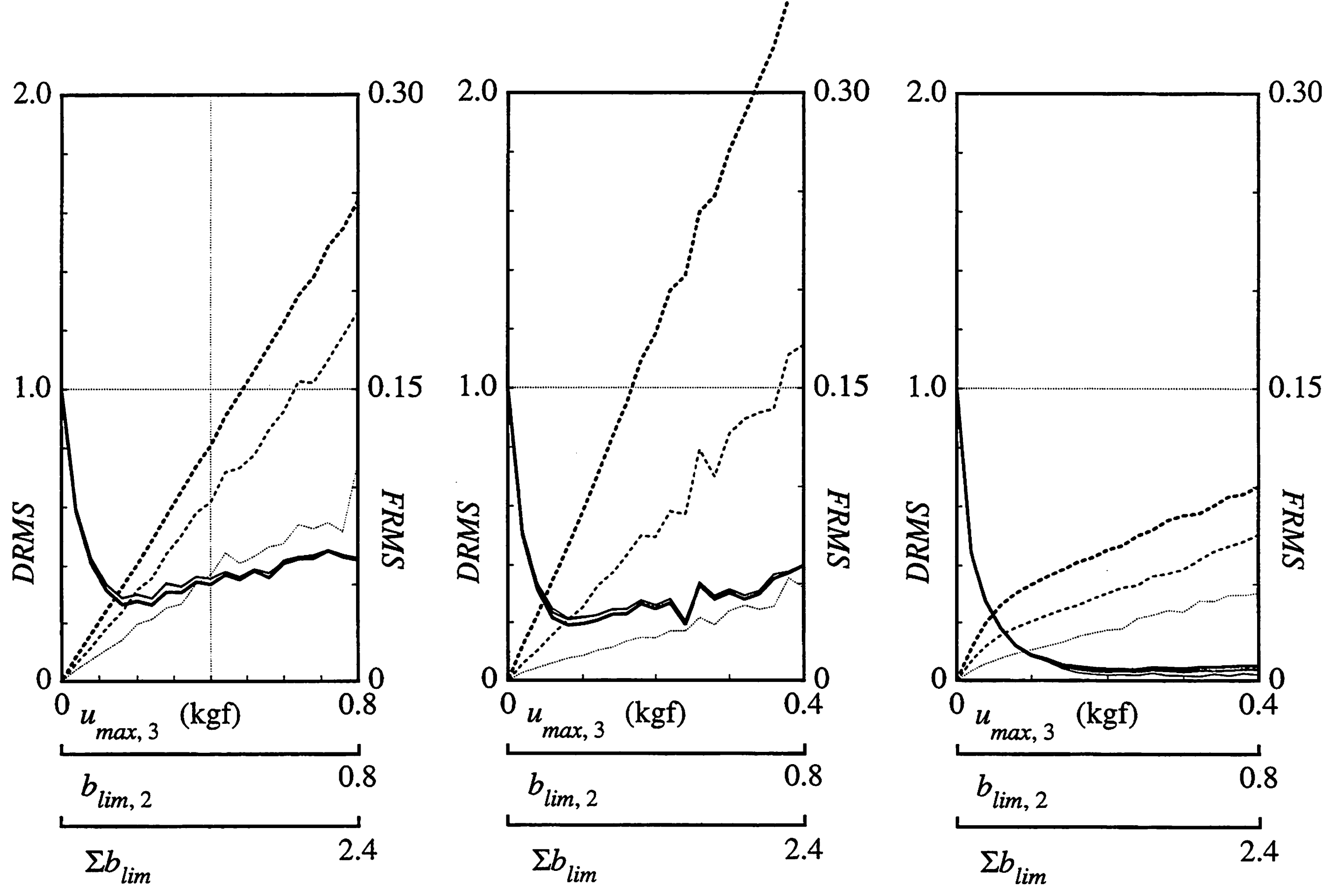
(d) Case-3,

Fig. 4.4.2.1 Control performances in the case of the universal searching algorithm.



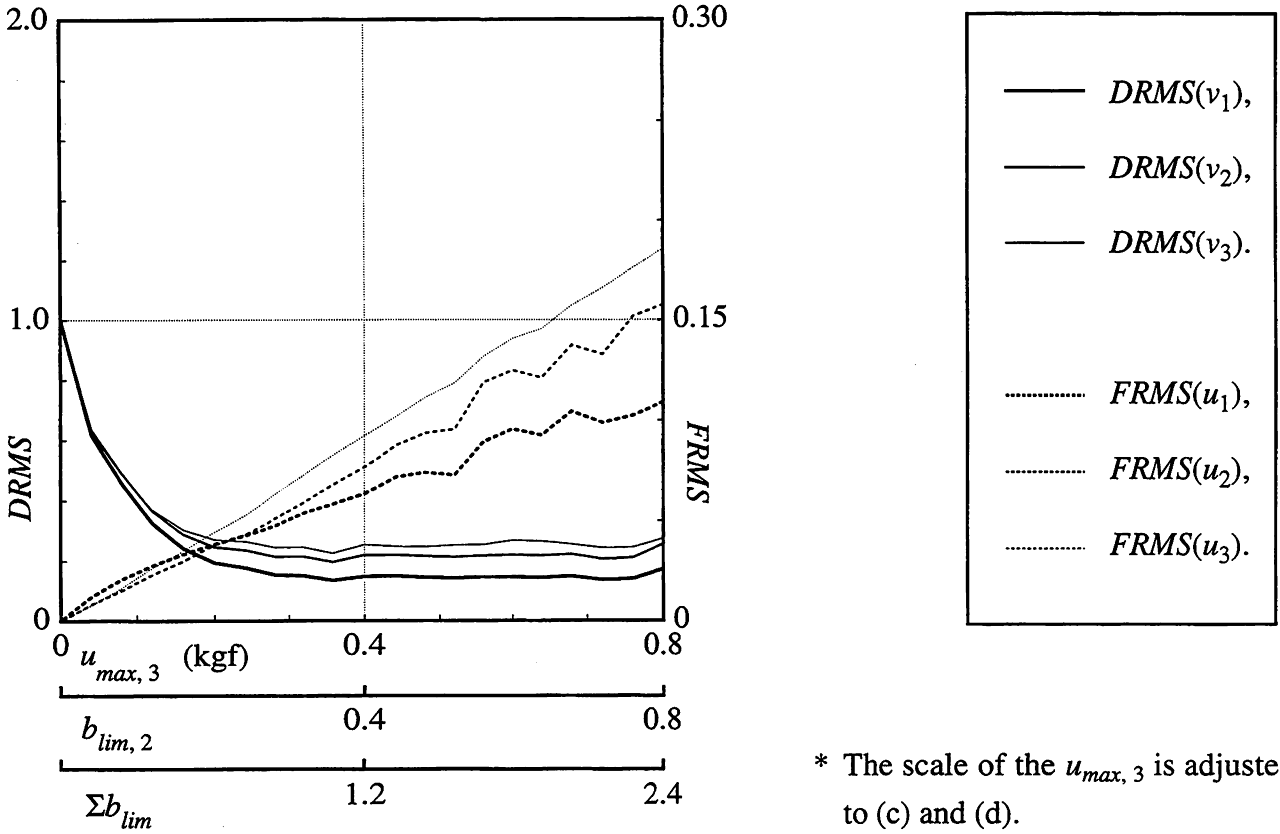
* The scale of the $u_{max,3}$ is adjusted to (c) and (d).

(a) Case-1 *,



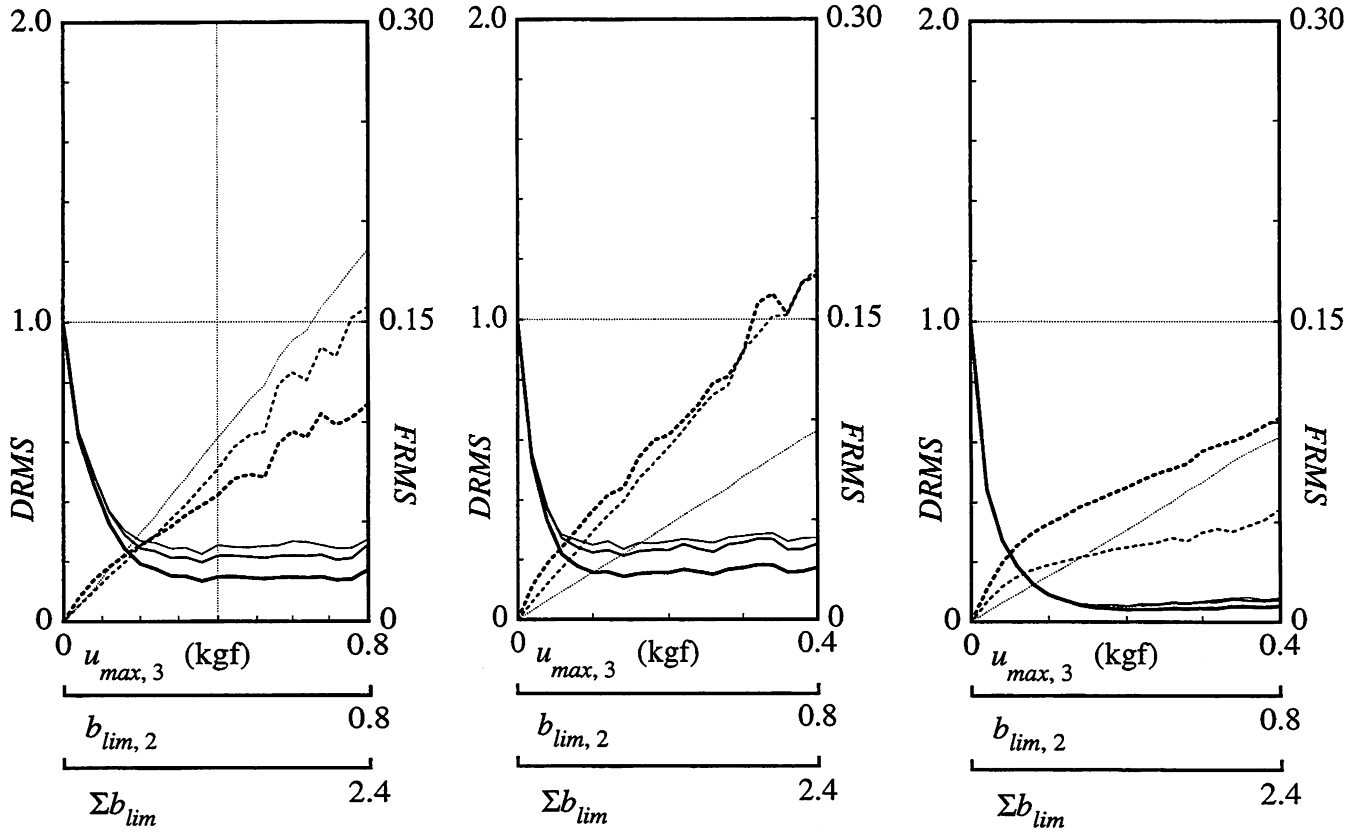
(b) Case-1, (c) Case-2, (d) Case-3,

Fig. 4.4.2.2 Control performances in the case of the step-up searching algorithm.



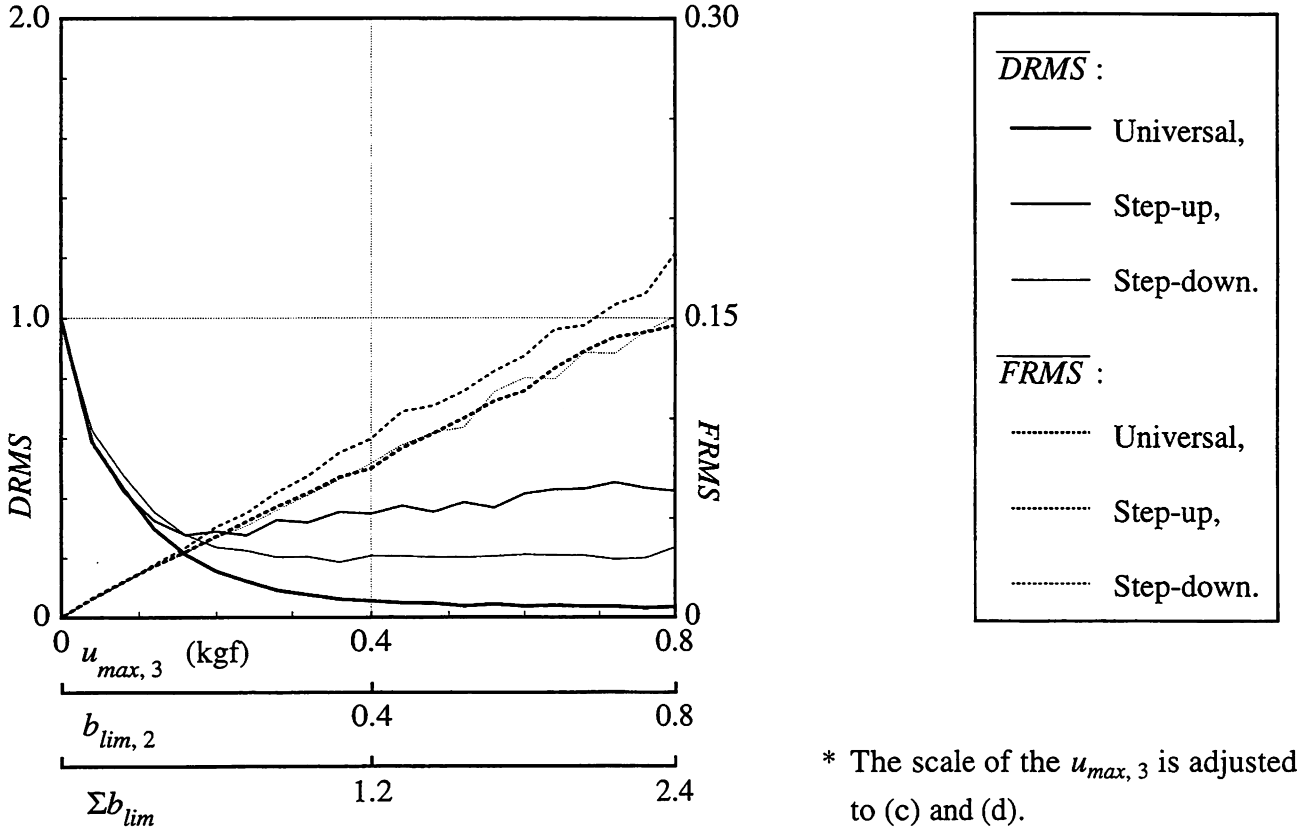
* The scale of the $u_{max,3}$ is adjusted to (c) and (d).

(a) Case-1 *,



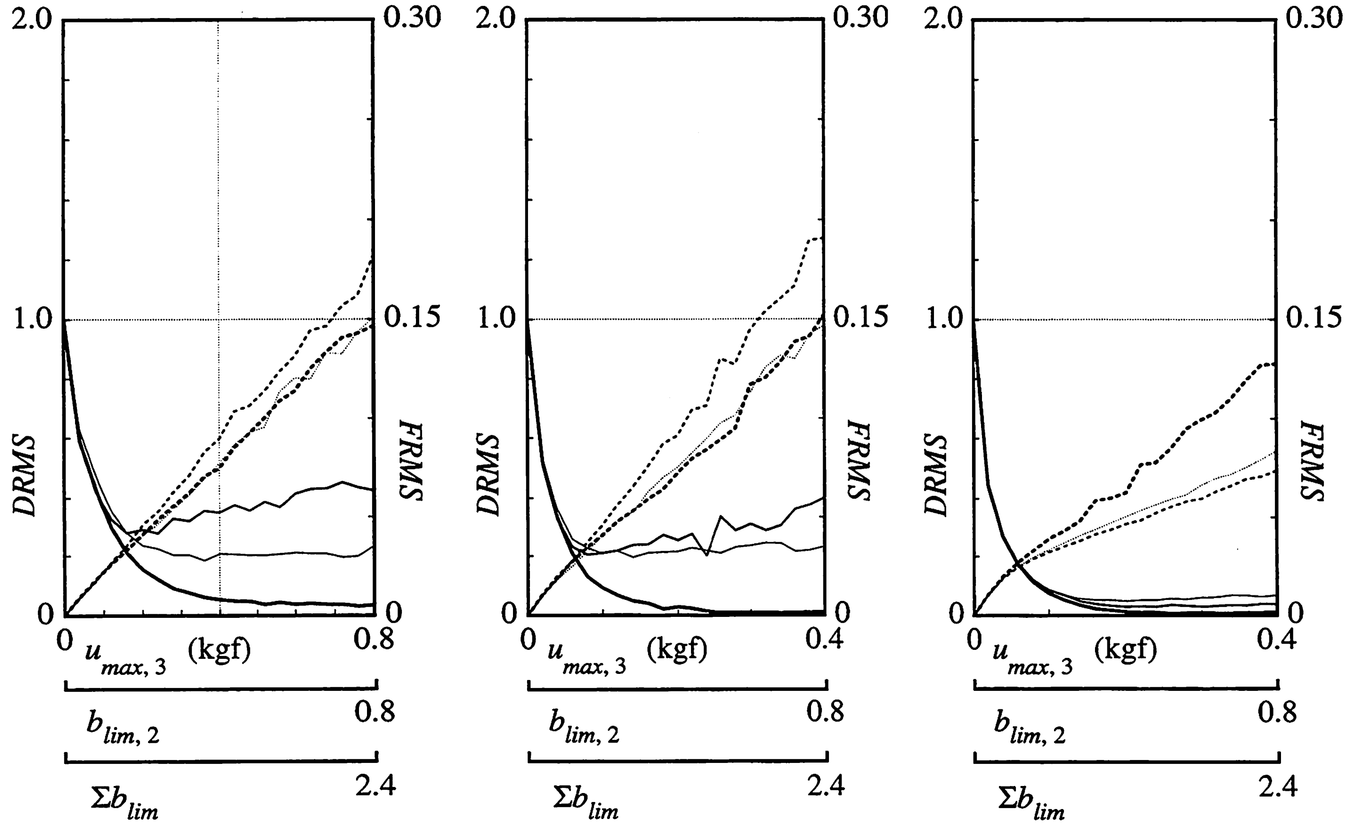
(b) Case-1, (c) Case-2, (d) Case-3,

Fig. 4.4.2.3 Control performances in the case of the step-down searching algorithm.



* The scale of the $u_{max,3}$ is adjusted to (c) and (d).

(a) Case-1 *,



(b) Case-1, (c) Case-2, (d) Case-3,

Fig. 4.4.2.4 Control performances ($\overline{DRMS}$ and $\overline{FRMS}$).

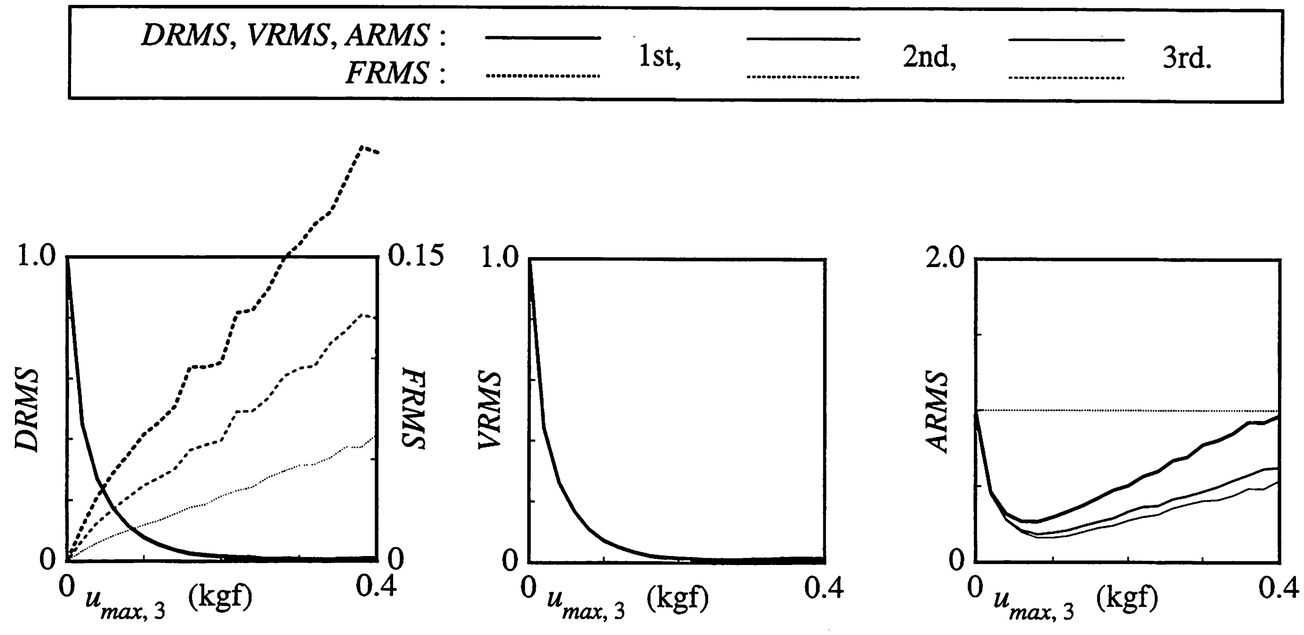
on the multi-located inter-story active brace system, effective control performances can be operated, and also, by introducing the System-2, both the step-up searching and the step-down searching algorithm for the quasi-optimizing control method can generate effective aseismic response controller as much as the universal searching algorithm. As the remarks, since the partial responsibilities of inter-story control forces supposed to the inter-story active braces can be adjusted as the sensible arrangement of story shear forces by installation of the System-2, it may be regarded that those constrained arrangements of the capacities of the inter-story active braces are simultaneously satisfied the conditions for the effective arrangements which are resulted from the considerations for the System-1 in the previous sections.

***Study (4.4) - 2b* :**

As the next step, to discuss in the more details for the control performances by introducing the lumped-node control force system (System-2), the numerical results in the Study (4.4)-2a are investigated from the view of the other indicates which are indexed by the velocities controlled factor (*VRMS*) and the accelerations controlled factor (*ARMS*) for the Case-3.

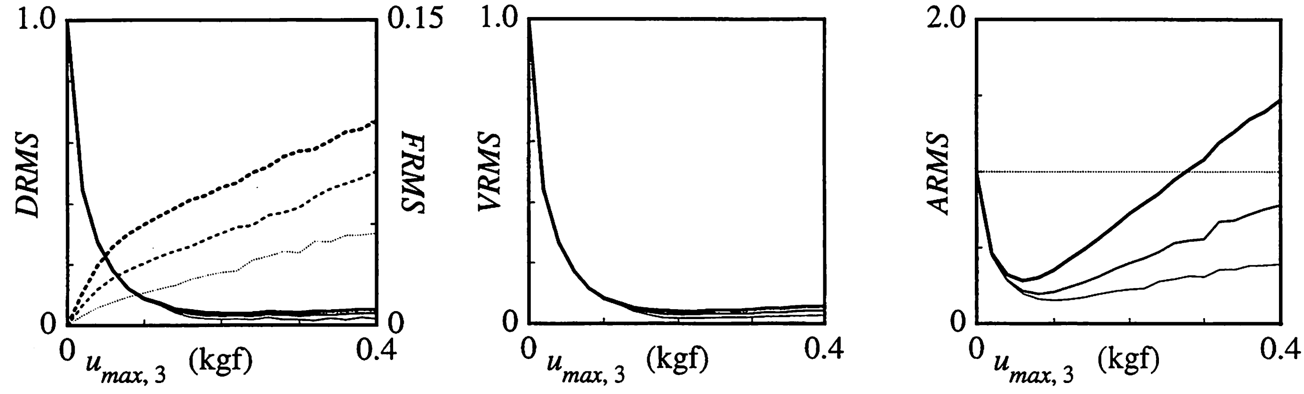
Figs. 4.4.3.1, 4.4.3.2 and 4.4.3.3 show the three kinds of indicates for response reductions and the control manipulation factors (*FRMS*) in the cases that are installed the universal searching, the step-up searching and the step-down searching algorithm, respectively. In those figure, (a) show the displacements controlled factors (*DRMS*) and the control manipulation factors (*FRMS*), and (b) and (c) show the velocities controlled factor (*VRMS*) and the accelerations controlled factor (*ARMS*), respectively. Those figures are corresponding to the results for the Case-3 in the Study (4.4)-2a, namely, Figs. 4.4.3.1 (a), 4.4.3.2 (a) and 4.4.3.3 (a) show the same results in Figs. 4.4.2.1 (d), 4.4.2.2 (d) and 4.4.2.3 (d), respectively.

By comparing those figures, the fluctuations of the *DRMS* and the *VRMS* according to the variations of the total capacities of all control devices (the inter-story active braces) $\Sigma\, b_{lim}$ may be regarded as the quite similar, and effective reductions of the *DRMS* and the *VRMS* can be observed whenever any kinds of the searching algorithms is introduced. As the reason of this, it may be considered that those quantities for indicated by the *DRMS* and the *VRMS* (which are the inter-story displacements and the inter-story velocities) are directly optimized in the penalty indexes introduced on the quasi-optimizing control method. On the other hand, reductions of acceleration responses evaluated by the *ARMS* may be operated by increasing the total capacities of all control devices $\Sigma\, b_{lim}$, however, those effects may be deteriorated by increasing of the $\Sigma\, b_{lim}$ after reaching at the bottom state, since it seems that those effects are appeared as the results which are indirectly dragged by reductions of displacements and velocities. By comparing (c) of those figures, the acceleration responses of the 1st floor evaluated by the *ARMS*(ξ_1) are effectively reduced to the same level in the cases by introducing the universal searching and the step-down searching algorithm in comparison with the case for the step-up searching algorithm. When the universal searching algorithm is introduced, the further reductions of the *ARMS*(ξ_2) and the *ARMS*(ξ_3) are operated in comparison with the case for step-down searching algorithm. As the reason of this, it may be considered that the required control forces evaluated by the *FRMS* for the universal searching algorithm are enlarged



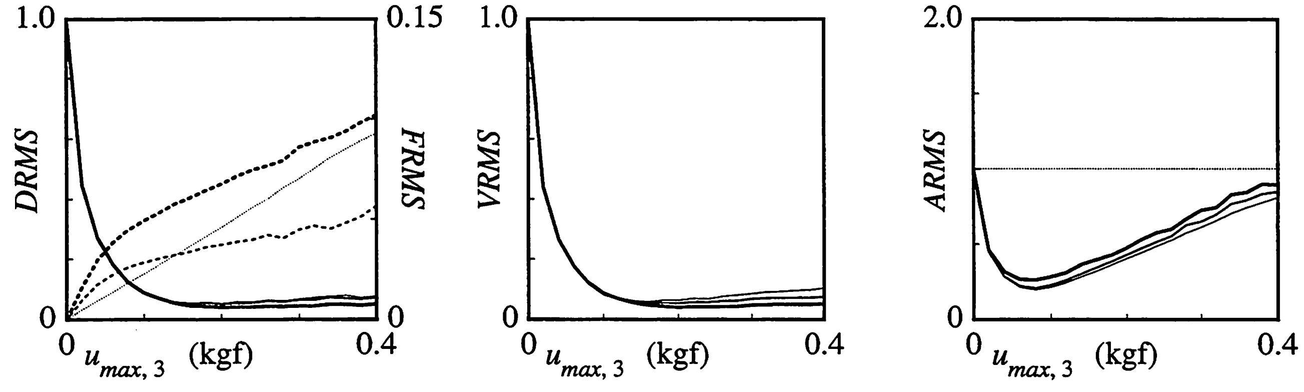
(a) *DRMS* and *FRMS*, (b) *VRMS*, (c) *ARMS*,

Fig. 4.4.3.1 Control performances in the case of the universal searching algorithm (System-2).



(a) *DRMS* and *FRMS*, (b) *VRMS*, (c) *ARMS*,

Fig. 4.4.3.2 Control performances in the case of the step-up searching algorithm (System-2).



(a) *DRMS* and *FRMS*, (b) *VRMS*, (c) *ARMS*,

Fig. 4.4.3.3 Control performances in the case of the step-down searching algorithm (System-2).

in comparison with the other case. When the step-up searching algorithm is introduced, it is observed that the *ARMS*(ξ_1) may be deteriorated in comparison with the other case, however, the *ARMS*(ξ_2) and the *ARMS*(ξ_3) are reduced effectively. Namely, it seems that the searching sequence of the step-up searching algorithm may introduce the constrained conditions as like the seismic isolation effects in the lower story. When the step-down searching algorithm is introduced, it is regarded that all value of the *ARMS* may be observed as the quite similar level, since it seems that the searching sequence of the step-down searching algorithm may adjusted to the order of the priority which is related to the body forces resulted from the Study (4.4)-1. Through those considerations, the following two points for effective syntheses to the quasi-optimizing controllers may be appeared :

Point-1.1) Controlled structural responses which are evaluated as the *DRMS* and the *VRMS* are reduced by enlarging the values of the maximum trial control forces, however, the supplied control forces evaluated as the *FRMS* may be increased. Namely, the maximum trial control forces should be allocated by considering to the trade-off performances in the demand for the reductions of responses (which are considered from the values of the indicates as the *DRMS* and the *VRMS*) and the power supply required for the control devices (which are considered from the values of the indicates as the *FRMS*).

Point-1.2) Acceleration responses which are evaluated as the *ARMS* may be reduced as the results which are indirectly dragged by reductions of displacements and velocities in the comparative small values of the maximum trial control forces are supposed, however, those effects may be deteriorated by enlarging the values of the maximum trial control forces. It may be regarded that those indicates of the *ARMS* can assign to the another index which is related to the trade-off for the control performances as much as the considerations on the Point-1.1. When the maximum trial control forces are supposed as the comparative small values and the reductions of the *DRMS* and the *VRMS* are evaluated as not to be enough, the reductions of the *ARMS* may be also evaluated as not to be enough. When the maximum trial control forces are evaluated as too large values although the reductions of the *DRMS* and the *VRMS* are operated effectively, the indicates of the *ARMS* may be deteriorated in the sense of the reductions of accelerations, in this case, it seems that the influences caused by too much supply of the control forces may be directly and sensitively appeared in the acceleration response. Namely, it seems very significant that the limitations of the maximum trial control forces should be also allocated by evaluating for the fluctuations of the *ARMS*.

***Study (4.4) - 2c* :**

As the further considerations, to investigate for the numerical results in the Study (4.4)-2a for the Case-3 from the Viewpoint-2, the supplied control forces by introducing the lumped-node control force system (System-2) are evaluated. For this aim, the manipulated control forces in the Case-3 are supposed for the following two type of multi-devices control systems.

Type-1) The manipulated control forces are evaluated as the control forces allocated on the inter-stories to actualize the para-systems of control forces, which are supplied via the multi-located active braces on every inter-stories.

Type-2) The manipulated control forces are evaluated as the directly actualized control force system allocated on the mass, which are supplied via the multi-located active mass dampers on every floors or via the multi-located base-connected active braces between each floor and basement.

In the following discussions, to evaluating the required control forces in sense of the total power supply imposed to control devices for the cases using those different types of control devices, the following two kinds of indicates which is indexed to supplied control forces are introduced.

(i) *Ratio of the manipulated inter-story forces* :

To estimate the directly participated control forces to control device of the Type-1, the ratio of the manipulated inter-story forces $Rb_{rms}(i)$ is used as the indicate to evaluate the additional shear forces. The $Rb_{rms}(i)$ is defined as the ratio the RMS value of the supplied control force via the control device of the Type-1 located on the i-th story $b_{rms,\,i}$ (during 30 seconds of the ground motion inputs times) with the total mass of the structural system, namely,

$$Rb_{rms}(i) = b_{rms,\,i} \ / \sum_{j=1}^{3} m_j \ , \ i = 1, 2, 3, \tag{4.4.8a}$$

in which, m_j means the mass of the j-th story. The average of the $Rb_{rms}(i)$ is denoted by $\overline{Rb_{rms}}$ as follow,

$$\overline{Rb_{rms}} = \{\sum_{i=1}^{3} Rb_{rms}(i)\} \ / \ 3 \ . \tag{4.4.8b}$$

(ii) *Ratio of the manipulated body forces* :

To estimate the directly participated control forces to control device of the Type-2, the ratio of the manipulated body forces $Rf_{rms}(i)$ is used as the indicate to evaluate the additional body forces. The $Rf_{rms}(i)$ is defined as the ratio the RMS value of the supplied control force via the control device of the Type-2 located on the i-th floor $f_{rms,\,i}$ (during 30 seconds of the ground motion inputs times) with the total mass of the structural system, namely,

$$Rf_{rms}(i) = f_{rms,\,i} \ / \sum_{j=1}^{3} m_j \ , \ i = 1, 2, 3, \tag{4.4.9a}$$

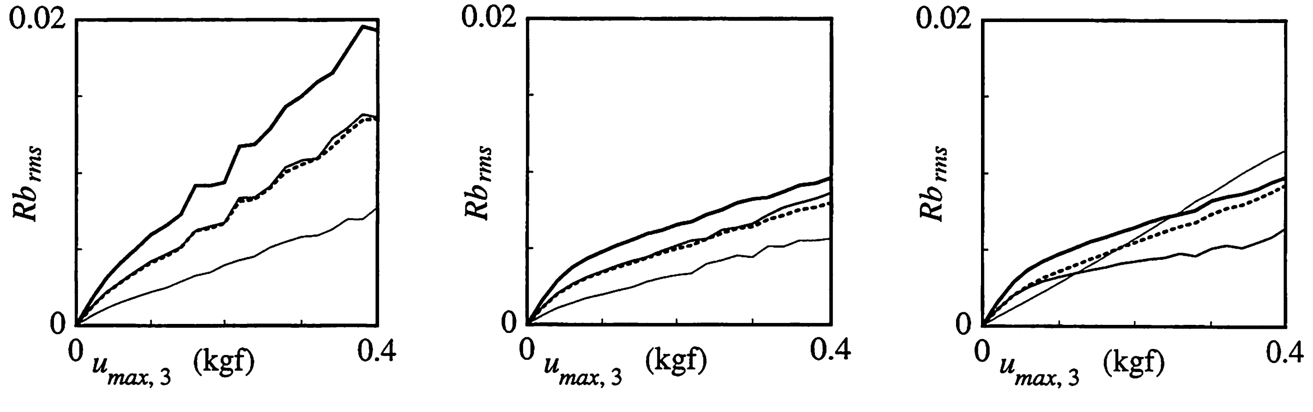
in which, m_j means the mass of the j-th story. The average of the $Rf_{rms}(i)$ is denoted by $\overline{Rf_{rms}}$ as follow,

$$\overline{Rf_{rms}} = \{\sum_{i=1}^{3} Rf_{rms}(i)\} \ / \ 3 \ . \tag{4.4.9b}$$

Figs. 4.4.4.1 and 4.4.4.2 show the supplied control force via the control device of the Type-1 and the Type-2, respectively. In those figures, (a), (b) and (c) show the cases that are installed the universal searching, the step-up searching and the step-down searching algorithm, respectively.

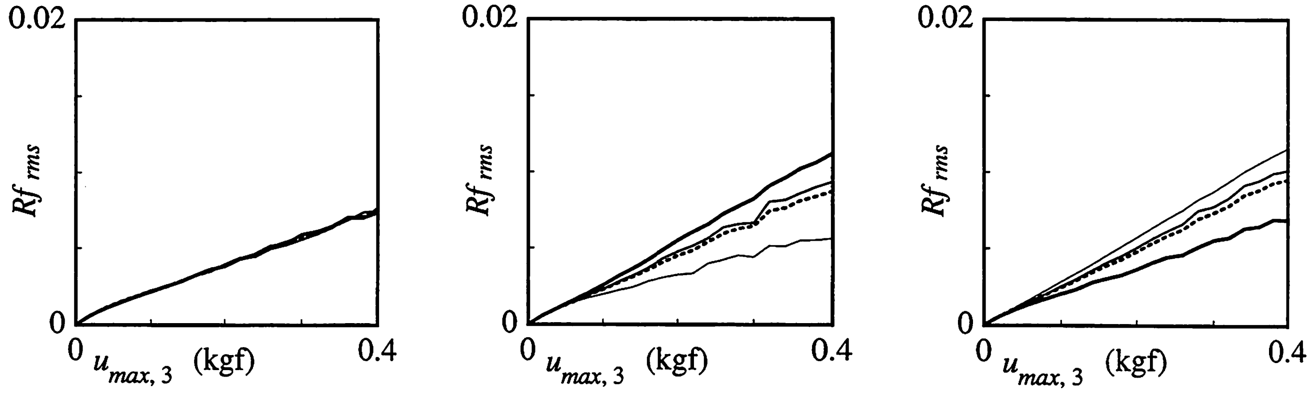
Those figures are corresponding to the results for the Case-3 in the Study (4.4)-2a, namely, (a), (b) and (c) of those figures are reconsidered by the another view for the results as shown in Figs. 4.4.2.1 (a), 4.4.2.2 (a) and 4.4.2.3 (a), respectively.

——— 1st, ——— 2nd, ——— 3rd, ········ Average.



(a) Universal searching, (b) Step-up searching, (c) Step-down searching,

Fig. 4.4.4.1 Required control forces in System-2 by using the control device of the Type-1.



(a) Universal searching, (b) Step-up searching, (c) Step-down searching,

Fig. 4.4.4.2 Required control forces in System-2 by using the control device of the Type-2.

By comparing Figs. 4.4.4.1, the total required control forces for the control devices of the Type-1 evaluated by the $\overline{Rb_{rms}}$ are observed as the quite large values in the case by introducing the universal searching algorithm for the other cases. When the step-up searching and the step-down searching algorithms are supposed, the fluctuations of the Rb_{rms} in those cases according to the variations of the maximum trial control forces may be regarded as almost the same levels except that the required control forces of the top story $Rb_{rms}(3)$ in the case for the step-down searching algorithm may be proportionally enlarged. And also, the total required control forces for the control devices of the Type-1 evaluated by the $\overline{Rb_{rms}}$ in those cases may be regarded as almost the same level.

By comparing Figs. 4.4.4.2, the total required control forces for the control devices of the Type-2 evaluated by the $\overline{Rb_{rms}}$ in all cases by introducing those three kinds of searching algorithm are observed as almost the same level, and the fluctuations of those values are proportionally increased according to the variations of the maximum trial control forces. When the universal searching algorithm is supposed, the fluctuations of the Rb_{rms} may be regarded as almost the same levels for every control devices. When the step-up searching algorithms is supposed, the required control forces of the top story $Rb_{rms}(3)$ is reduced while the required control forces of the bottom story $Rb_{rms}(1)$ is enlarged. When the step-down searching algorithms is supposed, the required control forces of the bottom story $Rb_{rms}(1)$ is reduced while the required control forces of the top story $Rb_{rms}(3)$ is enlarged.

By comparing Figs. 4.4.4.1 and 4.4.4.2, when comparative small values of the maximum trial control forces are supposed, the total required control forces for the control devices of the Type-1 evaluated by the $\overline{Rb_{rms}}$ are enlarged for the cases of the control devices of the Type-2. However, when the values of the maximum trial control forces are increased, the total required control forces for the control devices of either the Type-1 or the Type-2 evaluated by the $\overline{Rb_{rms}}$ in the all cases except the case of the universal searching algorithm by introducing the control device of the Type-1 can be regarded as to be almost the same levels. Namely, when the lumped-node control force system (System-2) is supposed as the mediational coordinate of the trial control force vectors on the quasi-optimizing control method, it may be regarded that the total required control forces for the control devices of the Type-1 evaluated by the $\overline{Rb_{rms}}$ by introducing via the multi-located active braces on every inter-stories can be remained into the almost same levels with the case for using the control devices the Type-2 (under the constraint conditions which the multi-layer searching algorithms are supposed for the control devices of the Type-1. Through those considerations (also by referring the results from the Study (4.4)-1), the following two points for the practical consideration to actualize advantages of the multi-devices active control system by introducing the quasi-optimizing controllers may be appeared :

Point-2.1) By introducing the lumped-node control force system (System-2) as the constraint control forces for the multi-devices control systems of both the Type-1 and the Type-2, more effective control performances may be actualized than the cases of the single-device active control systems.

Point-2.2) It may be regarded as the attractive considerations that abilities and effectiveness of the lumped-node control force system (System-2) may be replaced as the mimetic control forces via the control devices of the Type-1 without disadvantage and also with the almost same supply of the control forces required in the control devices of the Type-2. Because, the constraints to equip the control devices of the Type-1 (such as the active braces installed on every inter-stories) on practical buildings may be considered as to be very little, while it seems that the control devices of the Type-2 (such as the active mass dampers located on every floors or the base-connected active braces equipped on every floors) may be comparatively difficult to introduce in the sense of the practical installation.

***Study (4.4) - 3* :**

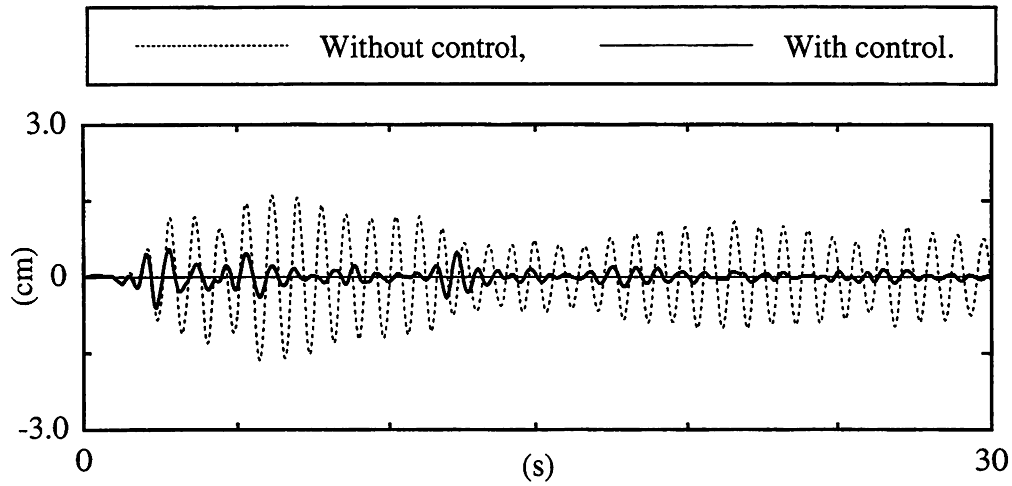
As the last step of investigating for the control performances of the System-1 and the System-2, the time histories of controlled behaviors of the system are comparatively evaluated through the numerical simulations and the experimental tests. Experimental tests for the CTAC system are executed by using the shaking table under the input of El Centro (1940) NS and JMA-Kobe (1995) NS which are scaled down to the maximum acceleration amplitude of 30 (cm/s^2). As the experimental structural model, the three-stories of the CTAC standard model which is surveyed as seen in the Fig.4.2.1 of the Section 4.2 is used. Three active braces are equipped on every stories of this structural model. The Case-2 and the Case-3 which are mentioned in the Study (4.4)-2a are investigated. Also, numerical simulations are executed under the same conditions with the experimental tests as the comparative studies.

For the installations of the quasi-optimizing control method, the maximum trial control forces of the top floor $u_{max,3}$ is selected as 0.12 (kgf) in both cases. So that, the arrangements of the maximum trial control forces are supposed as $u_{max,1} = 0.36$, $u_{max,2} = 0.24$ and $u_{max,3} = 0.12$ (kgf) in the Case-2 and the arrangements of the maximum trial control forces are supposed as $u_{max,1} = 0.12$, $u_{max,2} = 0.12$ and $u_{max,3} = 0.12$ (kgf) in the Case-3. In which, the coordinate of the trial control forces is related to the inter-story forces in the Case-2, the $u_{max,i}$ ($i = 1, 2, 3$) directly means the capacity of the j-th inter-story active brace $b_{lim,i}$ and the coordinate of the trial control forces is related to the body forces in the Case-3, the $b_{lim,i}$ are supposed as $b_{lim,1} = 0.36$, $b_{lim,2} = 0.24$ and $b_{lim,3} = 0.12$ (kgf). Namely, in both cases, the capacities for each control device $b_{lim,i}$ is supposed as $b_{lim,1} : b_{lim,2} : b_{lim,3} = 3 : 2 : 1$. The number of trial control forces of every control devices are supposed as to be equal to 5. The step-down searching algorithm are supposed for those studies (Study (4.4)-3).

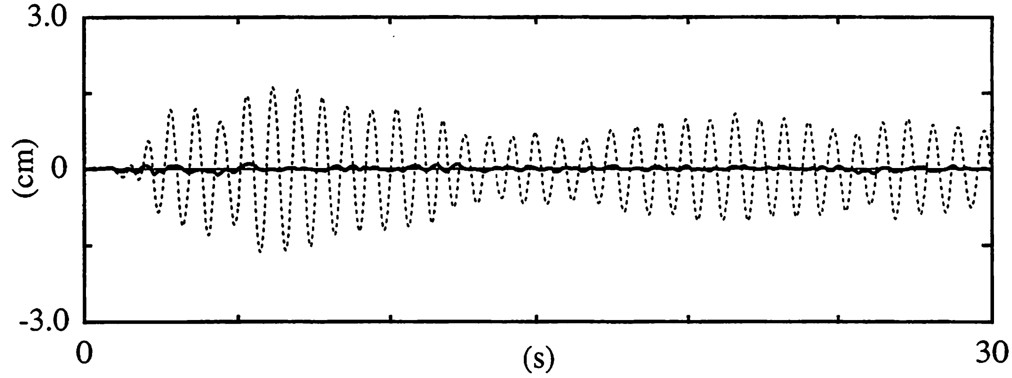
Figs. 4.4.5.1 and 4.4.5.2 show the displacements of the top floor for the inputs of El Centro NS resulted from the numerical simulations and the experimental tests, respectively. Figs. 4.4.6.1 and 4.4.6.2 show the displacements of the top floor for the inputs of JMA-Kobe resulted from the numerical simulations and the experimental tests, respectively. In those figures, (a) and (b) show the results for the cases for the Case-2 and the Case-3, respectively. In which, the Case-2 and the Case-3 are corresponding to introducing the linked-path control force system (System-1) and the lumped-node control force system (System-2), respectively.

By comparing Figs. 4.4.5.1 (a) and (b), and also by comparing Figs. 4.4.6.1 (a) and (b), the more effective reductions of response can be observed in the System-2 as the numerical results for both inputs of the El Centro and JMA-Kobe. Moreover, by comparing Figs. 4.4.5.2 (a) and (b), and also by comparing Figs. 4.4.6.2 (a) and (b), the more effective reductions of response can be observed in the System-2 as the experimental results for both of two kinds of inputs. The control effects which are observed by experimental tests are less than those by numerical simulations. As the reason for this, it may be regarded that the experimentally supposed control forces are depended on the time delay of the practical control system. However, it seems that those mechanical loss of control manipulations may be quite small and insignificant, and it may be considered that effective control performances are also operated on the experimental model.

As concluding remarks of this section, the two kinds of para-systems of control forces to be generated by the multi-device active control system are introduced to evaluate for the responsibilities of the control devices in the physical meanings. Those control force systems are supposed as that the actualized control forces are subjected as the inter-story forces or subjected as the body forces. Control performances by introducing those two kinds of control force systems are comparatively estimated through numerical simulations and experimental tests. Moreover, actualizations of the mimetic control forces are evaluated for the cases by installing two kinds of multi-devices system which are 1) the active braces located on every inter-stories and 2) the active mass dampers located on every floors or the base-connected active braces equipped on every floors.

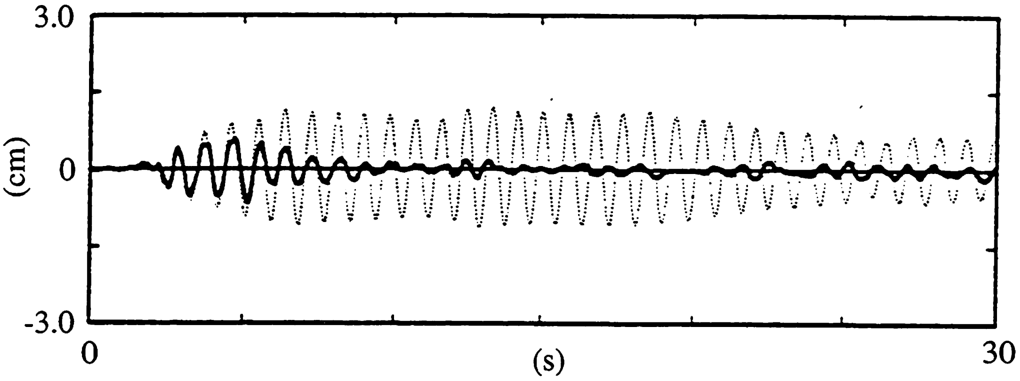


(a) Case-2 (the linked-path control force system (System-1)),

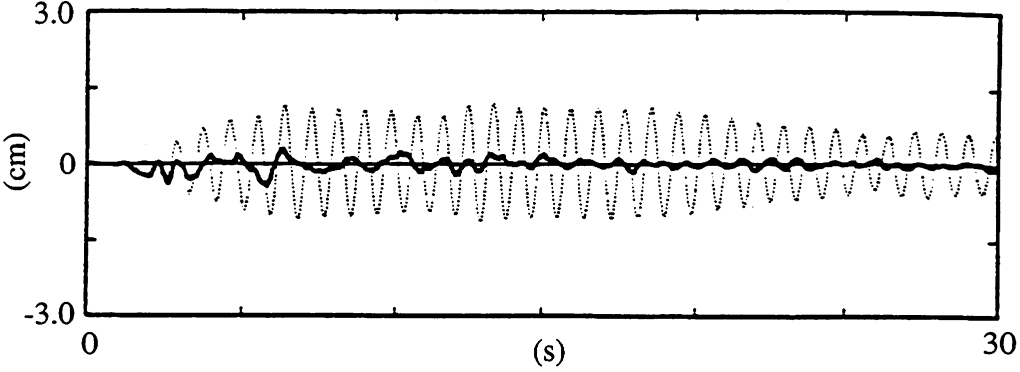


(b) Case-3 (the lumped-node control force system (System-2)),

Fig. 4.4.5.1 Displacements of the top floor (Numerical results, El Centro).

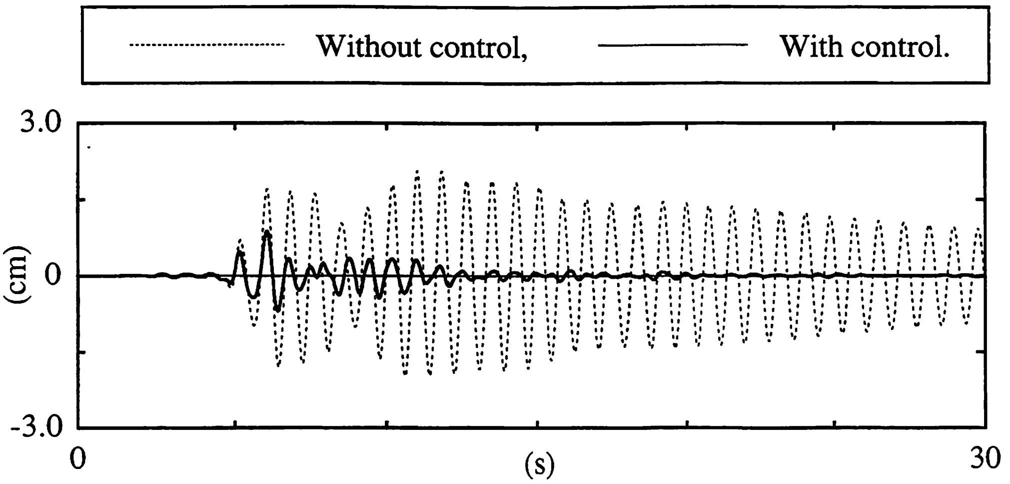


(a) Case-2 (the linked-path control force system (System-1)),

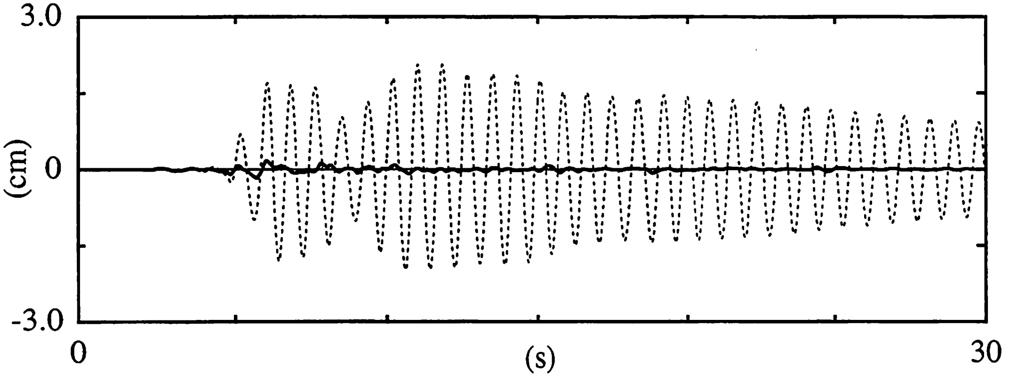


(b) Case-3 (the lumped-node control force system (System-2)),

Fig. 4.4.5.2 Displacements of the top floor (Experimental results, El Centro).

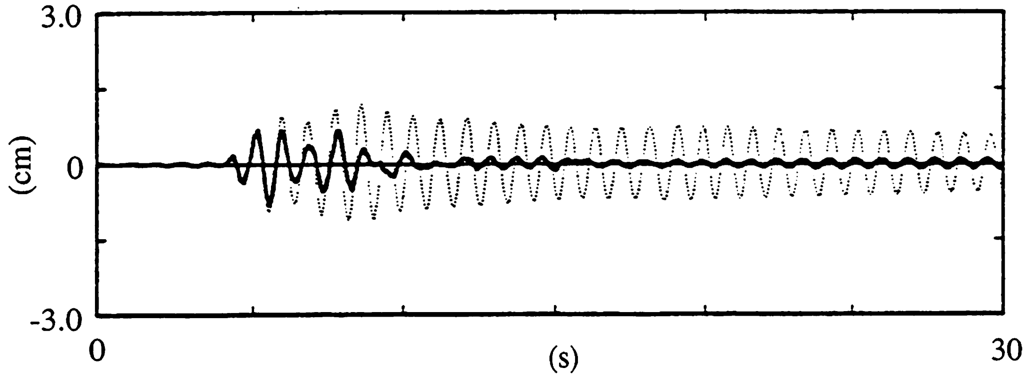


(a) Case-2 (the linked-path control force system (System-1)),

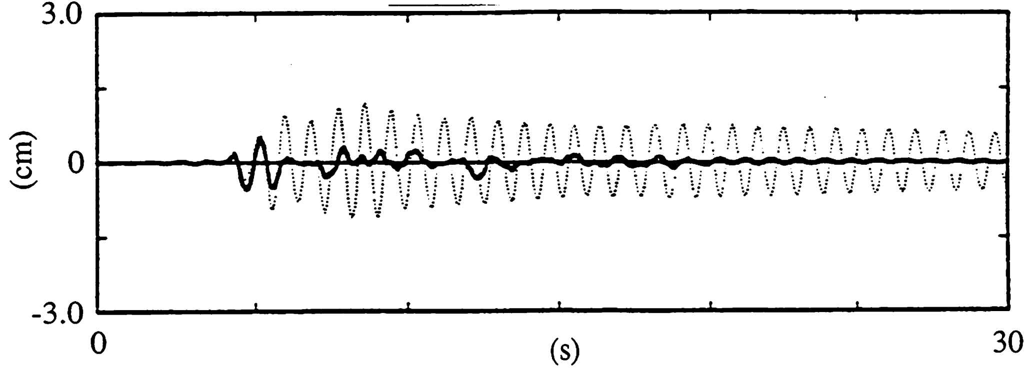


(b) Case-3 (the lumped-node control force system (System-2)),

Fig. 4.4.6.1 Displacements of the top floor (Numerical results, JMA-Kobe).



(a) Case-2 (the linked-path control force system (System-1)),



(b) Case-3 (the lumped-node control force system (System-2)),

Fig. 4.4.6.2 Displacements of the top floor (Experimental results, JMA-Kobe).

4. 5 Investigation for syntheses of trial control forces

The para-systems of the control forces which are introduced as to the coordinates of the trial control force vectors for operating the quasi-optimizing procedures are discussed to improve control performances for the multi-devices active aseismic response control system in the Section 4.4. When the quasi-optimizing control force vectors are related to the lumped-node control force systems which are supposed by the actualized control forces as to be constrained for the coordinates of the body forces mimetically, effective control performances may be operated in comparison with the linked-path control force systems which are supposed by the actualized control forces as to be subjected to the coordinates of the inter-story shear forces. In which, the effective arrangements of the partial responsibilities of the inter-story control forces manipulated via the inter-story active braces may be explained and resulted to the sensible arrangement of the inter-story shear forces which are simultaneously adjusted by installation of the lumped-node control force systems, in the physical meanings. Through those considerations in the Section 4.4, the further significant problems for syntheses of the trial control forces may be appeared. As the general sense for the aseismic syntheses of the controllers, the maximum control forces have to be macroscopically adjusted as to be provided the sufficient capacities for the targeted maximum level of the external inputs, at the same time, the aseismic controllers should be provided the efficiency to be able to operate effective control performances for any unreached external inputs to the presumed maximum level. However, by considering to Figs. 4.4.3.1 (c), 4.4.3.2 (c) and 4.4.3.3 (c) as seen in the Section 4.4 (which show the fluctuations of the acceleration responses according to the variations of the maximum trial control forces), it seems that the limitations of the maximum trial control forces are requested by evaluating for the reductions of acceleration responses. Namely, those problems which may prevent for installation of the quasi-optimizing controller as the aseismic response control system may be assigned as that the constraint of the maximum trial control forces for a certain targeted external input level has been specified by the control performances evaluated for the acceleration responses, especially, as that the controlled acceleration responses under the smaller excitations are deteriorated by supposing those specified values of the maximum trial control forces.

As the final step of the installations of the quasi-optimizing control method as the practical aseismic response control algorithm, improvements of control performances of the acceleration responses are investigated. For this aim, the synthesis of the set of the trial control forces which is supposed as the uniform division type (as presented in Exp. (4.2.5)) is verified and the other division type of the trial control forces may be also proposed. As the first verifications, the digits of the trial control forces are considered. When the uniform division type of trial control forces are introduced and the large values are supposed as the maximum trial control forces to suspect the comparative strong external excitations, the digits of the trial control forces may be allocated as the large values and some cases that those values are too wide and are out-of-scale for control operations may be occurred under the smaller external inputs. As the one of possibilities to avoid those kinds of problems, it may be considered that the number of the trial control forces are increased according to the provided values of the maximum trial control forces as like to suppose the enough small values of the digits of the trial control forces. In which, it may be very important to consider for the practical applicability of the universal searching algorithm. Since it may be explicit that the universal searching algorithm requires the quite large numbers of the trial manipulations on the quasi-optimizing controller when the multi-devices control systems are supposed, the universal searching algorithm may be considered as to be able to be introduced for the practical use only under the restricted conditions. For instance, if the limitation of number of the trial manipulations without time delay is supposed as to 125 times under the assumptions that a certain computer is introduced and that a certain control time interval is supposed, the restricted cases of either 11 kinds as the maximum number of the trial control forces for 2 control devices, 5 kinds for 3 control devices or 3 kinds for 4 control devices may be practicable for the installations of the universal searching algorithm. On the other side, for the installations of the multi-layer searching algorithm, lots of cases from 61 kinds for 2 control devices to 3 kinds for 41 control devices can be practicable. Moreover, through the previous considerations in the Section 4.4, it is assured that the effective control operations by the installations of the multi-layer searching algorithm can be actualized as much as the cases of the universal searching algorithm under the conditions that the lumped-node control force system is supposed as the para-systems of control forces for the multi-devices active response control systems. So that, it may be regarded as to be practicable that to integrate the multi-layer searching algorithm should be premised as the installations of the quasi-optimizing control method when the multi-devices active response control systems are supposed. At this point, the universal searching algorithm may be placed and utilized as the evaluative indications to estimate for the abilities actualized by the practicable installations of the quasi-optimizing control method based on the multi-layer searching algorithms as contrast of the possibilities as the strict solutions of the quasi-optimizing control method. From the sense of those, emphasis is put on the practical syntheses of the quasi-optimizing control method as the aseismic response control algorithm, the following discussions may be executed for the quasi-optimizing control method based on the multi-layer searching algorithms.

Study (4.5) - 1 :

At first, allocations of the digits in the uniform division type of the trial control forces are verified under the conditions that the lumped-node control force system is supposed as the para-system of control forces for the multi-located inter-story active braces system. Three kinds of sets of the uniform division type of the trial control forces are evaluated through numerical simulations under the input of El Centro (1940) NS which is scaled down to the maximum acceleration amplitude of 30 (cm/s^2). In this study, the maximum values of the trial control forces which are supposed for the quasi-optimizing operations are selected the same value for the all components of the mediate control force vectors, namely, $u_{max,\,1}$, $u_{max,\,2}$ and $u_{max,\,3}$ are supposed as to be equal to u_{max} , and also, the number of the trial control forces are selected the same number for the all components of the mediate control force vectors, namely, N_1 , N_2 and N_3 are supposed as to be equal to N (at the same time, the mesh level of the trial control forces L_1 , L_2 and L_3 are supposed as to be equal to L

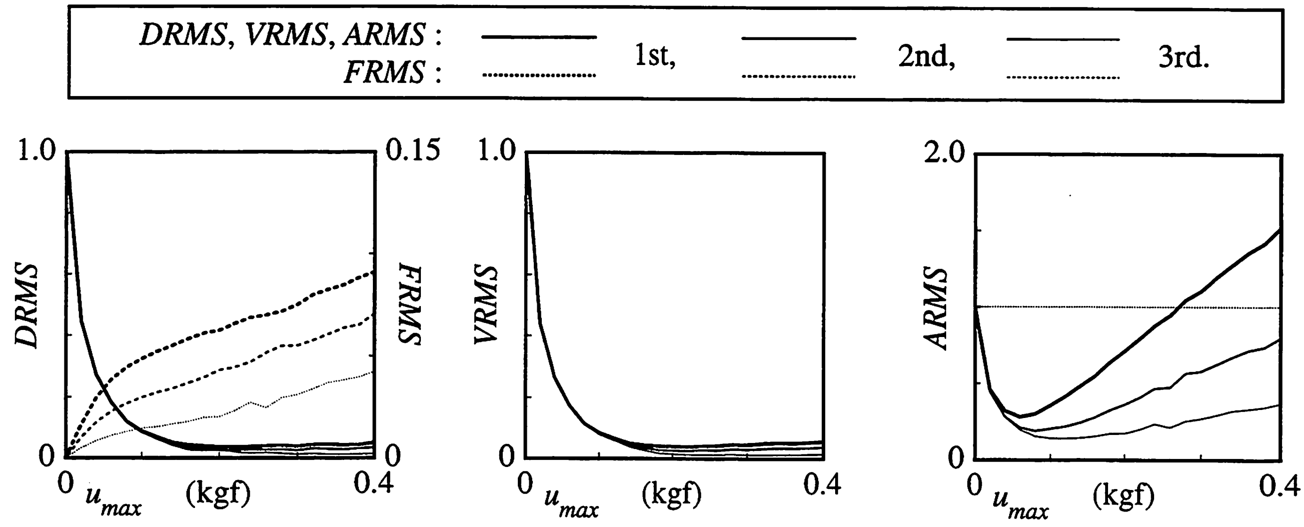
that is expressed as $L = (N - 1) / 2$). The division of the trial control forces of the j-th component of the mediate control force vectors (j =1, 2, 3) is proposed as Exp. (4.2.5) in the Section 4.2. Those three cases which are investigated in this study are supposed as the cases of N =9, 17 and 33, and the mesh level of the trial control forces L according to those three cases are supposed as L =4, 8 and 16, respectively. Namely, the digits of the trial control forces u_{div} (in which, $u_{div,1}$, $u_{div,2}$ and $u_{div,3}$ are also supposed as to be equal to u_{div}) for those cases are provided as the 1/4, 1/8 and 1/16 of values for the maximum trial control forces, respectively. Those investigations are operated for the two cases by using the step-up searching and the step-down searching algorithms.

Figs. 4.5.1.1, 4.5.1.2 and 4.5.1.3 show the three kinds of indicates for response reductions and the indicate of the manipulated control forces by introducing the step-up searching algorithm in the cases which are selected as the number of the trial control forces $N = 9$, 17 and 33 (corresponding to the digits of the uniform division type of the trial control forces $u_{div} = (1/4) \cdot u_{max}$, $(1/8) \cdot u_{max}$ and $(1/16) \cdot u_{max}$), respectively. Figs. 4.5.2.1, 4.5.2.2 and 4.5.2.3 show the three kinds of indicates for response reductions and the indicate of the manipulated control forces by introducing the step-down searching algorithm in the cases which are selected as the number of the trial control forces $N = 9$, 17 and 33, respectively. In those figure, (a) show the displacements controlled factors (*DRMS*) and the control manipulation factors (*FRMS*), and (b) and (c) show the velocities controlled factor (*VRMS*) and the accelerations controlled factor (*ARMS*), respectively.

By considering Figs. 4.5.1.1, 4.5.1.2 and 4.5.1.3, also by comparing those figures with Figs. 4.4.3.2 as shown in the Study (4.4)-2b in the Section 4.4 (which is supposed to the case of $N = 5$ (corresponding to $u_{div} = (1/2) \cdot u_{max}$)), in the cases by introducing the step-up searching algorithm, the fluctuations of the *DRMS* and the *VRMS* according to the variations of the maximum trial control force u_{max} may be observed as very similar in all cases, and the fluctuation curves for the *ARMS* except for the *ARMS*(ξ_1) are gradually reduced by installing the sets of trial control forces which is included smaller digits, and the same time, the fluctuation curves for the *FRMS* are gradually reduced according to subdividing the set of the trial control forces into components by the smaller digits.

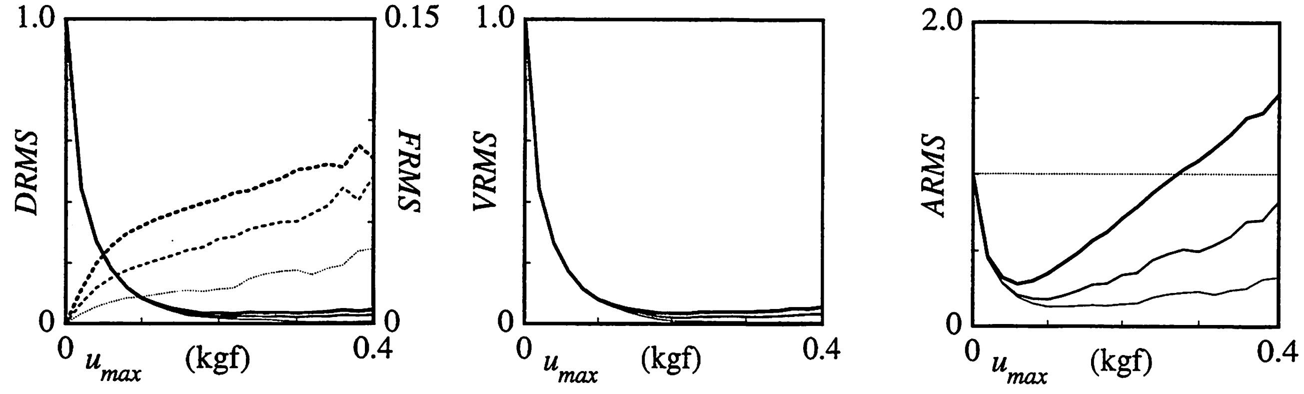
By considering Figs. 4.5.2.1, 4.5.2.2 and 4.5.2.3, also by comparing those figures with Figs. 4.4.3.3 as shown in the Study (4.4)-2b in the Section 4.4, in the cases by introducing the step-down searching algorithm, the fluctuations of the *DRMS* and the *VRMS* according to the variations of the maximum trial control force u_{max} may be also observed as very similar in all cases, and the fluctuation curves for the *ARMS* except for the *ARMS*(ξ_3) are gradually reduced by installing the sets of trial control forces which is included smaller digits. However, the fluctuation curves for the *FRMS* may be observed as very similar in all cases regardless to subdividing the set of the trial control forces into components by the smaller digits.

Through those consideration, it may be assured that a little tendency to improvement of the control performances evaluated for the acceleration responses are observed on the installations of the uniform division type of the trial control forces when the enough numbers of the trial control forces are supposed as like to be allocated comparative small digits on the set of the trial control forces according to some selected values of the maximum trial control forces. However, since



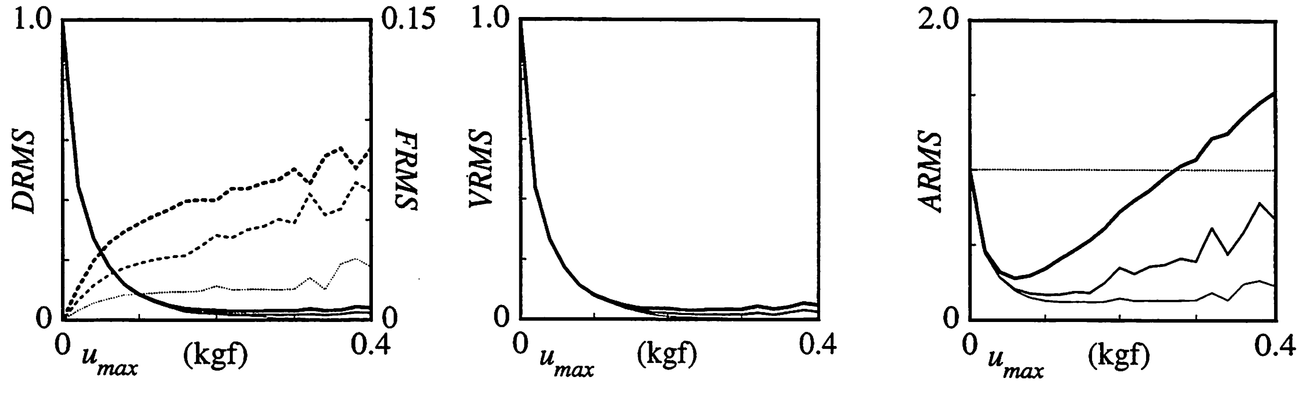
(a) *DRMS* and *FRMS*, (b) *VRMS*, (c) *ARMS*,

Fig. 4.5.1.1 Control performances in the case of the step-up searching algorithm ($N = 9$).



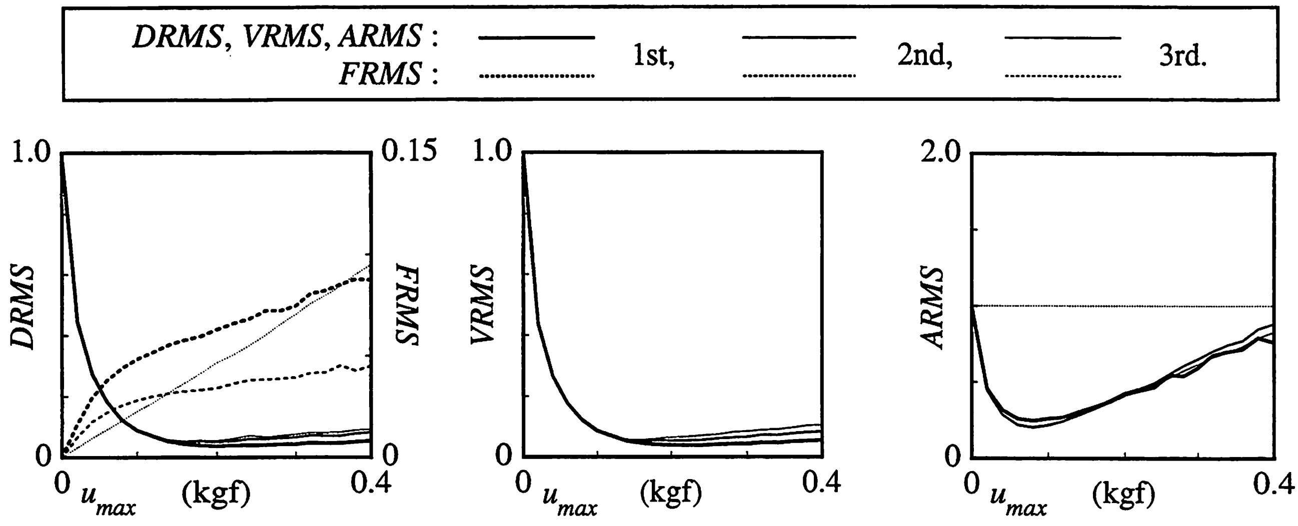
(a) *DRMS* and *FRMS*, (b) *VRMS*, (c) *ARMS*,

Fig. 4.5.1.2 Control performances in the case of the step-up searching algorithm ($N = 17$).



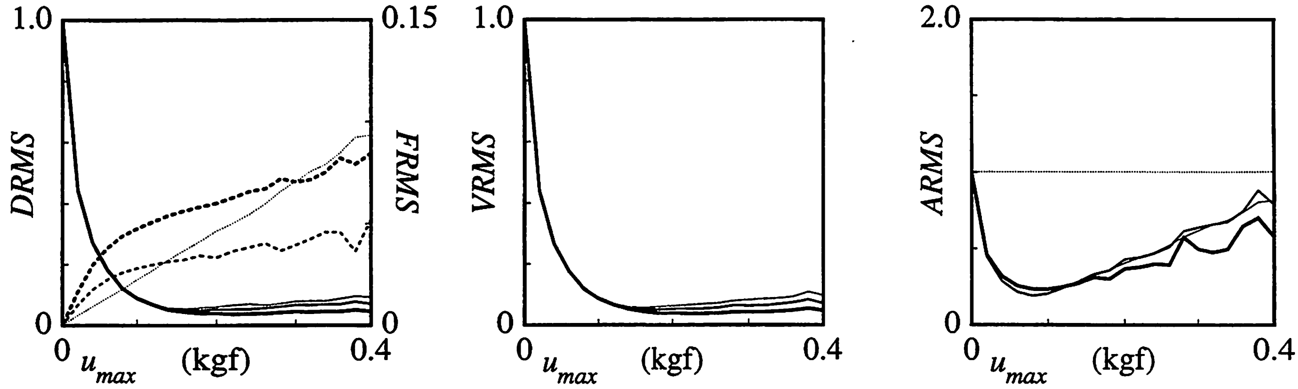
(a) *DRMS* and *FRMS*, (b) *VRMS*, (c) *ARMS*,

Fig. 4.5.1.3 Control performances in the case of the step-up searching algorithm ($N = 33$).



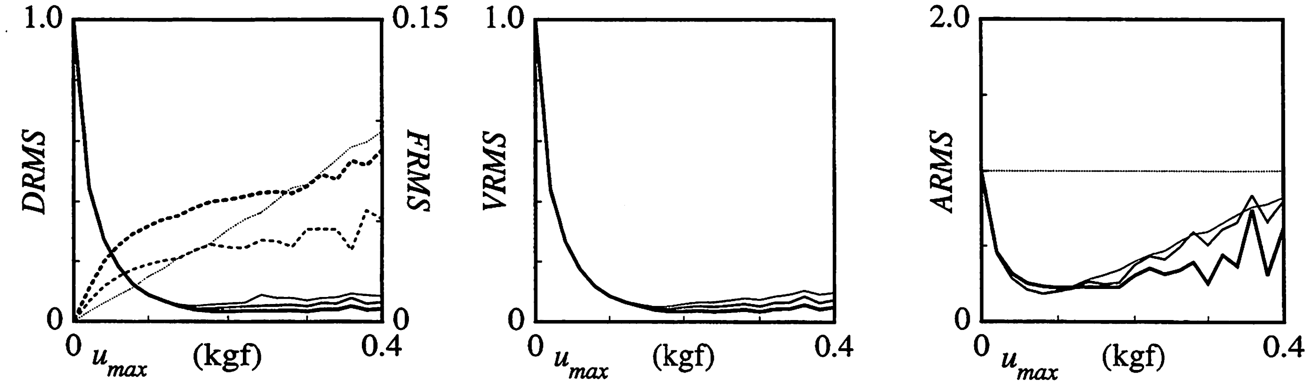
(a) *DRMS* and *FRMS*, (b) *VRMS*, (c) *ARMS*,

Fig. 4.5.2.1 Control performances in the case of the step-down searching algorithm ($N = 9$).



(a) *DRMS* and *FRMS*, (b) *VRMS*, (c) *ARMS*,

Fig. 4.5.2.2 Control performances in the case of the step-down searching algorithm ($N = 17$).



(a) *DRMS* and *FRMS*, (b) *VRMS*, (c) *ARMS*,

Fig. 4.5.2.3 Control performances in the case of the step-down searching algorithm ($N = 33$).

those kinds of installations may not be dominative for the improvement of the control performances by introducing the quasi-optimizing control method and may not be enough to install this method as the aseismic active response control algorithm, the other primary factors should be investigated. At this point, discussions are reached to the instructions of the another division type of set of the trial control forces.

The small digits on the set of the trial control forces may be installed for the purpose as to avoid the out-of-scale of ranges and resolutions of the trial control forces for control operations when the comparative small external inputs are supposed. For instance, it may be reasonable that the mesh level of the j-th set of the of the trial control forces is increased as to be $L_j = 2$ (the number of the trial control forces $N_j = 5$) and the control forces $\pm u_{div,j} = (1/2)\cdot u_{max,j}$ are additionally provided as the middle trial under the uniform division type to improve control performance on the case that the mesh level are supposed as to be $L_j = 1$ (the number of the trial control forces $N_j = 3$) and that the control forces $\pm u_{div,j} = u_{max,j}$ and 0 are only provided as the set. However, when the mesh level of the trial control forces is increased as to be $L_j = 4$ (the number of the trial control forces $N_j = 9$) and the control forces $\pm u_{div,j} = (1/4)\cdot u_{max,j}$ and $\pm u_{div,j} = (3/4)\cdot u_{max,j}$ are additionally provided for the case that the mesh level are supposed as to be $L_j = 2$, it seems that the provision of the $\pm u_{div,j} = (3/4)\cdot u_{max,j}$ may not be necessary in the purpose to improve control performance on the case that the mesh level $L_j = 2$ and that, if anything, those additional provision ($\pm u_{div,j} = (3/4)\cdot u_{max,j}$) may be obstructive. So that, instead of introducing the uniform division type, it may be reasonable to synthesize as that the additionally provided trial according to the increment of the mesh level of set of trial control forces are always allocated at the smaller values than the minimum digit provided on the lower mesh level.

For this aim, the another syntheses of the division type of the set of trial control forces may be introduced. To present the general instruction for this new syntheses of the division type of the set of trial control forces, discussions may be moved back again to the n degrees-of-freedom structural system equipped with r of control devices which is mentioned by Eq. (4.1.1) in the Section 4.1. At first, it is assumed that the value of the maximum trial control force of the j-th set of the of the trial control forces is selected as a certain value $u_{max,j}$. Let $<\hat{u}_j \in \lambda(j)>$ denote the sub-set of the trial control forces of the class $\lambda(j)$ (which is defined as the non-negative integer number) as follows.

$$<\hat{u}_j \in \lambda(j)> = <0>, \text{ when } \lambda(j) = 0, \text{ and}$$

$$<\hat{u}_j \in \lambda(j)> = <-u_{div,j}^{\in\lambda(j)}, u_{div,j}^{\in\lambda(j)}>, \; u_{div,j}^{\in\lambda(j)} = \alpha^{\lambda(j)-1}\cdot u_{max,j}, \text{ when } \lambda(j) \geq 1,$$

$$(j = 1, 2, \cdots, r). \tag{4.5.1}$$

In which, α means the coefficient of the geometric progression to define the minimum digit $u_{div,j}^{\in\lambda(j)}$ (which is named as the span of the digit in the following) for the sub-set belonging to the class $\lambda(j)$. The set of the trial control forces of the mesh level L_j defined as follow.

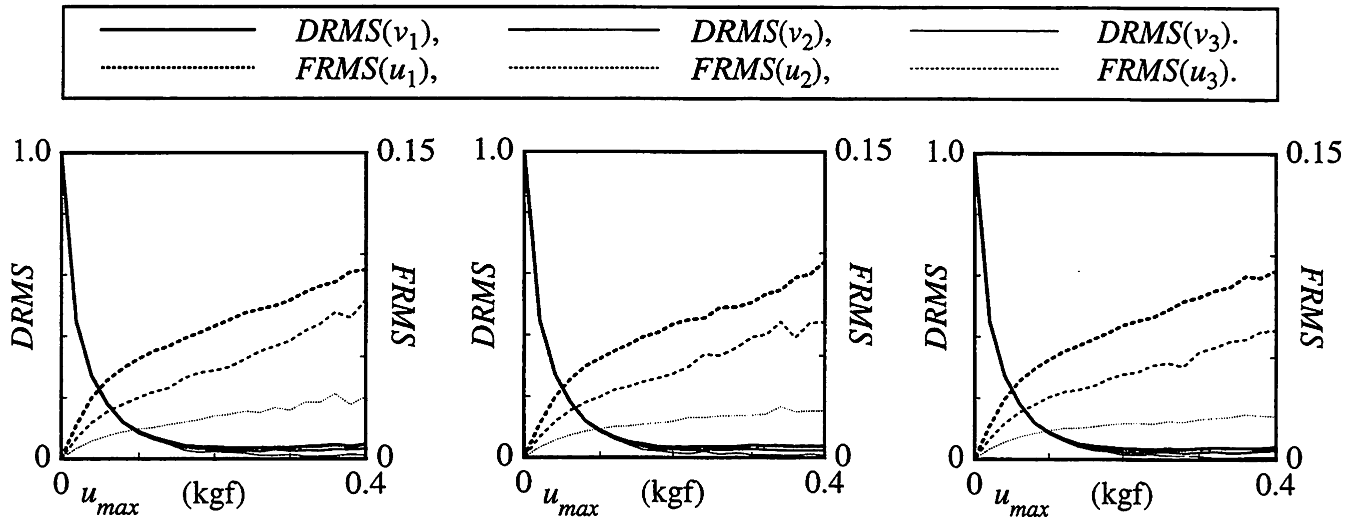
$$<\hat{u}_j> = \bigcup_{\lambda(j)=0}^{L_j} <\hat{u}_j \in \lambda(j)>. \tag{4.5.2}$$

In the set < $\hat{u}_j$ >, the total number of trial control forces N_j are supposed by ($2 \cdot L_j + 1$) = N_j . In which, the maximum class of the sub-sets included to those set of the trial control forces are proposed as the same value with the mesh level L_i. When the new division type of the set of the trial control forces proposed as the Exp. (4.5.2) is supposed, the additionally provided trial according to the increment of the mesh level of set of trial control forces are provided as the geometric progression for the minimum digit belonging to the just under the class. So that, those kinds of division type is named as a 'geometric fractional division' type of the trial control forces.

Study (4.5) - 2 **:**

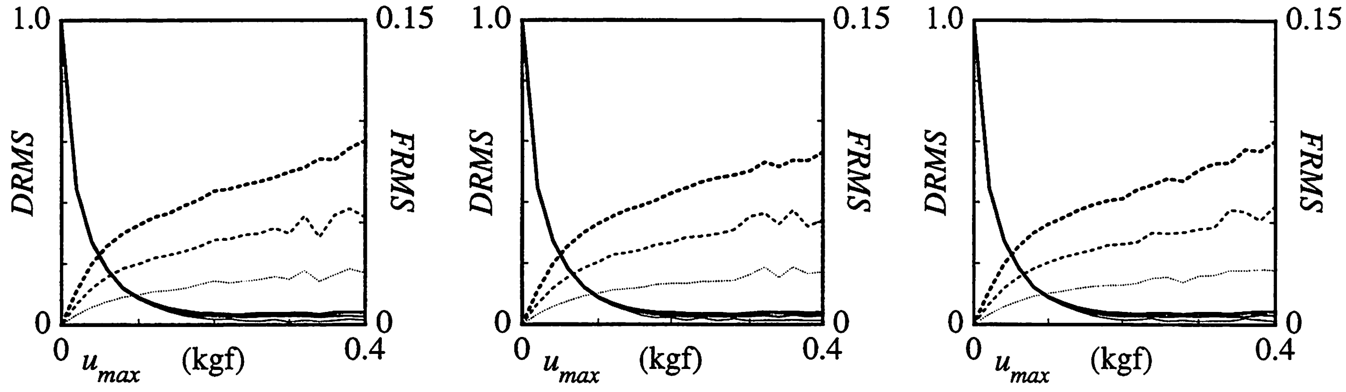
To investigate for the syntheses by introducing the geometric fractional division type of the trial control forces, numerical evaluations are executed. At first, the control performances and the improvement of the acceleration responses which is related to the mesh level, the span of the digit of the geometric fractional division type of the trial control forces are evaluated. The numerical simulations are operated on the three-stories of the CTAC standard model under the input of El Centro (1940) NS which is scaled down to the maximum acceleration amplitude of 30 (cm/s^2). The quasi-optimizing control method are installed under the conditions that the lumped-node control force system is supposed as the para-system of control forces for the multi-located inter-story active braces system. The maximum values of the trial control forces are selected the same value for the all components of the mediate control force vectors ($u_{max,\,1}$, $u_{max,\,2}$ and $u_{max,\,3}$ are supposed as to be equal to u_{max}), and the span of digits, the mesh level and the number of the trial control forces are selected the same number for the all components of the mediate control force vectors, and those quantities are denoted as α, L and N (which is supposed by $N = 2 \cdot L + 1$), respectively. The division of the trial control forces of the j-th component of the mediate control force vectors (j =1, 2, 3) is proposed as Exp. (4.5.1) and Exp. (4.5.2). Every three cases which are supposed as the cases of $N = 7$, 9 and 11 (corresponding to $L = 3$, 4 and 5) are evaluated for the three kinds of the span of digits $\alpha = 0.5$, 0.3 and 0.1. Those investigations are operated for the two cases by using the step-up searching and the step-down searching algorithms.

Figs. 4.5.3.1, 4.5.3.2 and 4.5.3.3 show the displacements reductions factor (*DRMS*) and the manipulated control forces (*FRMS*) by introducing the step-up searching algorithm in the cases which are selected as the span of digits of the trial control forces $\alpha = 0.5$, 0.3 and 0.1, respectively. Figs. 4.5.4.1, 4.5.4.2 and 4.5.4.3 show the accelerations reductions factor (*ARMS*) by introducing the step-up searching algorithm in the cases which are selected as the span of digits of the trial control forces $\alpha = 0.5$, 0.3 and 0.1, respectively. Figs. 4.5.4.1, 4.5.4.2 and 4.5.4.3 show the displacements reductions factor (*DRMS*) and the manipulated control forces (*FRMS*) by introducing the step-down searching algorithm in the cases which are selected as the span of digits of the trial control forces $\alpha = 0.5$, 0.3 and 0.1, respectively. Figs. 4.5.6.1, 4.5.6.2 and 4.5.6.3 show the accelerations reductions factor (*ARMS*) by introducing the step-down searching algorithm in the cases which are selected as the span of digits of the trial control forces $\alpha = 0.5$, 0.3 and 0.1, respectively. In those figure, (a), (b) and (c) are corresponding to three cases which are supposed as the number of the trial control forces $N = 7$, 9 and 11, respectively.



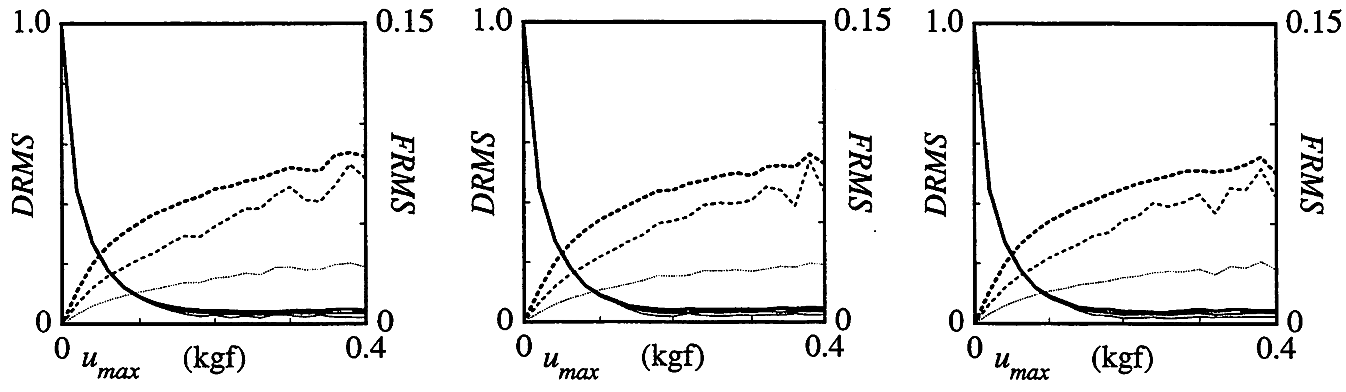
(a) $N = 7$, (b) $N = 9$, (c) $N = 11$,

Fig. 4.5.3.1 *DRMS* and the *FRMS* in the case of the step-up searching algorithm ($\alpha = 0.5$).



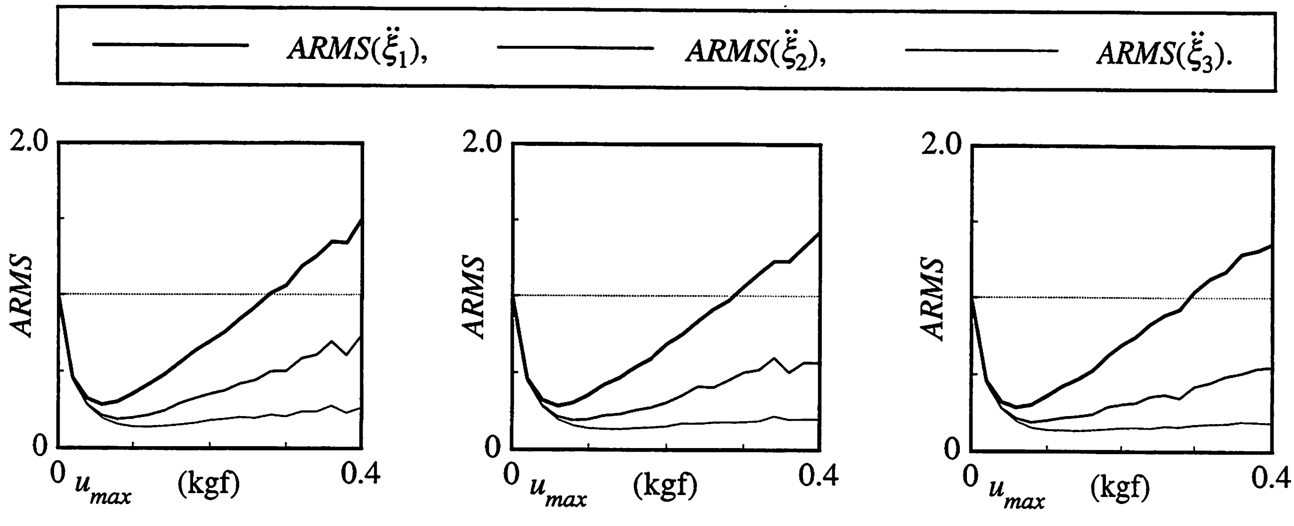
(a) $N = 7$, (b) $N = 9$, (c) $N = 11$,

Fig. 4.5.3.2 *DRMS* and the *FRMS* in the case of the step-up searching algorithm ($\alpha = 0.3$).



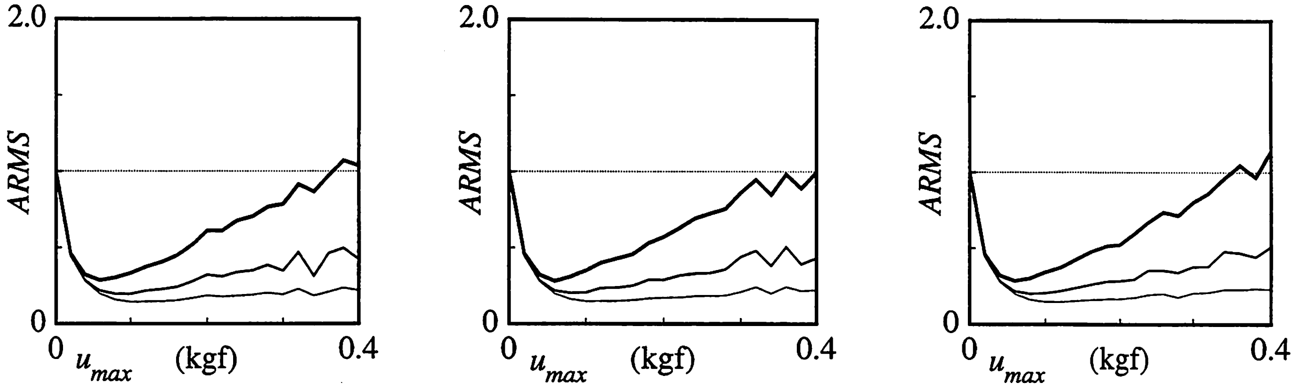
(a) $N = 7$, (b) $N = 9$, (c) $N = 11$,

Fig. 4.5.3.3 *DRMS* and the *FRMS* in the case of the step-up searching algorithm ($\alpha = 0.1$).



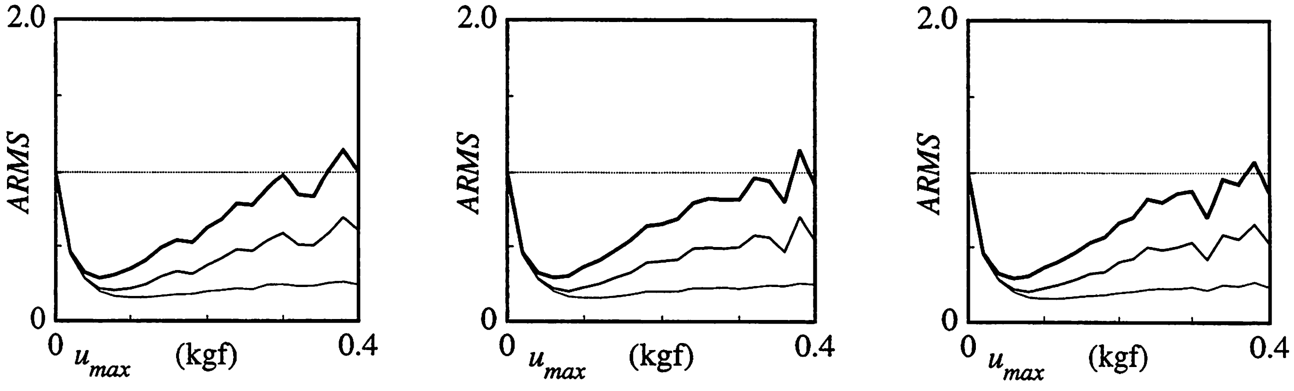
(a) $N = 7$, (b) $N = 9$, (c) $N = 11$,

Fig. 4.5.4.1 *ARMS* in the case of the step-up searching algorithm ($\alpha = 0.5$).



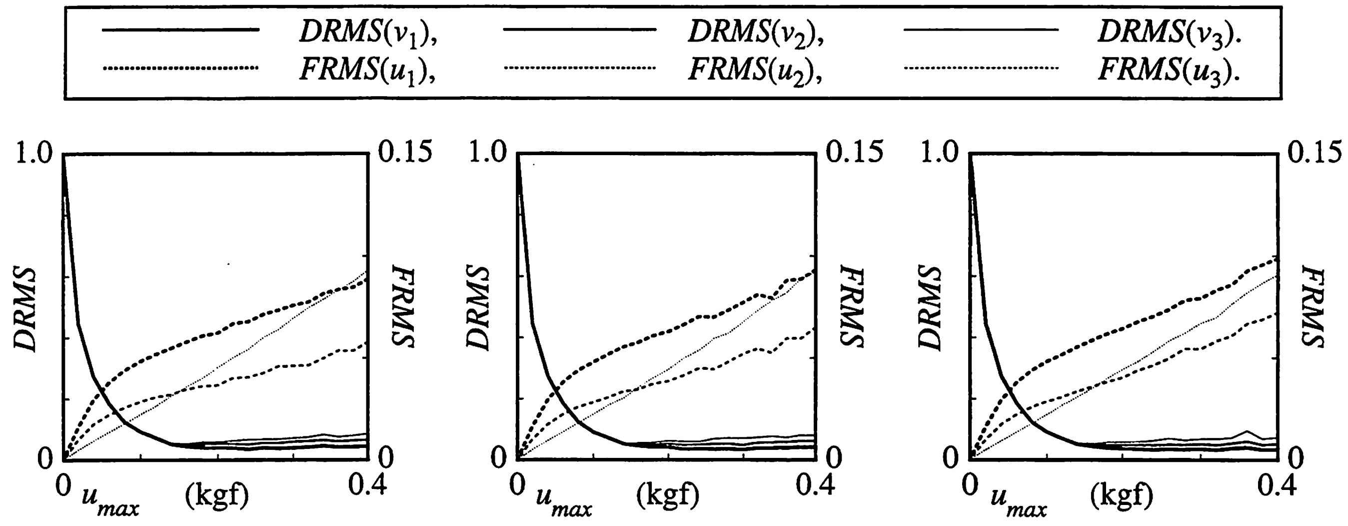
(a) $N = 7$, (b) $N = 9$, (c) $N = 11$,

Fig. 4.5.4.2 *ARMS* in the case of the step-up searching algorithm ($\alpha = 0.3$).



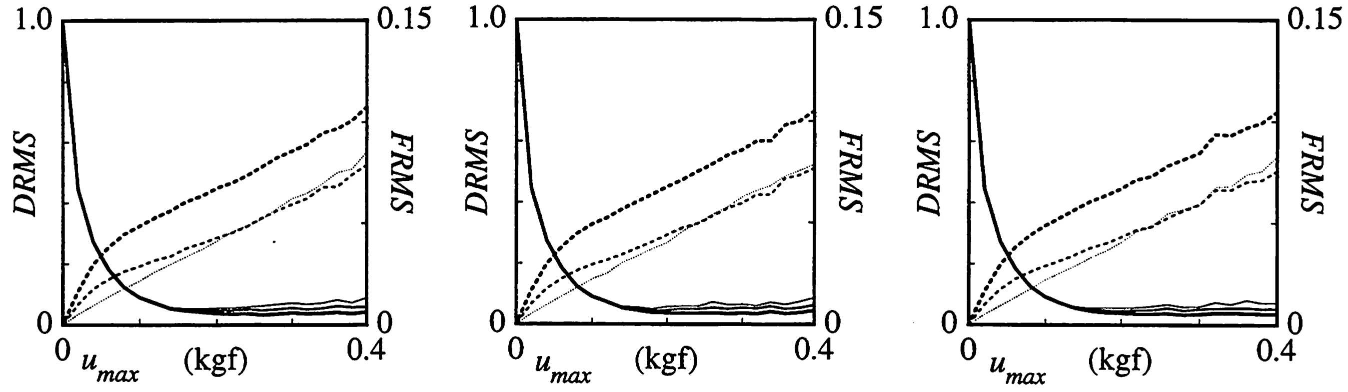
(a) $N = 7$, (b) $N = 9$, (c) $N = 11$,

Fig. 4.5.4.3 *ARMS* in the case of the step-up searching algorithm ($\alpha = 0.1$).



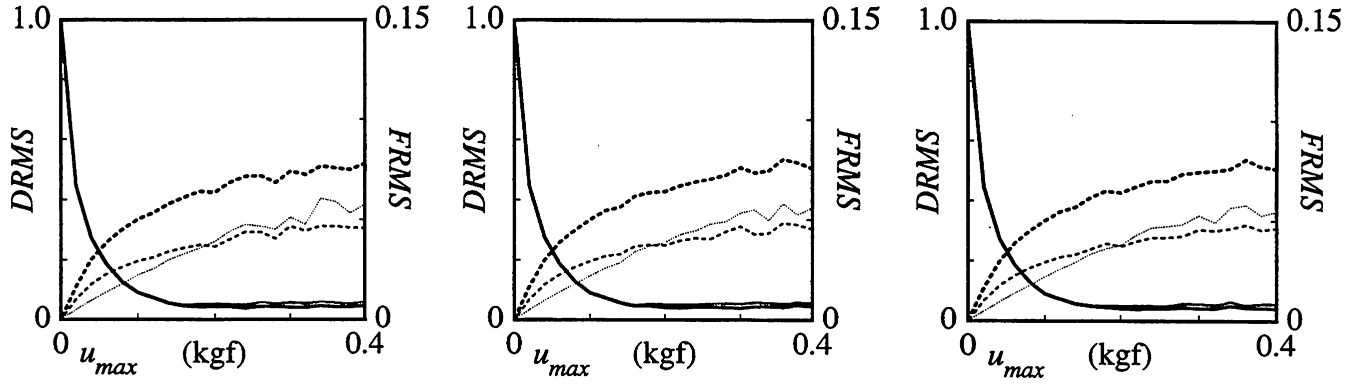
(a) $N = 7$, (b) $N = 9$, (c) $N = 11$,

Fig. 4.5.5.1 *DRMS* and the *FRMS* in the case of the step-down searching algorithm ($\alpha = 0.5$).



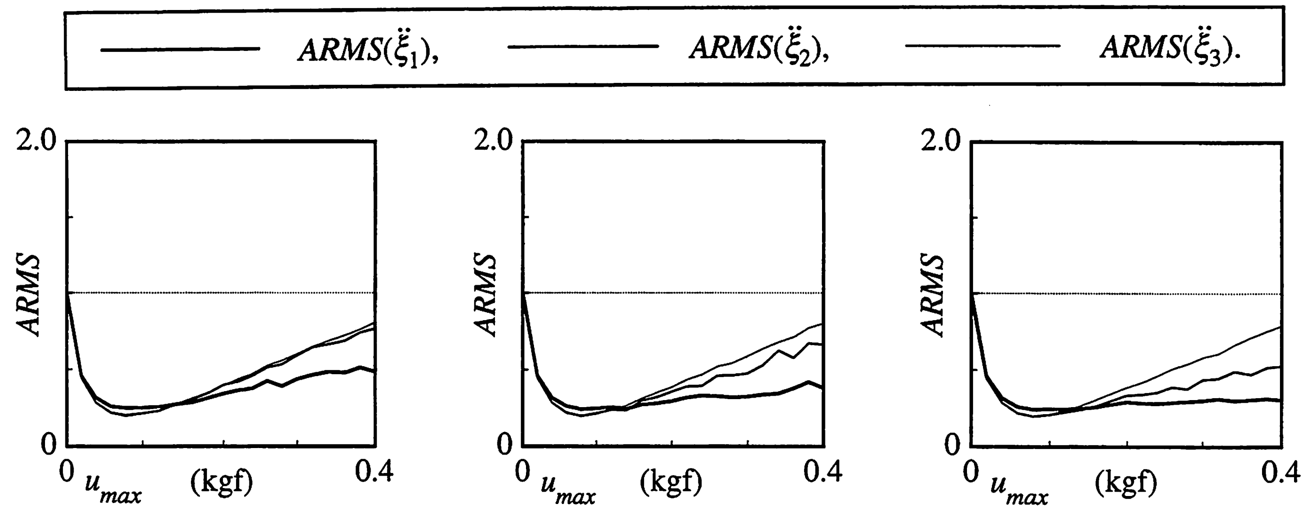
(a) $N = 7$, (b) $N = 9$, (c) $N = 11$,

Fig. 4.5.5.2 *DRMS* and the *FRMS* in the case of the step-down searching algorithm ($\alpha = 0.3$).



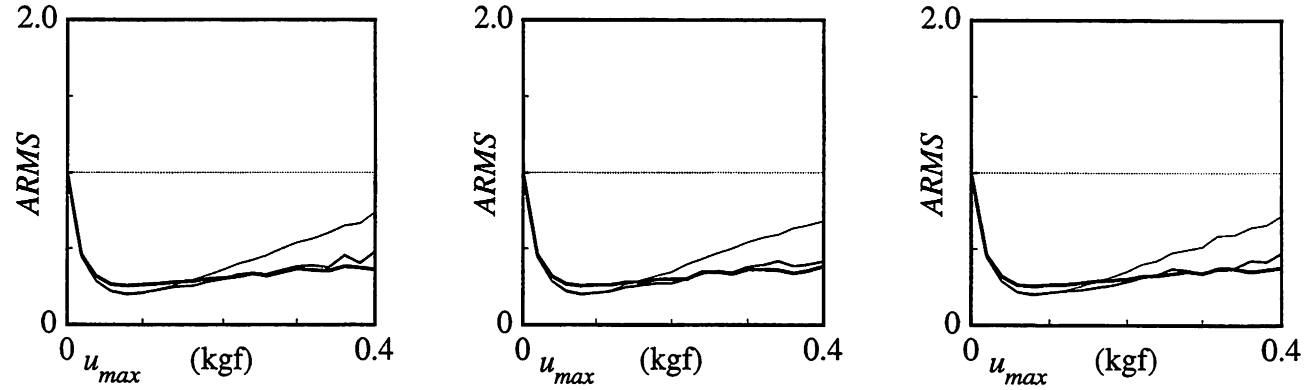
(a) $N = 7$, (b) $N = 9$, (c) $N = 11$,

Fig. 4.5.5.3 *DRMS* and the *FRMS* in the case of the step-down searching algorithm ($\alpha = 0.1$).



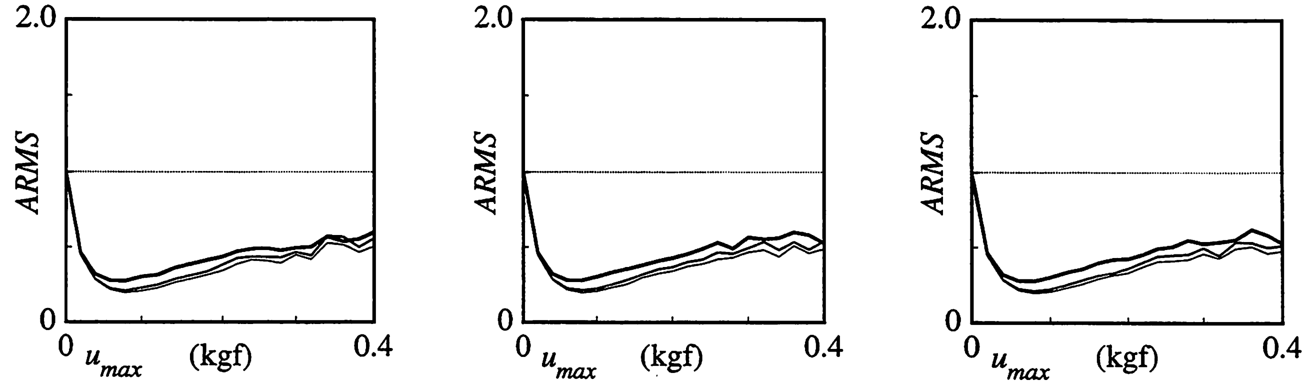
(a) $N=7$, (b) $N=9$, (c) $N=11$,

Fig. 4.5.6.1 *ARMS* in the case of the step-down searching algorithm ($\alpha = 0.5$).



(a) $N=7$, (b) $N=9$, (c) $N=11$,

Fig. 4.5.6.2 *ARMS* in the case of the step-down searching algorithm ($\alpha = 0.3$).



(a) $N=7$, (b) $N=9$, (c) $N=11$,

Fig. 4.5.6.3 *ARMS* in the case of the step-down searching algorithm ($\alpha = 0.1$).

By considering Figs. 4.5.3.1, 4.5.3.2 and 4.5.3.3, in the cases by introducing the step-up searching algorithm, the fluctuations of the *DRMS* according to the variations of the maximum trial control force u_{max} may be observed as very similar in all cases, and the fluctuations of the *FRMS* may be also regarded as very similar in all cases although a little differences are observed on the fluctuation curves for the $FRMS(u_2)$. By comparing Figs. 4.5.4.1, 4.5.4.2 and 4.5.4.3, the most reductions of the acceleration responses may be observed in the case of the span of the digit $\alpha = 0.3$ as the effect by installation of the geometric fractional division type of the trial control forces when the step-up searching algorithm is supposed. However, in those cases, it seems that the reductions of acceleration responses of the lowest story ($ARMS(\ddot{\xi}_1)$) may not be enough, and that the improvements of control performances may not be sufficiently achieved at the purpose to compose effective aseismic response controllers. In which, those tendencies may be observed regardless of the differences of the number of the trial control forces except the case of the span of the digit $\alpha = 0.5$.

By considering Figs. 4.5.5.1, 4.5.5.2 and 4.5.5.3, in the cases by introducing the step-down searching algorithm, the fluctuations of the *DRMS* according to the variations of the maximum trial control force u_{max} may be observed as very similar in all cases, and the fluctuation curves for the *FRMS* may be enlarged in the cases of the span of the digit $\alpha = 0.3$ and may be reduced in the cases of the span of the digit $\alpha = 0.1$. By comparing Figs. 4.5.6.1, 4.5.6.2 and 4.5.6.3, the effective reductions of the acceleration responses may be observed in all cases, and the most effective improvements may be seen in the cases which are supposed as the span of the digit $\alpha = 0.1$. In which, those tendencies may be observed regardless of the differences of the number of the trial control forces except the case of the span of the digit $\alpha = 0.5$. When the step-down searching algorithm is supposed, by introducing the geometric fractional division type of the trial control forces and by synthesizing the set of the trial control forces by the span of the digit $\alpha = 0.1$, it is assured that the acceleration responses evaluated by the *ARMS* may be effectively and equality reduced for all stories of the structural model as to cover comparative wide range of the variations of the maximum trial control forces, namely, it seems that the improvements of control performances may be sufficiently achieved at the purpose to compose effective aseismic response controllers.

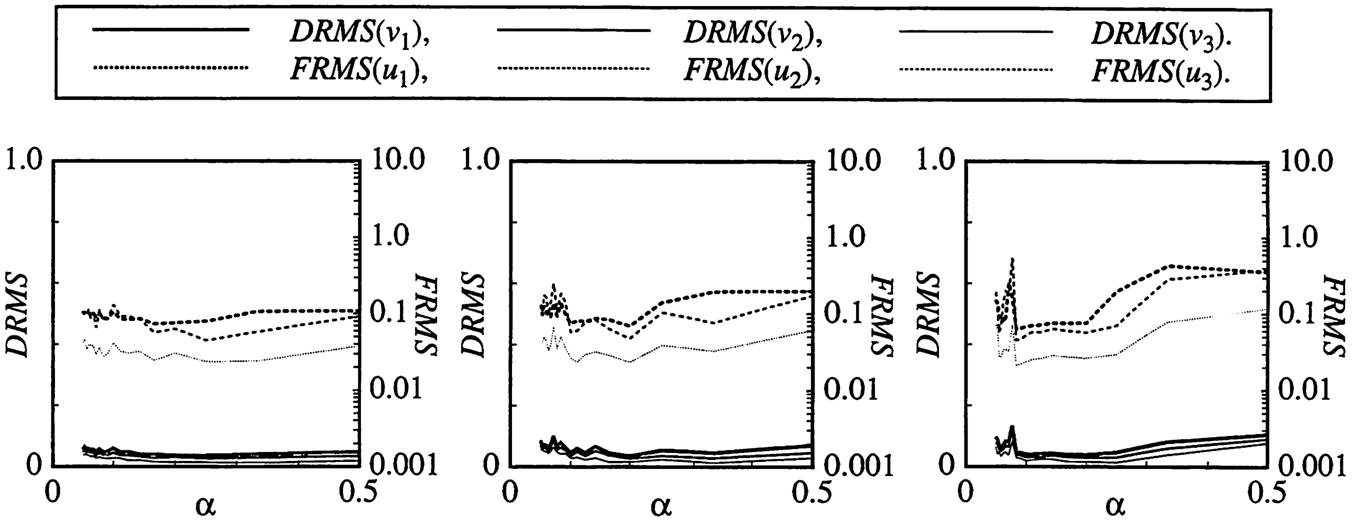
Study (4.5) - 3a :

Through the consideration in the Study (4.5)-2, it is appeared that the syntheses of the span of the digit may be significant to improve control performances of the quasi-optimizing controllers based on the geometric fractional division type of the trial control forces. In this study, the suitable value of the span of digit for those geometric progression may be evaluated. The numerical simulations are executed under the input of El Centro (1940) NS which is scaled down to the maximum acceleration amplitude of 30 (cm/s^2). Every three kinds of cases of the maximum values of the trial control forces which are supposed as $u_{max} = 0.5$, 1.0 and 2.0 (kgf) (which are selected the same value for the all components of the mediate control force vectors) are evaluated for the three kinds of the number of the trial control forces $N = 7$, 9 and 11 (which are selected the same number for the all components of the mediate control force vectors). The division of the trial control forces of the j-th component of the mediate control force vectors (j =1, 2, 3) is proposed as Exp. (4.5.1) and (4.5.2). The span of digits α are estimated as the variation from 0.05 to 0.5. Those investigations are operated for the two cases by using the step-up searching and the step-down searching algorithms.

Figs. 4.5.7.1, 4.5.7.2 and 4.5.7.3 show the displacements reductions factor (*DRMS*) and the manipulated control forces (*FRMS*) by introducing the step-up searching algorithm in the cases which are selected as the number of the trial control forces N = 7, 9 and 11, respectively. Figs. 4.5.8.1, 4.5.8.2 and 4.5.8.3 show the accelerations reductions factor (*ARMS*) by introducing the step-up searching algorithm in the cases which are selected as the number of the trial control forces N = 7, 9 and 11, respectively. Figs. 4.5.9.1, 4.5.9.2 and 4.5.9.3 show the displacements reductions factor (*DRMS*) and the manipulated control forces (*FRMS*) by introducing the step-down searching algorithm in the cases which are selected as the number of the trial control forces N = 7, 9 and 11, respectively. Figs. 4.5.10.1, 4.5.10.2 and 4.5.10.3 show the accelerations reductions factor (*ARMS*) by introducing the step-down searching algorithm in the cases which are selected as the number of the trial control forces N = 7, 9 and 11, respectively. In those figure, (a), (b) and (c) are corresponding to three cases which are supposed as the maximum trial control forces u_{max} = 0.5, 1.0 and 2.0 (kgf), respectively.

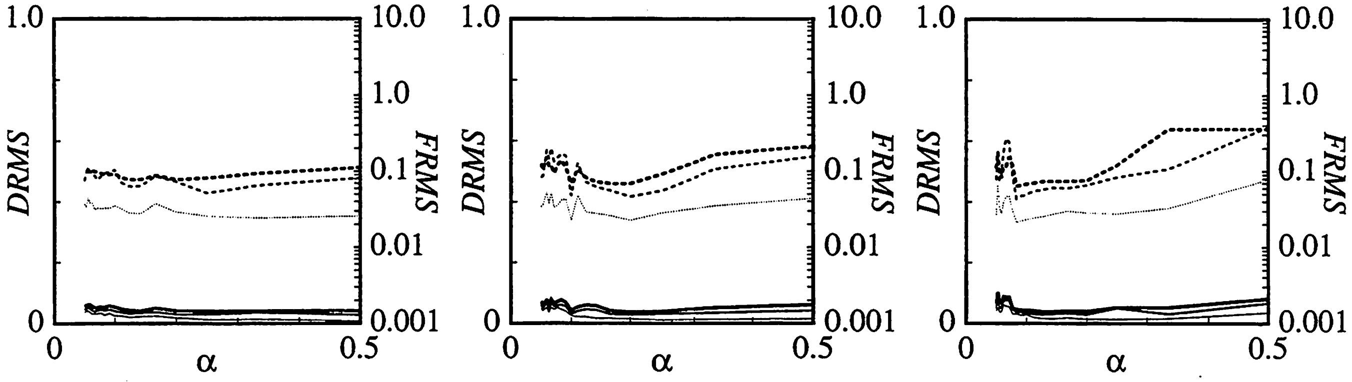
By considering Figs. 4.5.7.1, 4.5.7.2 and 4.5.7.3, in the cases by introducing the step-up searching algorithm, the fluctuations of the *DRMS* according to the variations of the span of digits α may be observed as not to be so sensitive for the differences of the span of digits in all cases. While, the supplied control forces evaluated by the *FRMS* may be explicitly reduced by the cases which are supposed the values from about 0.1 to 0.2 as the span of digits α, when the maximum trial control forces are selected as u_{max} = 1.0 and 2.0, although, when the maximum trial control forces are selected as u_{max} = 0.5, the explicit differences of the *FRMS* may not be appeared regardless the variations of the span of digits. Those tendencies may be observed regardless of the differences of the number of the trial control forces. By comparing Figs. 4.5.8.1, 4.5.8.2 and 4.5.8.3, the acceleration responses evaluated by the *ARMS* may be explicitly sunk within the extents which are supposed by the values from about 0.1 to 0.2 as the span of digits α, when the maximum trial control forces are selected as u_{max} = 1.0 and 2.0. When the maximum trial control forces are selected as u_{max} = 0.5, those extents that the *ARMS* are reduced may be a little dragged from about 0.2 to 0.3 as the span of digits α, however, those effects may be considered as not to be so explicitly different in comparison with the case of u_{max} = 1.0 and 2.0. Those tendencies may be also observed regardless of the differences of the number of the trial control forces. At this point, under the condition that the step-up searching algorithm is supposed for the quasi-optimizing controllers, whenever the geometric fractional division type of the trial control forces is installed, dominative improvement of the control performances may be regarded as not to be enough for the purpose to install this method as the aseismic active response control algorithm.

On the other side, by considering Figs. 4.5.9.1, 4.5.9.2 and 4.5.9.3, in the cases by introducing the step-down searching algorithm, the fluctuations of the *DRMS* according to the variations of the span of digits α may be observed as not to be so sensitive for the differences of the span of digits in all cases. While, the supplied control forces evaluated by the *FRMS* may be explicitly reduced by



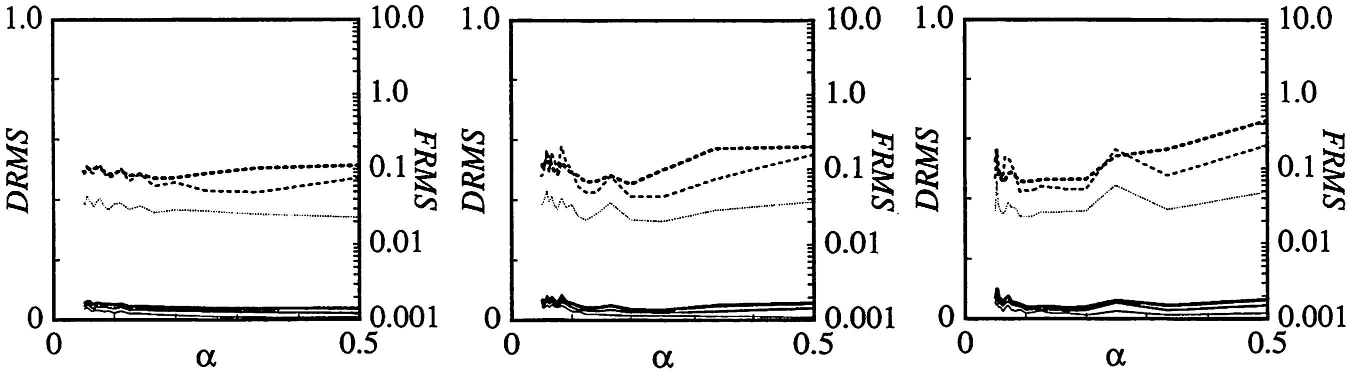
(a) $u_{max} = 0.5$, (b) $u_{max} = 1.0$, (c) $u_{max} = 2.0$,

Fig. 4.5.7.1 *DRMS* and the *FRMS* in the case of the step-up searching algorithm ($N = 7$).



(a) $u_{max} = 0.5$, (b) $u_{max} = 1.0$, (c) $u_{max} = 2.0$,

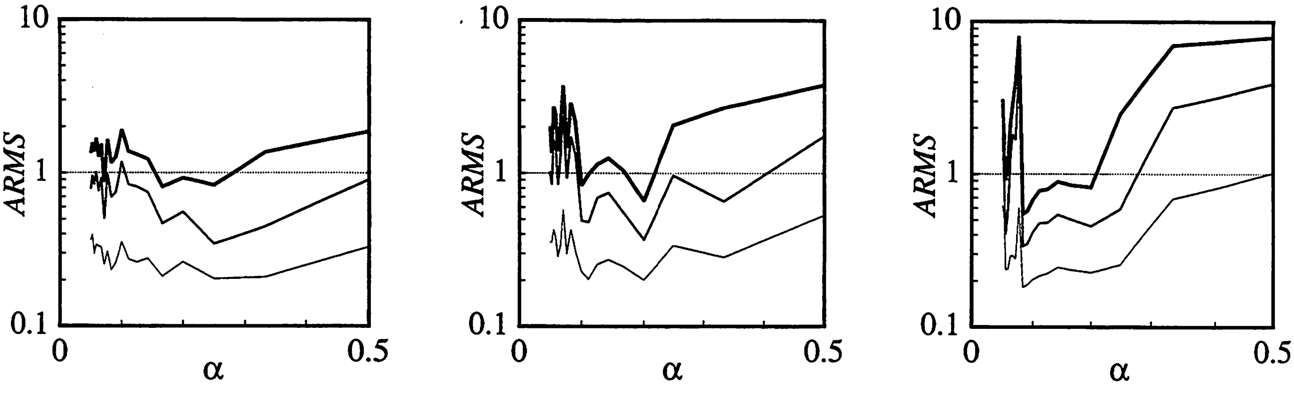
Fig. 4.5.7.2 *DRMS* and the *FRMS* in the case of the step-up searching algorithm ($N = 9$).



(a) $u_{max} = 0.5$, (b) $u_{max} = 1.0$, (c) $u_{max} = 2.0$,

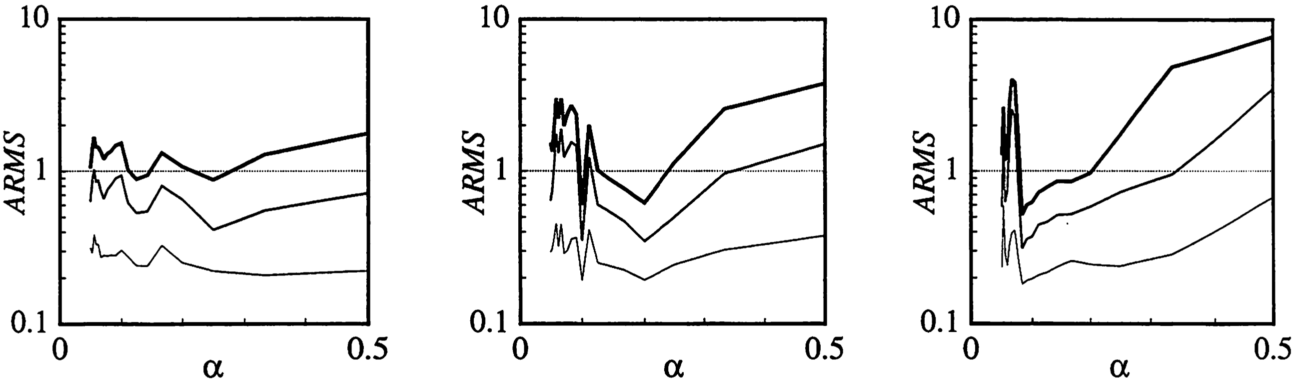
Fig. 4.5.7.3 *DRMS* and the *FRMS* in the case of the step-up searching algorithm ($N = 11$).

—— ARMS($\ddot{\xi}_1$), —— ARMS($\ddot{\xi}_2$), —— ARMS($\ddot{\xi}_3$).



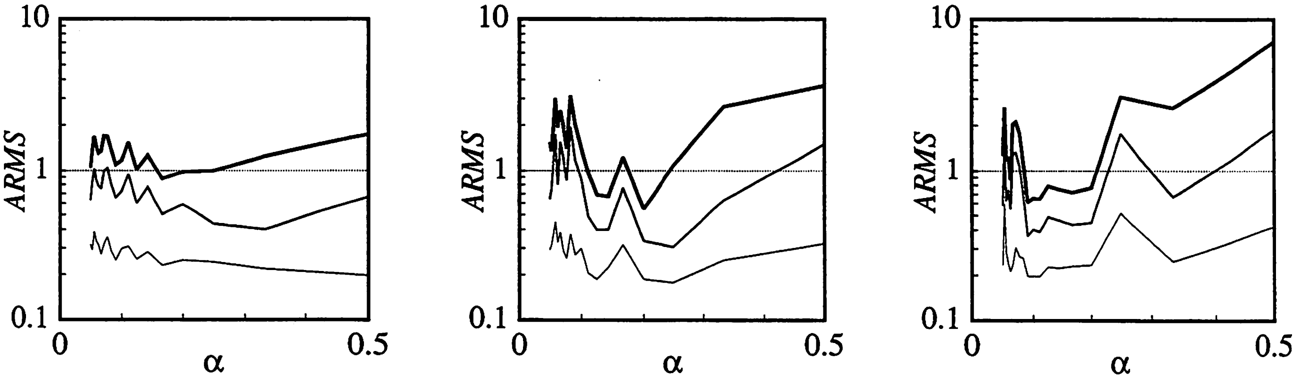
(a) $u_{max} = 0.5$, (b) $u_{max} = 1.0$, (c) $u_{max} = 2.0$,

Fig. 4.5.8.1 *ARMS* in the case of the step-up searching algorithm ($N = 7$).



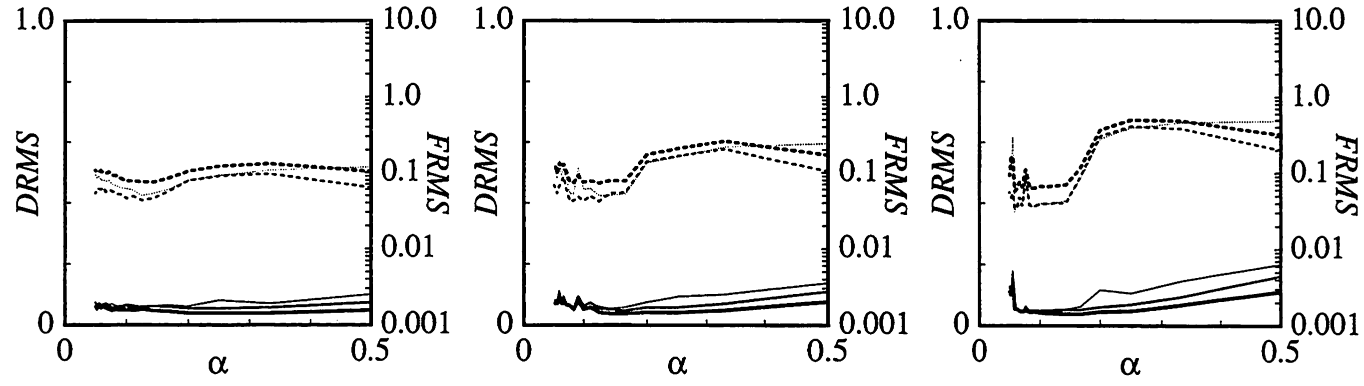
(a) $u_{max} = 0.5$, (b) $u_{max} = 1.0$, (c) $u_{max} = 2.0$,

Fig. 4.5.8.2 *ARMS* in the case of the step-up searching algorithm ($N = 9$).



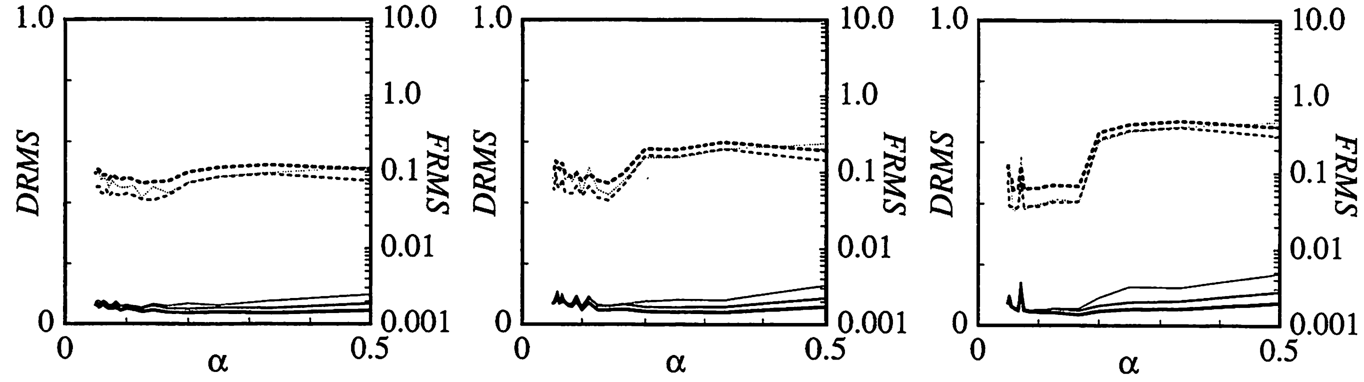
(a) $u_{max} = 0.5$, (b) $u_{max} = 1.0$, (c) $u_{max} = 2.0$,

Fig. 4.5.8.3 *ARMS* in the case of the step-up searching algorithm ($N = 11$).



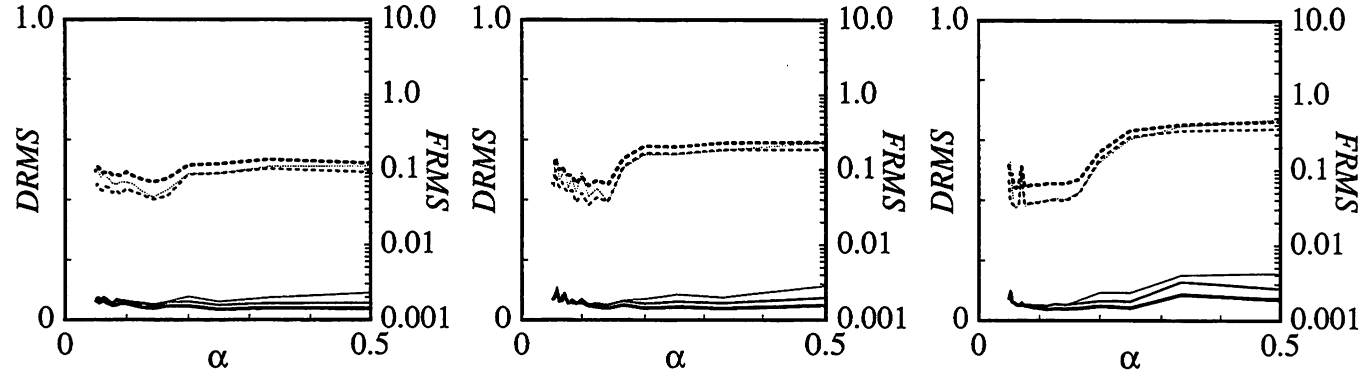
(a) $u_{max} = 0.5$, (b) $u_{max} = 1.0$, (c) $u_{max} = 2.0$,

Fig. 4.5.9.1 *DRMS* and the *FRMS* in the case of the step-down searching algorithm ($N = 7$).



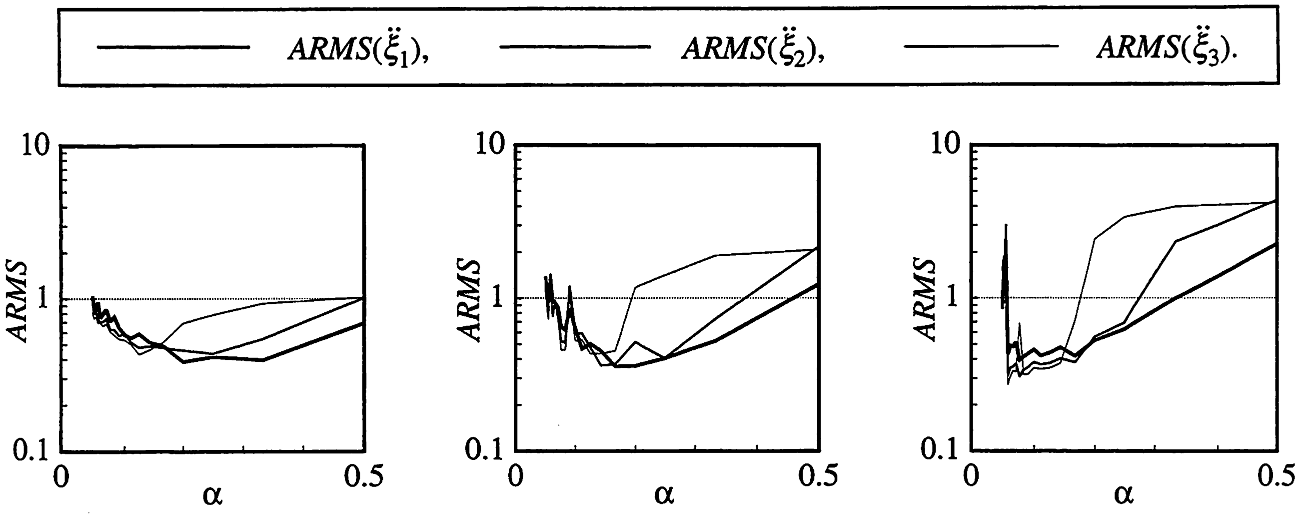
(a) $u_{max} = 0.5$, (b) $u_{max} = 1.0$, (c) $u_{max} = 2.0$,

Fig. 4.5.9.2 *DRMS* and the *FRMS* in the case of the step-down searching algorithm ($N = 9$).



(a) $u_{max} = 0.5$, (b) $u_{max} = 1.0$, (c) $u_{max} = 2.0$,

Fig. 4.5.9.3 *DRMS* and the *FRMS* in the case of the step-down searching algorithm ($N = 11$).

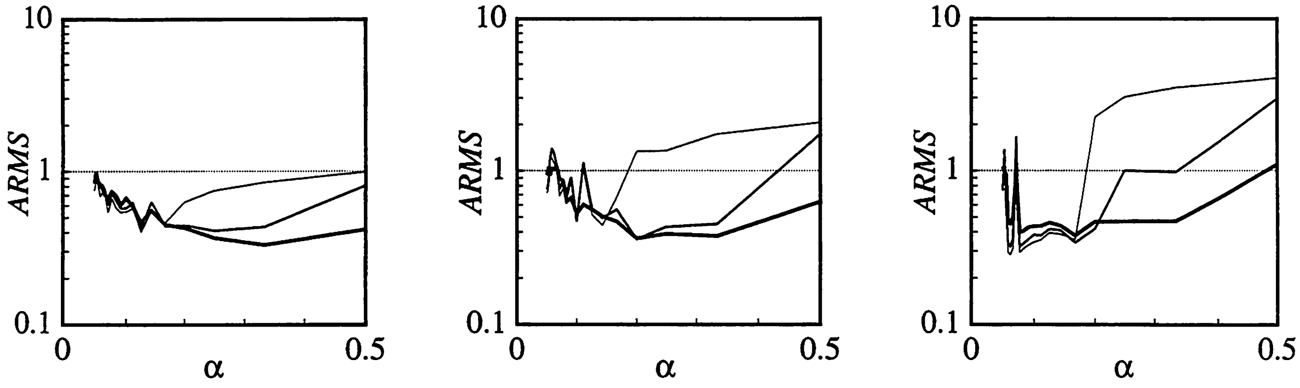


(a) $u_{max} = 0.5$,

(b) $u_{max} = 1.0$,

(c) $u_{max} = 2.0$,

Fig. 4.5.10.1 *ARMS* in the case of the step-down searching algorithm ($N = 7$).

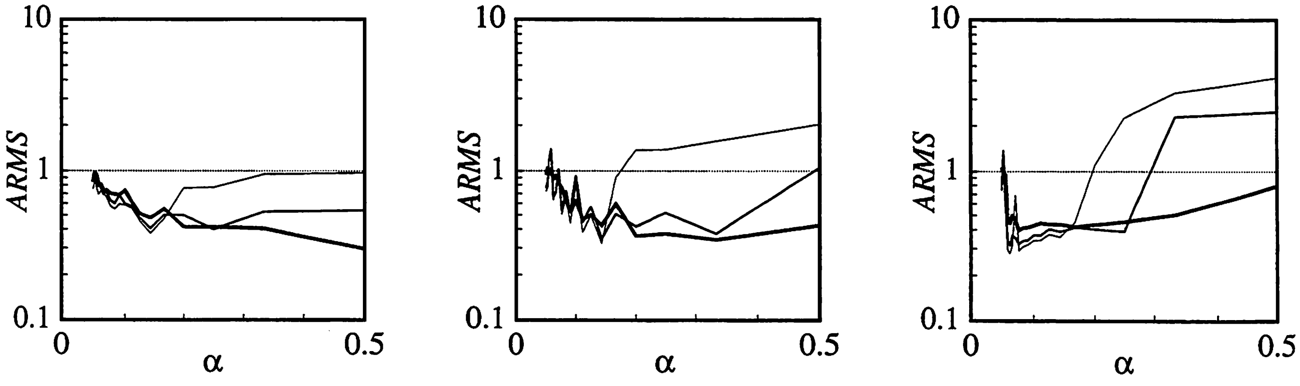


(a) $u_{max} = 0.5$,

(b) $u_{max} = 1.0$,

(c) $u_{max} = 2.0$,

Fig. 4.5.10.2 *ARMS* in the case of the step-down searching algorithm ($N = 9$).



(a) $u_{max} = 0.5$,

(b) $u_{max} = 1.0$,

(c) $u_{max} = 2.0$,

Fig. 4.5.10.3 *ARMS* in the case of the step-down searching algorithm ($N = 11$).

the cases which are supposed the values from about 0.1 to 0.15 as the span of digits α in all cases that the maximum trial control forces are selected as u_{max} = 0.5,1.0 and 2.0. Those tendencies may be observed regardless of the differences of the number of the trial control forces. By comparing Figs. 4.5.10.1, 4.5.10.2 and 4.5.10.3, the acceleration responses evaluated by the *ARMS* may be also explicitly sunk within the extents which are supposed by the values from about 0.1 to 0.15 as the span of digits α. In those cases which is supposed the step-down searching algorithm under the conditions by introducing the geometric fractional division type of the trial control forces, it is assured that the acceleration responses evaluated by the *ARMS* may be effectively and equality reduced for all stories of the structural model within those extents for the suitable values of the span of the digits which can improve the *ARMS* effectively, and that those efficiency may be also warranted regardless of the differences of the number of the trial control forces.

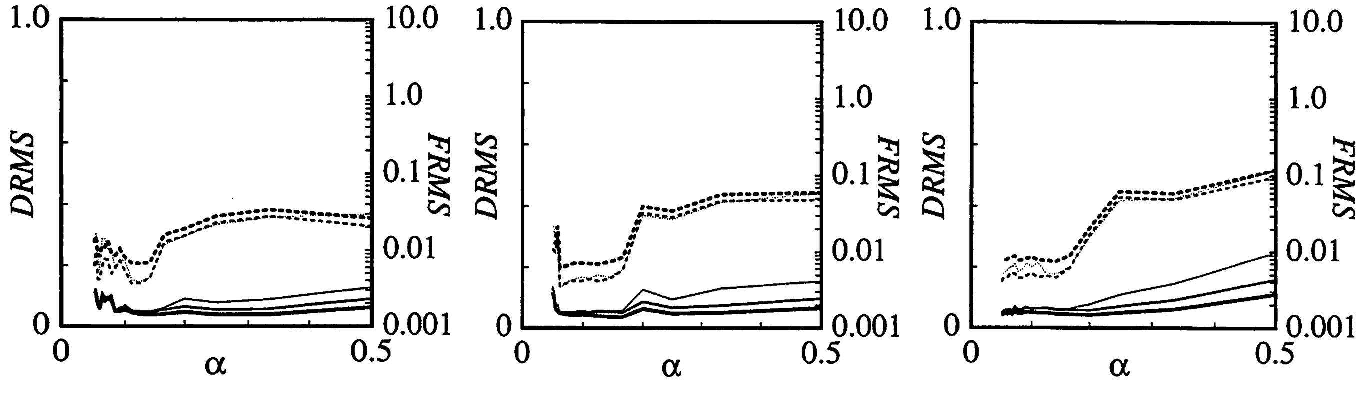
***Study (4.5) - 3b* :**

Through the consideration in the Study (4.5)-3a, it is assured that the quasi-optimizing control method based on the step-down searching algorithm may be introduced as the effective aseismic response controllers under the conditions that the geometric fractional division type of the trial control forces are supposed. In the Study (4.5)-3a, for a certain level of the external input (which is supposed as the input of El Centro (1940) NS which is scaled down to the maximum acceleration amplitude of 30 (cm/s^2)), when the span of the digits are supposed as the values of about 0.1 to 0.15, it is assured that the control performance of the quasi-optimizing controllers that are evaluated by the reductions of displacements and the required control forces may be operated the most effectively, and that the acceleration responses may be also improved as to warrant reductions for the non-control responses. Moreover, it is assured that those suitable extents of the values of the span of the digits to synthesize the geometric fractional division type of the trial control forces may be supposed as the fixed values regardless the difference of the number of the trial control forces.

As the further importance, it is appeared that the dependence on the different external input levels should be investigated for those suitable extents of the values of the span of the digits. For this aim, the additional numerical simulations are executed under the three kinds of input of El Centro (1940) NS which is scaled down to the maximum acceleration amplitude of 3, 10 and 100 (cm/s^2). Those investigations are operated for the quasi-optimizing controllers based on the step-down searching algorithms and the number of the trial control forces is selected as N = 11. For every three kinds of cases of the different external input levels, three cases for the different values of the maximum values of the trial control forces (which are selected the same value for the all components of the mediate control force vectors) are evaluated. When the inputs of the 3 (cm/s^2) of the maximum acceleration amplitude is supposed, evaluations are executed for the cases of u_{max} = 0.125, 0.25 and 0.5 (kgf). When the inputs of the 10 (cm/s^2) of the maximum acceleration amplitude is supposed, evaluations are executed for the cases of u_{max} = 0.25, 0.5 and 1.0 (kgf). When the inputs of the 100 (cm/s^2) of the maximum acceleration amplitude is supposed, evaluations are executed for the cases of u_{max} = 1.0, 2.0 and 4.0 (kgf). The division of the trial control forces of the j-th component of the mediate control force vectors (j =1, 2, 3) is proposed as Exp. (4.5.1) and

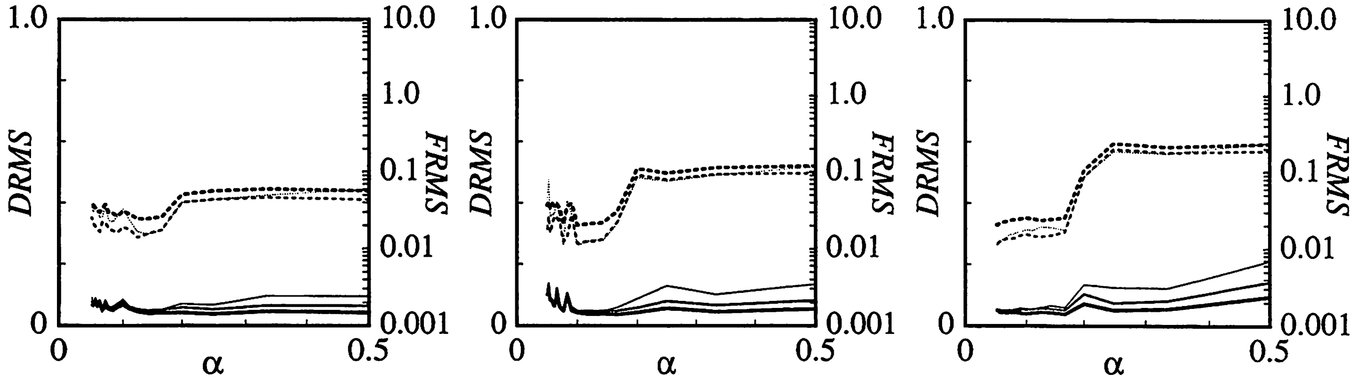
——— $DRMS(v_1)$, ——— $DRMS(v_2)$, ——— $DRMS(v_3)$.

········· $FRMS(u_1)$, ········· $FRMS(u_2)$, ········· $FRMS(u_3)$.



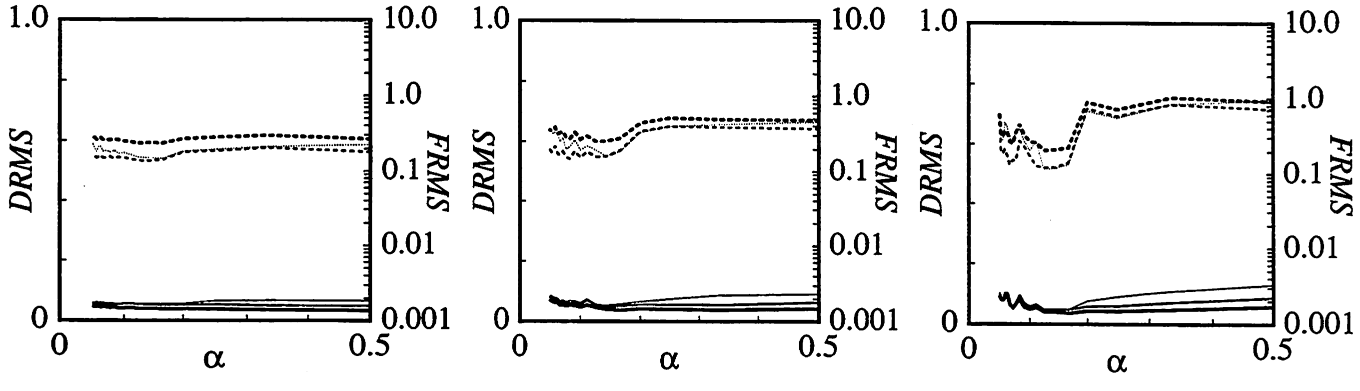
(a) $u_{max} = 0.125$, (b) $u_{max} = 0.25$, (c) $u_{max} = 0.5$,

Fig. 4.5.11.1 *DRMS* and the *FRMS* (El Centro, the maximum amplitude of 3 (cm/s^2)).



(a) $u_{max} = 0.25$, (b) $u_{max} = 0.5$, (c) $u_{max} = 1.0$,

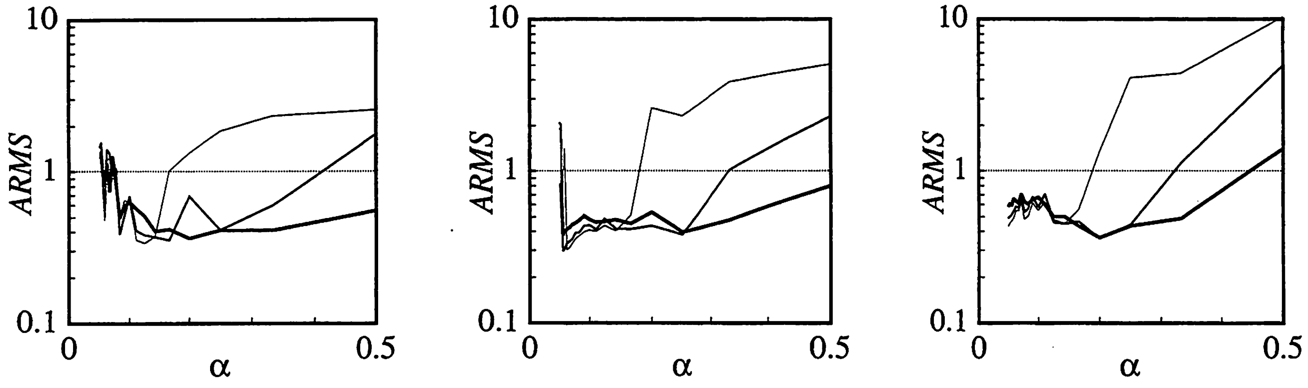
Fig. 4.5.11.2 *DRMS* and the *FRMS* (El Centro, the maximum amplitude of 10 (cm/s^2)).



(a) $u_{max} = 1.0$, (b) $u_{max} = 2.0$, (c) $u_{max} = 4.0$,

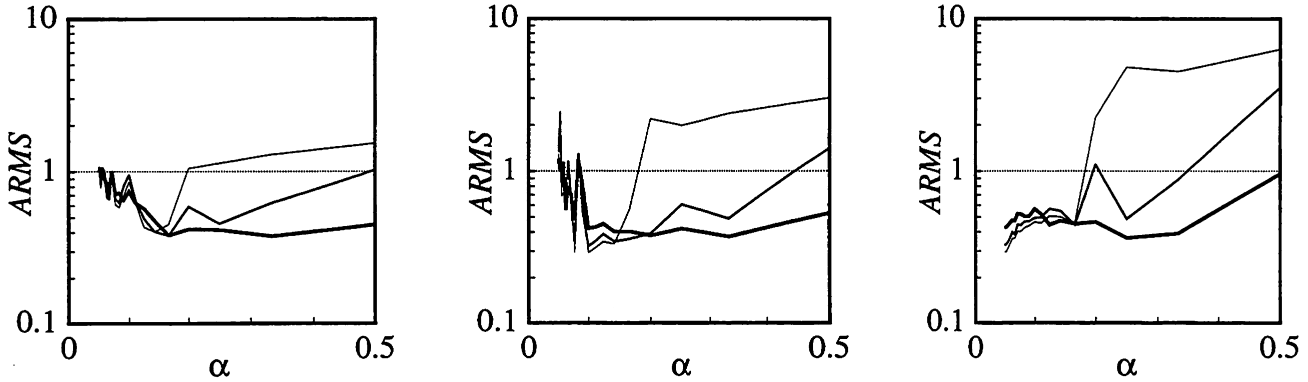
Fig. 4.5.11.3 *DRMS* and the *FRMS* (El Centro, the maximum amplitude of 100 (cm/s^2)).

——— ARMS($\ddot{\xi}_1$), ——— ARMS($\ddot{\xi}_2$), ——— ARMS($\ddot{\xi}_3$).



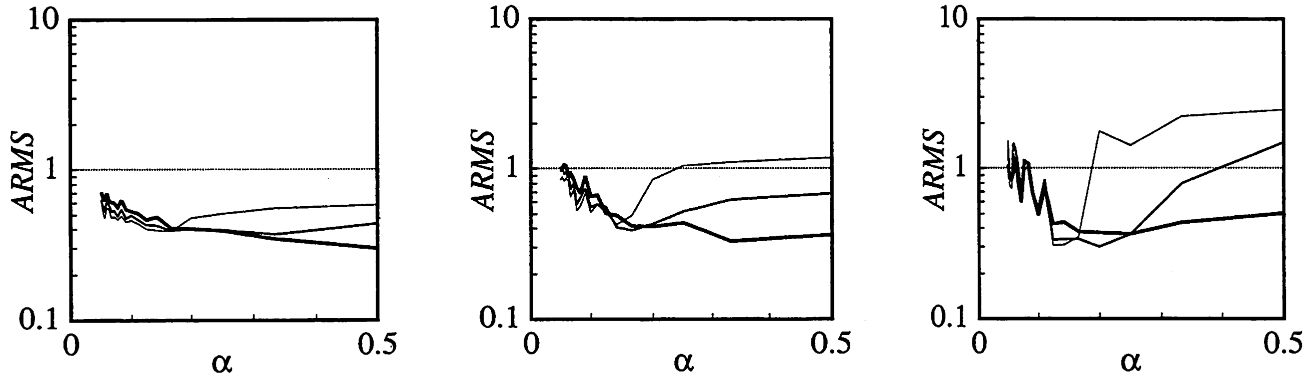
(a) $u_{max} = 0.125$, (b) $u_{max} = 0.25$, (c) $u_{max} = 0.5$,

Fig. 4.5.12.1 *ARMS* (El Centro, the maximum amplitude of 3 (cm/s^2)).



(a) $u_{max} = 0.25$, (b) $u_{max} = 0.5$, (c) $u_{max} = 1.0$,

Fig. 4.5.12.2 *ARMS* (El Centro, the maximum amplitude of 10 (cm/s^2)).



(a) $u_{max} = 1.0$, (b) $u_{max} = 2.0$, (c) $u_{max} = 4.0$,

Fig. 4.5.12.3 *ARMS* (El Centro, the maximum amplitude of 100 (cm/s^2)).

(4.5.2). The span of digits α are estimated as the variation from 0.05 to 0.5.

Figs. 4.5.11.1 show the displacements controlled factor (*DRMS*) and the control manipulation factors (*FRMS*) in the cases which are subjected by the external inputs of the 3 (cm/s^2) of the maximum acceleration amplitude and Figs. 4.5.12.1 show the accelerations controlled factor (*ARMS*) corresponding to the results of Figs. 4.5.11.1. In those figures, (a), (b) and (c) are corresponding to three cases which are supposed as the maximum trial control forces u_{max} = 0.125, 0.25 and 0.5 (kgf), respectively. Figs. 4.5.11.2 show the displacements controlled factor (*DRMS*) and the control manipulation factors (*FRMS*) in the cases which are subjected by the external inputs of the 10 (cm/s^2) of the maximum acceleration amplitude and Figs. 4.5.12.2 show the accelerations controlled factor (*ARMS*) corresponding to the results of Figs. 4.5.11.2. In those figures, (a), (b) and (c) are corresponding to three cases which are supposed as the maximum trial control forces u_{max} = 0.25, 0.5 and 1.0 (kgf), respectively. Figs. 4.5.11.3 show the displacements controlled factor (*DRMS*) and the control manipulation factors (*FRMS*) in the cases which are subjected by the external inputs of the 10 (cm/s^2) of the maximum acceleration amplitude and Figs. 4.5.12.3 show the accelerations controlled factor (*ARMS*) corresponding to the results of Figs. 4.5.11.3. In those figures, (a), (b) and (c) are corresponding to three cases which are supposed as the maximum trial control forces u_{max} = 0.5, 1.0 and 2.0 (kgf), respectively. Those results are represented for the cases by introducing the step-down searching algorithm.

By considering Figs. 4.5.11.1, 4.5.11.2 and 4.5.11.3, and also, by considering Figs. 4.5.9.3 (which is comparatively supposed to the case of the external inputs of the 30 (cm/s^2) of the maximum acceleration amplitude), the fluctuations of the *DRMS* according to the variations of the span of digits α may be observed as not to be so sensitive for the differences of the span of digits in all cases (however, in the case that the comparative large values of the maximum trial control forces are supposed, the fluctuation curves for the *DRMS* may be observed as to be dragged to a little swelling by connecting to the fluctuation of the *FRMS*. The supplied control forces evaluated by the *FRMS* may be explicitly reduced by the cases which are supposed the values from about 0.1 to 0.15 as the span of digits α in all cases of the different levels of the external inputs regardless the difference of the supposed maximum trial control forces.

By comparing Figs. 4.5.12.1, 4.5.12.2 and 4.5.12.3, and also, by considering Figs. 4.5.10.3 (which is comparatively supposed to the case of the external inputs of the 30 (cm/s^2) of the maximum acceleration amplitude), the acceleration responses evaluated by the *ARMS* may be also explicitly sunk within the extents which are supposed by the values from about 0.1 to 0.15 as the span of digits α regardless the differences of both the levels of the external inputs and the supposed maximum trial control forces. Namely, when the step-down searching algorithm under the conditions by introducing the geometric fractional division type of the trial control forces is introduced, as the significant considerations, it is assured that the values from about 0.1 to 0.15 as the suitable values of the span of the digits should be selected as to operating the effective control performances of the quasi-optimizing controllers.

In the following studies, the appropriateness of the geometric fractional division type of the trial control forces for the quasi-optimizing controllers may be investigated, and also, the physical meanings which are concerned to those suitable extent of the values of the span of the digits may be evaluated for the installations of the geometric fractional division type of the trial control forces.

***Study (4.5) - 4a* :**

Discussions may be begun to talk how much width of range of the external input levels as to operate the effective response control can be allocated by introducing a certain value of the trial control force. Through numerical simulations, controlled responses by introducing the quasi-optimizing control method based on the step-down searching algorithm are investigated under the external input levels as the parameters which are supposed by using the inputs of El Centro (1940) NS scaled down to the maximum acceleration amplitude from 1 to 1000 (cm/s^2). Those evaluations are executed in the following conditions : 1) the maximum values of the trial control forces (which are selected as the same value for the all components of the mediate control force vectors) are supposed by the fixed values as $u_{max} = 0.2$ and 2.0 (kgf), 2) the set of the trial control forces are composed as the three kinds of trials ($N = 3$) by $< -u_{max}, 0, u_{max} >$. Namely, since the mesh level of the set of the trials are proposed by $L = 1$, this set of the trials is adopted as the minimum size of the set which is defined on both the uniform division type and the geometric fractional division type of the trial control forces.

Figs.4.5.13 (a), (b) and (c) show the fluctuations of the *DRMS*, the *VRMS* and the *ARMS* according to the variations of the external inputs levels, respectively. In those figures, solid lines and broken lines of curves are corresponding to the cases of the maximum trial control forces $u_{max} = 0.2$ and 2.0 (kgf), respectively. As the basic estimations for this study, the following six items may be pointed to discuss for the syntheses of the trial control forces on the quasi-optimizing controllers.

Item-1) *Suitable target* :

By comparing Figs.4.5.13 (a) and (b), the quite similar fluctuation curves may be observed for both of the *DRMS* and the *VRMS*. As seen in those figures, it is assured that the external input levels of about 30 and 300 (cm/s^2) of the maximum amplitude (El Centro) may be specified as to be operated the most effective reductions of the *DRMS* and the *VRMS* by introducing those two kinds of the fixed values of the trial control forces $u_{max} = 0.2$ and 2.0 (kgf), respectively. For the present, those external input levels as that the *DRMS* and the *VRMS* are minimized by the fixed trials are regarded as 'suitable targets'.

Item-2) *Available target* :

By considering Fig.4.5.13 (c), it is assured that the external input levels of about 70 and 700 (cm/s^2) of the maximum amplitude (El Centro) may be also specified as to be operated the most effective reductions of the *ARMS* by introducing those two kinds of the fixed values of the trial control forces $u_{max} = 0.2$ and 2.0 (kgf), respectively. For the present, those external input levels as that the *ARMS* are minimized by the fixed trials are regarded as 'available targets'. When the fixed value of the trial control forces is supposed, the available target for the *ARMS* may be appeared as the larger value than the value of the suitable target for the

DRMS and the *VRMS*.

Item-3) *Critical target* :

As the conditions that the *ARMS* can be reduced as not exceeding 1 (100 %), namely, that the *ARMS* may not be enlarged exceed the non-controlled acceleration responses, the lower limited values of the external input levels may be observed as the values about 14 and 140 (cm/s^2) for the two cases which are supposed the fixed values u_{max} = 0.2 and 2.0 (kgf) as the trial control forces, respectively (as seen in Fig.4.5.13 (c)). For the present, those lower limited values of the external input levels as that the reductions of the *ARMS* can be warranted by the fixed trials are regarded as 'critical targets'. When the fixed value of the trial control forces is supposed, the critical target for the *ARMS* may be appeared as the smaller value than the value of the suitable target for the *ARMS*.

Item-4) *Abandoned target* :

It may be observed that the control operations of the quasi-optimizing controller by introducing the fixed trial may be stopped when the external input levels are supposed as the values below a certain limitation. This limitation may be observed as the external input level of about 4 (cm/s^2) for the fixed value of the trial control force u_{max} = 2.0 kgf (it may be considered that the external input level of about 0.4 (cm/s^2) may be allocated as the limitation for the fixed value of the trial control force u_{max} = 0.2 kgf). For the present, those limitations of the external input levels as not to give up the control operation by introducing the fixed trials are regarded as 'abandoned targets'. When the fixed value of the trial control forces is supposed, the abandoned target for the *ARMS* may be evaluated as about 1/100 times of value of the suitable target for the *DRMS* and the *VRMS*.

By considering the trade-off performances evaluated for the fluctuations of the *DRMS*, the *VRMS* and the *ARMS*, it may be regarded that the effective control operations by introducing the fixed value of the trial can be actualized when the targeted external input levels are supposed within the 'effective range' from the suitable target to the available target. When the larger external inputs than the available target are supposed, reductions of the *DRMS*, the *VRMS* and the *ARMS* may be deteriorated by the shortage of supply of the control forces. When the smaller external inputs than the suitable target are supposed, reductions of the *DRMS* and the *VRMS* may be also deteriorated by the surplusage of supply of the control forces and the *ARMS* may be also enlarged. Those considerations may be very significant to synthesize the set of the discrete trial control forces for the quasi-optimizing controllers. When the variations of the external input levels are supposed, the variations of the effective control forces should be also evaluated, because that the values of the suitable targets and the available targets are considered as the variables as to be proportioned for the size of the trials. Namely, to discretize the range of those variations of the trial control forces into the limited number of the trials, it may be required that the 'margin of targets' as that a certain value of the trial can take charge of the effective control operations are allowed. On the other side, by considering to the penalty indexes of the quasi-optimizing controllers are defined as the linear quadratic indexes for the displacements and the velocities, it seems that the control performances for the *ARMS* can not be directly considered on the on-line quasi-optimizing procedures. So that, when a certain trial is considered, to synthesize the upper limit of the margin of targets as the available target, the lower limit of the margin of targets can not be allocated to the suitable target. Since both of the *DRMS* and the *VRMS* corresponding to the available target are observed as about 0.1 (10 %), to include the available target as the jurisdiction of the fixed trial, the range of any targets as that both of the *DRMS* and the *VRMS* are not exceeded about 0.1 (10 %) may be regarded as to be equality with this effective range of the external input levels on the quasi-optimizing controllers. Namely, the lower limit of the margin of targets may be allocated to the smaller value than the suitable target while the upper limit of the margin of target may be allocated as to the available target. To consider the 'allowable margin of the targets' for each trial in the set of the discrete control forces on the quasi-optimizing controllers, it may be required that those extra ranges of targets accompanying to the effective ranges of targets are accepted.

Item-5) *Satisfied range of targets* :

To evaluate the 'allowable margin of the targets', as the range of the external input levels that the *DRMS* and *VRMS* can be limited as not exceeding 0.1 (10 %) by introducing the fixed values of the trial control forces, the range from about 10 to 60 (cm/s^2) and the range from about 100 to 600 (cm/s^2) on average can be observed for the two cases which are supposed the fixed values $u_{max} = 0.2$ and 2.0 (kgf) as the trial control forces, respectively (in which, the lower limits for those ranges may be evaluated as a little large values for the fluctuation curves of the *VRMS*). For the present, those ranges of the external input levels as that enough reductions of the *DRMS* and *VRMS* can be operated by introducing the fixed values of the trial control forces are regarded as 'satisfied ranges of targets' for the *DRMS* and the *VRMS* (as seen in Fig.4.5.14 (a) and (b)).

Item-6) *Safety range of targets and unsafety range of targets* :

When the smaller external input levels than the critical target are supposed, the control performances by introducing the fixed trial may be turned to unsafe in the sense not to be able to reduce acceleration response below the non-controlled responses. For the present, under the installation of the a certain value of the trial, those range of the smaller external input levels than the values of the critical target for the *ARMS* is called as 'unsafety range of targets' for the *ARMS* and the range of the larger external inputs than the values of the critical target for the *ARMS* is called as 'safety range of targets' for the *ARMS* (as seen in Fig.4.5.14 (c)).

By considering the Item-5, it may be regarded that the allowable margin of targets for a certain trial on the quasi-optimizing controllers is corresponded to the satisfied range of targets for the *DRMS* and *VRMS*. At this point, when the lower limit and the upper limit of the allowable margin of the targets (which is evaluated as the satisfied range of targets for this specified trial) are considered, it seems that those limits are also allocated as the values close to the critical target and the available target, respectively. Since any external input levels larger than the critical target for this specified trial may be always allocated as the safety range of targets for the *ARMS*, it may be regarded that the allowable margin of targets are also allocated within the range for the *ARMS* evaluated as not to be enlarged exceed the non-controlled acceleration responses by considering the Item-6. Namely, the allowable margin of targets which is allocated for the fixed value of the trial may be considered to the range of the external input levels as that the *DRMS* and *VRMS* can be reduced below a certain objective value and as that the *ARMS* can be controlled as not exceeding the non-controlled acceleration responses.

To synthesize the quasi-optimizing controller under the allowance for the variations of the external input levels, it may be considered that the allowable margins of targets (which are evaluated as the satisfied ranges of trials) corresponding to the maximum trial and the minimum trial included in the set of the trial control forces should be allocated as to cover the lower limit and the upper limit of those variations of the external input levels. For this aim, at first, it may be required that both of the targeted maximum and the targeted minimum external input levels should be supposed. When the value of the maximum trial control force is selected as that the targeted maximum external input level can be allocated within the allowable margin of the targets for this trial, the enough capacities of the control devices as not to be shortage of the supply control forces may be warranted for the targeted range of the variations of the external input levels. And also, when the value of the minimum trial control force is additionally included in the set of the trial control forces as that the targeted minimum external input levels can be allocated within the allowable margin of the trials for this trial, at least, the choice of the quasi-optimizing controllers as that the targeted range of the variations of the external input levels can be covered within the safety range of target for the *ARMS* may be provided. Namely, the provisions of the minimum trial should be synthesized as that the targeted minimum external input level can be allocated as the smaller value than the critical target in the sense not to enlarge acceleration responses exceed the non-controlled responses for the lower limit of the variations of the targeted external input levels.

However, those syntheses may become not to be enough, when the targeted ranges of the variations of the external input levels are considered as to be comparative wide. If the allowable margins of the targets for the maximum and the minimum trials can not be connected continuously, the effective control performance may not be operated under the external input levels within those gap of the range. To fill up those gap of the range of the external input levels, the further additional trials should be installed as to be inserted between the maximum and the minimum trials. At this point, by introducing a certain value of the trial, it seems that this specified trial can be regarded as to be enough in charge for any external input levels within the allowable margin of targets. In which, it may be significant to pay attentions for the range of the smaller external input levels than the lower limit of the allowable margin of the targets, because that the small external input levels below the critical target for this specified trial may be always allocated as the unsafety range of targets for the *ARMS*. If the smaller external inputs than the critical target for this specified trial are supposed, the other smaller trial control forces should be additionally provided as to be able to allocate those smaller external input levels within the safety range of targets for the *ARMS*. To bring the lower limit of the targeted external input levels for the effective response control on the quasi-optimizing controllers down, it may be reasonable to be additionally installed the enough number of the other smaller trial control forces as that the set of the satisfied ranges of targets allocated by each of those smaller trials can complement the unsafety range of targets for the maximum trial control force.

Namely, when every allowable margins of targets for each component of the set of trials can complement the continuous range of the external input levels, at least one of the trials in this set of the trials may be allocated as to actualize the control performances evaluated for the suitable range of target under any external input levels within targeted continuous range of the variations of the external input levels. For this aim, when the fixed value of the maximum trial control force is reached to the lower limit of the allowable margin of targets under a certain level of the external input (which may be appeared as the smaller level than the targeted maximum external input level), it may be reasonable that new smaller trial is installed as that this specified external input level can be allocated as the upper limit of the margin of targets, and that the following new trials are also installed according to this rule until the minimum trial may be allocated as that the minimum targeted external input level can be covered with the allowable margin of targets.

As the further significant remarks, it may be observed that the satisfied range of targets is appeared as to have the width which is proportioned to difference of the values of the selected trial control forces, to put it concretely, the satisfied range of targets for the fixed value of the trial control force $u_{max} =$ 2.0 (kgf) may be enlarged as about 10 times of the width corresponding to the case for the trial control force $u_{max} =$ 0.2 (kgf) . It may be regarded that the allowable margins of the targets (which is evaluated as the satisfied ranges of the targets) for any value of the trials are evaluated as to be uniform on the logarithm scale. Namely, to synthesize the quasi-optimizing controller under considerations for the variations of the external input levels, it may be considered that the set of the trials should include at least the sub-set of the series of the discrete trials in geometrical progression. At this point, significant conditions to synthesize the trial control forces of the quasi-optimizing controllers may be appeared for the two kind of division type of the set of the trial control forces.

When the uniform division type of the set of the trials is supposed, at first, the maximum and the minimum trial control forces are required to be fixed as that the allowable margins of the targets for those trials can be allocated as to include the upper and the lower limits for the targeted range of the variations of the external input levels, and also, the additional trials to cover the disparity between the allowable margins of the targets for the maximum and the minimum trials should be installed by introducing the digit of trials which is selected as to be equal to the size of the minimum trial. The uniform division type of the set of the trials which is synthesized under those conditions can be included the sub-set of the series of the discrete trials enough to complement the targeted variations of the external input levels by the allowable margins of the targets.

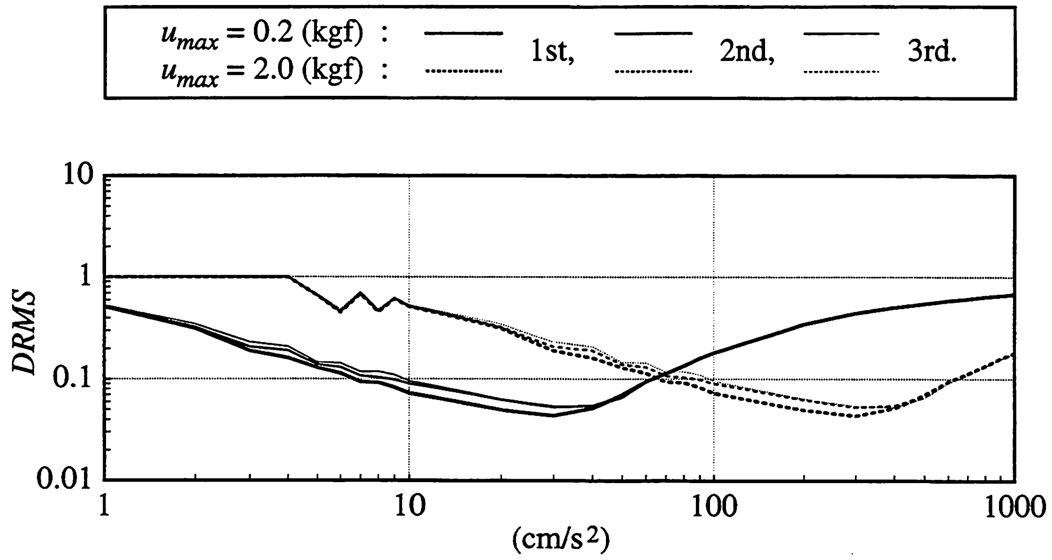
On the other side, when the geometric fractional division type of the set of the trials is introduced, it may be pointed that the reciprocal of the span of the digit of the trials means the geometric ratio for the variations of the width of the allowable margins of the targets allocated by every components in the set of the trial control forces. Namely, it may be significant that the span of the digit of the trials should be selected as the value that the allowable margins of targets allocated for any trials from the minimum to the maximum values in the set can complement the targeted variations of the external input levels.

From those conditions, the practical problems for the installations of the two kinds of division types of the set of the trial control forces may be discussed. For instance, it may be regarded that the value of about 1/1000 of the maximum trial control forces should be included as the minimum trial control force in the set in order to improve control performances of the quasi-optimizing controllers for the range of the variations of the external inputs from 1 to 1000 (cm/s^2). To satisfy this condition, the uniform division type of the set of the trial control forces may be required to suppose the mesh level as $L = 1000$, while the geometric fractional division type of the set of the trial control forces may be enough to provide the far small mesh levels, for instance, only the values from 4 to 6 as the mesh levels L may be requested in the cases that the spans of the digits α are supposed as the value from 0.1 to 0.2 (which are appeared as the effective extent of the spans of the digits in the Study (4.5)-3). Now that things have come to this pass, it may be regarded that the uniform division type of the set of the trial control forces are not practicable in the meaning to improve equally the control effects for reductions of acceleration responses under the comparative wide range of the external inputs by considering to the requirement for the extensive number of the trial control forces in the sets.

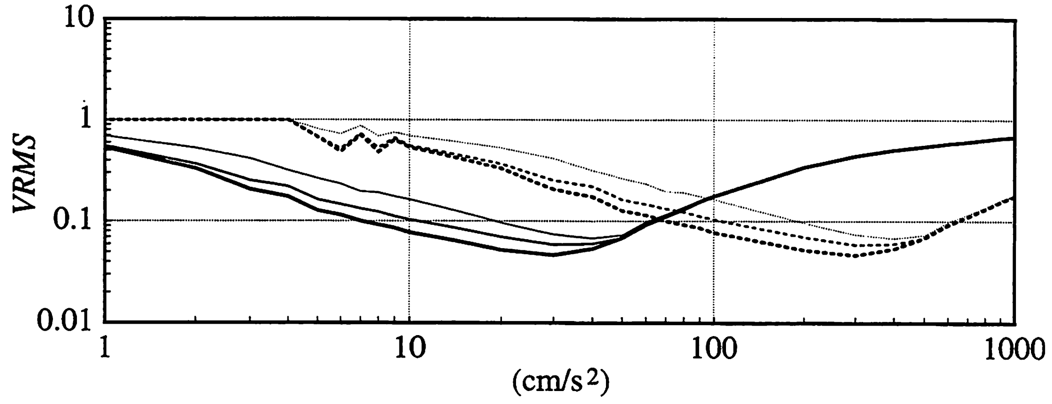
Through those considerations in this study, the illustrations for the appropriateness to introduce the geometric frictional division type of the trial control forces on the quasi-optimizing controller may be appeared. And also, from the meaning to be able to allocate the number of the trial control forces as the possible values in the practical sense, the advantage of the geometric fractional division type of the trials may be assured. As the further discussions to indicate appropriateness for this division type, the physical meanings of the suitable extent of the spans of the digits to syntheses the geometric frictional division type of the trial control forces are evaluated in the following studies.

***Study (4.5) - 4b* :**

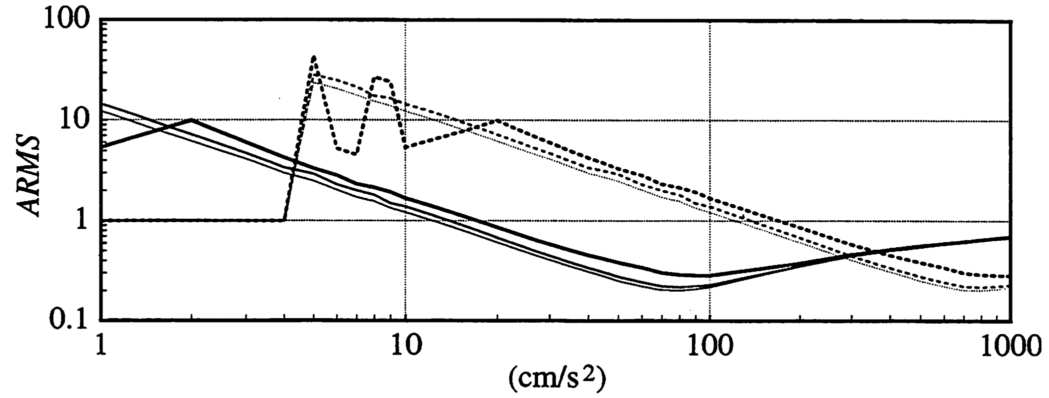
Evaluations on this study are discussed by considering the results in the Study (4.5)-4a from the another indicates. Numerical simulations are executed as the same conditions with the Study (4.5)-4a, so that, controlled responses by introducing the quasi-optimizing control method based on the step-down searching algorithm are investigated under the external input levels as the parameters which are supposed by using the inputs of El Centro (1940) NS scaled down to the maximum acceleration amplitude from 1 to 1000 (cm/s^2). Those evaluations are executed in the following conditions : 1) the maximum values of the trial control forces (which are selected the same value for the all components of the mediate control force vectors) are supposed by the fixed values as u_{max} = 0.2 0.3, 0.5 and 2.0 (kgf), 2) the set of the trial control forces are supposed as the three kinds of trials ($N = 3$) by $< -u_{max}, 0, u_{max} >$. In this study, the averages of the RMS values the inter-story displacements (which are denoted as $\overline{v_{rms}}$ or $\overline{v'_{rms}}$ for the controlled or the non-controlled responses, respectively), the averages of the RMS values of the inter-story velocities (which are denoted as $\overline{\dot{v}_{rms}}$ or $\overline{\dot{v}'_{rms}}$ for the controlled or the non-controlled responses, respectively) and the averages of the RMS values of the absolute accelerations (which are denoted as $\overline{\ddot{\xi}_{rms}}$ or $\overline{\ddot{\xi}'_{rms}}$ for



(a) *DRMS* (u_{max} = 0.2 and 2.0 (kgf)),



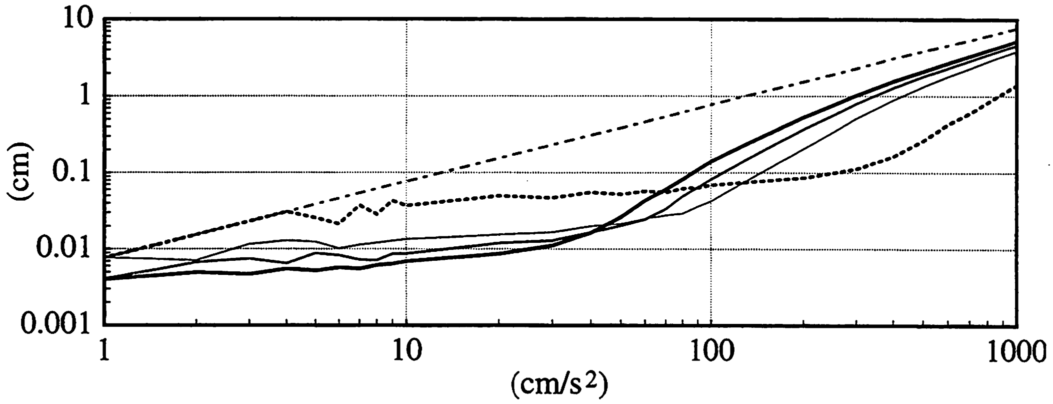
(b) *VRMS* (u_{max} = 0.2 and 2.0 (kgf)),



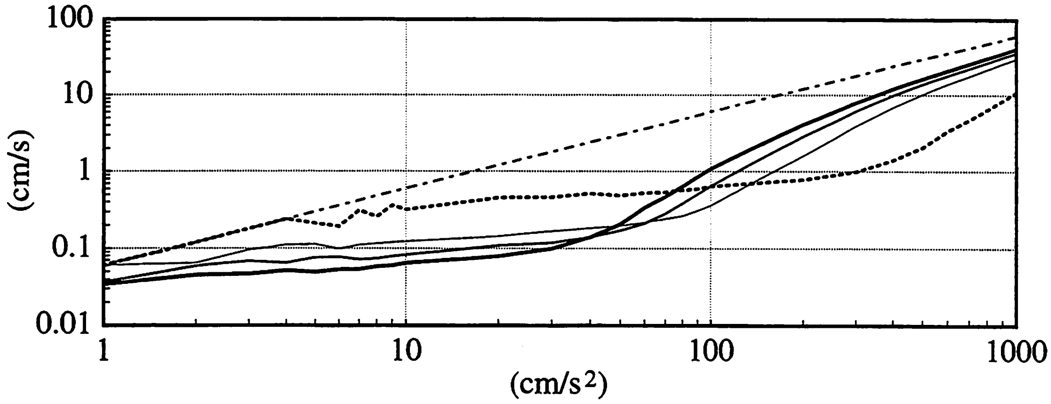
(c) *ARMS* (u_{max} = 0.2 and 2.0 (kgf)),

Fig. 4.5.13 Control performances for the variations of the external input levels (El Centro).

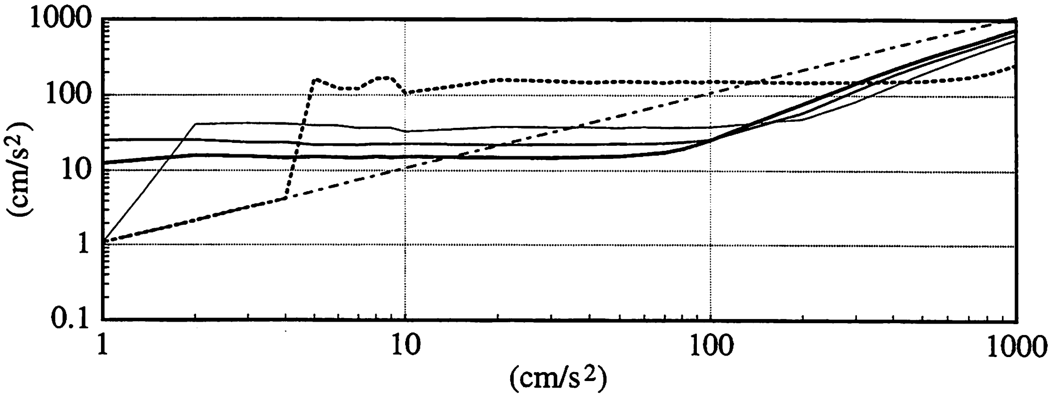
u_{max} (kgf) : - - - 0, —— 0.2, —— 0.3, —— 0.5, ········ 2.0.



(a) Average of the RMS of displacements (u_{max} = 0, 0.2, 0.3, 0.5 and 2.0 (kgf)),



(b) Average of the RMS of velocities (u_{max} = 0, 0.2, 0.3, 0.5 and 2.0 (kgf)),



(c) Average of the RMS of accelerations (u_{max} = 0, 0.2, 0.3, 0.5 and 2.0 (kgf)),

Fig. 4.5.14 Control performances for the variations of the external input levels (El Centro).

the controlled or the non-controlled responses, respectively) are evaluated. Figs.4.5.14 (a), (b) and (c) show the fluctuations of the averages of the RMS values the inter-story displacements, the averages of the RMS values the inter-story velocities and the averages of the RMS values of the absolute accelerations according to the variations of the external inputs levels, respectively.

By comparing Figs.4.5.14 (a) and (b), the quite similar fluctuation curves may be observed for both the averages of the RMS values the inter-story displacements and the averages of the RMS values the inter-story velocities. In those figures, when 0.2, 0.3 or 0.5 (kgf) of trial as the adjointing trial for the 2.0 (kgf) of trial is considered, the external input level to switch those two adjointing trials is observed as the value of about 70, 100 or 140 (cm/s^2), respectively. Those values of the external input level for switching trials may be evaluated as the cross points of the fluctuation curves of $\overline{v_{rms}}$ for those two adjointing trials, since the quasi-optimizing controllers may select the trial as to make the penalty indexes (which are defined as the linear quadratic indexes for the displacements and the velocities) minimize. By considering the geometric frictional division type of the set of the trial control forces, the value of the span of the digits which is corresponding to each case that 0.2, 0.3 or 0.5 (kgf) of trial is supposed as the adjointing trial for the 2.0 (kgf) may be estimated as to be 0.1, 0.15 or 0.4, respectively. When the two adjointing trials of 0.2 and 2.0 (kgf) are supposed (namely, when the span of the digits is supposed as $\alpha = 0.1$), the value of the external input level for switching trials may be allocated as the available trial for the smaller trial. When the two adjointing trials of 0.5 and 2.0 (kgf) are supposed (namely, when the span of the digits is supposed as $\alpha = 0.4$), the value of the external input level for switching trials may be allocated as the critical trial for the larger trial.

So that, when the span of the digits is synthesized as the comparative large value, the quota of the external input levels which is allocated for each components of the trials in the set (it may be possible that this quota is shrunk for the allowable margin of targets) may be narrowed and the selections as the quasi-optimizing control forces may not capture the available target for the *ARMS* in compensation to be able to escape from the critical target for the *ARMS*, and also, when the span of the digits is synthesized as the comparative small value, the quota of the external input levels for each components of the trials in the set (it may be possible that this quota is forced out of the allowable margin of targets) may be extended and the selections as the quasi-optimizing control forces may not avoid to include the unsafety range of targets for the *ARMS* in compensation to be able to capture the available target for the *ARMS*. To sum up, it may be regarded that the syntheses for the span of the digit on the geometric fractional division type of the set of the trial control forces may be depended on the trade-off conditions between capturing the available target for the *ARMS* and escaping from the critical target for the *ARMS*, for allocating the parts of the safety range of targets for the *ARMS* adequately in the quota of targets for each trials.

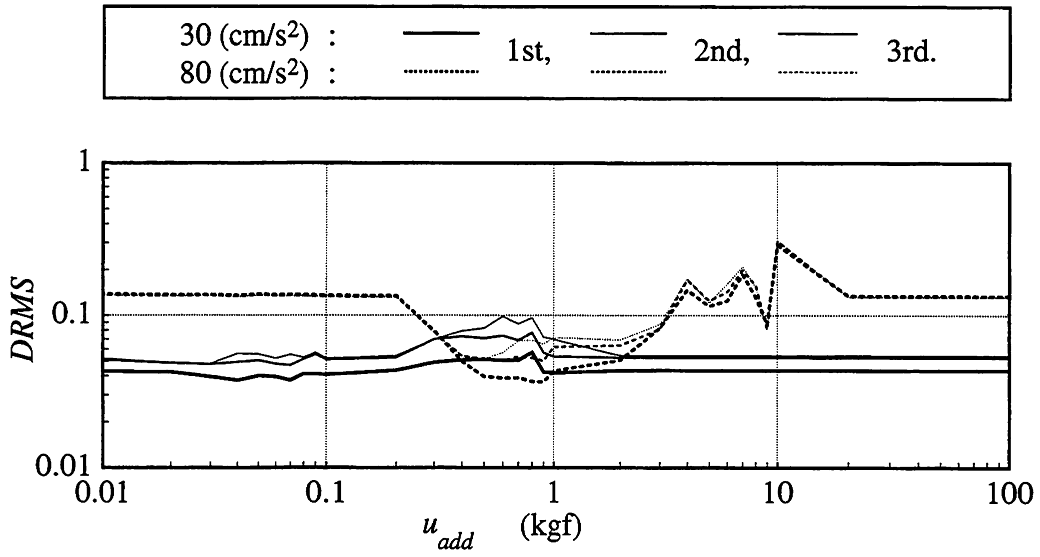
Study (4.5) - 4c :

Through the evaluations on the Study (4.5)-4a and the Study (4.5)-4b, it seems that the suitable extent of the spans of the digits to syntheses the geometric frictional division type of the trial control forces may be allocated as to be significantly subjected by the participations the neighbor trials. In this study, the influences for those distances between the two kinds of the neighboring trials are investigated by the numerical simulations. As seen in Figs.4.5.13, under the conditions that the minimum set of the trial control forces (which are composed as the three kinds of trials ($N = 3$) by $< - u_{max}, 0, u_{max} >$) are supposed, it may be confirmed that the specified external input level is allocated as the suitable target or the available target in the sense that the effective reductions of the response are actualized by the a certain value of the maximum trial control forces. When this specified trial u_{max} is supposed as to be 0.2 (kgf), the suitable target or the available target are observed as to be about 30 (cm/s^2) and about 80 (cm/s^2), respectively. In this case that the set of the trial control forces is introduced as <-0.2 (kgf), 0, 0.2 (kgf)>, it may be evaluated that the most reductions of the *DRMS* and the *VRMS* are actualized under the suitable target of the excitations and the most reductions of the *ARMS* are actualized under the available target of the excitations. At this point, the additional control effects for those control performances as evaluated by the *DRMS*, the *VRMS* and the *ARMS* by introducing the another one kind of the trials in this set may be considered. Accordingly, those evaluations are executed by using the set of the trial control forces are composed as the five kinds of trials ($N = 5$) by <-0.2 (kgf), 0, 0.2 (kgf)> $\cup$ $<- u_{add}, u_{add}>$. Namely, since the mesh level of the set of the trials are proposed by $L = 2$. In which, those additional trials - u_{add} and u_{add} are evaluated as the parameters, the values of u_{add} are considered from 0.01 to 100 (kgf). In those set of the trial control forces, $u_{add} / 0.2$ (at $u_{add} < 0.2$ (kgf)) or $0.2 / u_{add}$ (at $u_{add} > 0.2$ (kgf)) are corresponded to the span of the digits for the geometric fractional division type of the trial control forces. Through numerical simulations, controlled responses by introducing the quasi-optimizing control method based on the step-down searching algorithm are investigated under the external input levels as the parameters which are supposed by using the inputs of El Centro (1940) NS scaled down to the maximum acceleration amplitude by 30 (cm/s^2) and 80 (cm/s^2).

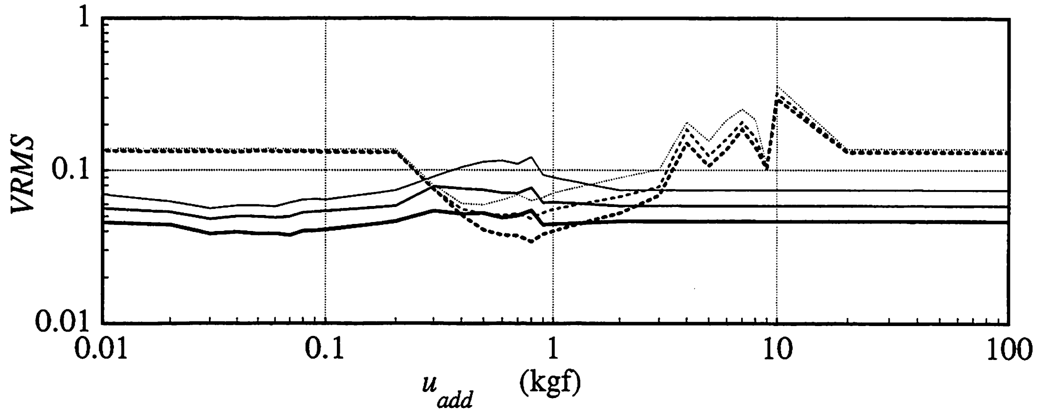
Figs.4.5.15 (a), (b) and (c) show the fluctuations of the *DRMS*, the *VRMS* and the *ARMS* according to the variations of the additional trials, respectively. In those figures, solid lines and broken lines of curves are corresponding to the cases of the maximum external input levels for 30 (cm/s^2) and 80 (cm/s^2), respectively.

At first, the cases as that the additional trial are supposed by $u_{add} < 0.2$ (kgf) are evaluated. By considering the solid lines as the cases that the 30 (cm/s^2) of the external input level (which are corresponded to the suitable target for 0.2 (kgf) of the value of the trial is supposed), it may be assured that the *DRMS*, the *VRMS* and the *ARMS* may be reduced by the installations for those smaller additional trials. By considering the broken lines as the cases that the 80 (cm/s^2) of the external input level (which are corresponded to the available target for 0.2 (kgf) of the value of the trial is supposed) are estimated. When the additional smaller trial are supposed by $u_{add} < 0.2$ (kgf), the *DRMS*, the *VRMS* and the *ARMS* may not be almost subjected by the installations for those additional trials. Accordingly, the following item may be pointed as the first significant consideration for the installations of the additional trials.

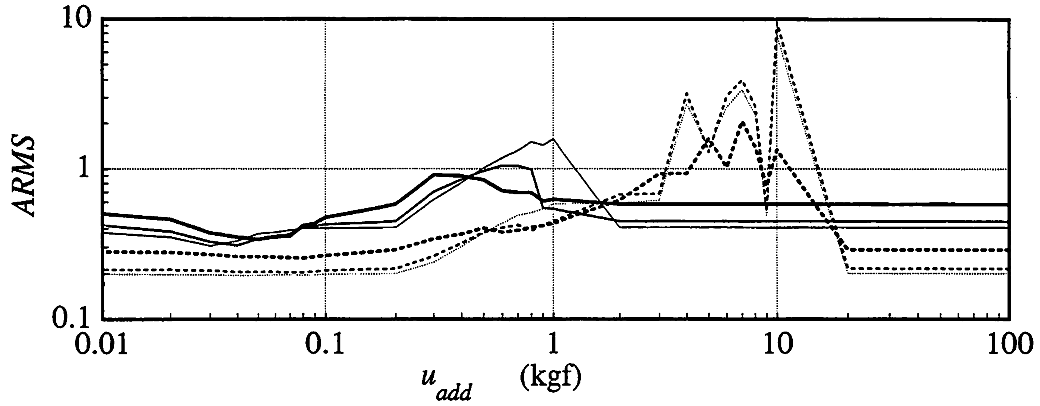
Point-1) When the smaller values of the trial are installed as the neighboring trial to the specified value of the trial in the set of trial control forces, the control effects may not be deteriorated



(a) *DRMS* (Under external input levels for 30 and 80 (cm/s^2)),



(b) *VRMS* (Under external input levels for 30 and 80 (cm/s^2)),



(c) *ARMS* (Under external input levels for 30 and 80 (cm/s^2)),

Fig. 4.5.15 Control performances by <-0.2 (kgf), 0, 0.2 (kgf)> $\cup$ <- u_{add} , u_{add} > (El Centro).

by the influences of those additional trial control forces.

As the next, the cases as that the additional trial are supposed by $u_{add} > 0.2$ (kgf) are evaluated. When the solid lines as the cases that the 30 (cm/s^2) of the external input level are estimated, the *DRMS*, the *VRMS* and the *ARMS* may be enlarged by the installations for those additional trials and those influences by accompanying the larger neighboring trials may not be avoided until those values additional trials are supposed as exceeding the values from about 1.0 (kgf) to about 2.0 (kgf). Since 30 (cm/s^2) of the external input level are allocated as the suitable target for the 0.2 (kgf) of the trial and the influences of larger neighboring trials may be affected as the surplusage of the control forces, it seems that moderate distances should be required between those neighboring trials. Accordingly, in the case that the external input levels are allocated for the suitable target for the smaller neighboring trial, it may be pointed that the lower limit of the additional trials are requested in order to avoid the deteriorations of the control effects caused by the surplusage of the control forces, and that the values from about 0.1 to 0.2 may be allocated as the upper limitations for the suitable extent for the span of the digits.

On the other hand, when the broken lines as the cases that the 80 (cm/s^2) of the external input level are estimated under the conditions by $u_{add} > 0.2$ (kgf), the *DRMS* and the *VRMS* may be reduced by the installations for those additional trials and those advantage effects by installations of the larger neighboring trials may be actualized on the cases as not exceeding the value of about 4.0 (kgf) as the additional trials. On the contrary, the *ARMS* may be enlarged by the installations for those additional trials. However, those influences by accompanying the larger neighboring trials may be regarded as the safety in the sense that the accelerations are not enlarged from the non-controlled responses during those values of the additional trials are supposed as not exceeding the value of about 3 (kgf). Since 80 (cm/s^2) of the external input level are allocated as the available target for the 0.2 (kgf) of the trial and the influences of larger neighboring trials may be affected as to be recover the shortage of the control forces in the sense that the more reductions of the *DRMS* and the *VRMS* should be actualized as to be warranted the safety conditions for the *ARMS*, it seems that moderate adjacency should be required between those neighboring trials. Accordingly, in the case that the external input levels are allocated for the available target for the smaller neighboring trial, it may be pointed that the upper limit of the additional trials are requested in order to participate for the improvements (as to be affected to the more reductions of the *DRMS* and the *VRMS* and as to be warranted the safety conditions for the *ARMS*) of the control effects caused by the shortage of the control forces, and that the values of about 0.067 may be allocated as the lower limitations for the suitable extent for the span of the digits. By summarizing those evaluations, the following two items may be pointed as the second significant considerations for the installations of the additional trials.

Point-2) When the larger values of the trials are installed as the neighboring trial to the specified value of the trial in the set of trial control forces under the conditions as that the external input levels are allocated as the suitable target for this specified smaller trial, the span of the digits should be synthesized as to be enough small value which can warrant the enough distances between those neighboring trials (namely, the span of the digits are allocated as to be smaller than the values from about 0.1 to 0.2).

Point-3) When the larger values of the trials are installed as the neighboring trial to the specified value of the trial in the set of trial control forces under the conditions as that the external input levels are allocated as the available target for this specified smaller trial, the span of the digits should be synthesized as to be enough large value which can warrant the enough adjacency between those neighboring trials (namely, the span of the digits are allocated as to be larger than the values of about 0.067).

From those considerations, it may be regarded that the suitable extent of the span of the digits are restricted as to be allocated by both of the upper and the lower limits. As pointed by the Point-2, and the point-3, it may be regarded that those limitations may be appeared from the considerations for the installations of the larger additional trials. At this point, the further significant evaluations may be assured on Fig.5.4.15. As seen in Fig.5.4.15 (a), it may be assured that both of the controlled displacements under the different external input levels of 30 and 80 (cm/s^2), may be actualized as to be reduced to the similar values of the response controlled factors (which are evaluated from the *DRMS*) by introducing the additional larger trials from about 1.0 to 2.0 (kgf). At the same time, by introducing the same values of the additional larger trials, the controlled velocities and the accelerations may be also reduced to the similar values of the response controlled factors (which are evaluated from the *VRMS* and the *ARMS*) for both of the external input levels. Accordingly, the value of the span of the digits which are supposed as from about 0.1 to 0.2 may be regarded as to be corresponded to the relations for the distances between the neighboring trials which can equalize the response controlled factors under the various kinds of the external input levels. To sum up, the following item may be pointed as the final significant consideration for the installations of the additional trials.

Point-4) When the relations for the distances between the neighboring trials are evaluated from the trade-off performances between the control effects for the *DRMS* and the *VRMS* and for the *ARMS*, it seems that the suitable arrangements of the neighboring trials can be synthesized as that the fluctuations of any response controlled factors (the *DRMS* , the *VRMS* and the *ARMS*) are equalized for various kinds of the external input levels. From those meanings, it may be regarded that the suitable arrangements of the neighboring trials can conduct the reasonability for the geometric fractional division type of the set of trial control forces.

Study (4.5) - 5 :

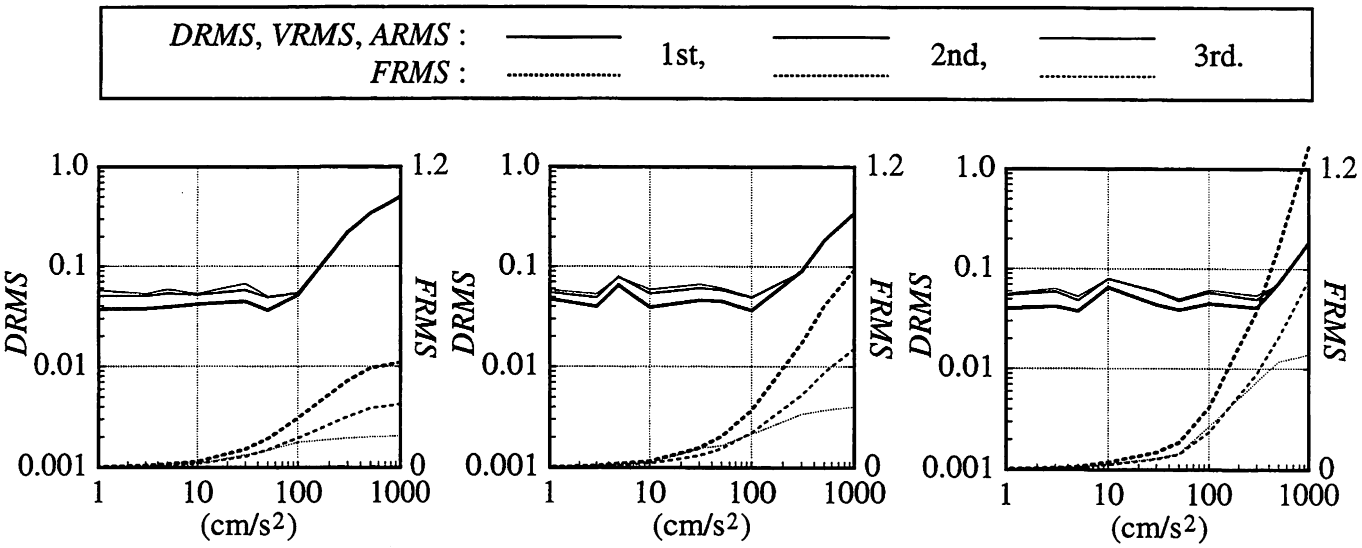
As the last step of the evaluations for the installations of the geometric frictional division type of the set of the trial control forces, the allowance of the variations of the external input levels are investigated through numerical simulations. Under the variations of the external input levels by using the inputs of El Centro (1940) NS scaled down to the maximum acceleration amplitude from

1 to 1000 (cm/s^2). To synthesize the geometric frictional division type of the set of the trials, the value of $\alpha = 0.15$ is selected as the span of the digits, and the mesh level of the trials is selected as $L = 5$ (namely, the number of the trial control forces in the set is supposed as $N = 11$). Control performances for the three cases of the different values of the maximum trial control forces which are supposed as $u_{max} = 0.5$, 1.0 and 2.0 (kgf) by introducing the quasi-optimizing control method based on the step-down searching algorithm are investigated. As the comparative case studies, the uniform division type of the set of the trial control forces are also evaluated. In this case, the mesh level of the trials is also selected as $L = 5$ (namely, the number of the trial control forces in the set is supposed as $N = 11$), and the three cases of the different values of the maximum trial control forces which are supposed as $u_{max} = 0.5$, 1.0 and 2.0 (kgf) are also evaluated.

The numerical results corresponding to the cases which are introduced the geometric frictional division type of the set of the trial control forces are shown in the Figs.4.5.16.1, 4.5.16.2 and 4.5.16.3. Figs.4.5.16.1 (a), (b) and (c) show the fluctuations of the *DRMS* and the *FRMS* according to the variations of the external inputs levels for the three cases which are supposed as $u_{max} = 0.5$, 1.0 and 2.0 (kgf) as the maximum trial control forces, respectively. Figs.4.5.16.2 (a), (b) and (c) show the fluctuations of the *VRMS* according to the variations of the external inputs levels for the three cases which are supposed as $u_{max} = 0.5$, 1.0 and 2.0 (kgf) as the maximum trial control forces, respectively. Figs.4.5.16.3 (a), (b) and (c) show the fluctuations of the *ARMS* according to the variations of the external inputs levels for the three cases which are supposed as $u_{max} = 0.5$, 1.0 and 2.0 (kgf) as the maximum trial control forces, respectively.

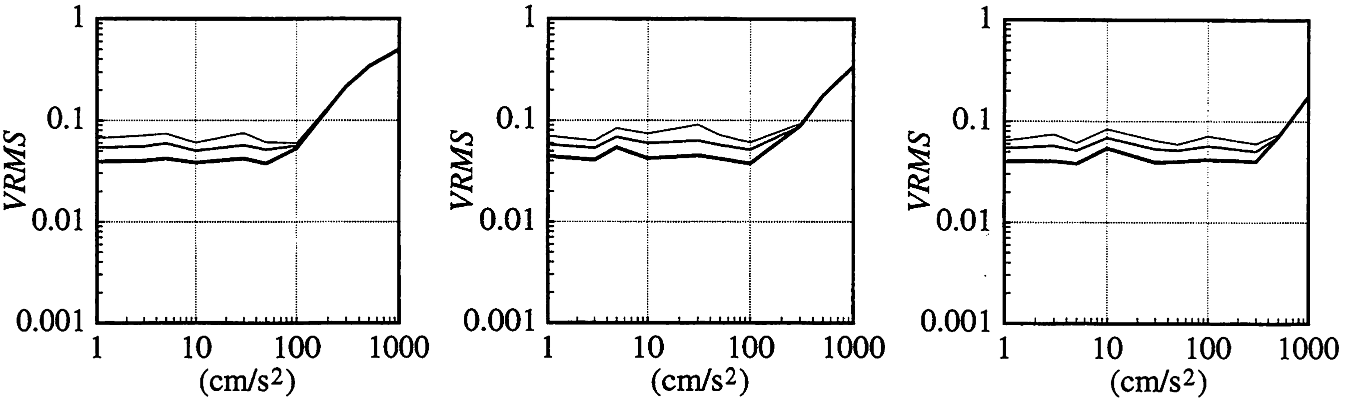
The numerical results corresponding to the cases which are introduced the uniform division type of the set of the trial control forces are shown in the Figs.4.5.17.1, 4.5.17.2 and 4.5.17.3. Figs.4.5.17.1 (a), (b) and (c) show the fluctuations of the *DRMS* and the *FRMS* according to the variations of the external inputs levels for the three cases which are supposed as $u_{max} = 0.5$, 1.0 and 2.0 (kgf) as the maximum trial control forces, respectively. Figs.4.5.17.2 (a), (b) and (c) show the fluctuations of the *VRMS* according to the variations of the external inputs levels for the three cases which are supposed as $u_{max} = 0.5$, 1.0 and 2.0 (kgf) as the maximum trial control forces, respectively. Figs.4.5.17.3 (a), (b) and (c) show the fluctuations of the *ARMS* according to the variations of the external inputs levels for the three cases which are supposed as $u_{max} = 0.5$, 1.0 and 2.0 (kgf) as the maximum trial control forces, respectively.

In this case study, it may be convenient to consider the compound allowable margin of targets under the conditions which are supposed the multi-number of the trials, namely, the compound allowable margin of targets can be regarded as corresponding to the broad sense of the suitable range of targets which is related to the range of the external input levels that the *DRMS* and *VRMS* can be limited as not exceeding 0.1 (10 %) by introducing the set of the multi-trials. And also, it may be convenient to consider the compound safety range and the compound unsafety range of targets under the conditions which are supposed the multi-number of the trials, namely, the compound safety range of targets can be regarded as corresponding to the larger range than the critical target in the broad sense as that the *ARMS* can be reduced as not exceeding 1 (100 %) by introducing the set of the multi-trials, and the compound unsafety range of targets can be regarded as corresponding



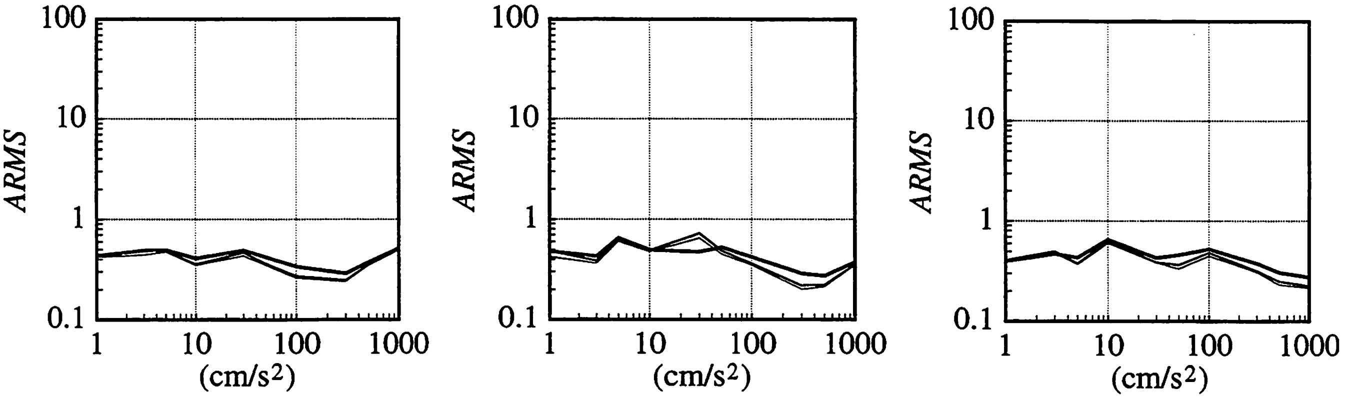
(a) $u_{max} = 0.5$, (b) $u_{max} = 1.0$, (c) $u_{max} = 2.0$,

Fig. 4.5.16.1 *DRMS* and the *FRMS* for the geometric fractional division type of the trials.



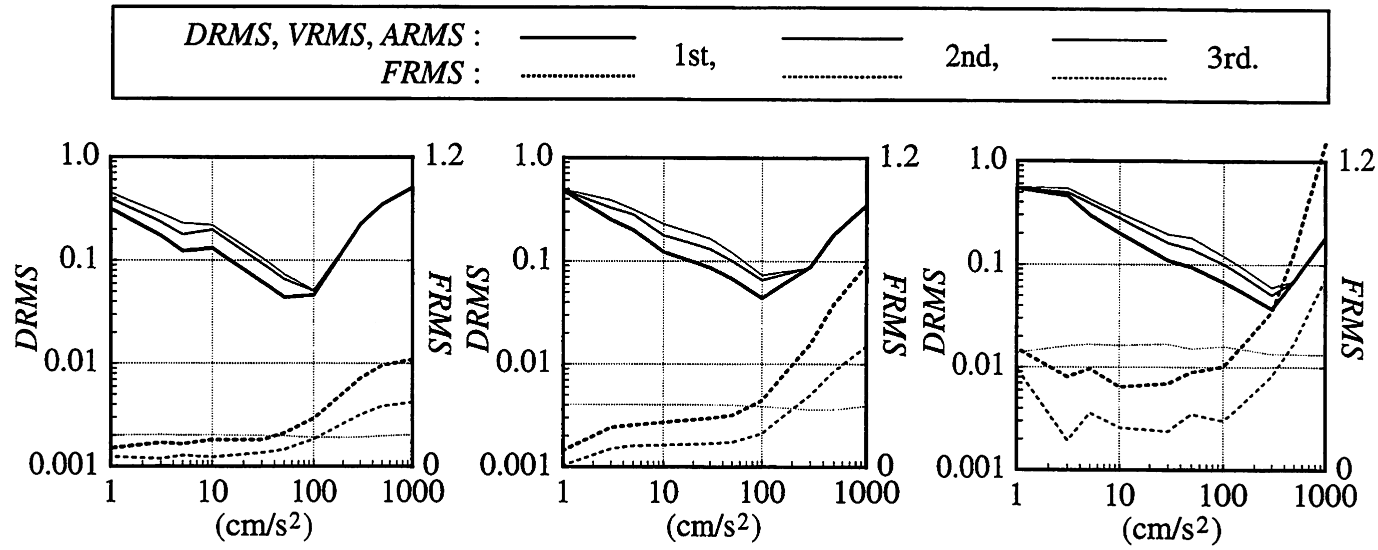
(a) $u_{max} = 0.5$, (b) $u_{max} = 1.0$, (c) $u_{max} = 2.0$,

Fig. 4.5.16.2 *VRMS* for the geometric fractional division type of the trials.



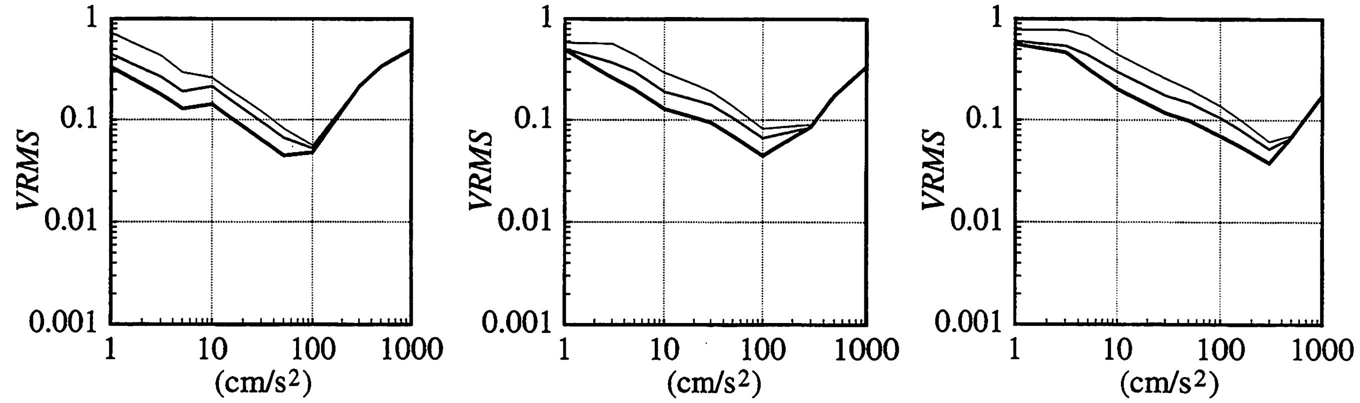
(a) $u_{max} = 0.5$, (b) $u_{max} = 1.0$, (c) $u_{max} = 2.0$,

Fig. 4.5.16.3 *ARMS* for the geometric fractional division type of the trials.



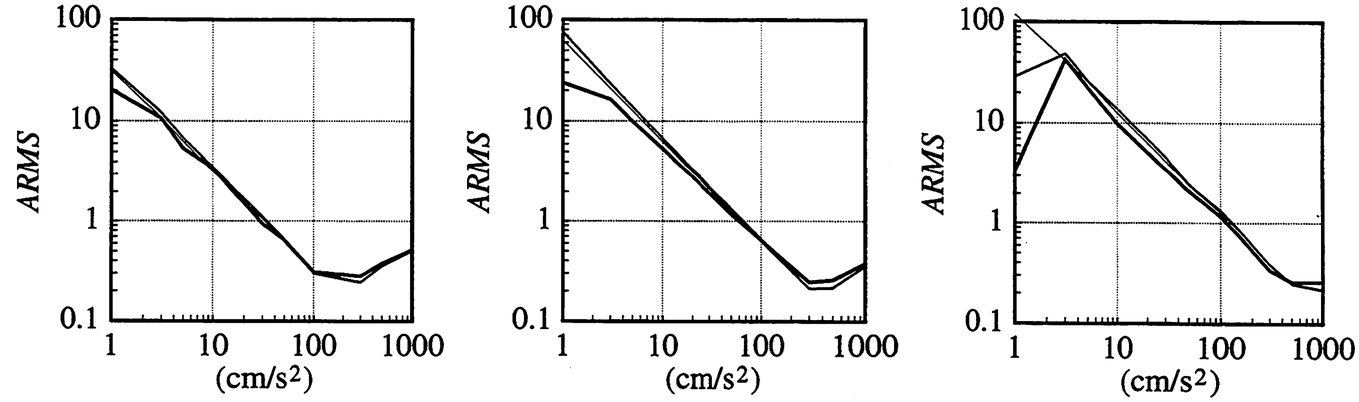
(a) $u_{max} = 0.5$, (b) $u_{max} = 1.0$, (c) $u_{max} = 2.0$,

Fig. 4.5.17.1 *DRMS* and the *FRMS* for the uniform division type of the trials.



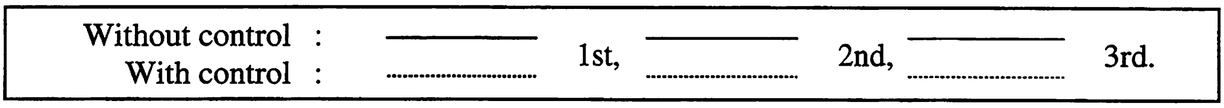
(a) $u_{max} = 0.5$, (b) $u_{max} = 1.0$, (c) $u_{max} = 2.0$,

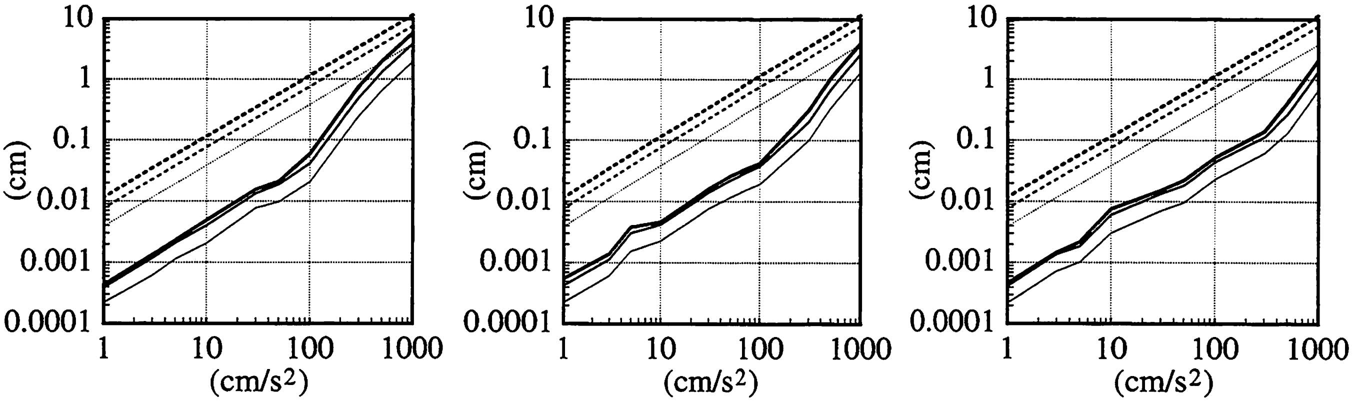
Fig. 4.5.17.2 *VRMS* for the uniform division type of the trials.



(a) $u_{max} = 0.5$, (b) $u_{max} = 1.0$, (c) $u_{max} = 2.0$,

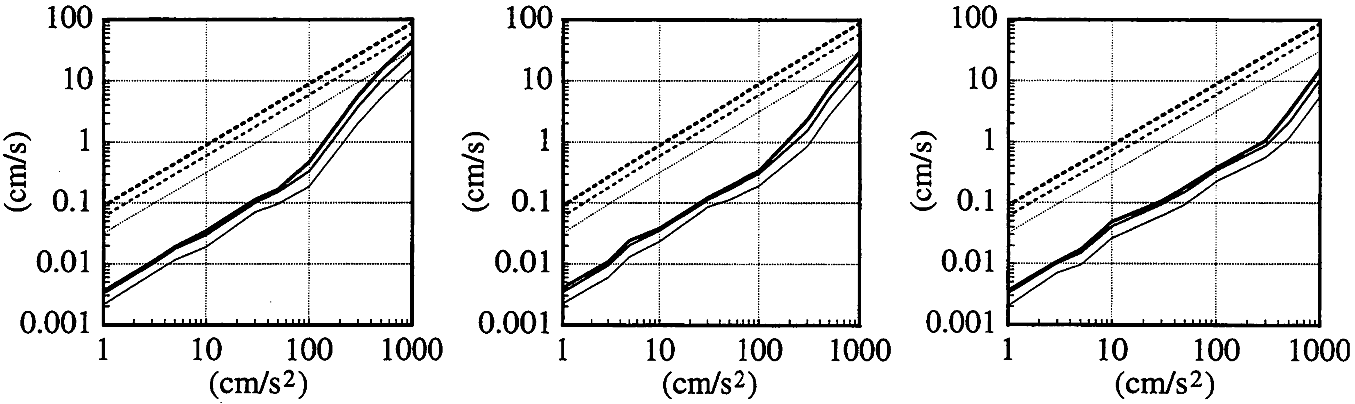
Fig. 4.5.17.3 *ARMS* for the uniform division type of the trials.





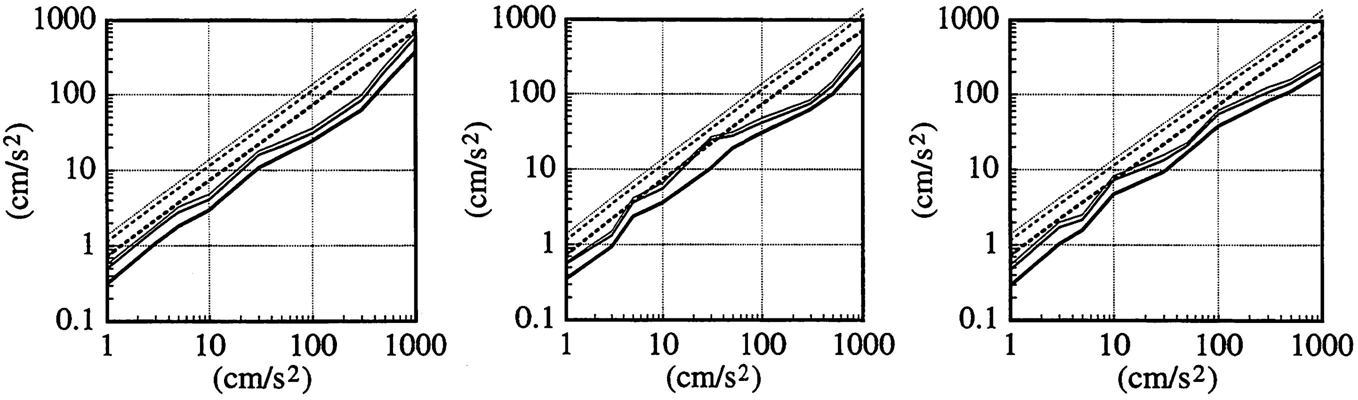
(a) $u_{max} = 0.5$, (b) $u_{max} = 1.0$, (c) $u_{max} = 2.0$,

Fig. 4.5.18.1 $\overline{v}_{rms}$ and $\overline{v'}_{rms}$ for the geometric fractional division type of the trials.



(a) $u_{max} = 0.5$, (b) $u_{max} = 1.0$, (c) $u_{max} = 2.0$,

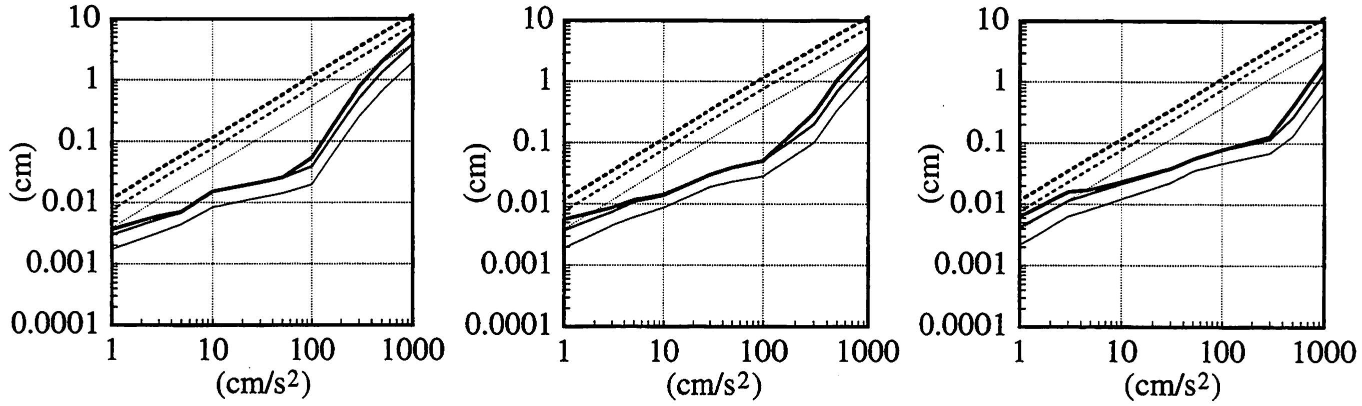
Fig. 4.5.18.2 $\overline{\dot{v}}_{rms}$ and $\overline{\dot{v}'}_{rms}$ for the geometric fractional division type of the trials.



(a) $u_{max} = 0.5$, (b) $u_{max} = 1.0$, (c) $u_{max} = 2.0$,

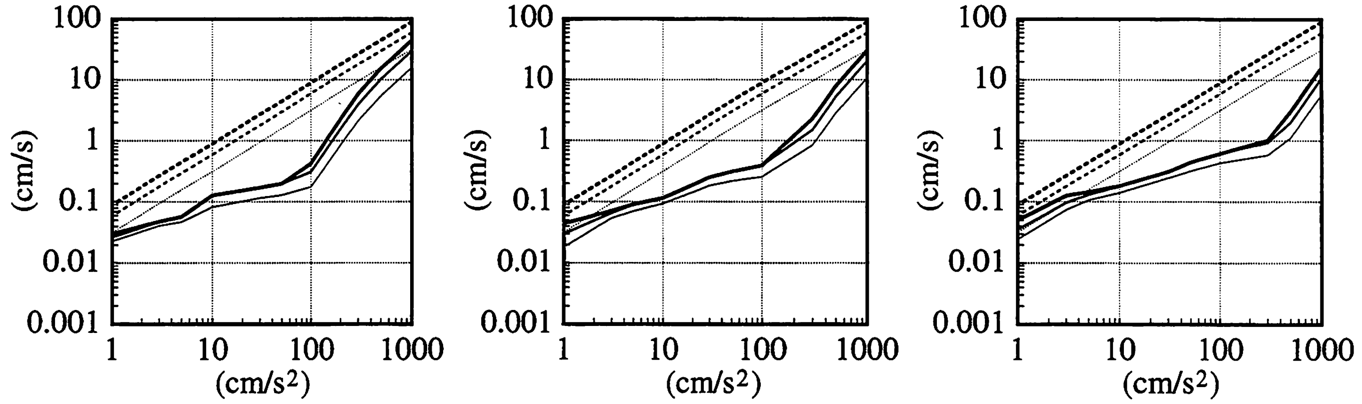
Fig. 4.5.18.3 $\overline{\ddot{\xi}}_{rms}$ and $\overline{\ddot{\xi}'}_{rms}$ for the geometric fractional division type of the trials.

Without control : 1st, 2nd, 3rd.
With control :



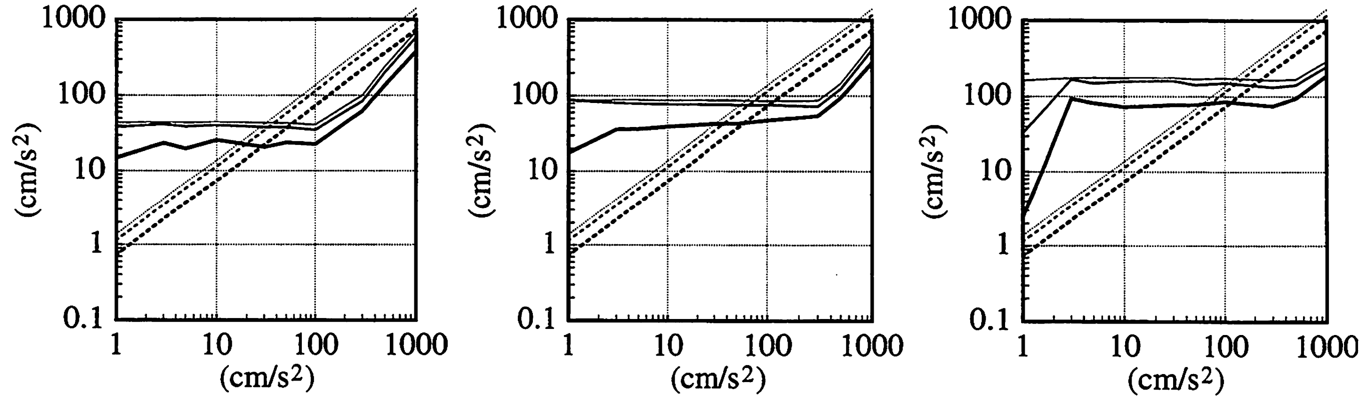
(a) $u_{max} = 0.5$, (b) $u_{max} = 1.0$, (c) $u_{max} = 2.0$,

Fig. 4.5.19.1 $\overline{v_{rms}}$ and $\overline{v'_{rms}}$ for the uniform division type of the trials.



(a) $u_{max} = 0.5$, (b) $u_{max} = 1.0$, (c) $u_{max} = 2.0$,

Fig. 4.5.19.2 $\overline{\dot{v}_{rms}}$ and $\overline{\dot{v}'_{rms}}$ for the uniform division type of the trials.



(a) $u_{max} = 0.5$, (b) $u_{max} = 1.0$, (c) $u_{max} = 2.0$,

Fig. 4.5.19.3 $\overline{\ddot{\xi}_{rms}}$ and $\overline{\ddot{\xi}'_{rms}}$ for the uniform division type of the trials.

to the smaller than the critical target in the broad sense as that the *ARMS* may be enlarged exceed the non-controlled acceleration responses.

By considering Figs.4.5.16.1 and 4.5.16.2, the upper limits of the compound allowable margins of targets for the *DRMS* and the *VRMS* may be observed as the values of about 200, 400 and 800 (cm/s^2) for the three cases which are supposed the maximum trial control forces as $u_{max} = 0.5$, 1.0 and 2.0 (kgf) on the geometric fractional division type of the set of the trials, respectively. Those compound allowable margins of targets which are related to all cases for the different values of the maximum trials may be allocated as to be able to include the continuous ranges from those upper limits to the external input level of 1 (cm/s^2). Moreover, by considering the Figs.4.5.16.3, any external input levels from 1 to 1000 (cm/s^2) can be allocated as the compound safety range of targets for all cases which are supposed those three values of the maximum trial control forces. Namely, it is assured that the geometric fractional division type of the set of the trial control forces may be provided enough efficiency to effectively improve the control performances even if the allowance of variations for the external input levels are considered as the comparative wide range, and that the controlled responses may be appeared as to have the almost equally ratio for the non-controlled response on each external input level within the targeted allowance of the external inputs.

On the other case that the uniform division type of the set of the trials is introduced, by considering the Figs.4.5.17.1 and 4.5.17.2 the compound allowable margins of targets for the *DRMS* and the *VRMS* may be observed as the limited ranges from about 30 to 200 (cm/s^2), from about 60 to 400 (cm/s^2) and from about 100 to 700 (cm/s^2) for three cases which are supposed the maximum trial control forces as $u_{max} = 0.5$, 1.0 and 2.0 (kgf), respectively. By considering the Figs.4.5.16.3, when the external input levels are supposed as the values below about 30, 60 and 120 (cm/s^2) for those three cases which are supposed the maximum trial control forces as $u_{max} = 0.5$, 1.0 and 2.0 (kgf), respectively, those external input levels may be allocated as the unsafety ranges of targets for the *ARMS*. At this point, by considering the case for $u_{max} = 2.0$ (kgf) (which is shown in Figs.4.5.17.1 (c), 4.5.17.2 (c) and 4.5.17.3 (c)), and also, by comparing those results with Figs.4.5.13 (a), (b) and (c) in the Study (4.5)-4a, it may be appeared that the compound allowable margins of targets and the safety or the unsafety ranges of targets related to $u_{max} = 2.0$ (kgf)) may not be almost amended by the deference of the mesh level of the trials under the installation of the uniform division type of the set of the trials. Moreover, when the case for $u_{max} = 1.0$ (kgf) (which is shown in Figs.4.5.17.1 (b), 4.5.17.2 (b) and 4.5.17.3 (b)) is considered, although the value of 0.2 (kgf) of trial in the set is included as the minimum trial, the satisfied range of the targets and the safety range of the targets which are allocated for the fixed trial of 0.2 (kgf) as observed in Figs.4.5.13 (a), (b) and (c) in the Study (4.5)-4a may not be appeared on this case study as that this fixed trial of 0.2 (kgf) is supposed as the minimum trial in the multi-number of the trials. By the way, by comparing Figs.4.5.16.1 and 4.5.17.1 as the evaluations from the *FRMS*, it may be observed that the surplusage of the supply of the control forces may be appeared on the case of the uniform division type on the comparative small range of the external input levels. Namely, when the multi-number of the trials are introduced, it may be regarded that enough disparity between the adjointing trials should be considered to use actively the efficiencies of the smaller trials.

Those results are also evaluated from the another indicates. Figs.4.5.18.1, 4.5.18.2 and 4.5.18.3 are also shown the numerical results corresponding to the cases which are introduced the geometric frictional division type of the set of the trial control forces. Figs.4.5.18.1 (a), (b) and (c) show the fluctuations of the RMS values of the inter-story displacements ($\overline{v_{rms}(i)}$ and $\overline{v'_{rms}(i)}$, ($i = 1, 2, 3$)) according to the variations of the external inputs levels for the three cases which are supposed as $u_{max} = 0.5$, 1.0 and 2.0 (kgf) as the maximum trail control forces, respectively. Figs.4.5.18.2 (a), (b) and (c) show the fluctuations of the RMS values of the inter-story velocities ($\overline{\dot{v}_{rms}(i)}$ and $\overline{\dot{v}'_{rms}(i)}$) according to the variations of the external inputs levels for the three cases which are supposed as $u_{max} = 0.5$, 1.0 and 2.0 (kgf) as the maximum trial control forces, respectively. Figs.4.5.18.3 (a), (b) and (c) show the fluctuations of the RMS values of the absolute accelerations ($\overline{\ddot{\xi}_{rms}(i)}$ and $\overline{\ddot{\xi}'_{rms}(i)}$) according to the variations of the external inputs levels for the three cases which are supposed as $u_{max} = 0.5$, 1.0 and 2.0 (kgf) as the maximum trial control forces, respectively. In those figures, solid lines and broken lines of curves are corresponding to the controlled responses and the non-controlled responses, respectively.

Figs.4.5.19.1, 4.5.19.2 and 4.5.19.3 are also shown the numerical results corresponding to the cases which are introduced the uniform division type of the set of the trial control forces. Figs.4.5.19.1 (a), (b) and (c) show the fluctuations of the RMS values of the inter-story displacements ($\overline{v_{rms}(i)}$ and $\overline{v'_{rms}(i)}$, ($i = 1, 2, 3$)) according to the variations of the external inputs levels for the three cases which are supposed as $u_{max} = 0.5$, 1.0 and 2.0 (kgf) as the maximum trial control forces, respectively. Figs.4.5.19.2 (a), (b) and (c) show the fluctuations of the RMS values of the inter-story velocities ($\overline{\dot{v}_{rms}(i)}$ and $\overline{\dot{v}'_{rms}(i)}$) according to the variations of the external inputs levels for the three cases which are supposed as $u_{max} = 0.5$, 1.0 and 2.0 (kgf) as the maximum trial control forces, respectively. Figs.4.5.19.3 (a), (b) and (c) show the fluctuations of the RMS values of the absolute accelerations ($\overline{\ddot{\xi}_{rms}(i)}$ and $\overline{\ddot{\xi}'_{rms}(i)}$) according to the variations of the external inputs levels for the three cases which are supposed as $u_{max} = 0.5$, 1.0 and 2.0 (kgf) as the maximum trial control forces, respectively. In those figures, solid lines and broken lines of curves are corresponding to the controlled responses and the non-controlled responses, respectively.

By considering the Figs.4.5.18.1 and 4.5.18.2, when the geometric fractional division type of the set of the trial control forces is introduced, the control performances in the sense of the reductions for the displacements and the velocities may be observed as to be quite similar for any external input levels below about 100 (cm/s^2) under those three cases which are supposed the maximum trial control forces as $u_{max} = 0.5$, 1.0 and 2.0 (kgf). This value of about 100 (cm/s^2) may be estimated as the upper limitation of external input level as not to be occurred the shortage of the supply of control forces for the specified maximum trial control forces as $u_{max} = 0.5$ (kgf). Those sense of the upper limitations of the external input level for $u_{max} = 1.0$ and 2.0 (kgf) may be evaluated as the values about 200 and 400 (cm/s^2), respectively. Moreover, by considering the Figs.4.5.18.1, the reductions of the *ARMS* can be also observed for any external input levels from 1 to 1000 (cm/s^2) in the all cases of the different values of the maximum trial control forces. Namely, it is assured that the quasi-optimizing method may be practically installed as the effective aseismic response controller which can make the equalized reductions of response regardless the variations of the external input levels when the geometric fractional division type of the set of the trial control forces may be introduced as to be provided enough value of the maximum trial and enough mesh level of trials.

On the other case that the uniform division type of the trial control forces is introduced, by considering the Figs.4.5.19.3, it is observed that the controlled acceleration responses for three cases of the maximum trial control force as $u_{max} = 0.5$, 1.0 and 2.0 (kgf) may not be reduced below the constant output levels as about 30, 50 and 100 (cm/s^2) on average under the smaller range of the external input levels than about 100, 200 and 400 (cm/s^2) of the external inputs, respectively. At this point, by comparing Fig.4.5.19.3 (c) and Fig.4.5.14 (c) in the Study (4.5)-4b for the evaluation for the case of $u_{max} = 2.0$ (kgf), this constant value of the unavoidable output levels which are appeared as the side effects on the control operations may be observed as the quite similar value, namely, it seems that the control performances may be almost dominated the maximum trials although the other smaller trials than the maximum trial control force by installing the multi-number of the trials in this case. And also, by considering the Figs.4.5.19.1 and 4.5.19.2, the control performances in the sense of the reductions for the *DRMS* and the *VRMS* may be deteriorated on the corresponding ranges that the controlled acceleration responses may remain stagnant for the constant output levels. Namely, when the uniform division type of the trials is supposed, it is appeared that this trial may not be adequately switched to the adjointing small value of the trial, even if a certain value of the trial in the set is allocated on the unsafety range of targets. As a reason of this, it may be considered that enough disparity between the comparative large values of the trials may not be allocated as to be able to make switching trials for avoiding the unsafety ranges of targets, since the digit of the trials may become narrow according to increasing the mesh level of the set of trials.

Through those considerations, it may be resulted that any smaller trials than the maximum trial control forces should be installed by considering as to provide enough disparity to avoid the surplusage of the supply of the control forces for the larger trials, those installations may be suggested the appropriateness for the geometric fractional division type of the set of the trials.

As the concluding remarks in this section, very significant problems to introduce the quasi-optimizing control method for practical aseismic response controllers are discussed. Those discussions are suggested as the effective provisions of the set of the trial control forces under the considerations for the variations of the external input levels. The geometric fractional division type of the set of the trial control forces is proposed for this aim, and the effectiveness and the appropriateness of the geometric fractional division type of the trial control forces for the quasi-optimizing controllers are estimated through the comparative studies with the uniform division type of the set of the trial control forces.

4. 6 Concluding remarks

Through the considerations in this chapter, practical problems of the aseismic response control system for building structures are estimated. Emphases are put on the syntheses of the device capacities and the actualizations of the effective manipulations on transitional states under the unforecastable external inputs. Accordingly, discussions have been begun to talk about the constructions of the stabilized controller which is provided the applicability under considerations of the saturations of control forces and which is also provided the additional feed-forward efficiencies for the mitigation to the disturbances caused from the external inputs. For those aim, the set of the discretized control forces are supposed to extract the limited kinds of the immediate future controlled behaviors of the system, and controllers which operate optimizations for the control performances are synthesized as to actualize the most adequate one of those limited kinds of the predicted future possibilities. This newly proposed concept for composing the aseismic response controllers is introduced as a quasi-optimizing control method, and the fundamental compositions of this new control method are presented in the Section 4.1.

On the quasi-optimizing control method, limited numbers of virtual control manipulations (which are introduced as the trial control forces) are supposed, and limited kinds of predicted responses of the system are computed and optimized by using digital time-dependent indexes. Since the quasi-optimizing control forces as the practically actualized trials are always selected from those pre-provided constants of several kinds of trial control forces, the allowance of the device capacities can be certainly considered and reflected on the off-line syntheses of those trial control forces. Moreover, on those quasi-optimizing process, the most adequate trials by every control time steps are selected from the conditions which are supposed as to be minimized the digital index functions by on-line. By utilizing those subjections of the quasi-optimizing procedures, it may be assured that the stabilities in the sense of *Lyapunov* on the controlled system are established under the newly supposed conditions as the 'parasitic stabilities' under introducing the quasi-optimizing control method.

The basic installations and estimations of the quasi-optimizing control method are executed by using the three-stories of the CTAC standard system in the Section 4.2 and the Section 4.3. Active control system which is composed by three active braces located on every inter-stories of the structural model is investigated through the experimental tests and the numerical simulations. By considering the practical applicability for the multi-devices active control systems, the supplemental algorithms to reduce the load of the CPU on the quasi-optimizing procedures are proposed. Namely, by introducing the searching sequence according to the priorities of the control devices, the multi-layer searching algorithms are installed as the proxy quasi-optimizing controllers for the universal searching algorithm. As the typical order of the priorities of the control devices, the step-up searching and the step-down searching sequences are supposed and evaluated. Through those case studies, effective arrangements of the control forces via the multi-located inter-story active braces are also estimated. As a result, it is appeared that the responsibilities of the control devices located on the lower stories are significant to operate effective control performances, and also, by considering this condition to synthesize for the arrangements of the device capacities, it is assured that the quasi-optimizing controllers based on the multi-layer searching algorithms can actualize effective control performances as to be apposition to the universal searching algorithm.

To make sure those physical meanings of the effective arrangements of the device capacities of the multi-located system and to present explicit syntheses for the responsibilities of the multi-control devices, discussions for the responsibilities of the 'control devices' may be extended for the arrangements of the acting points of the 'control forces' in the Section 4.4. For this aim, the para-systems of control forces which are actualized for the mediational coordinate of the control forces via the multi-devices active control system are introduced. As a result, when the lumped-node control force system are evaluated as to constraint the arrangements of the control forces via the active braces installed on every inter-stories, it is appeared that remarkable reductions of responses can be gained, and also, that the control performances on both the multi-layer searching algorithms and the universal searching algorithm can be equally actualized. At this point, it is also assured that the effective arrangements of the device capacities which are suggested in the Section 4.3 are related to the constraint conditions of the lumped-node control force system. Moreover, when this para-systems of control forces subjected under the conditions as the lumped-node control forces are supposed on the multi-located inter-story active braces, it is appeared that the control performances in the sense of the required control forces may be evaluated as not to be disadvantage in comparison with the case that those control forces are directly produced on the control devices such as the multi-located active mass dampers.

As the further considerations for the control performances of the quasi-optimizing control method, reductions of the acceleration responses are also evaluated in the Section 4.4. Through those evaluations, it is assured that the surplusage of the supply of control forces are sensitively appeared on the controlled accelerations, and that the controlled acceleration responses may be enlarged by exceeding the non-controlled responses if the comparative large trial control forces are supposed. To improve those behaviors on the quasi-optimizing controllers and to warrant the efficiencies on the quasi-optimizing control method as the aseismic response controller (which can be utilized for the variation of the external input levels), the syntheses of the set of the trial control forces are verified in the Section 4.5. The geometric fractional division type of the set of the trial control forces is proposed as the another syntheses for replacing the uniform division type of the set of the trial control forces. Through the numerical estimations, the effectiveness and the appropriateness of the geometric fractional division type of the trial control forces for the quasi-optimizing controllers are appeared when the step-down searching algorithm is supposed.

As the summary of the studies in this chapter, it is assured that the quasi-optimizing control method can be introduced as the effective aseismic response controller by considering the following items.

(1) It is required that the original system which is not installed the quasi-optimizing controller should be warranted its stability, namely, that the quasi-optimizing controller should be

additionally installed on the stabilized structural systems. On those conditions, it is assured that the syntheses based on the 'parasitic stabilities' can be utilized as the conditions to warrant the stability of the quasi-optimizing control method.

(2) To support the multi-devices active response control systems, it is required that the multi-layer searching algorithm is supposed on the installations of the quasi-optimizing control method. And also, it may be convenient to place the universal searching algorithm as the evaluative indicates to verify the control performances of the multi-layer searching algorithms.

(3) When the multi-located inter-story active braces are supposed as the control devices of the aseismic response controllers, it may be regarded that the arrangements of the device capacities should be synthesized by considering the sensible inter-story shear forces under the earthquake forces. To consider those conditions, it is regarded as to be attractive for introducing the lumped-node control force system as the para-systems of the control forces, since this mediational coordinate of the control forces may automatically suppose and constraint the manipulated control forces via the inter-story active braces into the sensible inter-story shear forces.

(4) When the different kinds of control devices which are supposed as that the manipulated control forces are directly related to the shear forces (such as the multi-located inter-story active braces) and as that the manipulated control forces are directly related to the body forces (such as the multi-located ground-connected active braces or the multi-located active mass dampers) are compared, power supplies which are required by every control devices may be evaluated as to be almost equal on both types of the control devices, to suppose the lumped-node control force system as the control forces of the quasi-optimizing controllers based on the multi-layer searching algorithms.

(5) To utilize the quasi-optimizing control method for the aseismic response control under the considerations for the variations of the external input levels, the set of the trial control forces should be synthesized as the geometric fractional division type, at the same time, the step-down searching algorithm should be installed to improve the controlled accelerations effectively.

Those significant items appeared through the discussions and considerations in this chapter may be regarded as very attractive for the practical installations of the aseismic response control systems, and also, the sufficient investigations for the syntheses of the quasi-optimizing control method may be mentioned from those case studies. As the further progressions to continue those evaluations for the quasi-optimizing control method, it may be suggested that the considerations for the systematic syntheses of the weight matrices on the penalty indexes (which are also included the weight matrix of the control forces) or the evaluations for the time delay problem on the practical use are also regarded as to be the important emphases.

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5 Active Control on Structural Responses under Wind-induced Disturbances

Very profound interests in wind-resistant structural syntheses are shown as the another purposes of response control of building structures as well as developments of aseismic response control systems. The greatest concernment for wind-resistant response control of building structures may be put on absorbing wind-induced structural vibration energy. Those response control systems are mainly installed to accomplish more comfortable residence, especially, on high-rise buildings. Various kinds of passive damper systems have been introduced to high-rise building structures in order to reduce wind-induced vibrations. And also, active response control systems have been adopted for the purpose of wind-resistant response control. An active mass damper (AMD) system is the most popularized active control device which is generally installed as a wind-resistant active response control system for practical use. To synthesize those kinds of active control systems such as the AMD, feedback controller may be installed as control algorithm, however, feed-forward controller may be difficult to construct because of the practical problems as like that many sensors which can measure wind pressure to be enough to identify wind loads are required, or that it may be very difficult to organize the internal models which include transfer characteristics of wind loads. Accordingly, it may be pointed that most of wind-resistant active response control systems which are installed on the practical building structures are classified to the type of 'absorption of internal vibration energy' in the sense that those controllers are constructed as the closed-loop feedback controllers. In which, passive damper systems may be also classified to the same type with absorption of internal vibration energy by evaluating for their control force mechanisms.

At this point, it may be considered that the wind loads which cause the structural vibrations on the high-rise buildings may be appeared as the results from the differences between every wind pressures acting on every building surfaces. So that, it may be pointed that the wind-induced structural vibrations are not only subjected to the structural dynamic properties, but also subjected to the surface configurations and the proportions of building structures. When the wind-resistant active control systems which are classified to the type of the absorption of internal vibration energy are introduced, it may be considered that any control forces via the response controllers are always actualized as to reduce internal structural vibrations which are appeared as the resulted behaviors from wind excitations. However, those control operations may not immediately manipulate for the aerodynamics of wind flows by on-line. By the another words, regardless those type of response control systems are installed by using the passive damper devices or installed by using the active control devices, it may be considered that the control effects are only appeared as to suppress the internal disturbances occurred as the structural responses.

On the other hand, when the cancellations or utilizations of aerodynamic effects of the wind are introduced as the additional control manipulations, wind-resistant response control system by providing the advanced efficiencies as like 'surface isolation' mechanisms to the wind flow may be considered. For instance, since the wind-induced structural vibrations may be significantly subjected to the surface configurations of building structures, structural responses may be controlled on a certain extent by synthesizing the surface conditions or the proportions of the targeted structures. From those sense, by additionally installing the configurations on building surfaces which are difficult to vibrate, the passive type of the wind-resistant syntheses of the building structures can be discussed. And also, it may be considered that those additional configurations of building surfaces as like to be difficult for vibrating are designed as the actively or passively controlled devices by on-line. So that, by introducing variable configurations into building surface conditions, a 'wind-resistant active isolation' system can be assembled to intercept the input energy from external disturbances. Installation of those kinds of mechanisms into building structures may be able to actualize energy absorption for the external inputs, namely, the para-system of the feed-forward controller on wind-resistant systems may be indirectly organized by manipulating the transmissions of the external inputs. To operate such kinds of control manipulations, it may be reasonable that some kinds of control devices which can change structural surface configurations are installed to buildings. At this point, the wind-resistant active isolation system may be more attractive than the active control systems of the type such as the AMD with respect to the points that no additional mass is required, and also that mechanical energy to be supplied on control devices may be decreased.

For this aim, a new kind of active control system which is named an 'active fin system' is proposed to actualize the wind-resistant response control by introducing variable configuration mechanism. The active fin system is the structural response control system by installing active rotor fins (which are named 'active fins') for reducing wind-induced building vibrations. The control device of the active fin system can change partial structural surface configurations according to the wind conditions and according to the structural responses at any moments, accordingly, the active fin system is manipulated for controlling the 'wind forces' acting on the fin according to the structural responses. In the sense to utilize the wind forces for the control manipulations, it may be considered that a 'virtual' wind-resistant active isolation mechanisms may be actualized by introducing the active fin system.

In this chapter, developments and verifications for an active fin system which is newly proposed as the wind-resistant response control system are described. At first, to investigate for the fundamental control effects of the active fin system as the concrete shapes, the pilot type of the control device of active fins is developed. This pilot model of active fins is designed as to be utilize the wind resistant forces along to the wind directions for controlling the parallel-wind structural vibrations. For introducing this pilot model of active fins on the wind-resistant active response control, the control method to manipulate the active fin system are constructed. Active control tests are executed by introducing the CTAC standard system on the wind tunnel. Those developmental studies as to evaluate the fundamental efficiencies of the active fin system are described in the Section 5.1 and the basic installations for this new type of the wind-resistant active control system are also discussed in this section.

In the first half of the Section 5.2, as the applicable considerations of the active fin system, discussions may be expanded to operate the multi-directional wind-resistant response control by using the active fin. Namely, as the reformed model for the pilot type of the control device of active fins which is investigated in the Section 5.1, a newly designed control device of active fins is introduced. By using this new model of active fins, efficiencies for the parallel-wind response control are verified again through the wind tunnel tests, and moreover, the control method to manipulate the active fin system for controlling the structural vibrations on the cross-wind direction are constructed and investigated on the wind tunnel. On those wind tunnel experiments, two kinds of the control algorithms are evaluated as the single-directional response control method. In later half of this section, those investigated results on the wind tunnel tests are expanded to the two-directional response control on horizontal plane. A large-scaled active fin system for a large-scaled experimental structure is introduced for this aim. Two kind of the single directional response control methods are reconstructed as the multi-directional response control methods. The preliminary tests of the two-directional response control by using this large-scaled model of active fins are executed under the strong natural wind flow. Through those large-scaled experimental tests, significant results are appeared as that the response control effects are observed only on the cross-wind direction.

To improve those controlled behaviors, the new type of the two-directional response control method is introduced in the Section 5.3. In the first half of this section, by using the large-scaled experimental system, this new type of the two-directional response control method is evaluated under the strong natural wind flow. On those experimental tests, two kinds of variations of the control method which are supposed as to reduce and to amplify the structural vibrations are investigated. As those experimental results, it is appeared that those control effects which are observed for two kind of control algorithms are inverted from the efficiencies to be expected by every control manipulations. Namely, by using the control algorithm to reduce responses, structural vibrations are enlarged, and, by using the control algorithm to amplify responses, structural vibrations are decreased. In the later half of this section, to make assure those phenomena on the wind tunnel, a new structural model for the CTAC evaluating system is developed as to be actualized the multi-directional responses on the horizontal plane. By using this new structural model and by executing the wind tunnel active control tests, it is assured that similar control effects with the natural wind tests are observed.

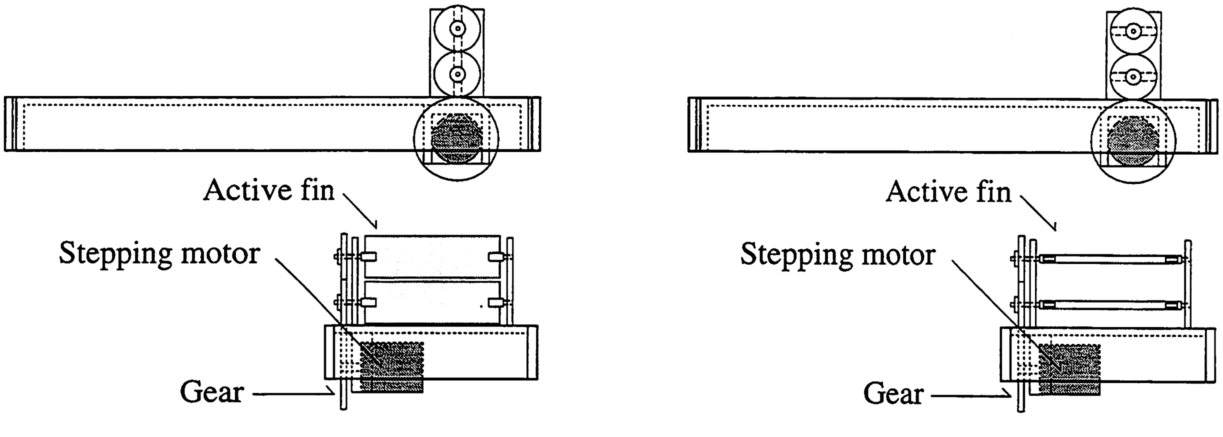
In the Section 5.4, the control operations based on those two kinds of the two-directional response control methods which are proposed in the Section 5.2 and the Section 5.3 are verified in detail. Through those verifications, it is evaluated that those controlled phenomena which are mentioned on the multi-directional response control tests are subjected to the influences for the complexed time delays which are caused by the manipulating time intervals to change the positionings of the active fin and which are caused by that the structural vibrations are appeared as to be close to the circular locus. To make assure those verified considerations, by evaluating for the acceleration responses as to predict the future structural vibrations and as to cancel the time delay effects by the circular locus of the structural vibrations, the wind tunnel tests are executed. By manipulating the two-directional response control based on those predicted responses, it is assured that the control effects by using the two-directional response control method (which are proposed in the Section 5.3) are fixed to the expected efficiencies on those control methods.

In the Section 5.5, aerodynamic wind force effects induced on rotating fins are evaluated on the wind tunnel tests and dynamic properties of the wind resistant forces acting on the fins may be assured as the mechanism based on the *Magnus* effects. By considering those aerodynamic wind force effects, two-directional control method are improved again, and by operating the active control tests on the wind tunnel, the effectiveness of this final version of the two-directional wind-resistant response control method are assured.

While various kinds of active control systems have been proposed in order to reduce wind-excited building vibrations, the active fin is very different from those systems at the point of using aerodynamic effects of wind flow for response control. Since the control forces supplied by the active fin generally depend on wind conditions, it is very difficult to evaluate theoretically control effects of the active fin system. Accordingly, since it seems that experimental investigations occupy very important part of researches for practical use, those developmental studies for the active fin system have been mainly executed through experimental tests. On those investigations in this chapter, the active fin system are polished up as to overcome the various practical problems which are appeared through the experimental tests.

5. 1 Developmental and fundamental study on active fin systems

An 'active fin' system is proposed as a new type of active control system for reducing wind-induced vibrations of building structures. Developmental investigations of the active fin system are discussed in this section. To make assure fundamental outlines of the active fin system as the concrete shape, a pilot model of the active fin for executing preliminary experimental tests is developed. The pilot type of the active fin are designed by the appearances as like a double door's sluice valve for wind flow to make the drag of the wind forces acting along the parallel-wind directions variable, namely, this type of the active fin may utilize wind forces acting on the fin as control forces by opening or closing this sluice valve depending on the responses of the structures. By introducing this pilot model of the active fin, control operations and control effects of the active fin system for building vibrations in parallel-wind direction are investigated. The CTAC system is used for those investigations and active response control tests for a three-stories structural model by equipping the active fin device are evaluated on the wind tunnel. Through those investigations, fundamental response control methods for parallel-wind direction by using active fin system may be assured.



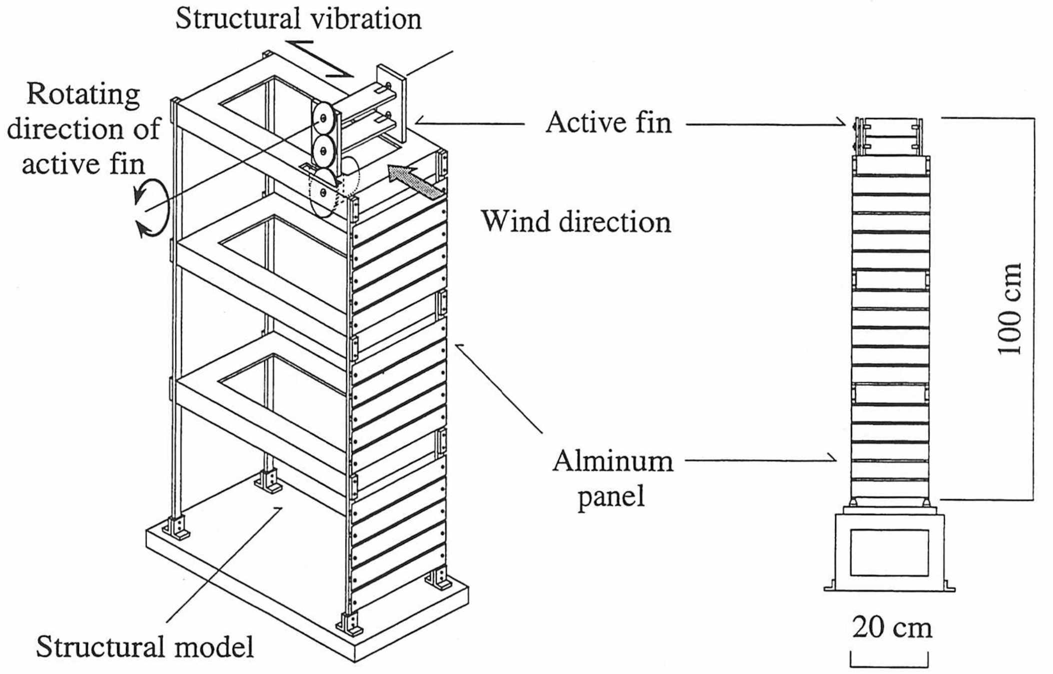
(a) Closed mode of the active fin, (b) Open mode of the active fin,

Fig. 5.1.1 Control device of the pilot type of the active fin.

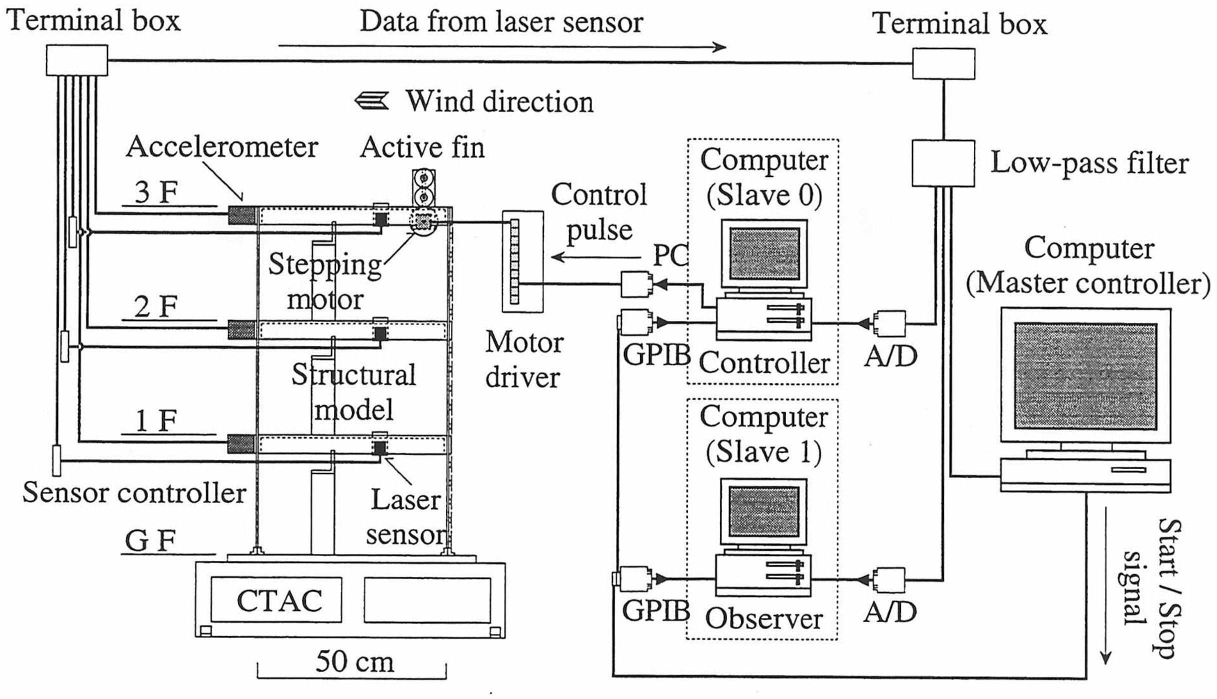
Control device of the pilot type of the active fin is shown in Fig.5.1.1. This control device is designed as to be equipped on the top floor of the experimental structural model. The response controller by installing the active fin is composed as the variable configuration manipulator based on the differences of wind resisting forces caused from the two kinds of configurations of the active fin as follows. One is a 'closed mode' which is fully received wind forces on the active fin as seen in Fig.5.1.1 (a), and the another one is an 'open mode' which is not received wind forces on the active fin as seen in Fig.5.1.1 (b). Those configurations are switched by rotating those double active fins.

Table 5.1.1 Natural period and damping ratio of the structural model.

	Natural periods (s)	Damping ratio
1st	1.138	0.56 (%)
2nd	0.379	-
3rd	0.253	-



(a) Isometric view, (b) Front view,



(c) Side view and flow diagram of the active fin control system,

Fig. 5.1.2 Configurations of the experimental structural model equipped the active fin.

The configurations of the experimental structural model which are equipped the active fin on the top floor and the flow diagram of the active fin control system are shown in Figs.5.1.2. On the experimental wind tunnel tests, the CTAC system which is composed with a three-stories structural model is introduced as the testing apparatus. This structural model is designed to be vibrated in the single direction, and the structural model is equipped on the wind tunnel as that this single vibrating direction of the structural model is adjusted along to the direction of wind flow. The windward surface of the structural model is covered with the aluminum plates which are equipped on the columns as not to participate in the stiffness of the inter-stories, the structural vibrations on the parallel-wind directions may be caused by that this side of surface is projected the wind flow. Total area of this projected surface of the structural model is 1800 (cm^2). The projected area of the active fin is designed as 150 and 5 (cm^2) for the closed mode and the open mode, respectively. Namely, the maximum value of the variations of the projected area of the active fin which is allocated as the difference between the closed mode and the open mode is 145 (cm^2), and this value is corresponding to 8 % for the projected surface of the structural model. Inter-story displacements on each story of the structural model are directly measured by three laser sensors. In order to avoid electric noise, the low-pass filter (which cut off the components of inputs below 10 Hz) are used. The absolute displacements or velocities which are used to determine control operations on the control algorithms are approximately computed by arithmetic sum or finite difference from those direct input data. According to those measured data and according to assigned control algorithms, the stepping motor is rotated and the control movements for the active fin are actualized. Natural periods and damping ratio are shown in Table 5.1.1. By examining the free vibration tests, those values for the dynamic characteristics of the structural model are estimated as the results from the Fast Fourier Transform (FFT) analysis and by logarithmic decrement, respectively.

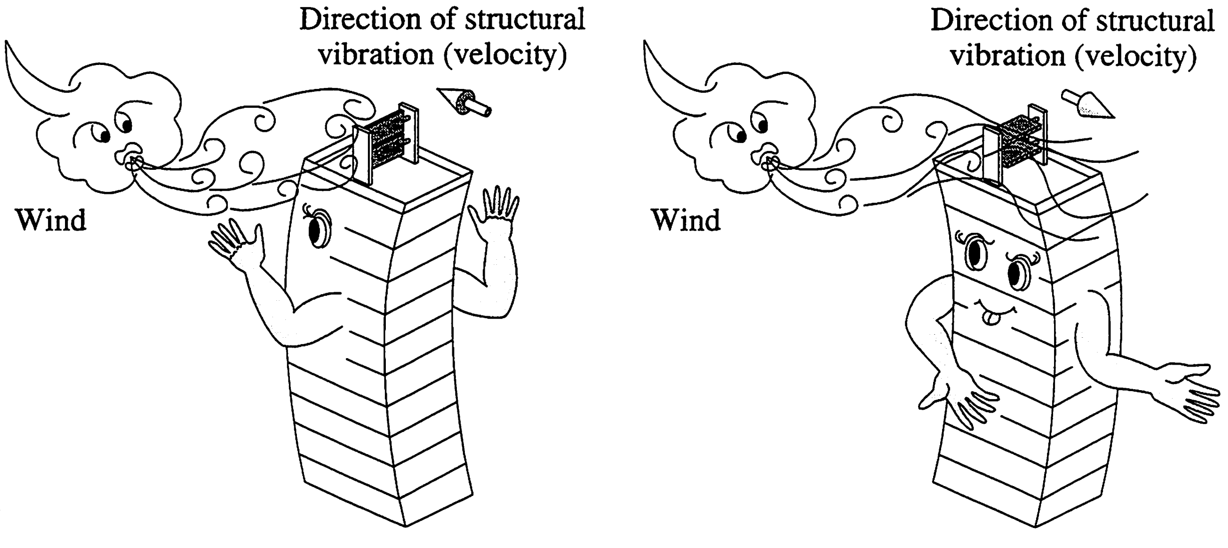


Fig. 5.1.3 Basic ideas for constructing the control algorithm of the active fin system.

To constructing the control algorithm of the active fin system, it is assured that the configuration of the active fin is selected from only two patterns that are the closed mode and the open mode as seen in Fig.5.1.1 (a) and (b), respectively. Those two kinds of configurations which are generated by the active fin equipped on the top floor of the structural model may be switched by on-line according to both dynamic transitions of the structural responses and the wind flow. The basic ideas for constructing the control algorithm of the active fin system are represented as following descriptions (those ideas are also represented as the conceptual illustrations which are shown as Fig.5.1.3) :

> *"When the structural model will move to windward,*
> *the active fin is closed and becomes to fully catch wind forces, or*
> *when the structural model will move to leeward,*
> *the active fin is opened and become not to catch wind forces".*

By introducing such kinds of operations on the active fin system, the wind forces may work as if those are control forces to reduce the vibrations of the structural model. Whether the direction of the structural vibrations is windward or leeward, is judged from the sign of the absolute velocity of the top floor (which is equipped the active fin device) at each discrete control time step. The time interval for each control step Δt_c is assigned as about 0.1 (s). This value is synthesized from the considerations that can be included about 0.05 (s) of the time interval which is required for the control actions of the active fin to change its configurations. When the absolute displacement of the i-th floor at the σ-th control time step (σ is assigned as the integer number) is denoted as $x_i(\sigma)$ (cm), the approximate absolute velocity $\Delta x_i(\sigma)$ (cm/s) can be expressed as,

$$\Delta x_i(\sigma) = (x_i(\sigma) + x_i(\sigma - 1)) / \Delta t_c \ , \qquad (5.1.1)$$

in which, the positive sign of $x_i(\sigma)$ and $\Delta x_i(\sigma)$ is corresponding to the quarter for windward. At this point, it may be pointed that control manipulations of the active fin to switch its configurations are operated on the turning point of the sign of $\Delta x_i(\sigma)$ in the nature of things. However, since $\Delta x_i(\sigma)$ is computed as the finite difference for the input data, it may be considered that the discretized errors which are mixed up via the A/D converter are appeared on those approximate values as the high frequency noise. Those injurious signals can not be removed on the low-pass filter, because those discretized errors are appeared on the signals which have gone through the low-pass filter. To remove those injurious signals, it may be reasonable to introduce the trigger level on the controller to separate the available signals from the microscopical errors. Namely, the value of the minimum velocity level Δx_{min} is used as the trigger level to judge the available signals.

$$\Delta x_{min} = \gamma \times \delta_{min} / \Delta t_c \ , \qquad (5.1.2)$$

in which, γ means a cut-off coefficient (which is assigned as the non-negative integer number), and δ_{min} (cm/s) (which is subjected as $\delta_{min} > 0$) means a 'digit' which is corresponding to the minimum resolution of the input signal from the laser sensors to computers, (this value is allocated as 0.00244 (cm) in this system). When this kind of high-cut filter is introduced, it should be taken notice for that the size of the trigger level also have the delay effects (namely, the size of the minimum velocity level Δx_{min} may dominate the sensitivities for the reaction of the controller). The control algorithm to reduce the structural vibrations may be proposed as the following compositions.

Control algorithm-P1(R) :

```
If        $| \Delta x_3(\sigma) | \leq \Delta x_{min}$ ,   then , keeping before mode,
else if   $\Delta x_3(\sigma) > \Delta x_{min}$ ,   then , closed mode,
else if   $\Delta x_3(\sigma) < \Delta x_{min}$ ,   then , open mode.
```

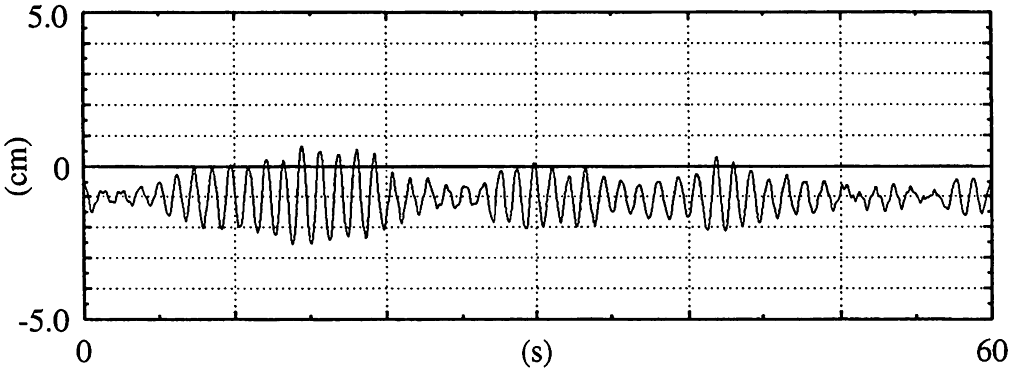
This control algorithm of the active fin system is introduced as very simple compositions in this study. The approximate absolute velocity of the top floor is only used in order to select the mode of the active fin by on-line. Since the active fin system is proposed as a new type of active control technique in the sense that the surface configurations can be changed according to the external inputs and that the transformed influences which are subjected by the external inputs may be evaluated as the indirect control effects, this newly proposed wind-resistant control system is conveniently classified into a type of the structural vibration control system as 'active variable configurations'.

In the following experimental studies, the wind tunnel tests are executed under the conditions that the average of the velocities of the wind is as 10.2 (m/s). By inserting a grid filter in the wind tunnel, laminar flow is changed to semi-turbulent flow in order to imitate practical wind flow.

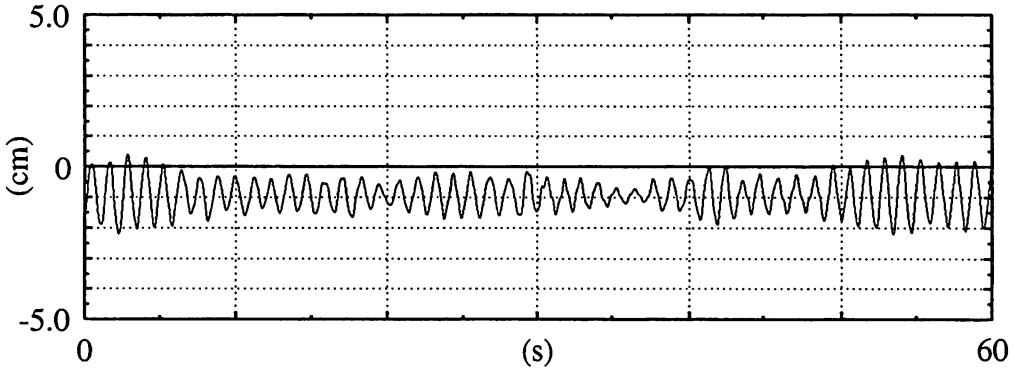
Study (5.1) - 1 :

It may be considered that some aerodynamic effects are arisen by setting the control device on the structural model whatever if it is controlled or not, so, to make assure this interest, two cases of the non-controlled responses are examined. One is for the case of the closed mode shown as Fig.5.1.1 (a), and the anther one is for the case of the open mode shown as Fig.5.1.1 (b). The displacements of the top floor corresponding to the closed mode and the open mode are shown in Fig.5.1.4 (a) and (b), respectively. By comparing those figures, significant differences may not be recognized, accordingly, both results are referred as non-controlled responses in the following discussions.

The control effects of the active fin system are investigated by introducing to the Control algorithm-P1(R). In this study, as to be also examined the influences of the electric noise, the two cases of the controlled responses under the conditions by installing and removing the low-pass filter are evaluated. In both of those cases, the cut-off coefficient γ is fixed on 3 (because the top floor's responses are calculated by using the arithmetic sum for the input data which are measured on three sensors). The displacements of the top floor corresponding to those two cases are shown in Fig.5.1.5 (a) and (b), respectively. By comparing those figures, it is observed that the control effects may be deteriorated on the case for removing the low-pass filter, namely, it may be appeared that the installations of the low-pass filter is effective to reduce sensitivities for the electric noise in this system. Moreover, by comparing controlled responses (as seen in Fig.5.1.5) with non-controlled responses (as seen in Fig.5.1.4), it is assured that the effective reductions of vibrations can be

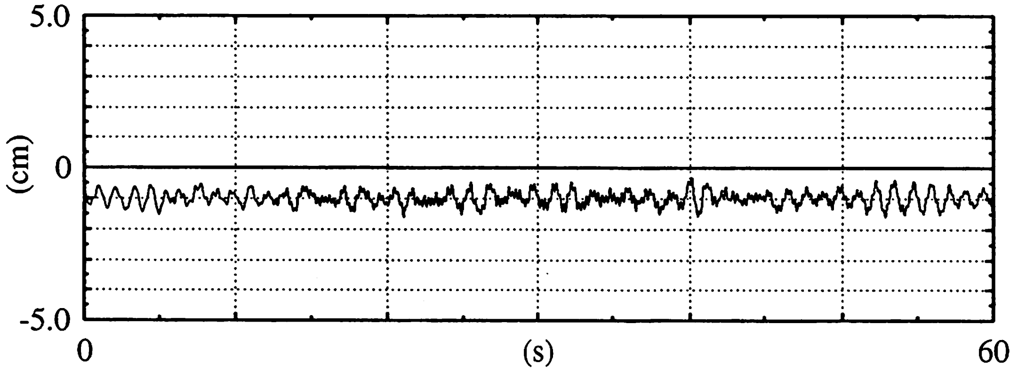


(a) Case of the closed mode,

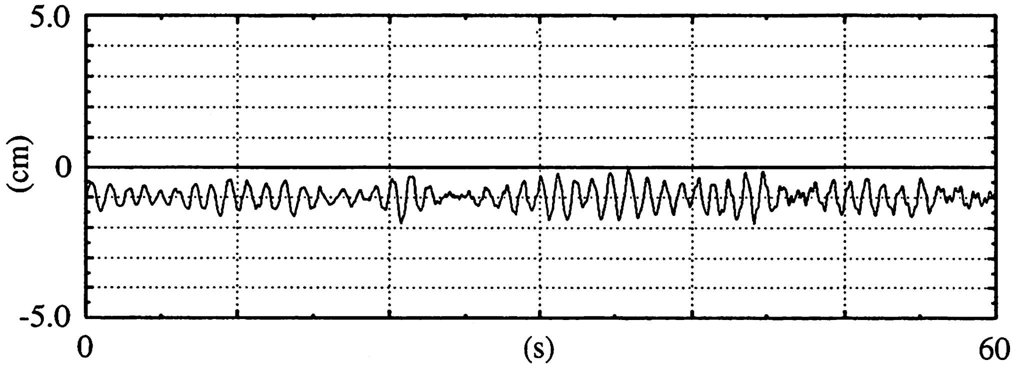


(b) Case of the open mode,

Fig. 5.1.4 Displacements of the top floor for the cases without control.



(a) Case of installing the low-pass filter ($\gamma = 3$),



(b) Case of removing the low-pass filter ($\gamma = 3$),

Fig. 5.1.5 Displacement of the top floor for the cases with control.

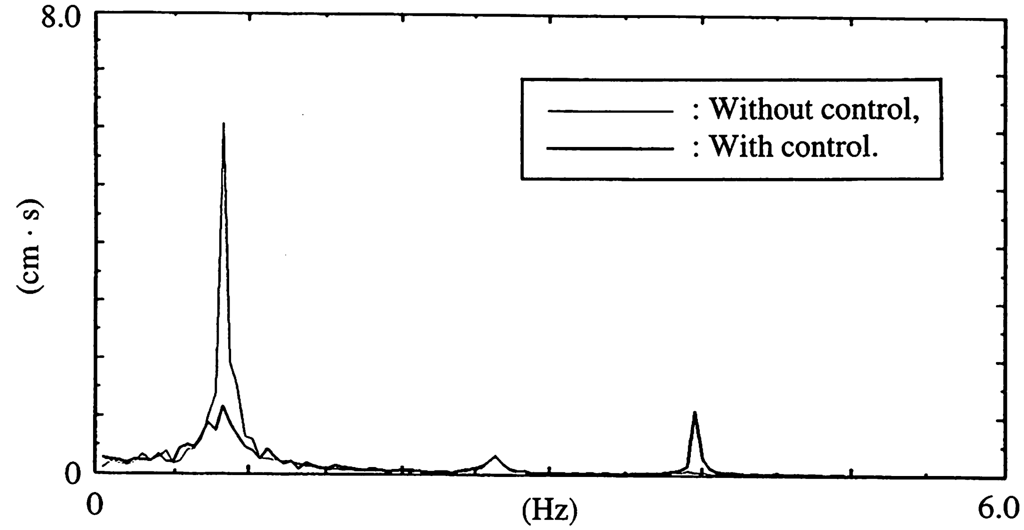
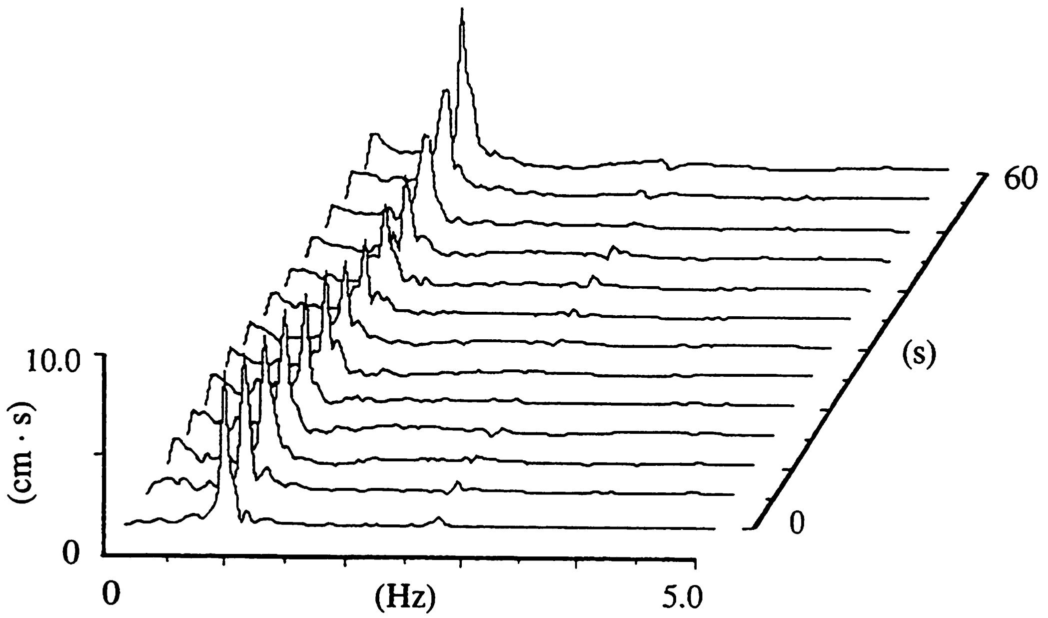
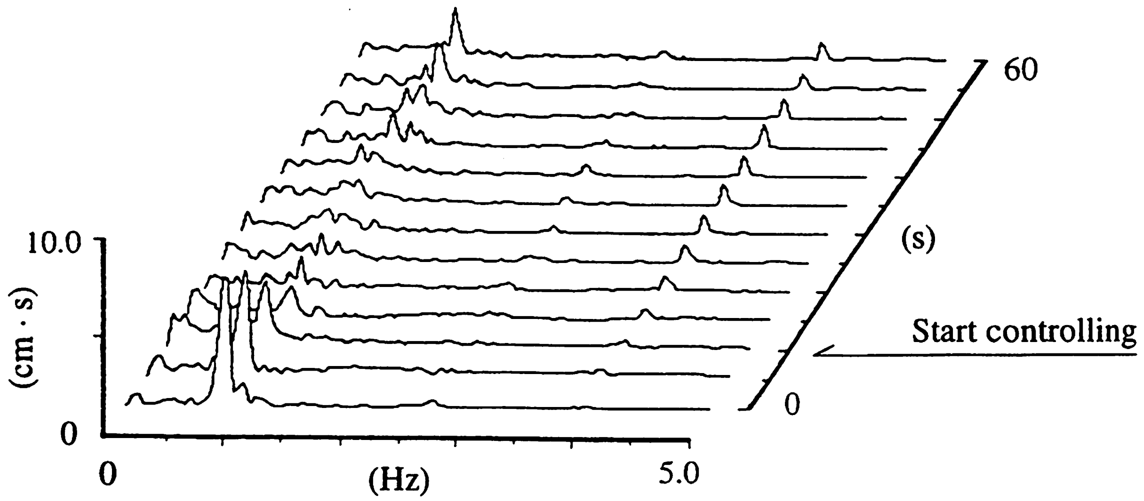


Fig. 5.1.6 Spectrum of the displacements of the top floor (Time duration : 90 (s)).



(a) Case of non-control (the open mode),



(b) Case of control, $\gamma = 3$ (installing the low-pass filter),

Fig. 5.1.7 Running spectrum of the displacements of the top floor.

observed by introducing the active fin system, and that the proposed control algorithm may be provided effective efficiency for the reductions of wind-induced vibrations.

Spectrum diagrams of the top floor's displacements for the case of the non-control (corresponding to the open mode) and the case of control (installing the low-pass filter) are shown in Fig.5.1.6. Running spectrum diagrams for those two cases are shown in Figs.5.1.7 (a) and (b), respectively. In those figures, it may be observed the fundamental frequency (near 0.8 Hz) on the first mode of the structural model is extremely dominant at the case of non-control. By using the Control algorithm-P1(R), it is observed that the frequency responses near 0.8 Hz are reduced to about 20 %. At this point, the frequency responses near 4.0 Hz are increased by control operations. As the reason of this, it is considered that the control actions of the active fin affect to high frequency components. However, as considering the controlled responses of the displacements of the top floor which are observed on the time-history (as seen in Fig.5.1.5 (a)) again, as the macroscopical effectiveness, it is regarded that stable reductions of responses are observed by introducing the control operations of the active fin. From those results, it is appeared that the effective control forces to reduce the structural vibrations are given by the control movements of the active fin by using the Control algorithm-P1(R).

Study (5.1) - 2 :

The another kind of the experimental test is examined to ensure the implicit ability of the active fin. This examinations are introduced from the point of view as that "it may be reasonable that the control algorithm can be used for 'amplifying' vibrations". For this aim, the following algorithm is introduced.

Control algorithm-P1(A) :

If $|\Delta x_3(\sigma)| \leq \Delta x_{min}$, ***then,*** keeping before mode,
else if $\Delta x_3(\sigma) > \Delta x_{min}$, ***then,*** open mode,
else if $\Delta x_3(\sigma) < \Delta x_{min}$, ***then,*** closed mode.

This control algorithm can be easily gained by replacing the word 'open' with 'closed' in the Control algorithm-P1(R). To evaluate the Control algorithm-P1(A) as the same conditions with the Study (5.1)-1, active control tests are executed by installing the low-pass filter, and the cut-off coefficient γ is fixed on 3.

The displacement of the top floor, and the running spectrum diagram for the case of using the Control algorithm-P1(A) are shown in Fig.5.1.8 and Fig.5.1.9, respectively. By considering those figures, it is assured that expected amplifying effects can be gained by using the Control algorithm-P1(A). In this case, as seen in Fig.5.1.9, it is observed that the fundamental frequency responses (near 0.8 Hz) are amplified radically, although high frequency components are not subjected under the influence of control.

Study (5.1) - 3 :

As the further considerations, to examine the influence of the cut-off coefficient γ, four cases are evaluated ($\gamma = 0$, 1, 3 and 5). The displacements of the top floor for those cases are shown in Figs.5.1.10. By comparing those figures with the case of $\gamma = 3$ (as seen in Fig.5.1.5 (a)), it is found that the control effects are decreasing whenever if the coefficient γ is smaller or larger than this specified value. The reasons of those results may be explained as follows. Since the control manipulations may be operated sensitively even for the comparative small level of vibrations (it seems that the most of those cases may be corresponded to the injurious high frequency signals) at the cases of $\gamma = 0$ and 1, it may be considered that the toxic control forces are often generated. And at the case of $\gamma = 5$, it seems that the timing of changing the mode of the active fin are delayed from the real turning points of the sign of velocity of the structural model. So that, it is significant to select the adequate value of the cut-off coefficient γ, in order to operate good performances of the response control on the case that the directly input data for the evaluated signals on the control algorithm are not used, and that those signals are computed by the approximate finite differences.

Those experimental results from the Study (5.1)-1, the Study (5.1)-2 and the Study (5.1)-3 are indicated in Table 5.1.2 as the values of the RMS (root mean square) and the maximum amplitude of the displacements of the top floor. By comparing those results, it may be assured that the active fin system by using the Control algorithm-P1(R) can reduce to about 50 % on both of RMS and the maximum amplitude of the top floor's displacements for the non-controlled responses. At the same time, by considering the amplifying effects by using the Control algorithm-P1(A), it is appeared that the active fin system can directly affect for characteristics of the transmissions of the wind forces into the structural system, because that it may be considered that any additional increments of the vibration energy are supplied from the only external wind forces. Namely, it seems that the control operations by introducing the Control algorithm-P1(R) may be considered as to also provide the surface-isolation effects for the external inputs in addition to the damping effects on the structural vibrations.

As the concluding remarks in this section, the active fin system is proposed as a new type of wind-resistant active control system. The pilot type of testing device of the active fin is developed and the response control for parallel-wind direction is examined. As a result, it is appeared that the active fin system is very effective for reducing the wind-induced structural vibrations for parallel-wind direction under installations of the very simple and explicit control algorithm.

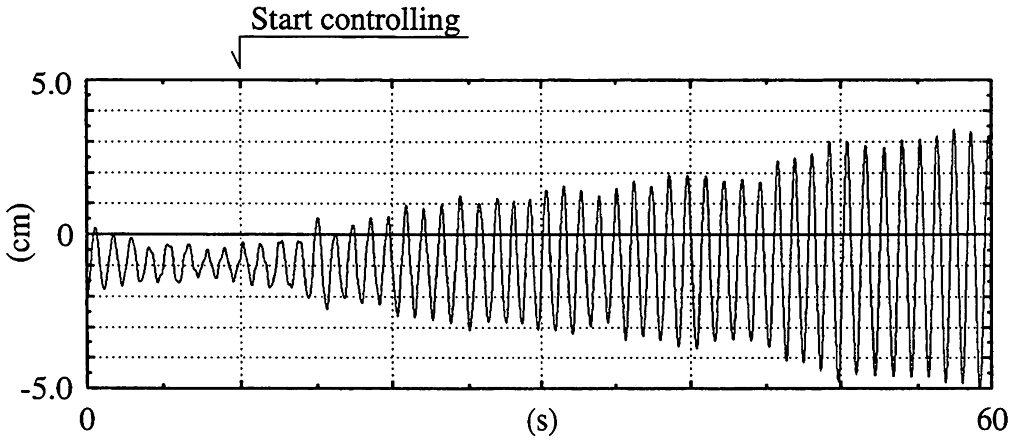


Fig. 5.1.8 Displacement of the top floor for the case of using the Control algorithm-P1(A).

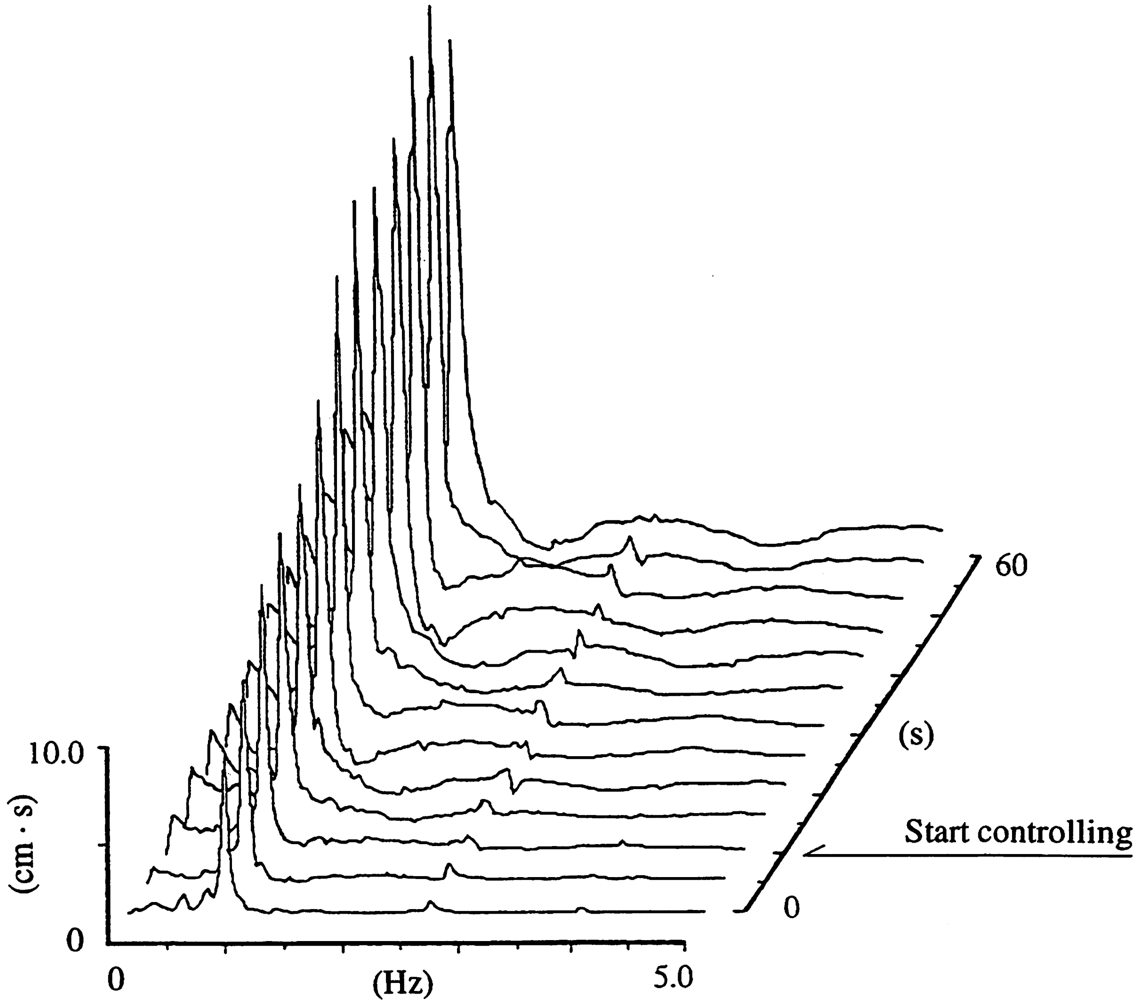
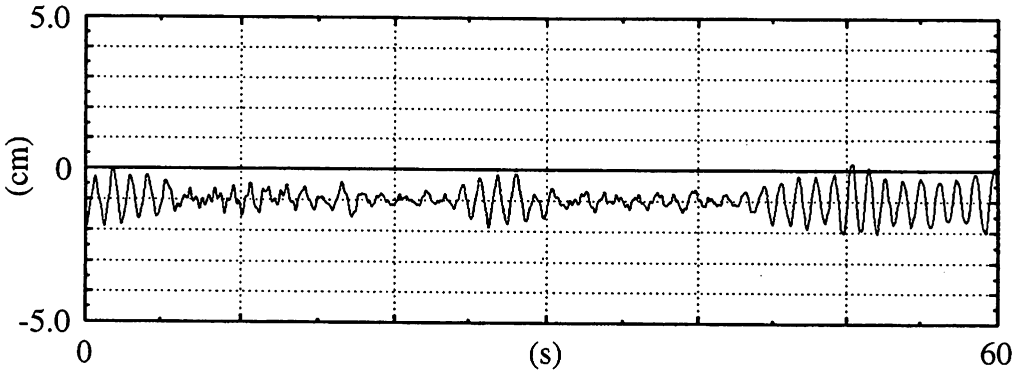
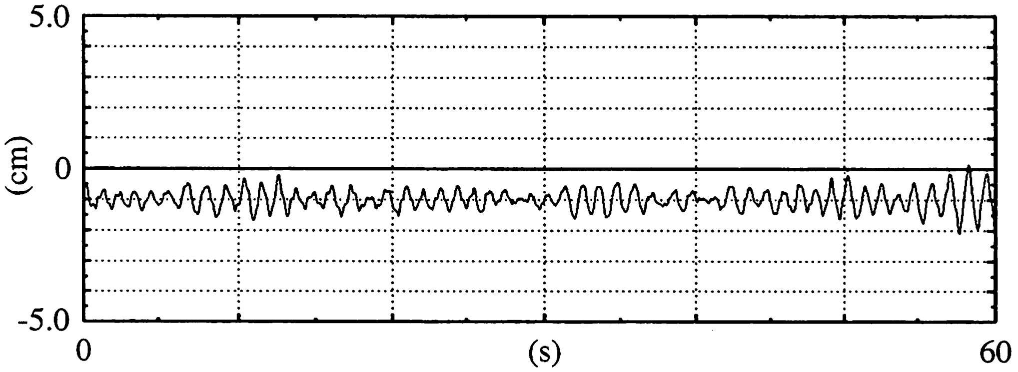


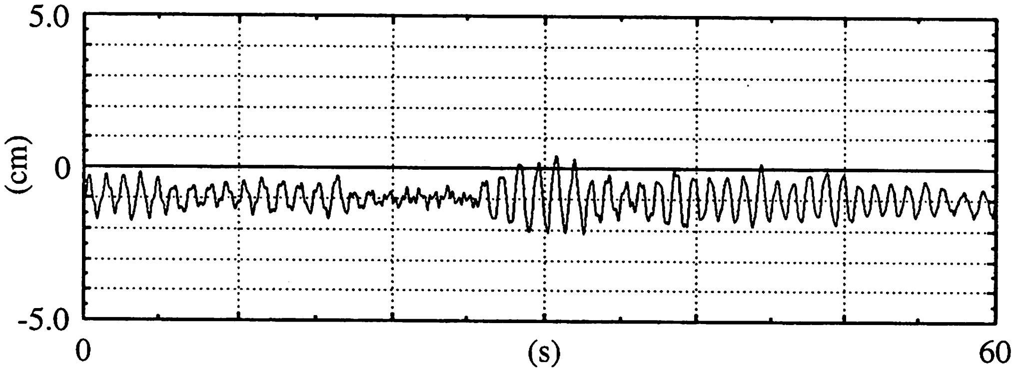
Fig. 5.1.9 Running spectrum of the displacement of the top floor
for the case of using the Control algorithm-P1(A).



(a) Case of control, $\gamma = 0$,



(b) Case of control, $\gamma = 1$,



(c) Case of control, $\gamma = 5$,

Fig. 5.1.10 Displacements of the top floor for the different values of the cut-off coefficient.

Table 5.1.2 Experimental results on wind tunnel tests.

Control type	Mode / Cut-off coefficient	RMS (cm)	The maximum amplitude (cm)
Without control	Closed mode	0.463	1.612
	Open mode	0.616	1.696
Control algorithm-P1(R)	$\gamma = 0$	0.403	1.136
	$\gamma = 1$	0.314	1.119
	$\gamma = 3$	0.254	0.928
	$\gamma = 5$	0.453	1.269
Control algorithm-P1(A)	$\gamma = 3$	2.106	4.224

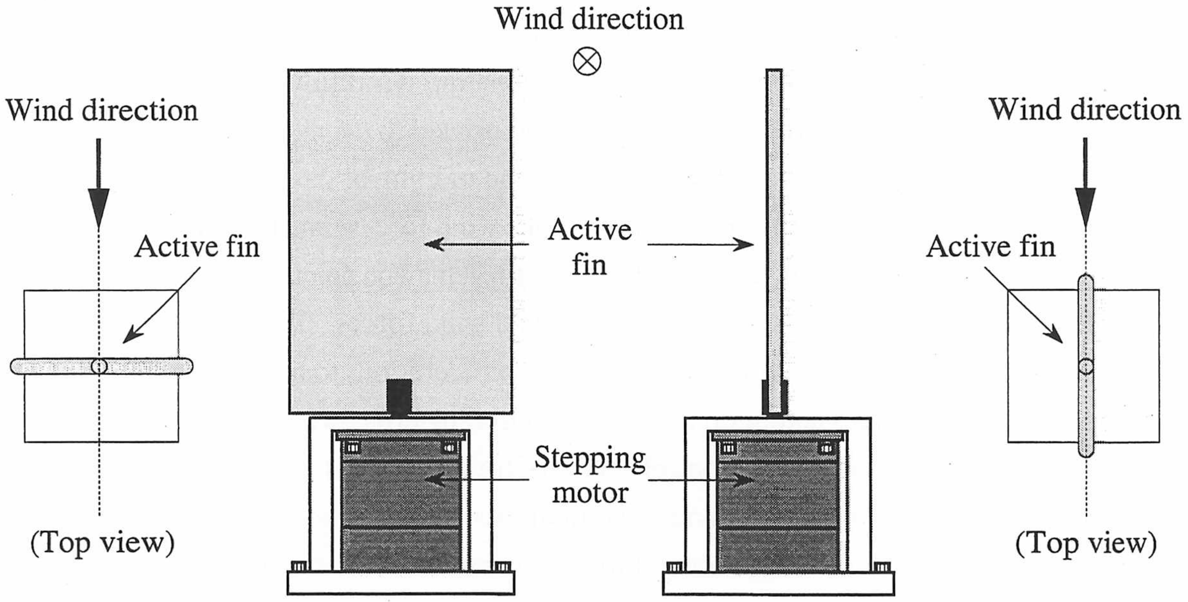
5. 2 Installation of active fin systems on large-scaled experimental structure

The active fin system to operate the wind-resistant response control for building structures is proposed, and the fundamental developments and investigations to make assure the effectiveness of this new kind of active response control system are executed by using the pilot model of the active fin in the Section 5.1. Through the preliminary experimental tests on the wind tunnel, it is assured that the effective reductions of wind-induced structural vibrations can be actualized by installing the active fin system which is manipulated on the very simple control algorithm. Those experimental studies are evaluated as the single-directional response control on the parallel-wind direction, because that the pilot model of the active fin is designed as to be able to utilize only the 'drag' (parallel-wind force) of the wind forces acting along the wind flow. From the following discussions, evaluations for the active fin system may be expanded to the multi-directional response control on the horizontal plane. Accordingly, a new type of control device of the active fin is introduced and also designed under the concept as to make wind forces transfer into control forces. As the improved efficiency of this new model of the active fin, it may be pointed that multi-directional control forces can be generated by using single-directional wind forces. The fundamental idea to arrive at this new model of the active fin is placed on the considerations to be able to utilize the 'lift' (cross-wind force) of wind forces acting on the fin for controlling cross-wind vibrations of building structures. For this aim, this new type of control device of the active fin is provided the appearances which have the thin plate to be rotated around its vertical axis, namely, the new model of the active fin may become as to be able to change both of the volumes and the directions of wind resistant forces acting on the fin by manipulating its projected angles to wind flow. In this section, developmental studies for this new model of the active fin system are introduced through the wind tunnel tests, and also, this new type of control device of the active fin is constructed as a large-scaled apparatus and installed on the large-scaled experimental structure.

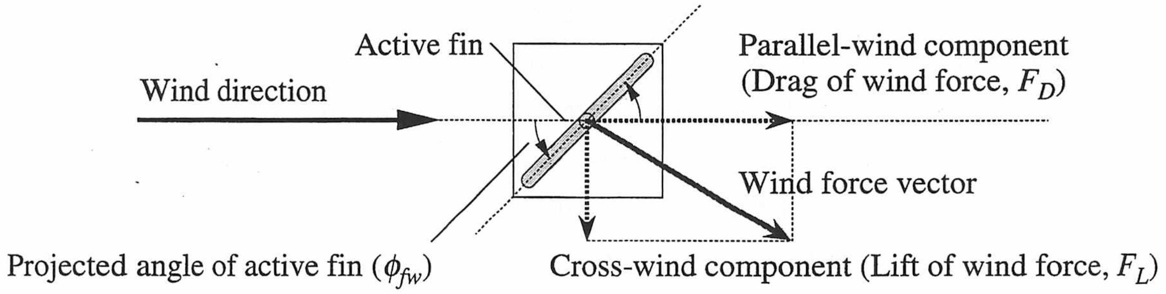
As the first half of this section, by using the small-sized control device of the new model of the active fin, the fundamental conditions to generate multi-directional control forces by utilizing wind flow are investigated on the wind tunnel tests. Those evaluations may be considered as the significant properties to construct the multi-directional control algorithm by installing this new type of control device of the active fin. To estimate that this new model of the active fin can be provided the efficiency as to be apposition to the pilot model of the active fin in the sense of the effectiveness for the response reductions on the parallel-wind direction, single-directional active control tests are executed again and the control effects on the parallel-wind direction by using this new type of control device are evaluated as the comparison with the control effects observed on the pilot model (which are shown in Section 5.1). Moreover, response control of the cross-wind vibrations of structural model are considered by installing this new model of the active fin. Control algorithm for the cross-wind direction is introduced as that the lift of wind forces can be utilized as the cross-wind control forces. Through the wind tunnel tests, those improved efficiency of the new model of the active fin may be investigated on the response control for the cross-wind direction.

As the latter half of this section, the large-scaled active fin system is developed and examined on the large-scaled experimental structure to make assure the control effects of the active fin system under the natural wind flow. In order to operate the response control for both parallel-wind and cross-wind directions at the same time, two-directional control algorithm is constructed and the fundamental abilities of the large-scaled active fin are investigated. Those evaluations may be discussed from the experimental results which are observed under the strong natural wind flow.

5. 2. 1 Development of newly designed model of active fin and investigation with wind tunnel



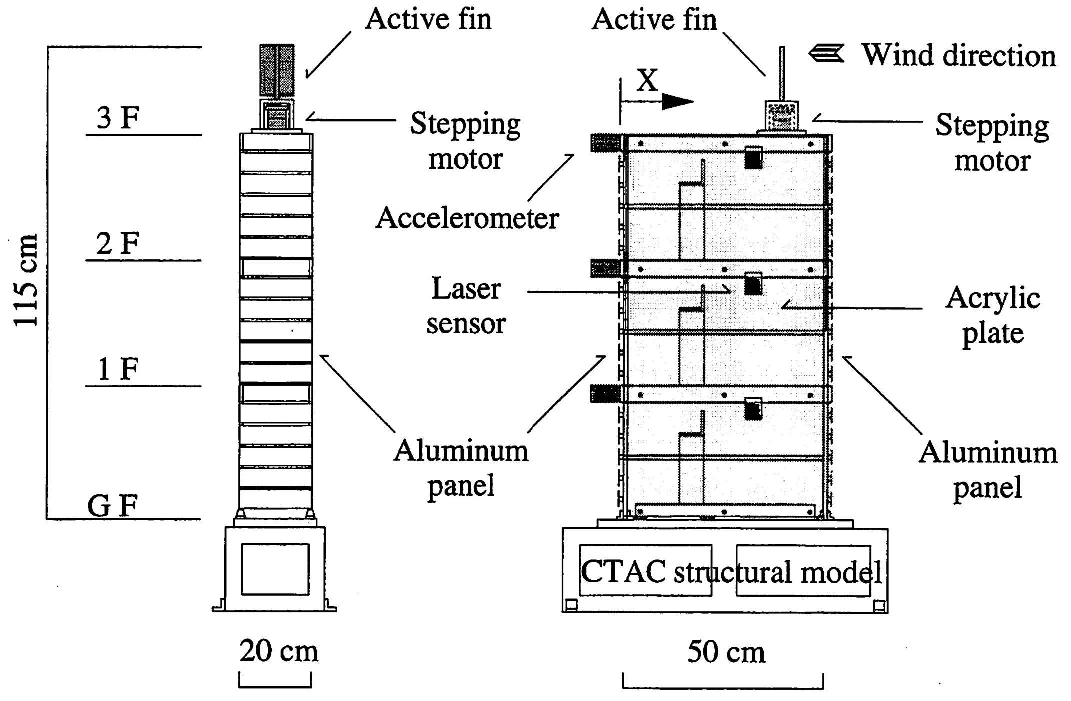
(a) Open mode, (b) Closed mode,



(c) Wind forces related to the projected angle of the active fin,

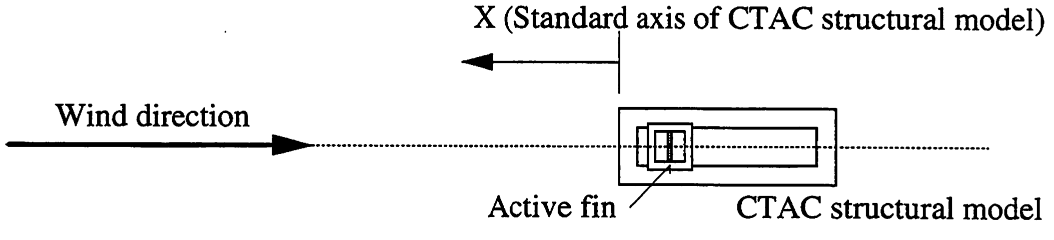
Fig. 5.2.1 New type of control device of the active fin system.

To consider the multi-directional response control on the horizontal plane by installing the active fin system, the newly designed control device of the active fin is proposed as the up-to-date model for the pilot model which is shown in the Section 5.1. Basic idea for introducing this new type of control device of the active fin system is picked with the control device such as a tail assembly of an aircraft or a sail of a yacht. Accordingly, the appearances of the new type of control device are shown in Figs.5.2.1. As seen in those figures, this new model of the active fin is assembled as that the single thin plate which is directly connected to motor shaft can be rotated around its vertical axis, namely, this new type of control device is introduced as to aim to operate active response controls for the structural vibrations on any directions induced by wind flow from all around on the horizontal plane. By introducing this new model of the active fin, both the volumes and the directions of the wind forces acting on the surface of the fin may become controllable.



(a) Front view,

(b) Side view,



(c) Top view (location for the parallel-wind response control tests),

Fig. 5.2.2 Outlook of the CTAC system equipped new model of active fin.

When only the drag of the wind forces acting on the fin is considered, since the volumes of the wind forces along the wind flow may be related to the 'projected area' of the active fin, those variations of the wind forces can be allocated from the open mode (which is defined as the parallel configuration to the wind flow, as seen in Fig.5.2.1 (a)) to the closed mode (which is defined as the orthogonal configuration to the wind flow, as seen in Fig.5.2.1 (b)). Accordingly, to provide the adjustment with the pilot model, the projected area of this new model of the active fin is also designed as 150 and 5 (cm^2) for the closed mode and the open mode, respectively. Namely, the maximum value of the variations of the projected area of the active fin which is allocated as the difference between the closed mode and the open mode is also 145 (cm^2). On the other hand, when both the drag (which is expressed as F_D in Fig.5.2.1 (c)) and the lift (which is expressed as F_D in Fig.5.2.1 (c)) of the wind forces acting on the fin are considered, those wind resistant forces acting on the fin should be considered as the vector quantities, and those wind force vector may be always diverted from the parallel-wind directions excepting the cases that the active fin is allocated to the open mode or the closed mode. Namely, under a certain direction of the wind flow, since the volumes and the directions of the wind forces may be related to the 'projected angle' of the active fin to the wind flow (which is expressed as ϕ_{fw}), the variations of the orientations of the wind force vectors can be allocated as the range from -90° to +90° of the projected angle of the active fin as seen in Fig.5.2.1 (c). In which the positive or the negative sign of the projected angle of the active fin is defined as the clockwise direction (which is called as the 'CW' direction in the following discussions) from the open mode or the counter clockwise direction (which is called as the 'CCW' direction in the following discussions) from the open mode, respectively.

In order to execute the experimental tests by introducing this new model of the active fin, a three-stories of structural model on the CTAC system is adopted. The new model of the active fin is also equipped on the top floor of the structural model. The outlook of the structural model which is equipped this new type of control device of the active fin is shown in Figs.5.2.2 (this structural model is the same one which is investigated on the previous wind tunnel tests in the Section 5.1, and the vibrated direction of this structural model is restricted on the single-direction (which is mentioned as the vibrated axis (standard axis) of the structural model as seen in the Fig.5.2.2 (c)) in the same way.

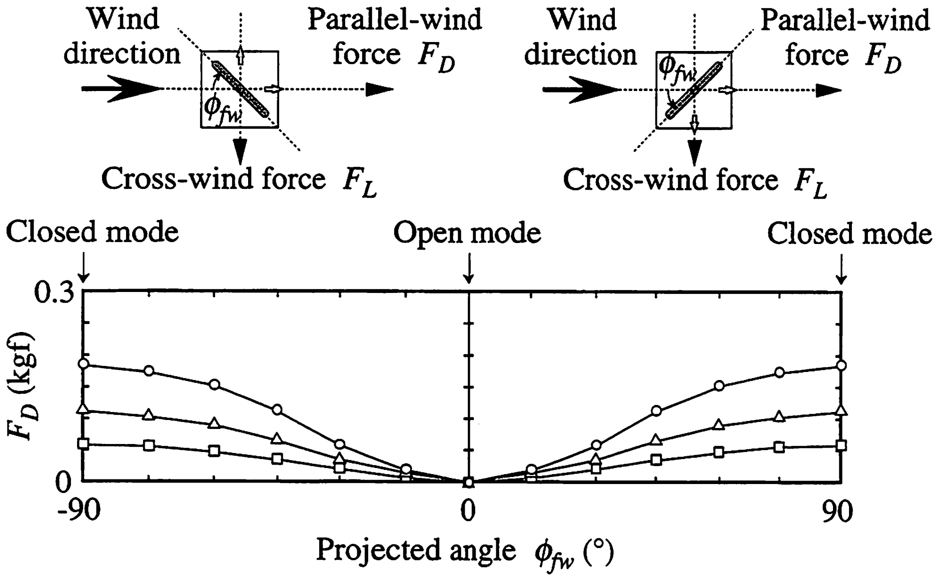
When the active response control tests on the parallel-wind direction are executed, the structural model is located on the wind tunnel as that the vibrated direction (X-axis) of the structural model is placed to be parallel to the wind flow. In this case, only the windward surface of the structural model is covered with the curtain wall of the aluminum plates as the same condition with the previous studies in the Section 5.1, and the structural vibrations on the parallel-wind directions may be caused by that the curtain wall of windward surface is projected the wind flow. On the other hand, in the case to operate the active control tests on the cross-wind direction by using this structural model, the curtain walls are installed on the all surfaces of the structural model. As seen in Fig.5.2.2 (a), the front and back surfaces on the vibrated axis of the structural model are covered with the aluminum plates which are equipped on the columns as not to participate in the stiffness of the inter-stories, and as seen in the Fig.5.2.2 (b), the both side surfaces of the structural model are also enveloped with the acrylic plates which are separated by every middle heights of the inter-stories. The structural model is located on the wind tunnel as that the vibrated direction (X-axis) of the structural model is placed to be perpendicular to the wind flow. The structural vibrations on the cross-wind directions may be caused by the aerodynamic differences of the wind pressures between

Table 5.2.1 Static properties.

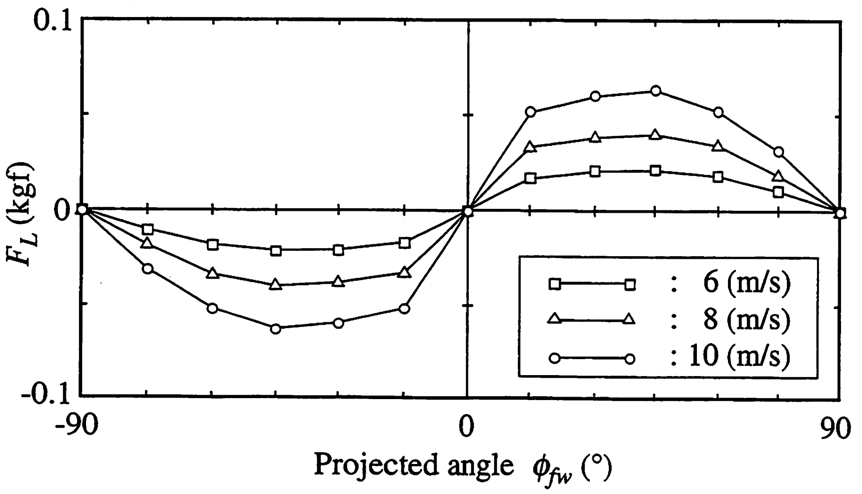
	Mass (kgf)	Stiffness (kgf/cm)
1st	13.0	1.95
2nd	13.0	2.50
3rd	14.0	3.15

Table 5.2.2 Dynamic properties.

	Natural period (sec)	
	Experimental	Numerical
1st	1.137	1.138
2nd	0.379	0.376
3rd	0.252	0.253
	Damping ratio (%)	
1st	0.42	



(a) Drag of wind forces (parallel-wind forces),



(b) Lift of wind forces (cross-wind forces),

Fig. 5.2.3 Wind resistant forces acting on the fin.

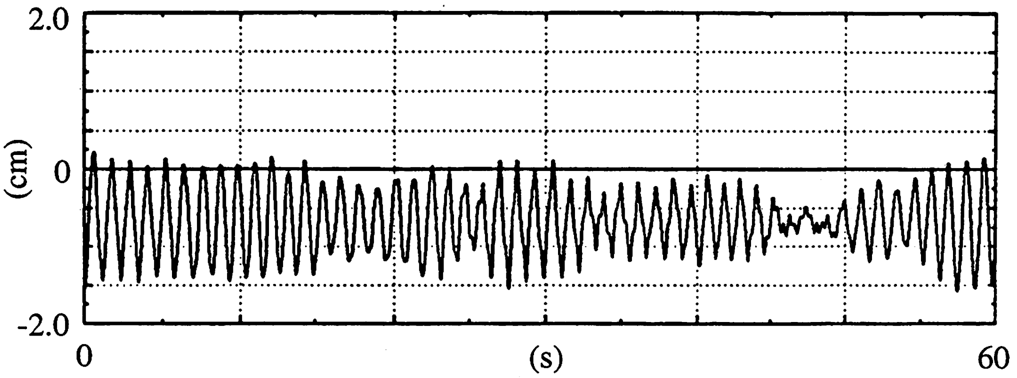
the both of surfaces on the vibrated axis of the structural model (which is orthogonally located to the wind direction) under the influences as that the wind flows which are reached to the windward side of the curtain wall are flowed out to the light and left.

Static and dynamic mechanical properties of the structural model are shown in Table 5.2.1 and Table 5.2.2, respectively. Experimental values and the numerical values of the natural periods of the structural model are computed by the free vibration tests and Eigen value analyses, respectively. The damping ratio is calculated as the mean of logarithmic decrements of the displacements on the free vibrations. To estimate the control forces which are supplied to the structural model by introducing this new model of the active fin, the relations between the projected angle of the fin and the wind resistant forces acting on the fin are examined on the wind-tunnel tests. Under laminar flow of 6, 8 and 10 (m/s), horizontal wind forces acting on the fin (those forces are described by the orthogonal coordinate composed by parallel-wind and cross-wind direction) are measured. The drag of the wind forces (the parallel-wind forces, F_D) and the lift of the wind forces (the cross-wind forces, F_D) which are generated on the active fin are shown in Fig.5.2.3 (a) and (b), respectively.

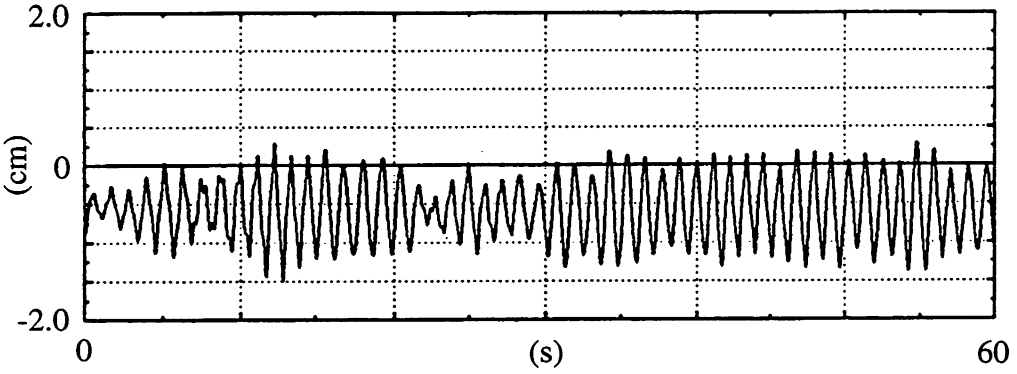
At first, as the comparative estimations with the previous studies in the Section 5.1, the efficiency to actualize the reductions of responses on the parallel-wind directions by installing the new type of the control device of the active fin are investigated on the wind tunnel. As the control algorithm of the active fin system, the 'Control algorithm-P1(R)' which is expressed in the Section 5.1 is also adopted for the new model of the active fin system. In the descriptions on the Control algorithm-P1(R), the configurations of the 'open mode' and the 'closed mode' for this new type of control device of the active fin are regarded as the two kind of appearances which is mentioned in Fig.5.2.1 (a) and (b), respectively. Accordingly, at the single-directional response control on the parallel-wind direction, by that the longitudinal axis of the active fin on the horizontal plane is allocated parallel or orthogonal to the wind flow, two kind of modes which are the open mode and the closed mode are manipulated via this new model of the active fin at each control step. To execute active response control tests, a lattice grid is inserted in the wind tunnel in order to actualize semi-turbulent flow. In the following discussions, the results for the cases that the mean of the wind velocity is about 8.0 (m/s) are focused.

Study (5.2) - 1 :

Control effects by introducing the active fin system are evaluated from the comparison between the non-controlled responses and the controlled responses. The non-controlled responses (displacements of the top floor) are observed as shown in the Figs.5.2.4. Fig.5.2.4 (a) and (b) are corresponded to the two cases which are keeping the configurations of the active fin in the open mode and the closed mode, respectively. By comparing those figures, significant difference between the closed mode and the open mode may not be recognized, so, both of those results are regarded as the non-controlled responses. The controlled responses (displacements of the top floor) which are manipulated by the Control algorithm-P1(R) are shown in Fig.5.2.5. By comparing this figure with Figs.5.2.4, it is assured that the effective reductions of responses may be gained by using this new model of the active fin. And also, by considering the results in the Section 5.1 (as the comparison



(a) Case of the closed mode,



(b) Case of the open mode,

Fig. 5.2.4 Displacements of the top floor for cases without control.

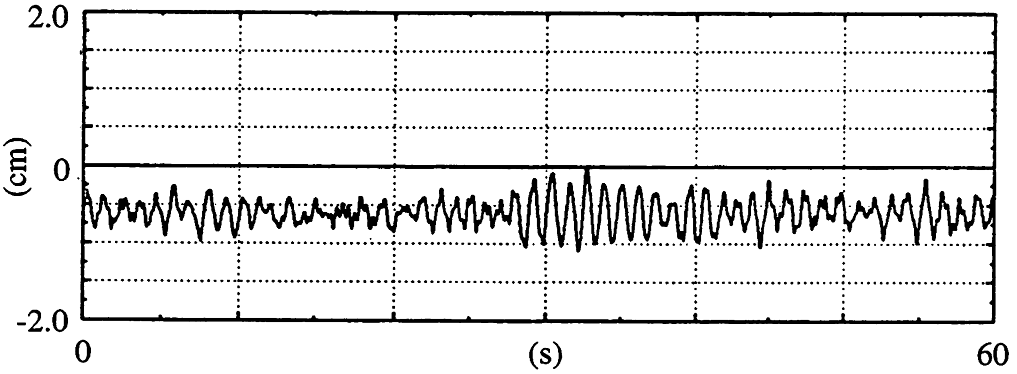


Fig. 5.2.5 Displacement of the top floor for case with control (Experimental results).

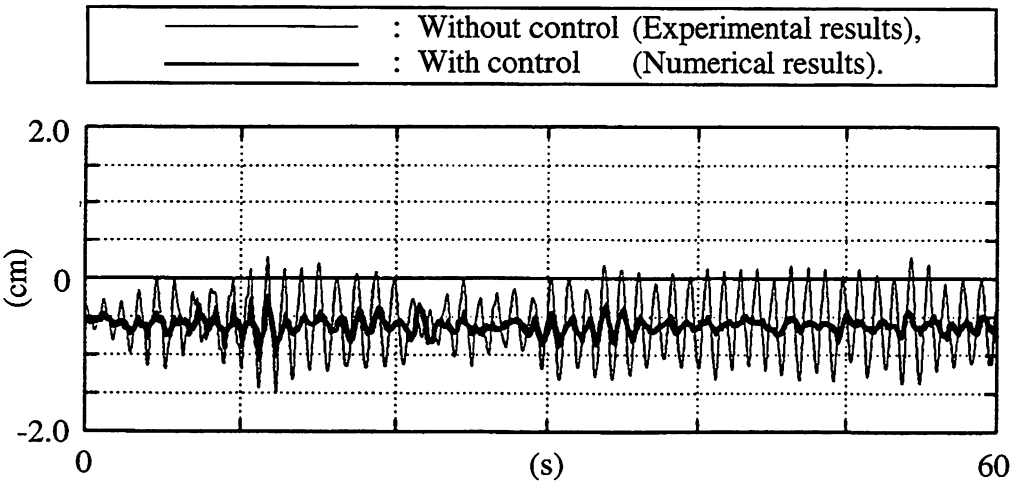


Fig. 5.2.6 Displacement of the top floor for case with control (Numerical results).

with Fig.5.13. and 5.1.4) again, this type of control device of the active fin can actualize very effective control performances on the parallel-wind directions as much as the pilot model of the active fin.

In those control operations on the parallel-wind direction, the direction of structural vibrations are corresponded to only windward or leeward and the required control forces are related to the minimum and the maximum of drag of wind forces acting on the fin. Namely, it may be appeared that the control algorithm which is related only to the volumes of projected area of the active fin is provided the enough efficiency to reduce wind-induce structural vibrations caused on the parallel-wind directions.

Study (5.2) - 2 :

The response control on the parallel-wind directions by introducing the active fin are evaluated from the numerical simulations. At first, the wind forces which cause the structural vibrations are computed by using the non-controlled responses which are measured on the case for keeping the active fin in the open mode (which is corresponded to the results in Fig.5.2.4 (a)). The wind forces vector $\{w\}_e$ acting on the structural model are estimated by introducing the equations of motions as follow,

$$\{w\}_e = [M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} , \qquad (5.2.1)$$

in which, $\{x\}$, $\{\dot{x}\}$ and $\{\ddot{x}\}$ represent displacement, velocity and acceleration vectors of the structural model, respectively, and $[M]$, $[C]$ and $[K]$ mean mass, damping and stiffness matrices, respectively. The wind forces acting on the structural model are assumed as concentrated horizontal loads acting on each mass. As the next, by using those simulated wind forces as the external inputs, numerical calculations for the response control by introducing the active fin are executed. Let denote the control force supplied by the active fin at the time instance $t_\sigma = \sigma \cdot \Delta t_c$ be $F(\sigma)$ (in which, Δt_c means the control time interval and σ means integer numbers). According to the configuration of the active fin (which is decided by the Control algorithm-P1(R)), the control forces which is supplied via the active fin are supposed as follows.

$$F(\sigma) = \begin{cases} \Delta F_f & \text{(corresponding to the 'closed mode'),} \\ 0 & \text{(corresponding to the 'open mode'),} \\ F(\sigma - 1) & \text{(corresponding to 'keeping before mode'),} \end{cases}$$

$$F(0) = 0, \qquad (5.2.2)$$

where, ΔF_f means the measured value of the wind resistant force acting on the fins, this value is evaluated as the difference of the drag of the wind resistant forces which are acting on the fin for the open mode and the closed mode under about 8.0 (m/s) of semi-turbulent flow. By examining the non-controlled responses for the closed mode and the open mode (which are shown in Figs.5.2.4), and by considering that the difference of the center of vibrations on those two kinds of configurations of the fin can be regarded as the disparity of the semi-static deformations which are caused by the drags of the wind resistant forces acting on the fin, the wind resistant forces ΔF_f are calculated as about 0.07 (kgf). As the control forces vector $\{f\}_f$ during the time interval from t_σ to $t_{\sigma+1}$, the following expression is obtained.

$$\{f(\sigma)\}_f = \{\ 0\ \ 0\ \ F(\sigma)\ \}^T, \tag{5.2.3}$$

Therefore, the equations of motions for the numerical simulations are expressed as follow.

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} \ = \{w\}_e + \{f\}_f. \tag{5.2.4}$$

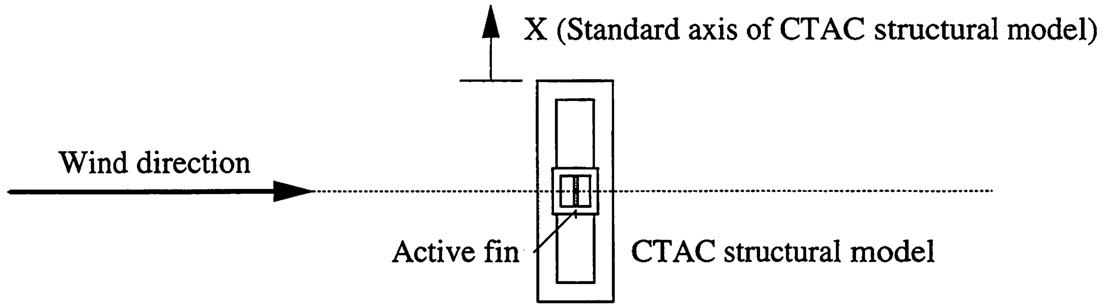
The numerical result of the displacements of the top floor is shown in Fig.5.2.6. In this figure, solid line is corresponding the numerical results of the controlled responses, and the broken line is corresponding to he experimental results of the non-controlled responses for the open mode which is the same with Fig.5.2.4 (a). By considering this numerical results, it is assured that the effective reductions of responses are gained by introducing the Control algorithm-P1(R) on the numerically simulated control manipulations of the active fin system. By comparing those numerical control effects with the experimental responses as shown in Fig.5.2.5, the numerical simulations may evaluate the controlled responses as to be a little smaller than the experimental results. As the reason for this, it may be considered that the influences of the time delay are included on the experimental tests. By the way, since it may be regarded that those conflicts are very small and it can be considered that the numerical simulations may be also introduced as the auxiliary evaluative way to investigate the control effects of the active fin system when the non-controlled structural responses are observed beforehand.

Study (5.2) - 3 :

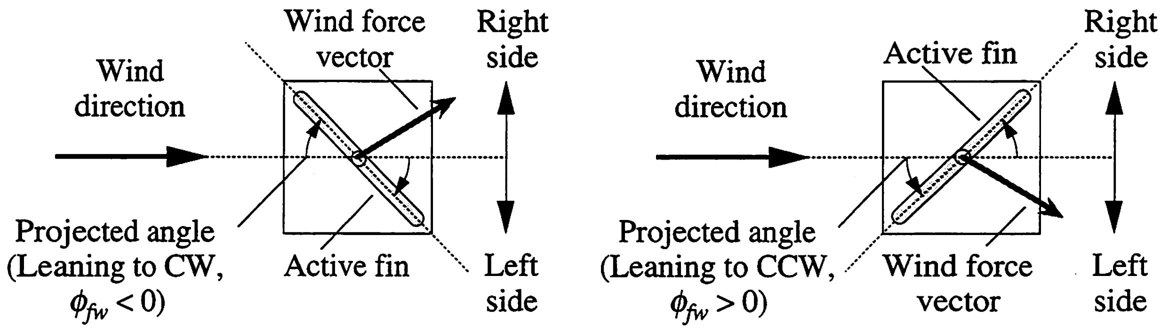
As the further considerations for the new model of the active fin system, the improved efficiencies on this type of control device as to be able to utilize the lift of the wind forces are evaluated by operating the response control on the cross-wind direction. To investigate those efficiencies of the new model of the active fin on the wind tunnel tests, the structural model on the CTAC system is located as that the vibrated axis of the structural model is adjusted to be orthogonal to the wind flow. Those installations of the structural model is shown in the Fig.5.2.7 (a). As the important notice to refer this figure, it is pointed that the horizontal two-directional coordinate is defined as that the vibrated direction of the structural model is allocated to the standard axis (the X-axis), namely, the X-direction of this coordinate is corresponded to the cross-wind direction to the wind flow in this case study.

By considering the Fig.5.2.3 (b), to generate the lift of the wind forces on the active fin, it may be appeared that the projected angle of the active fin to the wind flow should be allocated in the other configurations excepting the open mode and the closed mode. Namely, when the projected angle of the active fin is expresses as ϕ_{fw} ($-90° < \phi_{fw} \leq 90°$), it may be required that ϕ_{fw} should not be 0° and 90° to utilize the cross-wind forces. Accordingly, when the projected angle of the active fin is positioned by ϕ_{fw} ($-90° < \phi_{fw} < 0°$) of the right side (clockwise; CW) turn from the open mode, the lift of the wind forces may be appeared on the 'right side' plane as shown in Fig.5.2.7 (b).

And also, when the projected angle of the active fin is positioned by ϕ_{fw} ($0° < \phi_{fw} < 90°$) of the left side (counter clockwise; CCW) turn from the open mode, the lift of the wind forces may be appeared on the 'left side' plane as shown in Fig.5.2.7 (c). In which, the 'right side' or the 'left side' is regarded as the half-plane on the right side as the windward face or on the left side as the windward face, respectively.



(a) Top view of the structural model (location for the cross-wind response control tests),



(b) Rightward mode of the active fin, (c) Leftward mode of the active fin,

Fig. 5.2.7 Installations of the active fin system for the cross-wind response control tests.

To construct the cross-wind response control algorithm of the active fin system, it is assured that the configurations of the active fin are also selected from two patterns that are the 'rightward' mode and the 'leftward' mode as seen in Fig.5.2.7 (b) and (c), respectively. To switch those two kinds of configurations for the cross-wind response control according to both dynamic transitions of the cross-wind structural responses and the wind flow by on-line. The direction of structural vibrations are classified to right side or left side along the orthogonal direction for wind flow and those are judged from the sign of the absolute velocity of the top floor (which is equipped the active fin device) at each discrete control time step. By introducing those two kinds of configurations which are generated by the active fin, similar principal to operate response control for cross-wind direction may be introduced as much as the case for the parallel-wind direction. The basic outlines of the cross-wind response control algorithm of the active fin system are represented as following descriptions :

"When the structural model will move to left side for the windward face,
the active fin is leaned to right (CW) and generate rightward lift of wind forces, or
when the structural model will move to right side for the windward face,
the active fin is leaned to left (CCW) and generate leftward lift of wind forces".

By operating such kinds of manipulations of the active fin system, the lift of the wind forces may work as if those are control forces to reduce the cross-wind vibrations of the structural model. Namely, to make the lift of wind forces acting on the fin to the inverse orientation according to the positive or negative sign of the direction of the structural vibrations, the projected angle of the active fin should be leaned to left side (CCW) or right side (CW) by rotating the active fin, respectively. The single-directional control algorithm to reduce the structural vibrations on the cross-wind direction may be proposed as the following compositions.

Control algorithm-C1(R) :

```
If        $|\Delta x_3(\sigma)| \leq \Delta x_{min}$ ,   then , keeping before mode,
else if   $\Delta x_3(\sigma) > \Delta x_{min}$ ,      then , leftward mode,
else if   $\Delta x_3(\sigma) < \Delta x_{min}$ ,      then , rightward mode.
```

In this compositions of the Control algorithm-C1(R), the approximate absolute velocity $\Delta x_i(\sigma)$ (cm/s) and the minimum velocity level Δx_{min} are defined by Exps. (5.1.1) and (5.1.2) by referring as that the vibrated directions of the structural model are regarded as the X-direction (which is mentioned in Fig.5.2.7(a)). The Control algorithm-C1(R) can be gained by replacing a few words on the Control algorithm-P1(R).

On the response control for the cross-wind direction, it may be easily proposed the another kind of the control manipulations as to examine the implicit ability of the active fin, namely, the following control algorithm may be introduced from the point of view as that "it may be reasonable that the control algorithm can be used for 'amplifying' vibrations".

Control algorithm-C1(A) :

```
If        $|\Delta x_3(\sigma)| \leq \Delta x_{min}$ ,   then , keeping before mode,
else if   $\Delta x_3(\sigma) > \Delta x_{min}$ ,      then , rightward mode,
else if   $\Delta x_3(\sigma) < \Delta x_{min}$ ,      then , leftward mode.
```

This control algorithm can be easily gained by replacing the word 'leftward' with 'rightward' in the Control algorithm-C1(R).

The non-controlled cross-wind displacements of the top floor are shown in the Fig.5.2.8. The controlled displacements by installing the Control algorithm-C1(R) and the Control algorithm-C1(A) are shown in Fig.5.2.9 (a) and Fig.5.2.9 (b), respectively. On the installations the Control algorithm-C1(R) and the Control algorithm-C1(A) at those experimental tests, the rightward mode and the leftward mode are allocated as to be $\phi_{fw} = -45°$ and $\phi_{fw} = 45°$, respectively.

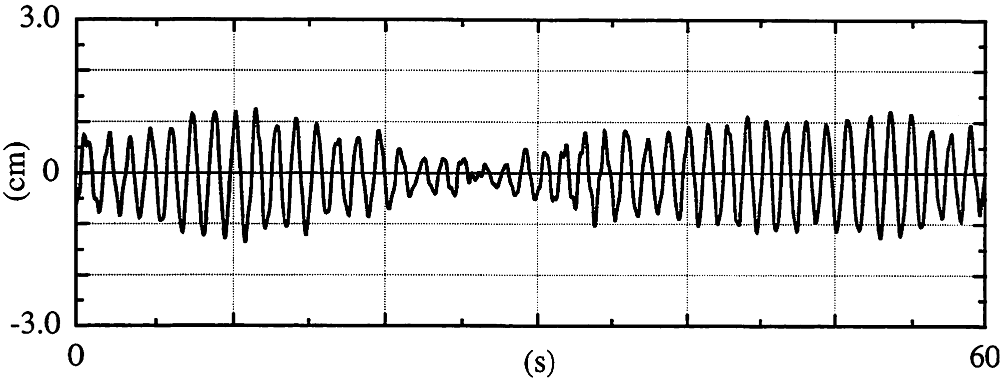
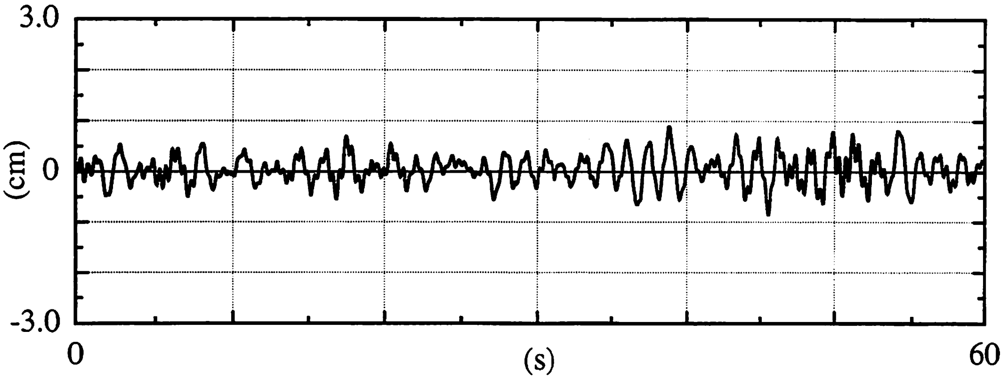
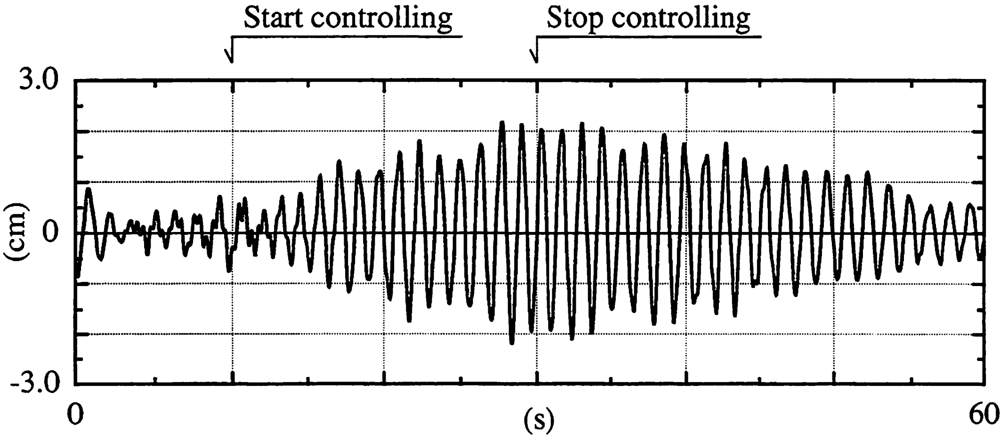


Fig. 5.2.8 Cross-wind displacements of the top floor for case without control.



(a) Case of the Control algorithm-C1(R),



(b) Case of the Control algorithm-C1(A),

Fig. 5.2.9 Cross-wind displacements of the top floor for cases with control.

By comparing the controlled responses with the non-controlled responses, it is assured that the effective reductions and the remarkable amplifications of the responses on the cross-wind directions can be actualized by introducing the Control algorithm-C1(R) and the Control algorithm-C1(A) on the new model of the active fin system, respectively. In the Fig.5.2.9 (b), the control manipulations are operated for 20 seconds from 10 (s) to 30 (s) because that the structural responses are amplified too large by using the Control algorithm-C1(A) and the control manipulations are stopped on the observing time durations. As the comparison of the response reductions on the parallel-wind and cross-wind directions, controlled responses may be deteriorated on the case for the cross-wind direction. As the reason of this, since the maximum value of the lift of wind forces may be evaluated as to be smaller than the maximum value of the drag of wind forces by considering Figs.5.2.3, it may be pointed that the shortage of the control forces affect to those results. By the way, it may be assured that the new model of the active fin can be provided the efficiency to actualize the response control on the cross-wind direction in this study.

Through the investigations in the first half of this section, the new type of the control device of the active fin system is developed and evaluated on the wind tunnel tests. As the improved efficiency to be provided on this new model of the active fin, multi-directional response control for the wind-induced structural vibrations is emphasized. By using the structural model which is vibrated on the single-direction, the fundamental efficiencies on this new model of the active fin ate investigated on both of the parallel-wind and cross-wind directions. In those cases, the control algorithm are introduced for the conditions that the direction of structural vibrations are supposed to be limited to a certain single-direction. In the next half of this section, structural vibrations are expanded to the two-direction on the horizontal plane and the control algorithm may be also modified to operate the two-directional response control by considering and utilizing the relations of the projected angles and the wind resistant force vectors acting on the fin.

5. 2. 2 Active control tests for natural wind with large-scaled model of active fin systems

To make sure of the control effects of the active fin system under the natural wind flow, the large-scaled control device of the active fin system is tested on the large-scaled experimental structure. In this study, experimental tests are executed under the conditions that the structural vibrations are caused on both of the parallel-wind and the cross-wind directions at the same time. As the first step of the large-scaled tests, emphasis is put on the constructions of the two-directional control algorithm. The control effects on the installations of the large-scaled active fin system are evaluated through the considerations for the practically measured responses of the large-scaled experimental structure under the strong natural wind flow.

The large-scaled experimental structure (18.3 (m) high and 5 × 9 (m) wide) is constructed as the 6-stories steel flame building which has a monitoring room enclosed on all sides with walls at the top story as shown in Photo.5.2.1. Total weight of this experimental structure is 154.41 (tf). The stairs tower which is located at the back side (north side) of this experimental structure is constructed by separating from the main flame. Photo.5.2.2 shows the appearance of the control device of the large-scaled active fin. The large-scaled active fin is equipped on the center of the top floor of the experimental structure. The main plate of the active fin is 2.0 (m) high, 1.0 (m) wide and 0.1 (m) thick. The rotating pole of this main plate is directly connected to the shaft of an AC servo motor, and planted along a vertical axis by joining with support flame. By rotating the active fin, the projected area of the active fin can be changed from 0.2 (m^2) (the 'open mode' which makes the minimum projected area to wind flow) to 2.0 (m^2) (the 'closed mode' which makes the maximum projected area to wind flow). The value of the maximum variations of the projected area of the active fin (which is evaluated as the difference between the open mode and the closed mode) is 1.8 (m^2), and this value is corresponding to about 12% and 7% for the projected area of the front and the side surfaces of the monitoring room, respectively.

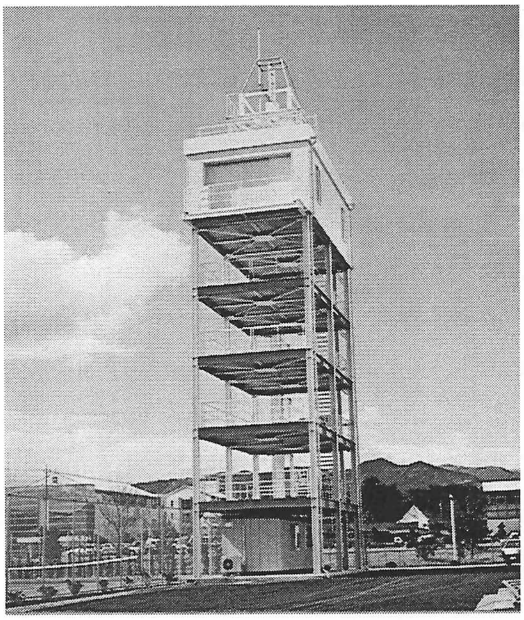


Photo. 5.2.1 Experimental structure.

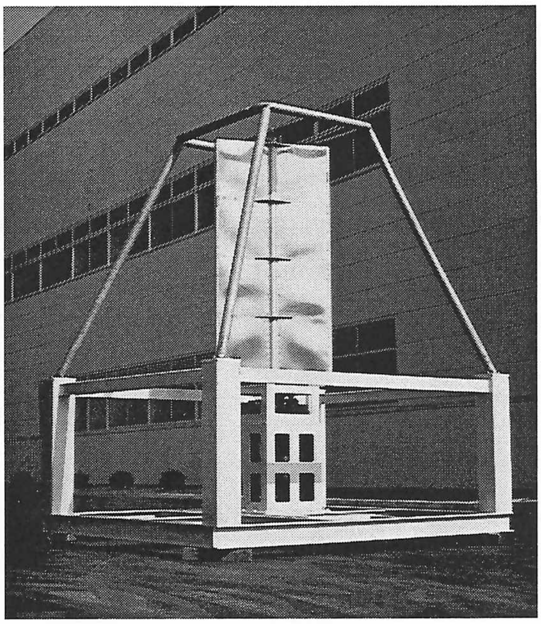


Photo. 5.2.2 Large-scaled active fin.

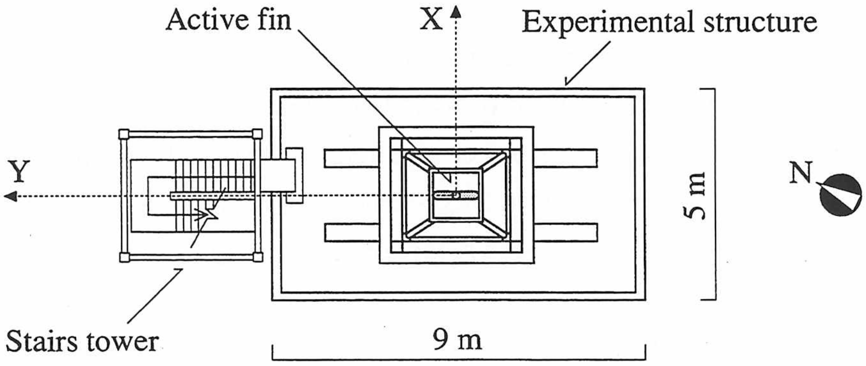


Fig. 5.2.10 Top view of the experimental structure.

The top view of the experimental structure is shown in Fig.5.2.10. The X-direction and Y-direction on a horizontal plane for this flame are allocated as to be subjected by this figure. Natural periods and dumping ratios are shown in Table 5.2.3. As shown in this table, the natural periods of both X-direction and Y-direction are computed as the quite similar values on this structure. The specifications for the manipulations of this large-scaled active fin are evaluated as the positioning intervals required to the rotated angles of the active fin as seen in Fig.5.2.11. By considering this figure, at least, it is assured that about 0.23 (s) of time interval on average is required as the control time interval to rotate the active fin, when the allowable rotated angles for every control time step are supposed as not exceeding 90°. Accordingly, on the following experimental study for the large-scaled active fin system, the time interval for each control step Δt_c is assigned as about 0.3 (s) by considering those specifications of the large-scaled active fin.

Table 5.2.3 Dynamic properties of the experimental structure.

	Natural period (s)	
	X-direction	Y-direction
1st	1.06	1.11
2nd	0.28	0.31
	Damping ratio (%)	
	X-direction	Y-direction
1st	1.0	1.0
	Projected area (Monitoring room) (m^2)	
	27.0 (East and west side)	15.0 (North and south side)

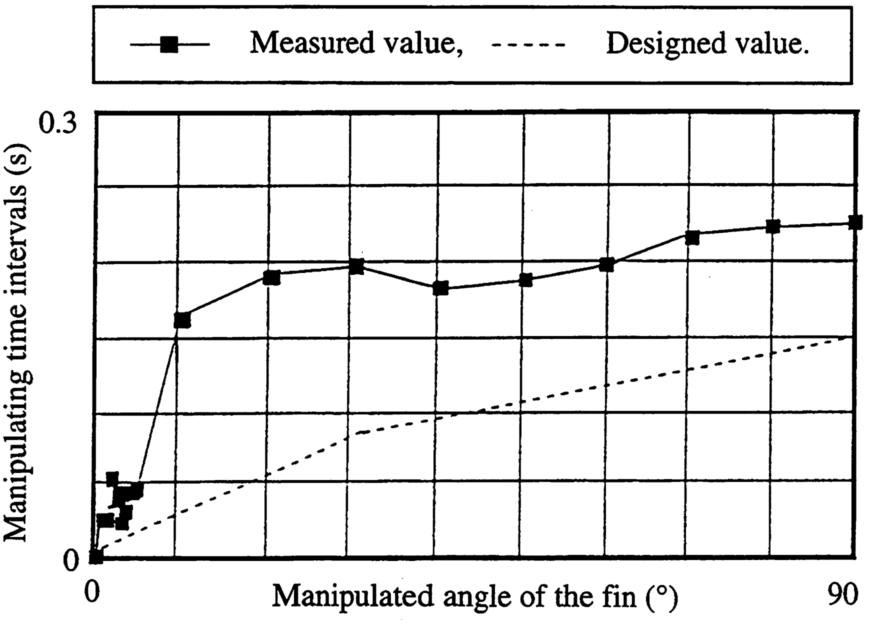


Fig. 5.2.11 Specifications on manipulations for rotating the active fin.

The configuration and the flow diagram of the large-scaled active fin system are shown in Fig.5.2.12. The velocities of the top floor and the 4th floor are measured by two-directional speedometers. The wind direction and the wind velocity are observed by a windmill anemometer equipped on the stairs tower as to be set on the almost same height with the active fin and as to be set back to about 5 (m) distance from the main plate of the active fin. Those responses and excitations data are input into computers via A/D converters. According to the control algorithm, the computer calculates increments of the rotating angle of the active fin, and then, outputs control signals to a motor driver. The active fin is directly rotated by AC servo motor.

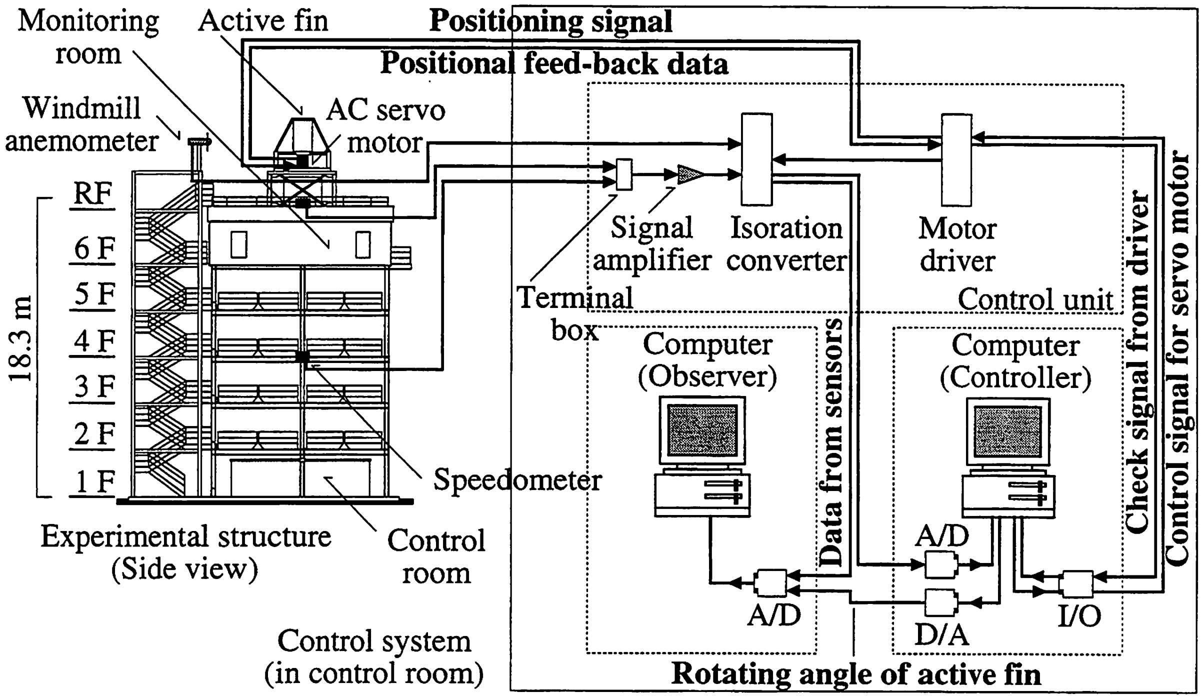


Fig. 5.2.12 Configuration and flow diagram of the active fin control system.

In order to construct the two-directional control algorithm for the active fin system, discussions may be begun to talk how to superpose the two kinds of the single-directional control algorithms for the parallel-wind direction and the cross-wind direction (which are examined in the previous studies on the wind tunnel) and how to recover for the other conditions (which are accompanied on the two-directional vibrations) as that those single-directional control algorithms can not be applied. To simplify those discussions, the following five cases may be classified as the typical conditions for the considerations on the two-directional control algorithm.

Case-1.1) The direction of the structural vibration is appeared as to go toward almost same directions of the wind flow.

Case-1.2) The direction of the structural vibration is appeared as to go toward almost opposite directions of the wind flow.

Case-1.3) The direction of the structural vibration is appeared as to go toward almost orthogonal directions of the wind flow.

Case-1.4) The direction of the structural vibration is appeared as to go toward the directions (excepting the conditions on the Case-1.1) on the half plane on the leeward side.

Case-1.5) The direction of the structural vibration is appeared as to go toward the directions (excepting the conditions on the Case-1.2) on the half plane on the windward side.

In those descriptions, the 'direction of the structural vibration' means the orientation of the top floor's velocity vector of the experimental structure, and the 'direction of the wind flow' means the orientation of the wind flow from windward to leeward. To classify approximately any states which are indicated by the structural vibrations and the wind flow into those limited kinds of conditions, the following two items are introduced as the indicates to describe the states of the wind flow and the structural vibrations.

(i) *Estimative wind direction* :

To operate the two-directional response control manipulations of the active fin under the natural wind flow, it may be required that the variations of the wind flow should be considered, and accordingly, that the states of the wind flow should be measured by on-line. However, on the measurements of the natural wind flow, it seems that the exact states of the wind flow in the vicinity of the fin may be difficult to be identified. Because, the wind flow may be disturbed by the structural equipments surrounding the vicinity of the fin and also by control movements of the active fin. Namely, unless those local variations of the wind flow are not observable, those states of the wind flow have to be macroscopically evaluated. Accordingly, the states of the wind flow are computed as the averaged quantities in the short time interval, and also, those quantities are approximately allocated to the discretized several kinds of orientations to avoid the sensitive reactions of the controllers. By using the windmill anemometer, the state of the wind flow are observed by separating to the wind velocity ζ_w (m/s) and the direction of the wind flow θ_w. In which, θ_w ($-180° < \theta_w \leq 180°$) is corresponded to the angle which is indicated with the X-direction of the experimental structure as the reference axis. Every control time interval Δt_σ is divided into the λ rounds of monitoring time interval Δt_τ , $E(\zeta_w)$ and $E(\theta_w)$ are calculated on the computer as the averaged quantities for the λ times of the monitorings during each control time interval. This averaged value of the direction of the wind flow at each control time step is approximately arranged into the nearest one of eight kinds of the clockwise orientations which are spanned by 45° from X-direction as the reference axis. This approximately arranged direction of the wind flow is used for control operations as the 'estimative wind direction' $\bar{\theta}_w$.

(ii) *Estimative vibrational direction* :

On the multi-directional response control, the 'direction of structural vibrations' is also regarded as the direction of the top floor's velocity as much as the cases for the single-directional response control algorithms. By using the two components of the velocity sensor equipped on the top floor of the experimental structure, the scalar velocities on the X-direction and the Y-direction are separately measured by every discrete control time steps. When the top floor's (6-th story's) velocity at the σ-th control time step (σ is assigned as the integer number) is directly input as $\dot{x}_6(\sigma)$ and $\dot{y}_6(\sigma)$ (cm/s) on the X-direction and the Y-direction via A/D convertors, respectively, the volume and the direction of the top floor's velocity are computed as ζ_r (cm/s) and θ_r, respectively. In which, θ_r ($-180° < \theta_r \leq 180°$) is corresponded to the angle which is indicated with the X-direction of the experimental structure as the reference axis. By introducing the λ rounds of monitoring time by every control time interval Δt_σ, $E(\zeta_r)$ and $E(\theta_r)$ are also calculated on the computer as the averaged quantities. This averaged value of the direction of the structural vibrations at each control time step is also approximately arranged into the nearest one of eight kinds of the clockwise orientations which are spanned by 45° from X-direction as the reference axis. This approximately arranged direction of the structural vibration is used for control operations as the 'estimative vibrational direction' $\bar{\theta}_r$.

By combining those estimative states of the structural vibrations and the wind flow, as the indicate to represent the classifications related to the input conditions, the following item is introduced on the two-directional control algorithm.

(iii) *Angle difference of the wind flow from the structural vibration* :

To indicate the relative difference between the estimative vibrational direction $\bar{\theta}_r$ and the estimative wind direction $\bar{\theta}_w$, the denotation for the 'angle difference of the wind flow from the structural vibration' $\bar{\phi}_{wr}$ is introduced by $\bar{\phi}_{wr} = \bar{\theta}_w - \bar{\theta}_r$. In which, $\bar{\phi}_{wr}$ is defined as to be included within the range of $\{ \bar{\phi}_{wr} \mid -180° < \bar{\phi}_{wr} \leq 180° \}$. If $\bar{\phi}_{wr}$ is calculated as to be out of this range, $\bar{\phi}_{wr}$ has to be corrected to the same phase of value which is included within this range by regarding that $\bar{\phi}_{wr}$ has cyclic properties with 360° of period. Since both of those estimative states which are indicated as the structural vibrations and the wind flow are allocated to the 8 kinds of the discretized orientations, the values of the angle difference of the wind flow from the structural vibration $\bar{\phi}_{wr}$ are limited to the 8 kinds of the classifications as $\bar{\phi}_{wr} = \{-135°, -90°, -45°, 0°, 45°, 90°, 135°, 180°\}$ (in which, the case by $\bar{\phi}_{wr} = -180°$ is regarded as the same phase with the case by $\bar{\phi}_{wr} = 180°$).

At this point, the classifications which are related to the combinations of the states of the structural vibrations and the wind flow can be approximately described by introducing the angle difference of the wind flow from the structural vibration $\bar{\phi}_{wr}$. Namely, the five items which are pointed from the Case-1.1 to Case-1.5 may be rewritten as the following conditions.

Case-2.1) The angle difference of the wind flow from the structural vibration is evaluated as to be $\bar{\phi}_{wr} = 0°$ (as corresponding to the Case-1.1).

Case-2.2) The angle difference of the wind flow from the structural vibration is evaluated as to be $\bar{\phi}_{wr} = 180°$ (as corresponding to the Case-1.2).

Case-2.3) The angle difference of the wind flow from the structural vibration is evaluated as to be $\bar{\phi}_{wr} = -90°$ or $\bar{\phi}_{wr} = 90°$ (as corresponding to the Case-1.3).

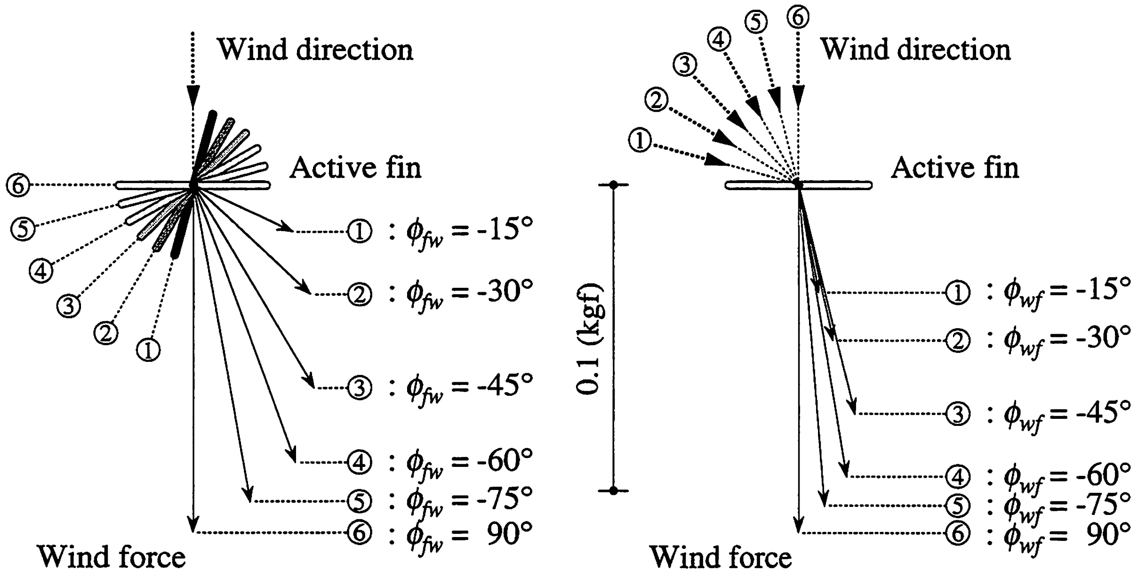
Case-2.4) The angle difference of the wind flow from the structural vibration is evaluated as to be $\bar{\phi}_{wr} = -45°$ or $\bar{\phi}_{wr} = 45°$ (as corresponding to the Case-1.4).

Case-2.5) The angle difference of the wind flow from the structural vibration is evaluated as to be $\bar{\phi}_{wr} = -135°$ or $\bar{\phi}_{wr} = 135°$ (as corresponding to the Case-1.5).

As the next step to consider the compositions of the two-directional control algorithm, discussions are moved about what kinds of configurations of the active fin are allocated by every variations of the angle difference of the wind flow from the structural vibration. To describe the positioning of the active fin, the following item is introduced.

(iv) *Direction of the active fin* :

The positioning of the active fin is indicated by the 'main axis of the active fin' which is corresponded to the longitudinal axis of the fin for the section on the horizontal plane. The 'direction of the active fin' θ_f is described as the angular coordinates based on the standard coordinate which is allocated on the experimental structure, namely, θ_f ($-90° < \theta_r \leq 90°$) is corresponded to the angle of the main axis of the active fin which is indicated with the X-direction of the experimental structure as the reference axis.



(a) Indication for projected angle ϕ_{fw}, (b) Indication for projecting direction ϕ_{wf},

Fig. 5.2.13 Estimations of wind resistant force vectors acting on the fin.

At this point, the relative relations between the directions of the wind resistant forces acting on the fin and the wind flow are evaluated according to the variations of the positioning of the active fin. For this aim, the wind resistant forces acting on the fin which are examined on the preliminary wind tunnel tests in this section are estimated again (as referring Fig.5.2.3). The states of the wind resistant force vectors acting on the fin are shown in Figs.5.2.13 (ζ_w = 8.0 (m/s)) as to be corresponded to the relations between the positionings of the active fin and the wind directions. Fig.5.2.13 (a) represents the wind resistant force vectors acting on the fin which are related to the variations of the positionings of the active fin under the fixed wind direction. In which, ϕ_{fw} is defined as the 'projected angle' of the active fin (as corresponding to the direction of the main axis of the fin) which is measured with the wind direction as the reference axis, namely, the projected angle of the active fin is expressed by $\phi_{fw} = \theta_f - \theta_w$. Fig.5.2.13 (b) represents the wind resistant force vectors acting on the fin which are related to the variations of the wind directions under the fixed positioning of the active fin. In which, ϕ_{wf} is defined as the 'projecting direction' of the wind flow which is measured with the positioning of the active fin (as corresponding to the direction of the main axis of the fin) as the reference axis, namely, the projecting direction of the wind flow is expressed by $\phi_{wf} = \theta_w - \theta_f$. As seen in Fig.5.2.13 (a), when a certain direction of the wind flow is supposed, it is assured that the wind resistant forces acting on the fin are always appeared on the inverted half plane with the surface of the active fin which is projected to the wind flow when the proper quantities of the projected angle of the active fin are supposed. Namely, in the cases that the cross-wind vibrations are dominant, it may be appropriate to select the middle positionings between the open mode ($\phi_{fw} = 0°$) and the closed mode ($\phi_{fw} = 90°$) as the configurations of the active fin. In those cases, those positionings of the active fin should be allocated as that the orientations of the structural vibrations are appeared on the front half plane with the surface of the active fin which is projected to the wind flow. As the another consideration, it may be pointed that the wind resistant force vectors may appear toward almost orthogonal directions for the main axis of the fin. Those characteristics may be explicitly observed by considering Fig.5.2.13 (b). When the active fin is allocated at a certain fixed position, it is regarded that the wind resistant force vectors can be allocated on almost orthogonal direction with the main axis of the fin under any directions of the wind flow. Namely, in any cases that the directions of the structural vibrations are not appeared along the parallel-wind or the cross-wind directions, the following items are pointed :

Point-1) When the main axis of the fin is allocated as to be parallel to the directions of the structural vibrations, the wind resistant force vectors may be almost orthogonally avert from this direction.

Point-2) When the main axis of the fin is allocated as to be orthogonal to the directions of the structural vibrations, the wind resistant force vectors may be almost parallel generated to this direction.

Those results may be utilized for the specified conditions which are accompanied on the two-directional vibrations and which can not be supposed by the two kinds of the single-directional control algorithms (which are mentioned on the previous studies). As the final step to construct the two-directional control algorithm of the active fin system, the five kinds of the configurations of the active fin are allocated by every classifications which are pointed from the Case-2.1 to Case-2.5 (which are described as to be related to the conditions of the angle difference of the wind flow from the structural vibration $\bar{\phi}_{wr}$). To describe those configurations of the active fin, the following two indicates are introduced for the two-directional control algorithm.

(v) *Referential angle of the active fin* :

To indicate the configurations according to the positionings of the active fin as to be related to the estimative states of the structural vibrations and the wind flow, the 'referential angle of the active fin' $\bar{\phi}_{fr}$ is introduced as the angle difference of the direction of the active fin θ_f from the estimative vibrational direction $\bar{\theta}_r$. In which, $\bar{\phi}_{fr}$ has the variations within the range of $\{\ \bar{\phi}_{fr}\ |\ -90° < \bar{\phi}_{fr} \leq 90°\}$.

(vi) *Windage angle of the active fin* :

As the another view point to describe the configurations of the active fin, the 'windage angle of the active fin' $\bar{\phi}_{fw}$ is introduced as the angle difference of the direction of the active fin θ_f from the estimative wind direction $\bar{\theta}_w$. In which, $\bar{\phi}_{fw}$ has the variations within the range of $\{\ \bar{\phi}_{fw}\ |\ -90° < \bar{\phi}_{fw} \leq 90°\}$.

The following five rules are expressed as the main components of the two-directional control algorithm of the active fin system. Those descriptions are considered as the arrangements of the referential angle of the active fin $\bar{\phi}_{fr}$ according to variations for the angle difference of the wind flow from the structural vibration $\bar{\phi}_{wr}$.

Rule-1) When the input conditions is evaluated as $\bar{\phi}_{wr} = 0°$ (as corresponding to the Case-2.1), the active fin is configured with $\bar{\phi}_{fr} = 0°$. This manipulation is corresponded to the case that the open mode is allocated on the single-directional control algorithm for the parallel-wind direction.

Rule-2) When the input conditions is evaluated as $\bar{\phi}_{wr} = 180°$ (as corresponding to the Case-2.2), the active fin is configured with $\bar{\phi}_{fr} = 90°$. This manipulation is corresponded to the case that the closed mode is allocated on the single-directional control algorithm for the parallel-wind direction.

Rule-3) When the input conditions is evaluated as $\bar{\phi}_{wr} = -90°$ or $\bar{\phi}_{wr} = 90°$ (as corresponding to the Case-2.3), the active fin is configured with $\bar{\phi}_{fr} = -45°$ or $\bar{\phi}_{fr} = 45°$, respectively. Those manipulations are corresponded to the cases that the leftward mode (the active fin is allocated as $\bar{\phi}_{fw} = 45°$ by the condition under $\bar{\phi}_{wr} = -90°$ and $\bar{\phi}_{fr} = -45°$) or the rightward mode (the active fin is allocated as $\bar{\phi}_{fw} = 45°$ by the condition under $\bar{\phi}_{wr} = -90°$ and $\bar{\phi}_{fr} = -45°$) is allocated on the single-directional control algorithm for the cross-wind direction.

Rule-4) When the input conditions is evaluated as $\bar{\phi}_{wr} = -45°$ or $\bar{\phi}_{wr} = 45°$ (as corresponding to the Case-2.4), the active fin is configured with $\bar{\phi}_{fr} = 0°$. Those manipulations are introduced by considering the Point-1 which is suggested through the evaluations for the relations between the positionings of the active fin and the wind directions.

Rule-5) When the input conditions is evaluated as $\bar{\phi}_{wr} = -135°$ or $\bar{\phi}_{wr} = 135°$ (as corresponding to the Case-2.5), the active fin is configured with $\bar{\phi}_{fr} = 90°$. Those manipulations are introduced by considering the Point-2 which is suggested through the evaluations for the relations between the positionings of the active fin and the wind directions.

Those five kinds of rules for the control manipulations of the active fin system are illustrated on the Fig.5.2.14 and Fig.5.2.15. Fig.5.2.14 is corresponding to the illustrations for the configurations of

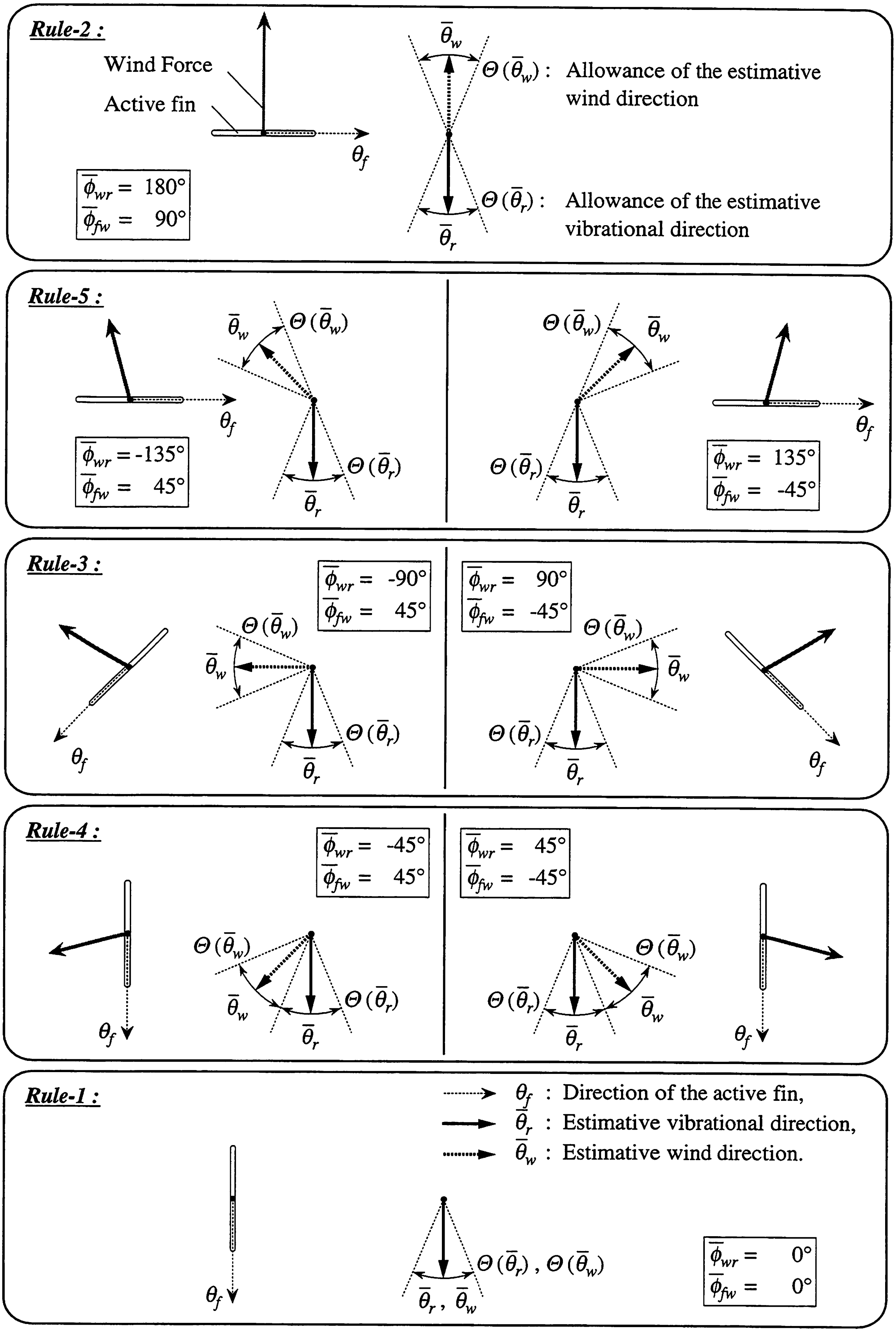


Fig. 5.2.14 Configurations of the active fin related to the variations of the wind flow.

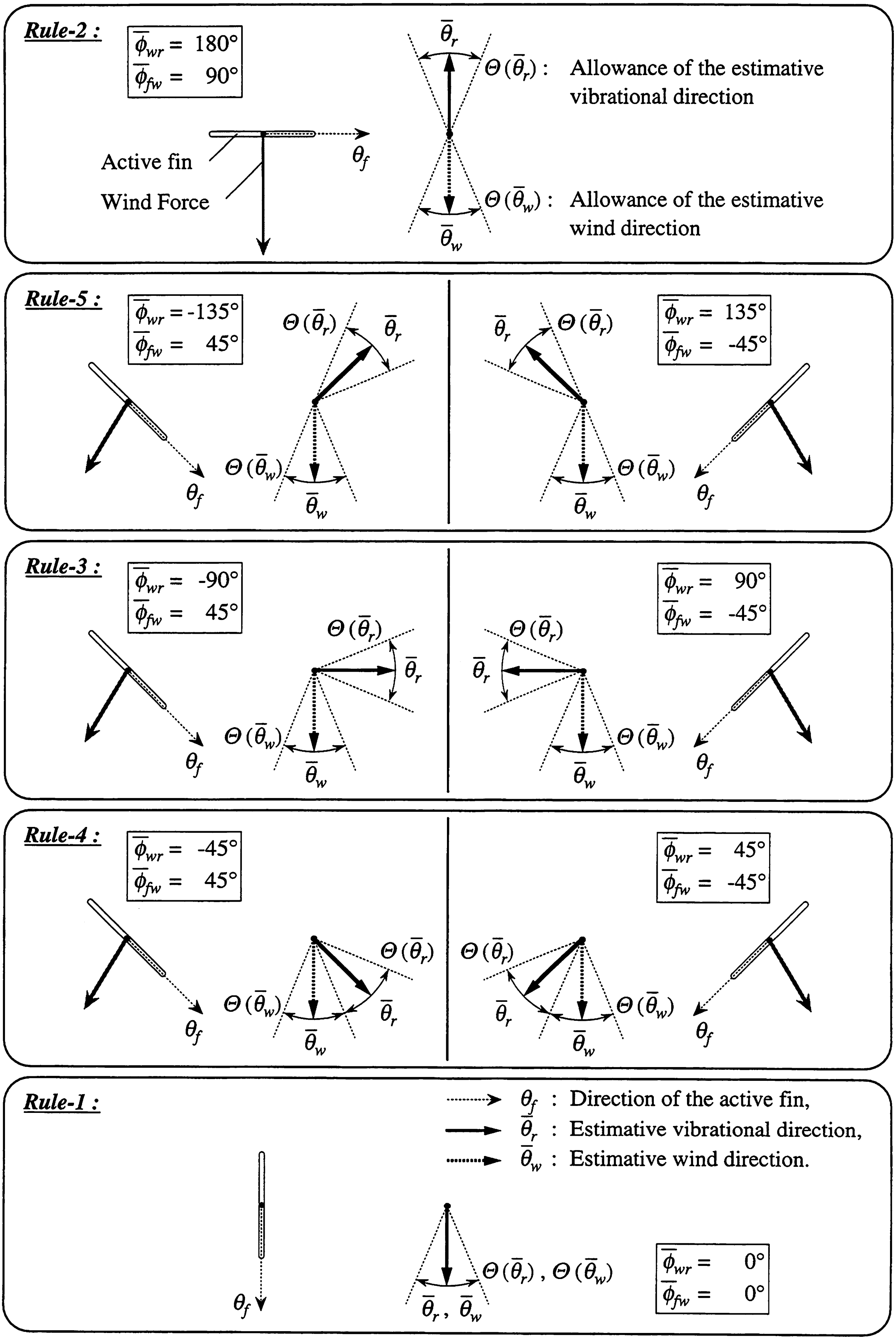


Fig. 5.2.15 Configurations of the active fin related to the variations of the structural vibrations.

the active fin related to the variations of the orientations of the wind flow (which is expressed from the view point of the fixed orientations of the structural vibrations). Fig.5.2.15 is corresponding to the illustrations for the configurations of the active fin related to the variations of the orientations of the structural vibrations (which is expressed from the view point of the fixed orientations of the wind flow). As seen in Fig.5.2.14, it may be confirmed that the control manipulations of the active fin system are operated as to drag the wind force vectors acting on the fin from the orientations of the structural vibrations under the installations of those five kinds of rules. In this figure, the eight kinds of configurations of the active fin are mentioned by the indicates related to the referential angle of the active fin. On the other hand, when the another indicate related to the windage angle of the active fin are used, it may be assured that those configurations of the active fin can be classified into only four kinds as seen in Fig.5.2.15. Accordingly, those four kinds of configurations of the active fin are defined as the following items.

Mode-1) *Estimative open mode* :

The main axis of the active fin is allocated as to be parallel to the estimative wind direction, namely, the windage angle of the active fin $\bar{\phi}_{fw}$ is supposed as to be 0°.

Mode-2) *Estimative closed mode* :

The main axis of the active fin is allocated as to be orthogonal to the estimative wind direction, namely, the windage angle of the active fin $\bar{\phi}_{fw}$ is supposed as to be 90°.

Mode-3) *Estimative rightward mode* :

The main axis of the active fin is allocated as to be projected to the estimative wind direction by turning to the rightward (CW), namely, the windage angle of the active fin $\bar{\phi}_{fw}$ is supposed as to be -45°.

Mode-4) *Estimative leftward mode* :

The main axis of the active fin is allocated as to be projected to the estimative wind direction by turning to the leftward (CCW), namely, the windage angle of the active fin $\bar{\phi}_{fw}$ is supposed as to be 45°.

By introducing those four kinds of the configurations of the active fin, the two-directional control algorithm to reduce the structural vibrations may be proposed as the following compositions.

Control algorithm-2(R) :

```
If       $\zeta_r \leq \zeta_{r,min}$ or $\zeta_w \leq \zeta_{w,min}$,
                                   then , keeping before mode,
else if  $\bar{\phi}_{wr} = 180°$,  then , estimative closed mode,
else if  $\bar{\phi}_{wr} = 0°$,    then , estimative open mode,
else if  $\bar{\phi}_{wr} > 0°$,    then , estimative rightward mode,
else if  $\bar{\phi}_{wr} < 0°$,    then , estimative leftward mode.
```

In which, zr_{min} and $\zeta_{w,\,min}$ are used as the trigger level for the volumes of the structural responses and the wind velocities, respectively. Those quantities are introduced as to avoid the sensitive reactions of control manipulations. On the experimental tests, those values are supposed as 0 (cm/s) of the top floor's velocity and 0.01 (m/s) of the wind velocity on the experimental tests, respectively. Namely, the trigger level for the structural vibrations is omitted and the trigger level for the wind velocities is corresponded to the one digit for the discretized input signal from the windmill anemometer via A/D convertor. In this control algorithm, the windage angle of the active fin $\bar{\phi}_{fw}$ is used as the indicate to allocate the configurations of the active fin which can generate the adequate control forces by referring the angle difference of the structural vibrations to wind flow $\bar{\phi}_{wr}$. To generate the output signal to manipulate the active fin at every control time step, the direction of the active fin θ_f is calculated as to the absolute positioning of the fin which is related to the standard coordinate. Since θ_f is determined by $\theta_f = \bar{\phi}_{fw} + \bar{\theta}_w$ and defined as to be included within the range of $\{\theta_f \mid -90° < \theta_f \le 90°\}$. If θ_f is calculated as to be out of this range, θ_f has to be corrected to the same phase of value which is included within this range by regarding that θ_f has cyclic properties with 180° of period. Namely, θ_f is supposed by the only four kinds of positions as $\theta_f = \{-45°, 0°, 45°, 90°\}$.

As the another kind of evaluations to ensure the implicit ability of the large-scaled active fin system, the following two-directional control algorithm is also examined from the point of view as that "it may be reasonable that the control algorithm can be used for 'amplifying' vibrations". For this aim, the following algorithm is introduced.

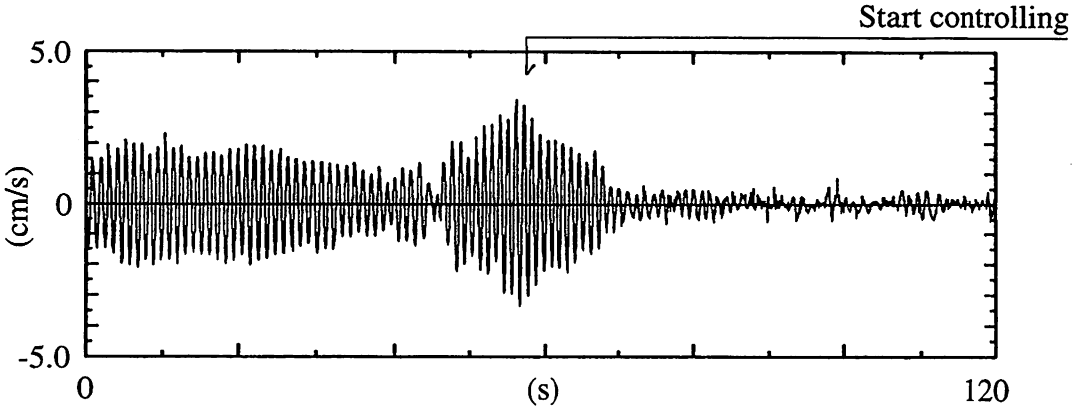
Control algorithm-2(A) :

```
If        $\zeta_r$          ≤   $\zeta_{r,\,min}$  or  $\zeta_w$   ≤   $\zeta_{w,\,min}$ ,
                                         then , keeping before mode,
else if   $\bar{\phi}_{wr}$   =   180°,   then , estimative open mode,
else if   $\bar{\phi}_{wr}$   =     0°,   then , estimative closed mode,
else if   $\bar{\phi}_{wr}$   >     0°,   then , estimative leftward mode,
else if   $\bar{\phi}_{wr}$   <     0°,   then , estimative rightward mode.
```

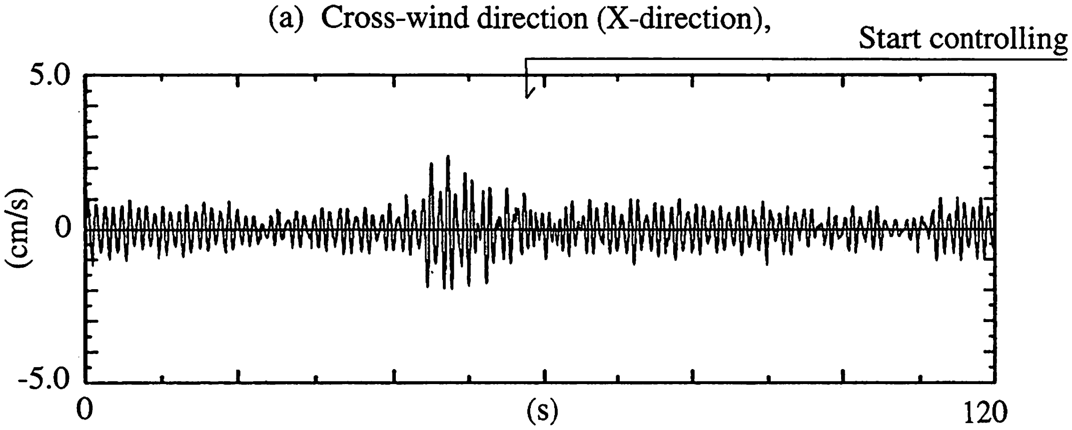
This control algorithm can be easily gained by replacing between the words 'open' and 'closed' and by replacing between the words 'leftward' and 'rightward' in the Control algorithm-2(R).

Study (5.2) - 4 **:**

The natural wind tests are executed under the practical strong wind flow. The mean of the wind velocity is measured about 15 (m/s) ± about 10 (m/s) and the wind directions are observed on average as to be closed to the north-west (± about 45°) which is corresponded to the almost same orientation with the Y-direction of the experimental structure. The two-directional control algorithm mentioned above are investigated. Velocities of the top floor are shown in Figs.5.2.16 and Figs.5.2.17 as the control effects on the installations of the Control algorithm-2(R) and the Control algorithm-

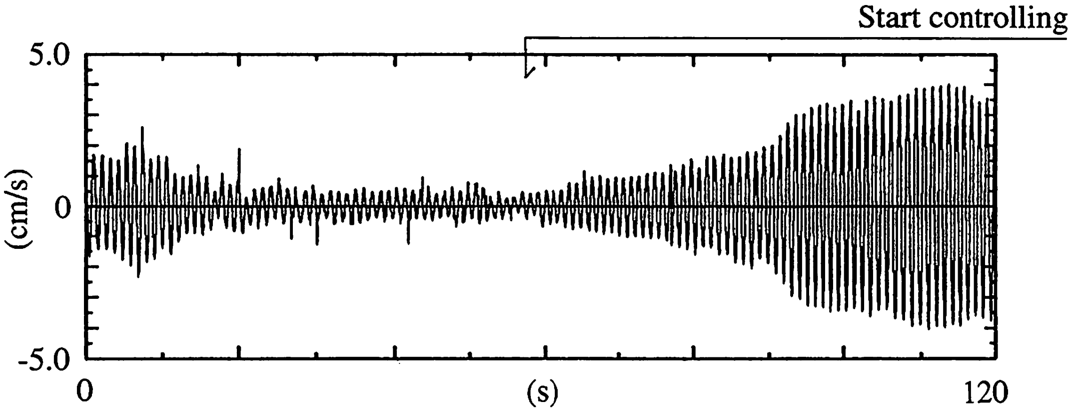


(a) Cross-wind direction (X-direction),

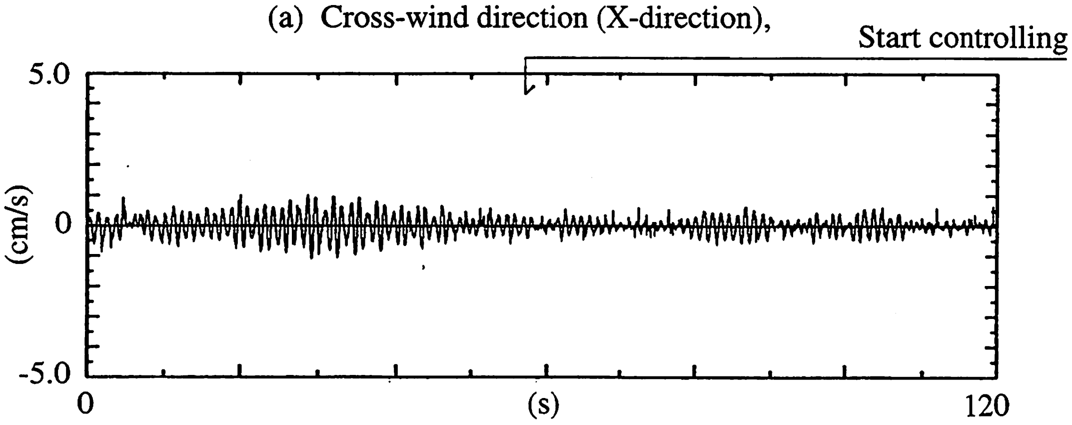


(b) Parallel-wind direction (Y-direction),

Fig. 5.2.16 Velocities of the top floor on the case of Control algorithm-2(R).



(a) Cross-wind direction (X-direction),

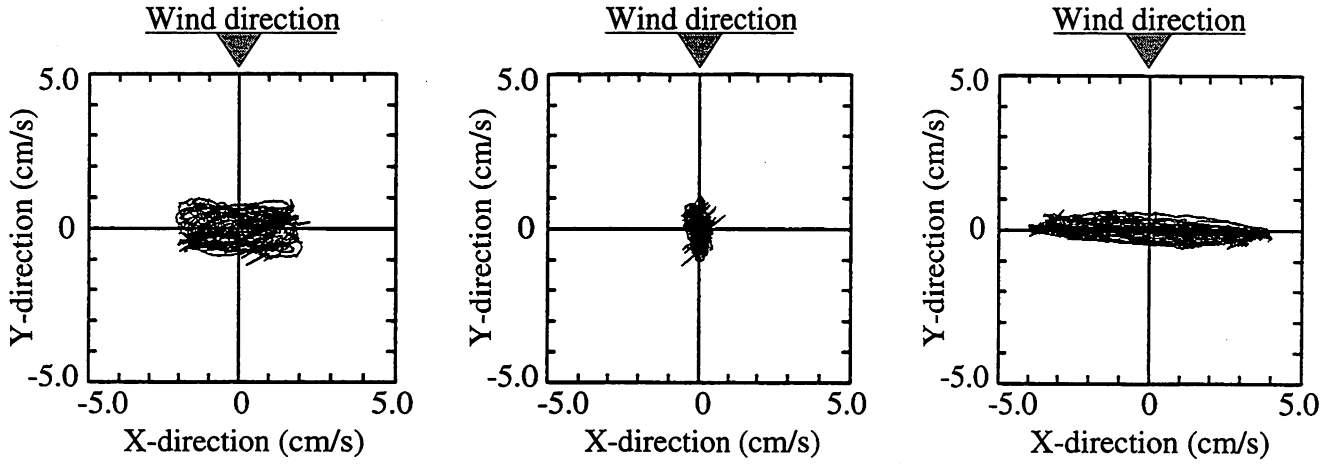


(b) Parallel-wind direction (Y-direction),

Fig. 5.2.17 Velocities of the top floor on the case of Control algorithm-2(A).

2(A), respectively. In those figures, the first half of the time histories shows the non-controlled responses, and the latter half shows the controlled responses, respectively.

As seen in Figs.5.2.16, effective reductions of the responses can be gained for the cross-wind direction by introducing the Control algorithm-2(R). However, the effectiveness by the control manipulations may not be observed on the parallel-wind direction. As seen in Figs.5.2.17, it is assured that expected amplifying effects can be gained on the cross-wind direction, by introducing the Control algorithm-2(A). In this case, the influences by the control manipulations may not be also on the parallel-wind direction. Those results may be explicitly assured by considering the trajectories of the velocities of the top floor as shown in Figs.5.2.18. In those figures, (a), (b) and (c) are corresponding the cases for the non-controlled responses , the controlled responses by the Control algorithm-2(R) and the controlled responses by the Control algorithm-2(A), respectively. By comparing those figures, it may be regarded that the control effects of the active fin system may be appeared on the almost the cross-wind directions by installing the two-directional control algorithms which are mentioned in this section.



(a) Without control, (b) Control algorithm-2(R), (c) Control algorithm-2(A),

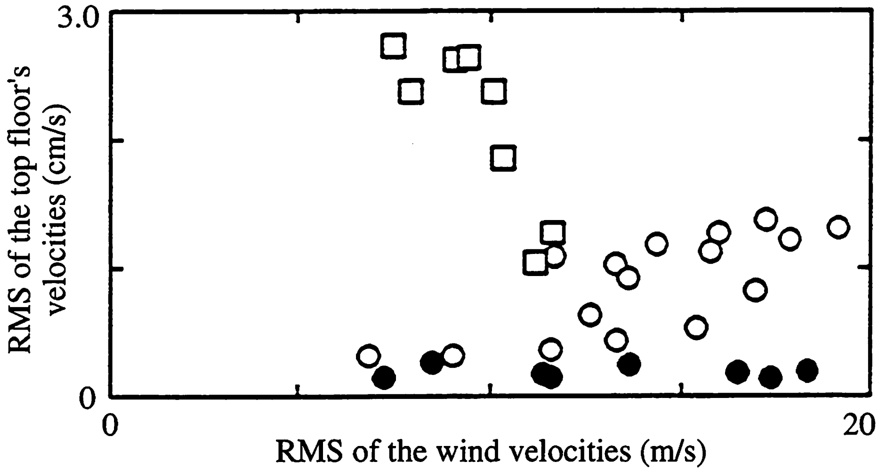
Fig. 5.2.18 Trajectories of the velocities of the top floor.

Table 5.2.4 RMS values of the velocities of the top floor.

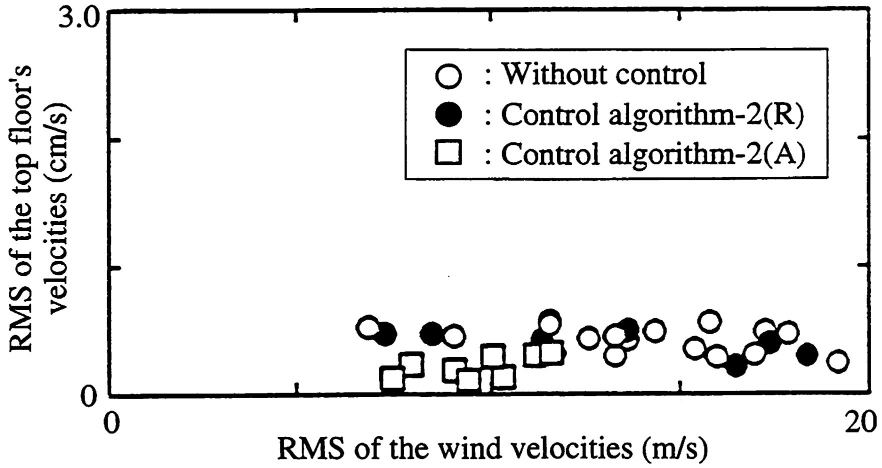
Observing case	Manipulation	Velocities of the top floor (cm/s)	
		X-direction	Y-direction
Control algorithm-2(R)	Non-control : 0 - 40 (s)	1.12	0.44
	Control : 80 -120 (s)	0.19 (17%)	0.43 (98%)
Control algorithm-2(A)	Non-control : 0 - 40 (s)	0.74	0.41
	Control : 80 -120 (s)	2.20 (297%)	0.23 (55%)

The RMS (Root Mean Square) values of the top floor's velocities (which are corresponding to those experimental results as shown in Figs.5.2.16 and Figs.5.2.17) are shown in Table 5.2.4.

When the Control algorithm-2(R) is installed, the RMS values of the controlled velocities of the top floor are reduced into about 17% for the cross-wind direction. And also, when the Control algorithm-2(A) is installed, the RMS values of the controlled velocities of the top floor are amplified into about 297% for the cross-wind direction. However, any reductions or amplifications may not be observed for both of the controlled responses on the parallel-wind direction by using those two kinds of control algorithms.



(a) RMS of the cross-wind velocities on the top floor (X-direction),



(b) RMS of the parallel-wind velocities on the top floor (Y-direction),

Fig. 5.2.19 Control effects evaluated by the RMS values.

Moreover, the relations between RMS values of the structural responses and the RMS values of the wind velocities are evaluated on the cross-wind and the parallel-wind direction, separately. Figs.5.2.19 show the relations between the RMS values of the volumes of the wind velocities and the RMS values of the top floor's velocities on the X-direction and the Y-direction. In which, each marked plots is corresponded to the RMS values by every 5 seconds (which are evaluated from the experimental results as shown in Fig. 5.2.16 and Figs.5.2.17). In Figs.5.2.19, (a) and (b) are corresponded to the cross-wind components and the parallel-wind components for the top floor's velocities of the experimental structure, respectively. As seen in Fig.5.2.19 (a), the remarkable reductions of the controlled responses can be observed for the cases of the Control algorithm-2(R) and the remarkable amplifications of the controlled responses can be observed for the cases of the Control algorithm-2(A), by the comparisons with the non-controlled responses. However, it may be confirmed that the explicit controlled effects by introducing those two kinds of control algorithms are not observed on the parallel-wind direction as seen in Fig.5.2.19 (b).

Accordingly, it may be regarded that the control effects by installing the two-directional control algorithm proposed in this section are remarkably effective for manipulating responses of the cross-wind direction. It may be considered that the reason of this phenomenon depends on rounding off the directions of the wind flow or the structural vibrations. Namely, by considering Fig.5.2.15, it seems that the cross-wind components of the wind forces may be strictly generated as to be allocated on the inverted orientations to the structural vibrations, while the variations for the parallel-wind components of the wind forces may become insensitive owing to those rounding off operations.

As concluding remarks in this section, to apply the active fin system for the two-directional response control, the newly designed control device is proposed in this section. At first, this new model of the active fin is examined on the wind tunnel, it is assured that this type of control device of the active fin is also provided the effective control efficiency as much as the pilot model of the active fin system. As the next step, the two-directional control algorithms are newly constructed, and the control operations by using this control algorithms are evaluated on the large-scaled active fin system which is installed to the large-scaled experimental structure. The fundamental efficiency of the two-dimensional control algorithm of the active fin system are investigated under the strong natural wind flow. As a result, it can be regarded that those control algorithm mentioned in this section can be available for controlling responses of the cross-wind direction induced by wind, and moreover, that those control algorithm adopted here are fairly effective for this aim.

5. 3 Investigation of multi-directional control algorithm of active fin systems

The control device of the active fin system is modified in the Section 5.2 to operate the multi-directional response control by utilizing the wind flow for any directions on the horizontal plane. This newly designed control device of the active fin is investigated on the wind tunnel and the effectiveness for the single-directional response control are assured on both the parallel-wind and the cross-wind directions. By considering the conditions of the wind force vectors generated by the active fin, those two kinds of single-directional response control algorithms are superposed and expanded for composing the two-directional response control algorithm. The two-directional response control algorithm of the active fin system is evaluated on the large-scaled experimental system under the strong natural wind flow. For this aim, the large-scaled control device of the active fin is constructed and this control device is installed on the large-scaled experimental structure. Through the large-scaled active control tests, it is assured that this two-directional control algorithm can effectively control the structural responses appeared on the cross-wind direction. However, the structural vibrations caused on the parallel-wind direction are not observed as to be controlled by this two-directional control algorithm proposed in the Section 5.2. As the reason of this, it may be considered that the indicates for the directions of structural vibrations and wind flow are simplified on this control algorithm. In this section, the mechanical properties of the wind forces acting on the fin are evaluated from the another view point and the two-directional control algorithm for the active fin system is reconstructed to improve the control performances of the active fin in the sense of the multi-directional active control algorithm.

As the first half of this section, the two-directional control algorithm is newly proposed as to aim for improving the control efficiencies on the parallel-wind direction. Emphasis is put on the considerations for the adequate allocations of the variations of the drag of the wind forces according to the structural responses on the parallel-wind directions. By evaluating the 'offset' of the wind resistant forces acting on the fin, the newly proposed two-directional control algorithm of the active fin system can be expressed as the explicitly reasonable rules. By using the large-scaled experimental system, this new type of two-directional control algorithm is investigated under the natural wind flow. Those large-scaled active control tests are executed for the two kinds of operations which are aimed to reduce and to amplify the structural vibrations. Those operations are based on the two type of variations of the newly installed two-directional control algorithm. Through those examinations, the significant problems may be appeared. Namely, although the reductions or the amplifications of the structural vibrations can be gained on both the cross-wind and the parallel-wind directions at the same time by introducing either one of those variations of the control algorithm, each control effect which is actualized by every variations of control algorithm is inverted from the expected control efficiencies.

On the latter half of this section, to verify those experimental results observed on the large-scaled active control tests, the wind tunnel tests are executed. For this aim, the new type of the experimental structural model for the CTAC system is developed as to be able to operate the two-directional response control tests. Accordingly, this structural model is designed as to be able to be vibrated for any directions on the horizontal plane. At first, by using the newly installed two-directional control algorithm proposed in this section, the reappearances of those controlled behaviors which are observed on the large-scaled active fin system are examined on the small-scaled testing apparatus at the wind tunnel. Through the wind tunnel active control tests, it is assured that the similar controlled behaviors on the small-scaled active fin system are also observed by using this newly proposed two-directional control algorithm. By considering those experimental results which are reappeared on the wind tunnel tests, discussions may be reached to the point that those control effects may be subjected by significant influences from the time delay which are caused by the growth of the wind forces according to switching the configurations of the active fin.

5. 3. 1 Installation of new control algorithm and large-scaled active control tests

Through the previous studies in the Section 5.1 and the Section 5.2, the fundamental abilities of the active fin system are evaluated in the sense to operate the active response control for the wind -induced structural vibrations. As the remarkable results from those studies, it may be pointed that the active fin system can be controlled for any directions of the structural vibrations by utilizing any directions of the wind flow, even if the structural vibrations are supposed as to be dominant on the specified single direction. Those knowledges are reached from the considerations for the single-directional active response control tests on the wind tunnel by installing the single-directional response control algorithms. On the other hand, the large-scaled experimental tests are executed as the first evaluations for the practical applications of the active fin system under the conditions subjected by the natural wind flow, and the fundamental installations of the two-directional control algorithm are investigated in the Section 5.2. Those large-scaled active control tests are operated on the large-scaled experimental structure. At this point, significant problems on the installations of the two-directional control algorithm are appeared, namely, the two-directional control algorithm which is proposed in the Section 5.2 may be only effective for controlling the structural responses caused on the cross-wind direction. Those results may be very interested in the meanings that the response control on the orthogonal direction by utilizing the wind flow are effectively actualized by the installations of the active fin system. However, in the sense of the multi-directional response control, the further considerations for the two-directional control algorithm may be required because that those control manipulations are regarded as to be in compensation for sacrificing the response control on the parallel-wind direction.

In this section, to reconstruct the two-directional control algorithm of the active fin system, discussions may be begun to consider for the configurations of the active fin as that the modulations of the parallel-wind forces are effectively applied. For this aim, the wind resistant force vectors acting on the fin are evaluated again. Let denote $\boldsymbol{F}_f(\phi_{fw}, \theta_w)$ as the wind force vector according to a certain projected angle of the active fin ϕ_{fw} (in which, θ_w means the orientation of the wind flow), and let denote $\phi_{cw}(\phi_{fw})$ as the angle difference of the wind force vector which is referred to the wind flow. The orientation of the wind force vector as the angular coordinate based on the standard coordinate which is allocated on the experimental structure can be described by $\theta_c\ (\phi_{fw},\ \theta_w) = \phi_{cw}\ (\phi_{fw}) + \theta_w$. As seen in Figs.5.2.3 in the Section 5.2, according to the variations of the positioning of the active fin, the drag of the wind forces are appeared on the single side to the leeward, while the lift of the wind forces are appeared on the both sides to the leftward and the rightward for the wind direction. Namely, the wind force vectors which are generated by the active fin may be considered as to be allocated only on the half side of the leeward on the horizontal plane (as also seen in Fig.5.2.13 in the Section 5.2).

At this point, as the fundamental mechanism of the response control for the parallel-wind direction on the active fin system, it may be pointed that the minimum and the maximum drag of the wind forces (which are actualized by the configurations of the active fin according to the open mode and the closed mode, respectively) are utilized as the control forces for the positive and the negative directions of the structural vibrations toward the wind flow. So that, it may be reasonable that those variations of the minimum and the maximum volumes of the drag of the wind forces are considered as to be related to the quasi-positive and the quasi-negative states which are referred for the neutral state as the middle volume for the range of the drag of the wind forces from the open mode to the closed mode. Accordingly, by considering the 'offset of the wind force vector' as to be allocated for this neutral state of wind force, the sign of the drag of the wind forces are introduced and the coordinate of the 'compensative wind force' vectors corresponding to the various configurations of the active fin are evaluated as shown in Fig.5.3.1 ($\zeta_w = 8.0$ (m/s)).

As seen in this figure, the offset of the wind force vector is introduced as the middle volume of wind forces for the maximum drags along to windward. When this offset of the wind force vector is denoted as $\boldsymbol{F}_{f,\,o}\,(\theta_w)$, the compensative wind force vector $\hat{\boldsymbol{F}}_f\ (\phi_{fw},\ \theta_w)$ is expressed as the following expressions,

$$\hat{\boldsymbol{F}}_f\ (\phi_{fw},\ \theta_w) = \boldsymbol{F}_f(\phi_{fw},\ \theta_w) + \boldsymbol{F}_{f,\,o}\,(\theta_w),$$

$$\boldsymbol{F}_{f,\,o}\,(\theta_w) = -\,(1/2)\cdot \boldsymbol{F}_f(\,90^\circ,\ \theta_w\,). \tag{5.3.1}$$

By considering Fig.5.3.1, the significant relations among the compensative wind force vector, direction of the wind flow and the positioning of the active fin may be appeared. Namely, it may be assured that the orientations of the wind flow and the compensative wind force are appeared as to be almost symmetrical for the normal direction of the main axis of the active fin. To be explicitly explained this mechanical characteristic, it may be convenient that the 'normal projected angle' of the active fin is introduced as the description for the positioning of the active fin instead of the projected angle of the active fin. This normal projected angle of the active fin ϕ'_{fw} is expressed by the orientation of the 'minor axis' of the active fin as follow,

$$\phi'_{fw} = \begin{cases} \phi_{fw} - 90^\circ, & (\,0^\circ < \phi_{fw} \leq 90^\circ), \\ \phi_{fw} + 90^\circ, & (\,-90^\circ < \phi_{fw} \leq 0^\circ). \end{cases} \tag{5.3.2}$$

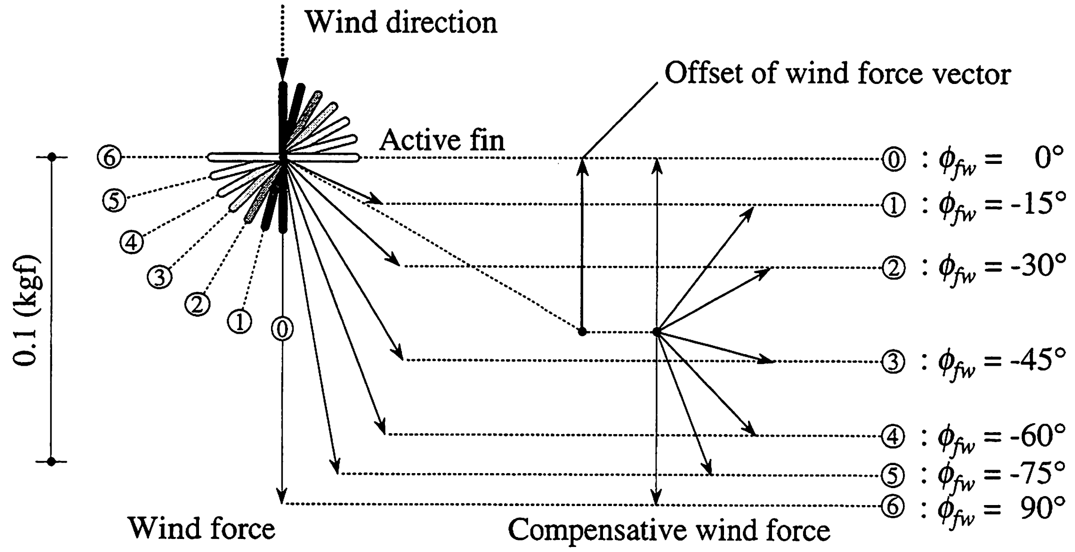
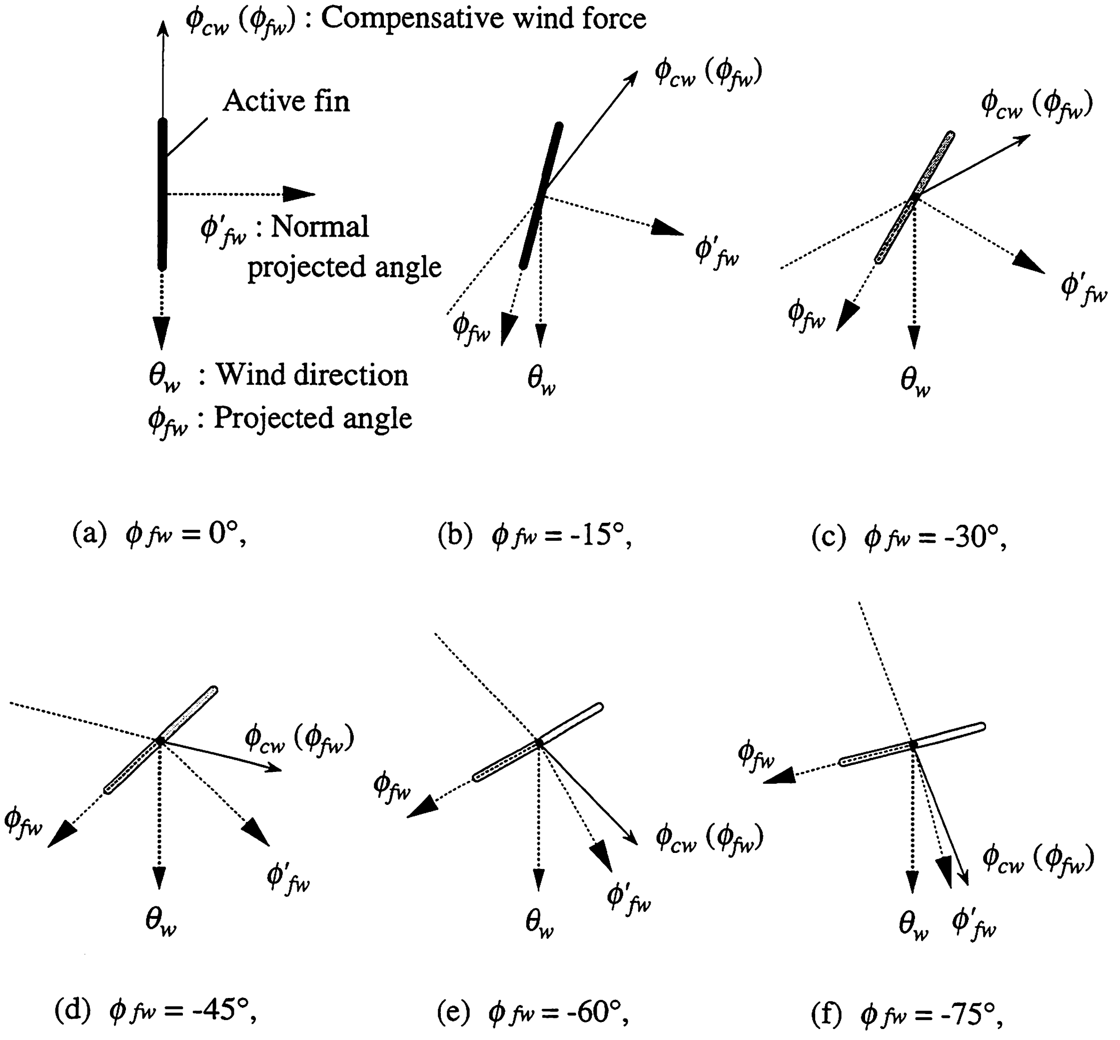


Fig. 5.3.1 Compensative wind force vectors by referring the offset of the wind force.



(a) $\phi_{fw} = 0°$, (b) $\phi_{fw} = -15°$, (c) $\phi_{fw} = -30°$,

(d) $\phi_{fw} = -45°$, (e) $\phi_{fw} = -60°$, (f) $\phi_{fw} = -75°$,

Fig. 5.3.2 Relations for the orientations of the wind flow and the compensative wind force.

By introducing the normal projected angle of the active fin ϕ'_{fw}, the relations for the orientations of the wind flow and the compensative wind force are represented in Figs.5.3.2. In which, when the projected angle of the active fin is supposed by $\phi_{fw} = 90°$, both of the normal projected angle ϕ'_{fw} and the direction of the compensative wind force $\phi_{cw}(\phi_{fw})$ may become 0° and those orientations are agreed to the wind direction.

As seen in Figs.5.3.2, when a certain orientation of the wind flow θ_w is supposed, it may be assured that the angle difference of the wind force vector from the wind flow $\phi_{cw}(\phi_{fw})$ can be always allocated as the almost twice quantity for the normal projected angle of the active fin ϕ'_{fw} from the macroscopical view. By considering this approximate relations between the positioning of the active fin and the generated wind force vector (which are referred for the compensative coordinate), discussions can be reached to the reconstructions of the new type of the two-directional control algorithm. As the fundamental compositions of the two-directional control algorithm, it may be suggested that the positioning of the active fin are manipulated as that the direction of the compensative wind force vectors can be always arranged as to be parallel to the direction of the structural vibrations. Accordingly, the compensative wind force vectors should be generated as to be inverse for the orientations of the structural vibrations to reduce the structural responses, and also, the compensative wind force vectors should be generated as to be same for the orientations of the structural vibrations to amplify the structural responses. By introducing the considerations for Fig.5.3.1 and Figs.5.3.2, those manipulations are actualized by selecting the conflagrations of the active fin as to be allocated under the following descriptions :

"To reduce the structural vibrations,
the main axis of the active fin is allocated on the middle position between
the orientations of the wind flow and the structural vibration, or
To amplify the structural vibrations,
the minor axis of the active fin is allocated on the middle position between
the orientations of the wind flow and the structural vibration".

In which, the 'structural vibration' means the orientation of the top floor's velocity vector of the structure, and the 'wind flow' means the orientation of the wind vector from windward to leeward. In this description, two kinds of manipulations on the newly proposed two-directional control algorithm are included, and it may be pointed that the conflagrations of the active fin to reduce or amplify the structural vibrations are depended on selecting the positioning of the active fin by the main axis or the minor axis. At this point, those suggestions may be assured as to be appropriate by considering that the same or the inverse orientations of the structural vibrations for the compensative wind force vectors are additionally illustrated on the Figs.5.3.2.

To express concretely the new type of the two-directional control algorithm, two kinds of indicates are prepared as to evaluate the 'direction of the structural vibration' and 'direction of the wind flow' by on-line. For those indicates, approximate classifications on those measured states for both of the wind flow and the structural vibrations as introduced in the previous control algorithm are not considered. Namely, instead of the 'estimative wind direction' $\bar{\theta}_w$ and the 'estimative vibrational direction' $\bar{\theta}_r$ which are used on the previous control algorithm, the 'averaged wind direction' $E(\theta_w)$ and the 'averaged vibrational direction' $E(\theta_r)$ are used as the evaluative indicates for the newly proposed two-directional control algorithm (in which, those denotations are defined in the Section 5.2). Accordingly, as the estimative indicates to express the newly proposed control algorithm, it may be regarded in the following discussions as that the 'angle difference of the structural vibrations from the wind flow' ϕ_{rw} (which are called as the 'windage angle of the structural vibrations' in the following discussions) is defined by $\phi_{rw} = E(\theta_r) - E(\theta_w)$, and that the projected angle of the active fin ϕ_{fw} is defined by $\phi_{fw} = \theta_f - E(\theta_w)$. The normal projected angle of the active fin ϕ'_{fw} is defined by the Exp. (5.3.2) under the this definitions of the ϕ_{fw}. On those preparations for describing the conflagrations of the active fin, the new type of two-directional control algorithm to reduce and to amplify the structural vibrations may be proposed as the following compositions.

Control algorithm-2(R)-II :

If $\quad \zeta_r \le \zeta_{r,\,min}$ or $\zeta_w \le \zeta_{w,\,min}$ ***then*** , keeping before positioning,
else if $\quad \phi_{fw} = (1/2)\cdot\phi_{rw}$.

Control algorithm-2(A)-II :

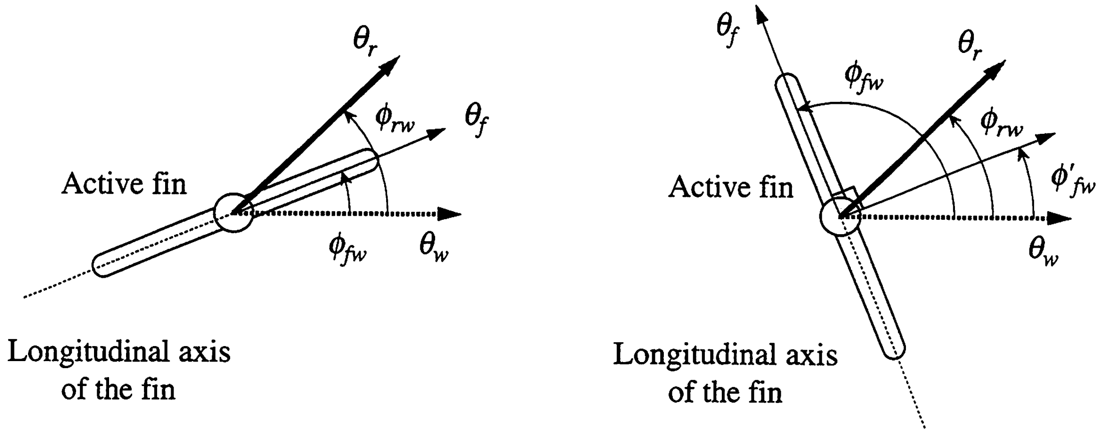
If $\quad \zeta_r \le \zeta_{r,\,min}$ or $\zeta_w \le \zeta_{w,\,min}$ ***then*** , keeping before positioning,
else if $\quad \phi'_{fw} = (1/2)\cdot\phi_{rw}$.

In which, $\zeta_{r,\,min}$ and $\zeta_{w,\,min}$ are used as the trigger level for the volumes of the structural responses and the wind velocities, respectively. On the large-scaled experimental tests, those values are supposed as 0 (cm/s) of the top floor's velocity and 0.01 (m/s) of the wind velocity, respectively. Those two kinds of operations based on this newly proposed two-directional control algorithm are also illustrated as shown in Figs.5.3.3.

By using the Control algorithm-2(R)-II, the projected angle of the fin will be kept in the middle direction between the wind and the structural vibration. It seems that this manipulation can regenerate the compensative wind forces acting on the fin in the conditions for cancelling the structural vibrations. This algorithm aims to use the wind forces as quasi-external damping forces. On the other hand, by using the Control algorithm-2(A)-II, the normal projected angle of the fin will be kept in the middle the direction between the wind and the structural vibration. It seems that this manipulation can regenerate the compensative wind forces acting on the fin in the conditions for amplifying the structural vibrations. Namely, control effects with the Control algorithm-2(A)-II may be contrasted with the Control algorithm-2(R)-II.

In those two kinds of variations of the control algorithm to aim the reductions and the amplifications of the structural vibrations, the projected angle of the active fin ϕ_{fw} or the normal projected angle of the active fin ϕ'_{fw} is used as the indicate to allocate the configurations of the active fin which can generate the adequate control forces by referring the windage angle of the structural vibrations ϕ_{rw}. To generate the output signal to manipulate the active fin at every control time step, the referential angle of the active fin θ_f is calculated as to the absolute positioning of the fin which is related to the standard coordinate. In those control manipulations, θ_f is determined by $\theta_f = \phi_{fw} + E(\theta_w)$ or $\theta_f = \phi'_{fw} + E(\theta_w)$ and defined as to be included within the range of $\{\theta_f \mid -90° < \theta_f \leq 90°\}$. If θ_f is calculated as to be out of this range, θ_f has to be corrected to the same phase of value which is included within this range by regarding that θ_f has cyclic properties with 180° of period.

θ_w : Direction of wind flow,
θ_r : Direction of structural vibration,
θ_f : Referential angle of active fin,
ϕ_{fw} : Projected angle of active fin,
ϕ'_{fw} : Normal projected angle of active fin,
ϕ_{rw} : Windage angle of structural vibration.



(a) Control algorithm-2(R)-II,

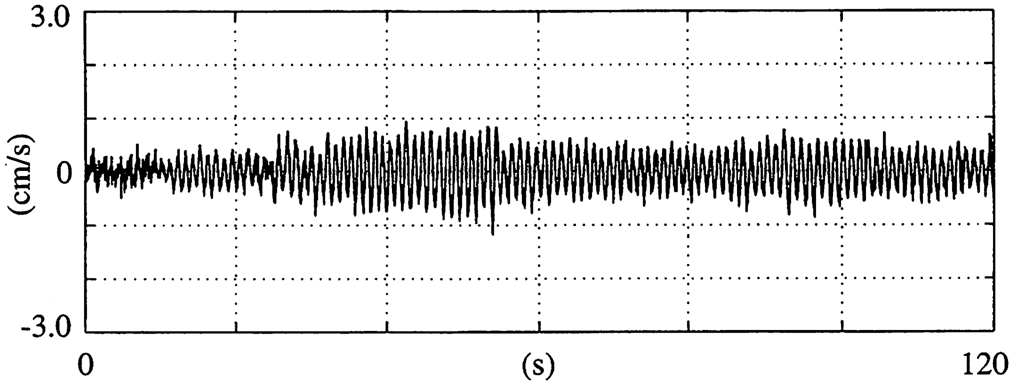
(b) Control algorithm-2(A)-II,

Fig. 5.3.3 Newly proposed two-directional control algorithm of the active fin system.

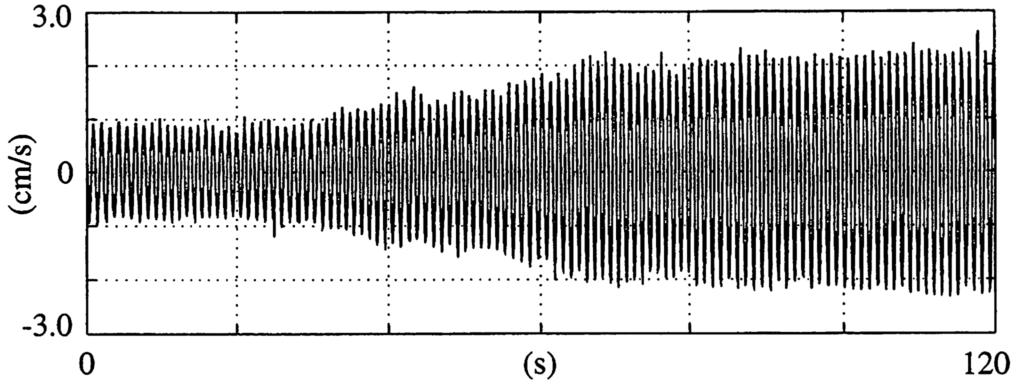
Study (5.3) - 1 :

The new type of two-directional control algorithms proposed in this section are investigated on the large-scaled experimental structure. The natural wind tests are executed under the practical strong wind flow. The mean of the wind velocity is measured about 10 (m/s) ± about 5 (m/s) and the wind directions are observed on average as to be closed to the north-west (± about 30°) which is corresponded to the almost same orientation with the Y-direction of the experimental structure. Velocities of the top floor are shown in Figs.5.3.4 and Figs.5.3.5 as the time histories on the X-direction (almost along to the cross-wind direction) and the Y-direction (almost along to the parallel-wind direction), respectively. In those figures, (a), (b) and (c) are corresponded to the structural responses under the non-controlled conditions and the controlled conditions by installing the Control algorithm-2(R)-II and the Control algorithm-2(A)-II, respectively.

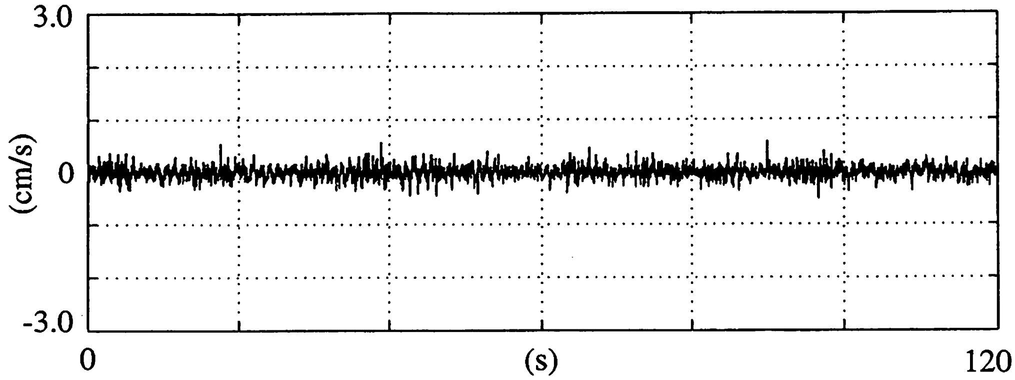
By comparing Figs.5.3.4 (b) with Fig.5.3.4 (a) and comparing Fig.5.3.5 (b) with Fig.5.3.5 (a), the structural responses which are appeared on both of the X-direction and the Y-direction of



(a) Without control,

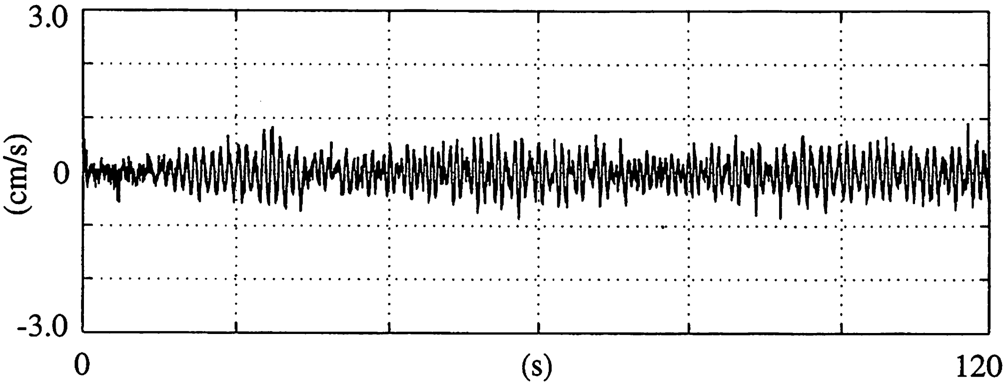


(b) Control by the Control algorithm-2(R)-II,

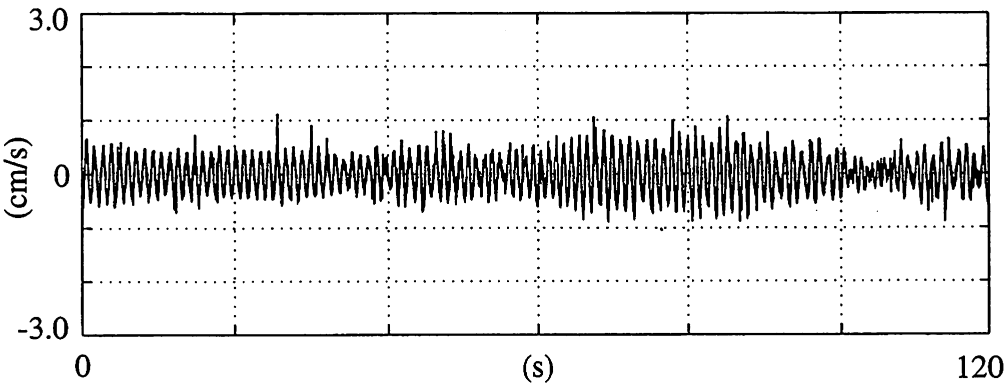


(c) Control by the Control algorithm-2(A)-II,

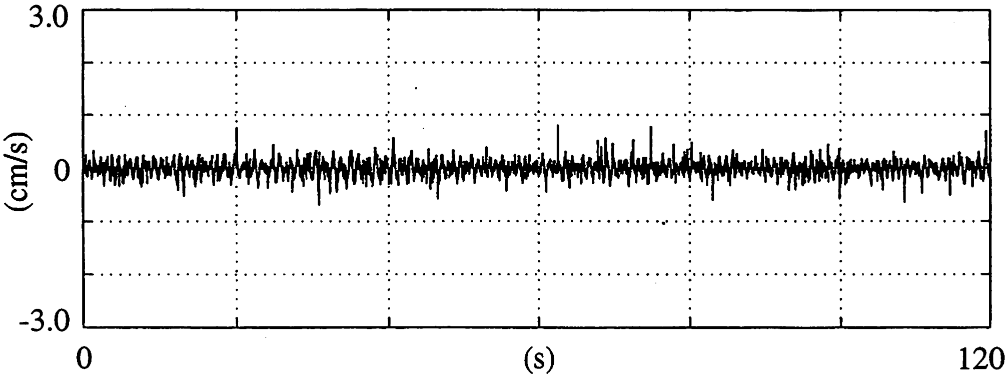
Fig. 5.3.4 Velocities of the top floor on the X-direction of the experimental structure.



(a) Without control,



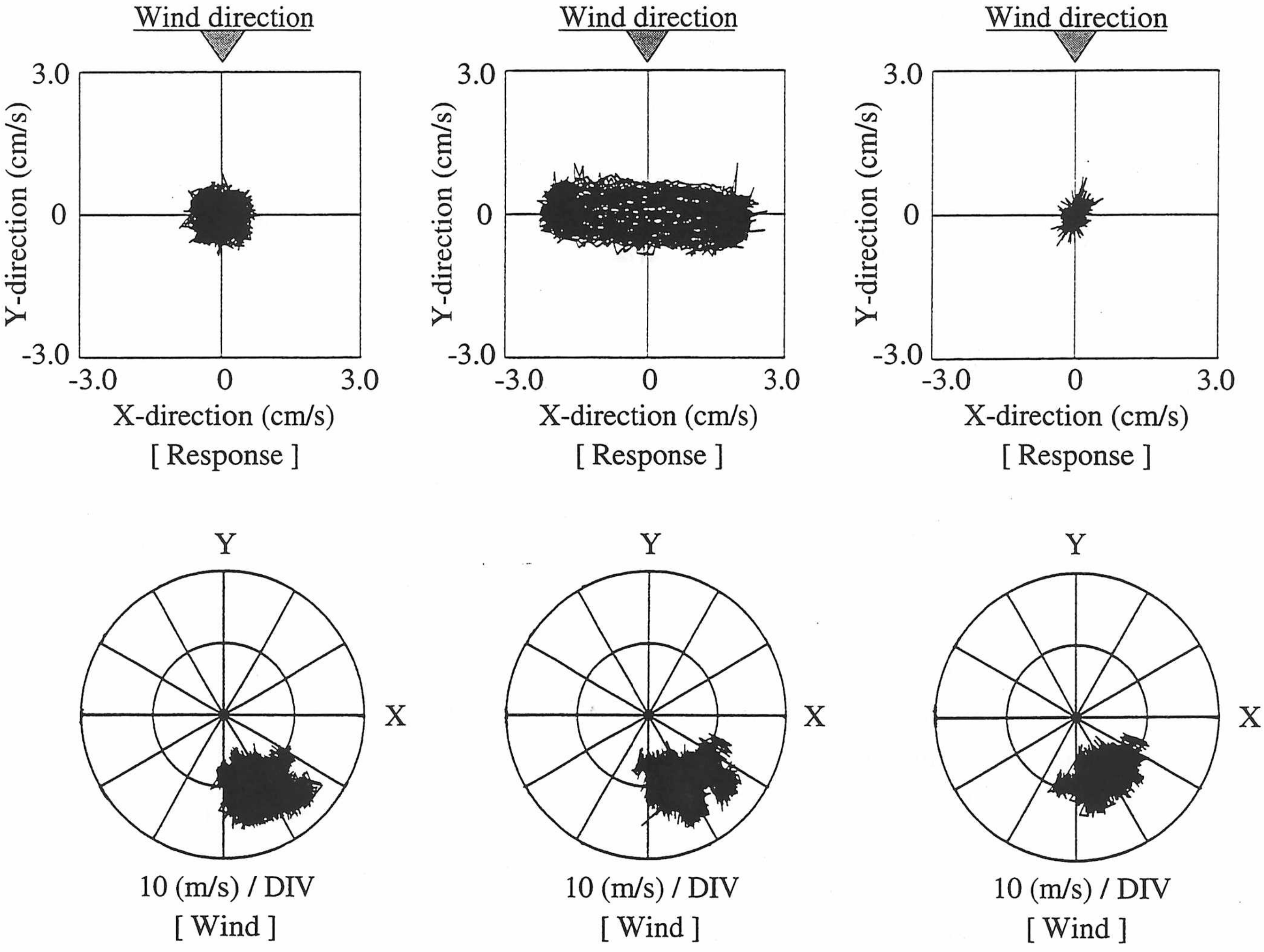
(b) Control by the Control algorithm-2(R)-II,



(c) Control by the Control algorithm-2(A)-II,

Fig. 5.3.5 Velocities of the top floor on the Y-direction of the experimental structure.

the experimental structure may be observed as to be enlarged by introducing the Control algorithm-2(R)-II. In this case, it may be assured that the amplification of the structural vibrations on the X-direction which is closed to the cross-wind direction are extremely appeared. By comparing Figs.5.3.4 (c) with Fig.5.3.4 (a) and comparing Fig.5.3.5 (c) and Fig.5.3.5 (a), the structural responses which are appeared on both of the X-direction and the Y-direction of the experimental structure may be observed as to be remarkably reduced by introducing the Control algorithm-2(A)-II. In this case, it may be assured that both of the reductions of the structural vibrations on the X-direction and the Y-direction are equally appeared, and that those control effects are uniformity actualized for both of the cross-wind and the parallel-wind directions.



(a) Without control, (b) Control algorithm-2(R)-II, (c) Control algorithm-2(A)-II,

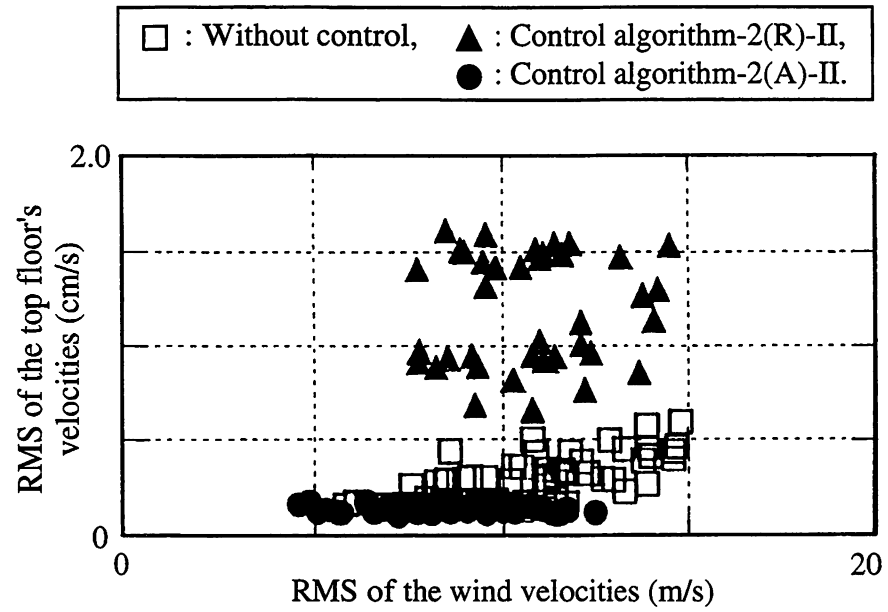
Fig. 5.3.6 Trajectories of the velocities of the top floor and the wind velocities.

Those results may be explicitly assured by considering the trajectories of the velocities of the top floor as shown in Figs.5.3.6. In those figures, (a), (b) and (c) are corresponding the cases for the non-controlled responses, the controlled responses by the Control algorithm-2(R)-II and the controlled responses by the Control algorithm-2(A)-II, respectively. The upper figures are corresponding to the locus of the structural velocity's vectors and the lower figures are corresponding to the locus of the vectorial wind flow.

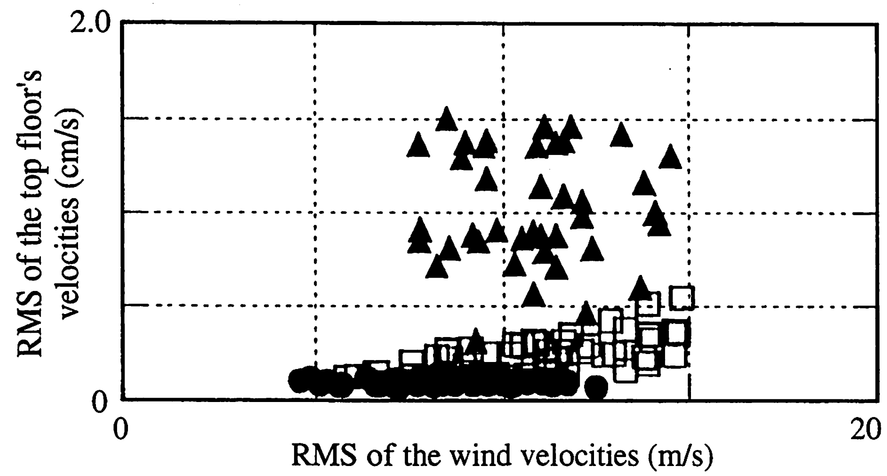
As seen in those figures, the average of the orientations of the wind flow can be evaluated about -60° (from the standard axis of the experimental structure (as corresponding to the positive orientation on the X-direction). Namely, the gap between the cross-wind direction and the X-direction (or also, the gap between the parallel-wind direction and the Y-direction) are considered as to be about 30°. By comparing those figures under the considerations for those gaps, it may be regarded that the control effects of the active fin system may be appeared as that both of structural vibrations on the cross-wind and the parallel-wind direction are reduced at the same time by installing the Control algorithm-2(A)-II, and that both of structural vibrations on the cross-wind and the parallel-wind direction are amplified at the same time by installing the Control algorithm-2(R)-II.

To make assure those results, the RMS (Root Mean Square) values of the top floor's velocities which are appeared on the cross-wind and the parallel-wind direction are separately evaluated. By regarding -60° of the orientation which are referred from the X-direction as the representative direction of the wind flow during the observation periods, the RMS values of the cross-wind and the parallel-wind components of the top floor's velocities are calculated. Figs.5.3.7 show the relations between the RMS values of the top floor's velocities and the volume of the wind velocities. In which, each marked plots is corresponded to the RMS values by every 5 seconds (which are evaluated from the experimental results as shown in Figs.5.3.4 and Figs.5.3.5). In Figs.5.3.7, (a), (b) and (c) are corresponded to the scalar values, the cross-wind components and the parallel-wind components for the top floor's velocities of the experimental structure, respectively.

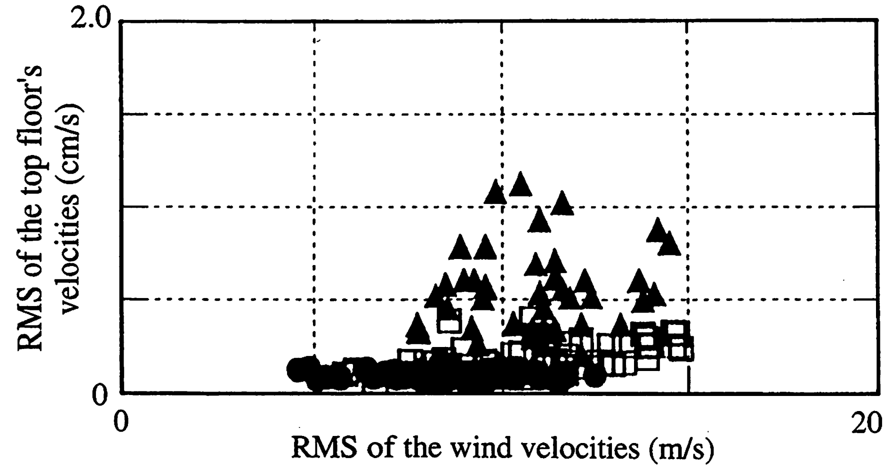
By comparing Fig.5.3.7 (b) and (c) with Fig.5.3.7 (a), quite similar control effects can be observed on both of the cross-wind and the parallel-wind direction as much as the evaluations for the scalar quantities. Accordingly, by introducing the two kinds of variations of the two-directional control algorithm proposed in this section, it may be assured that the multi-directional response control can be effectively operated. However, the significant problem may be newly arisen on the considerations for those experimental results. Namely, those control behaviors which are actualized by installing the Control algorithm-2(R)-II and the Control algorithm-2(A)-II are appeared as the inverse control effects for the expected efficiencies on those variations of the newly proposed two-directional control algorithm. While those experimental results may be very remarkable in the sense that the multi-directional response control can be effectively operated by the active fin system, it may be in trouble that the physical mechanism for the control operations can not be explained on those experimental results by applying the fundamental considerations which are mentioned on the constructions for this newly proposed two-directional control algorithm. As the natural sense, it seems that the Control algorithm-2(R)-II may reduce the wind-induced structural vibrations, and also, that the Control algorithm-2(A)-II may enlarge the wind-induced structural vibrations. Accordingly, it may be required the further considerations to find out some significant factors which are latently included on those experimental results as that the expected control efficiencies on those control algorithms are inverted. In the following half of this section, those experimental results are verified on the wind tunnel, and the physical mechanism which may actualize those control effects are investigated.



(a) RMS of the scalar velocities on the top floor,



(b) RMS of the cross-wind velocities on the top floor,



(c) RMS of the parallel-wind velocities on the top floor,

Fig. 5.3.7 Control effects evaluated by the RMS values.

5. 3. 2 Examination of new control algorithm with wind tunnel

To verify the new type of the two-directional control algorithm proposed in this section, the wind tunnel tests are executed. For this aim, the structural model on the CTAC system is newly developed as to operate the two-directional active response control tests on the wind tunnel. As shown in Photo.5.3.1 and Figs.5.3.8, the two-stories structural model is introduced. Two rigid floor mass are supported by four phosphor bronze columns which have 0.6 (cm) of diameter of the circle sections and this structural model has two translational motions and one rotational motion on each story, namely, this model has six degrees-of-freedom. All surfaces of the structural model are covered by stainless panels of curtain walls which are subjected to the wind. Those stainless panels are divided by heights of every stories and the upper sides of those panels are connected to each upper floor as that those stiffness are separated from the subjections of the structural deformations. This structural model are equipped on the wind tunnel as that the Y-direction is set to be on the parallel-wind direction and the X-direction is set to be on the cross-wind direction as shown in Fig.5.3.8 (b). The structural properties of the structural model are shown in Table 5.3.1. Stiffness, the first natural periods and damping ratios for the first vibrational mode are the same quantities on the both of the X-direction and the Y-direction. As the control device of the active fin, the small-scaled active fin which is developed in the previous wind tunnel tests in the Section 5.2 (as seen in Fig.5.2.1) and this control device is equipped at the center on the top floor of the structural model. The maximum projected area of the active fin (150 (cm^2)) is corresponding to about 4% of the projected area on the windward surface of this new structural model .

Study (5.3) - 2 :

At first, by using the new structural model on the CTAC system, the reappearances for the large-scaled experimental results (which are observed on the large-scaled active control tests by introducing the new type of control algorithm proposed in this section) on the wind tunnel are investigated. The experimental examinations to estimate for control effects of the active fin system are operated for the two kinds of conditions of the laminar wind flow which are measured as the wind velocities of about 5.5 (m/s) and about 8.0 (m/s) on the wind tunnel. The first condition (about 5.5 (m/s)) is decided as the wind velocity which cause resonant responses on the structural model. The another condition is selected as the same with the wind velocity which is adopted on the previous wind tunnel tests in the Section 5.2. The control effects on the Control algorithm-2(R)-II and the Control algorithm-2(A)-II are examined on those wind tunnel tests.

Figs.5.3.9, Figs.5.3.10 and Figs.5.3.11 are corresponded to displacements of the top floor of the structural model under the wind velocities of about 5.5 (m/s) on the non-controlled case and the controlled cases by the Control algorithm-2(R)-II and the Control algorithm-2(A)-II, respectively. Figs.5.3.12, Figs.5.3.13 and Figs.5.3.14 are corresponded to displacements of the top floor of the structural model under the wind velocities of about 8.0 (m/s) on the non-controlled case and the controlled cases by the Control algorithm-2(R)-II and the Control algorithm-2(A)-II, respectively.

Table 5.3.1 Properties of the structural model.

	Weight (kgf)	Stiffness (kgf/cm)
1st	33.0	9.9
2nd	33.0	11.0
	Natural period (s)	Damping ratio (%)
1st	0.62	0.4

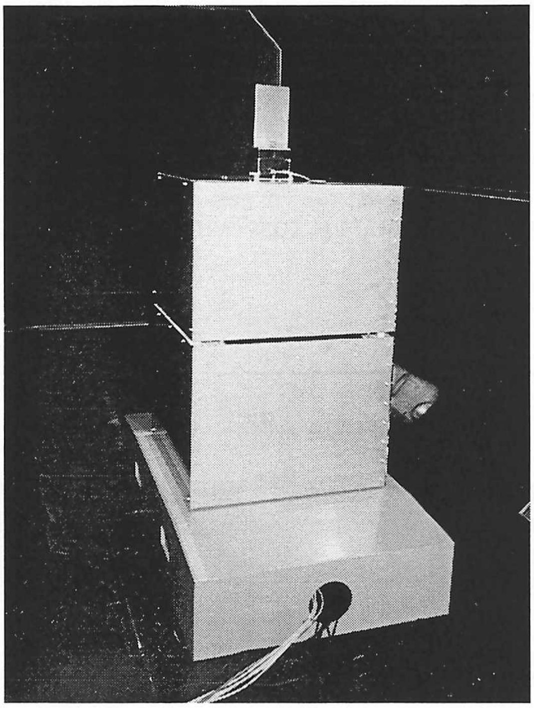
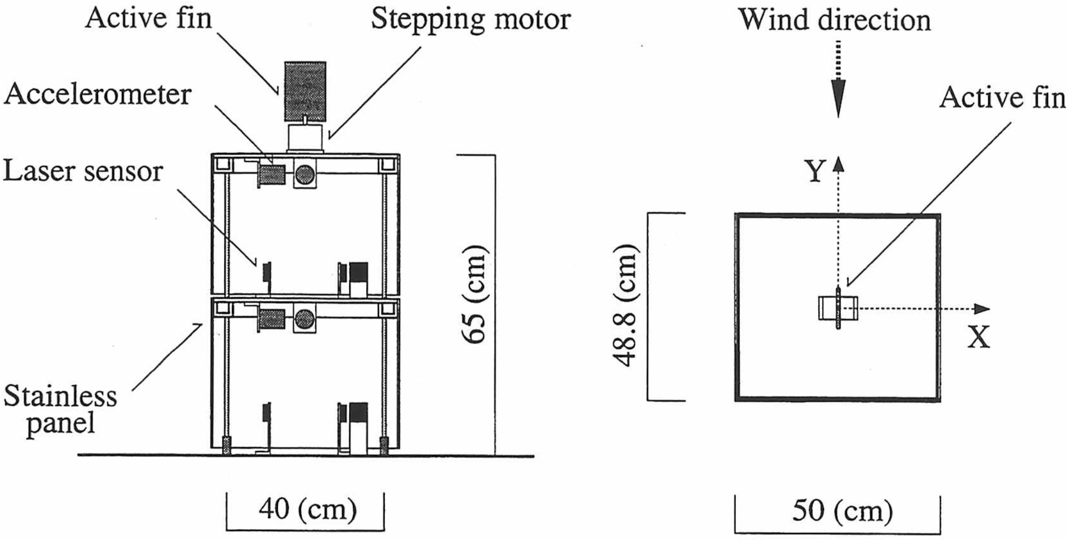
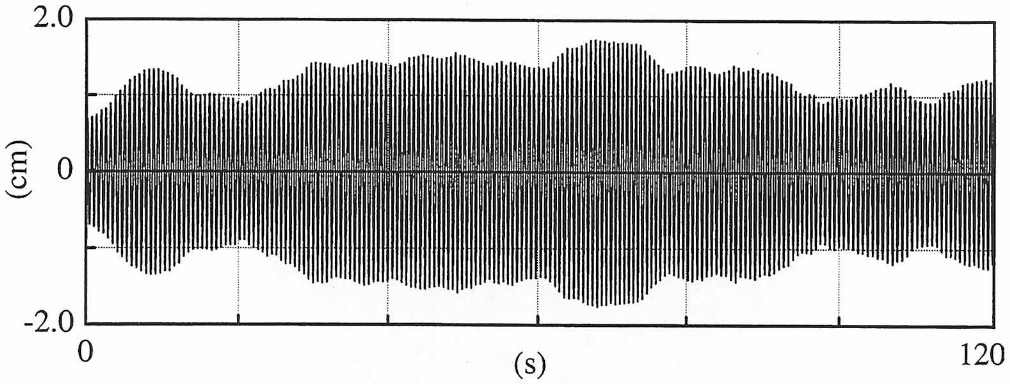


Photo. 5.3.1 Outlook of the new structural model.

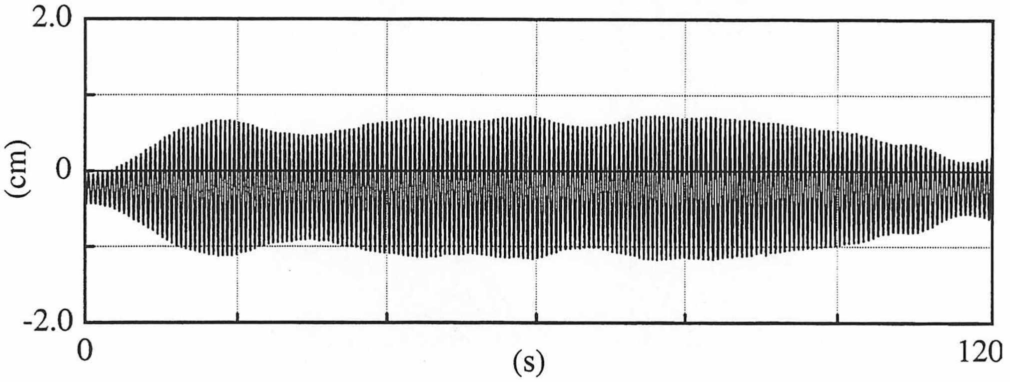


(a) Cross section, (b) Top view,

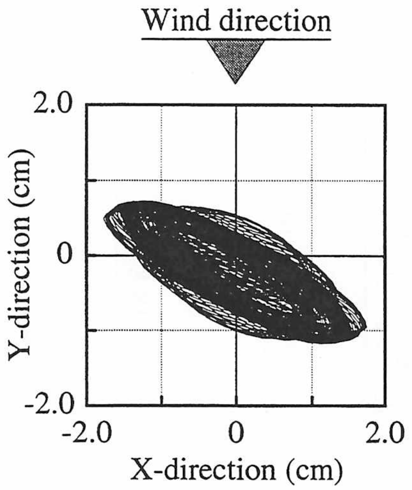
Fig. 5.3.8 Design of the new structural model.



(a) X-direction (Cross-wind direction),

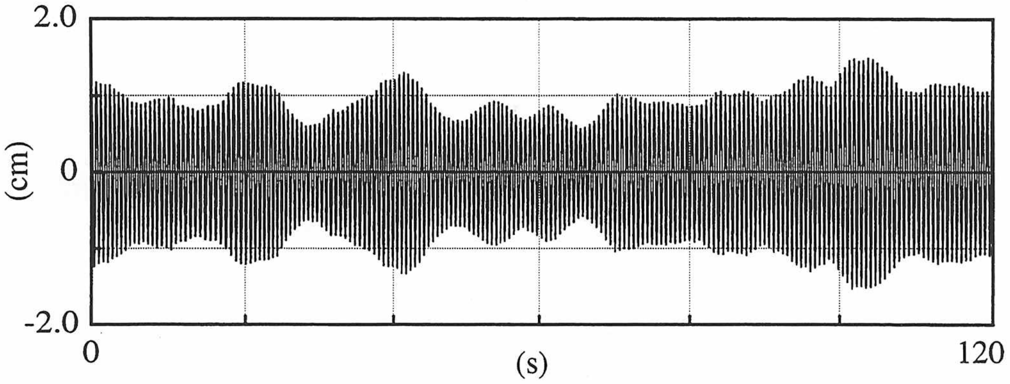


(b) Y-direction (Parallel-wind direction),

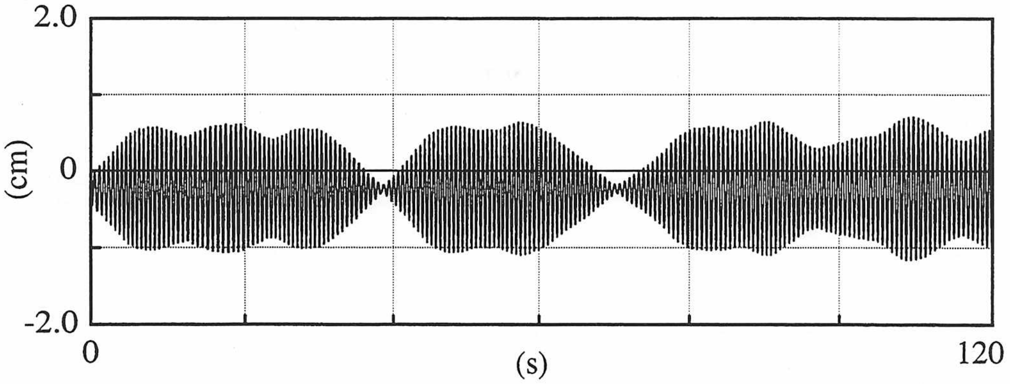


(c) Locus of displacements,

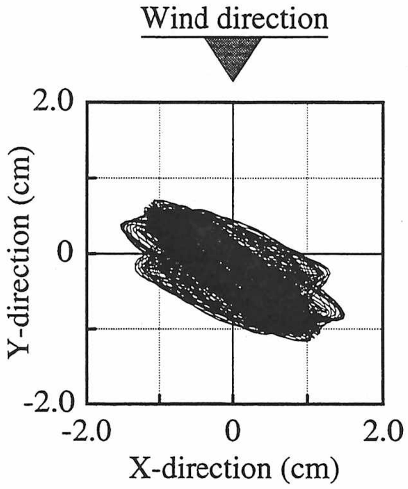
Fig. 5.3.9 Top floor's displacements (Without control, Wind velocity : 5.5 (m/s)).



(a) X-direction (Cross-wind direction),

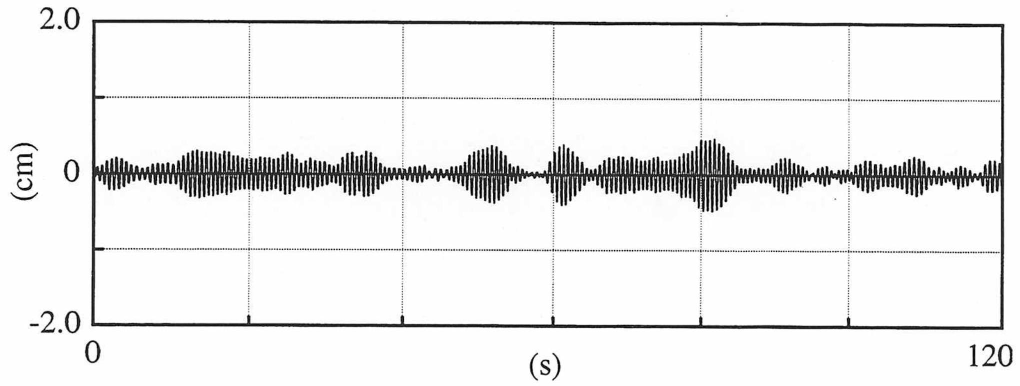


(b) Y-direction (Parallel-wind direction),

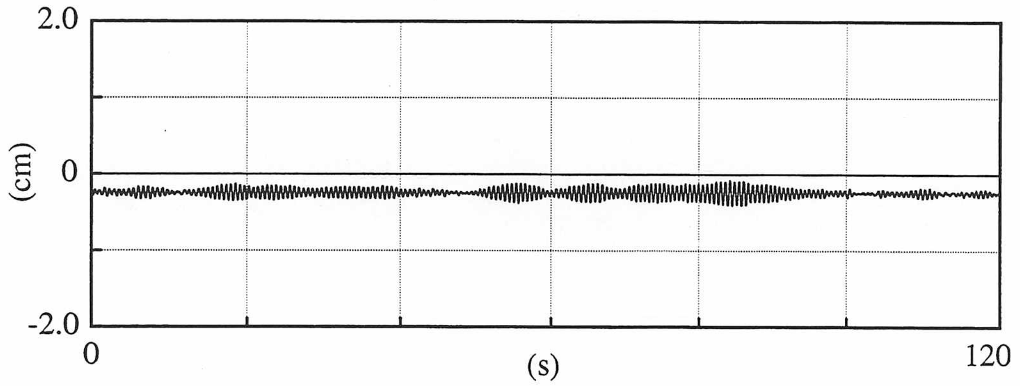


(c) Locus of displacements,

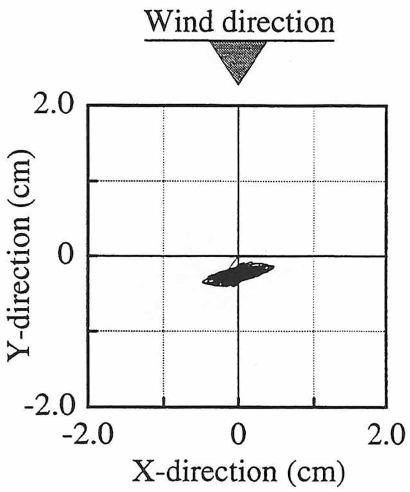
Fig. 5.3.10 Top floor's displacements (Algorithm-2(R)-II, Wind velocity : 5.5 (m/s)).



(a) X-direction (Cross-wind direction),

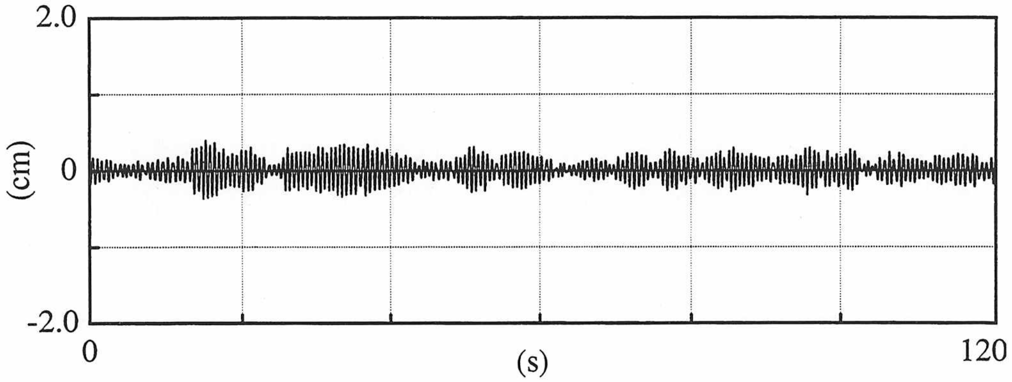


(b) Y-direction (Parallel-wind direction),

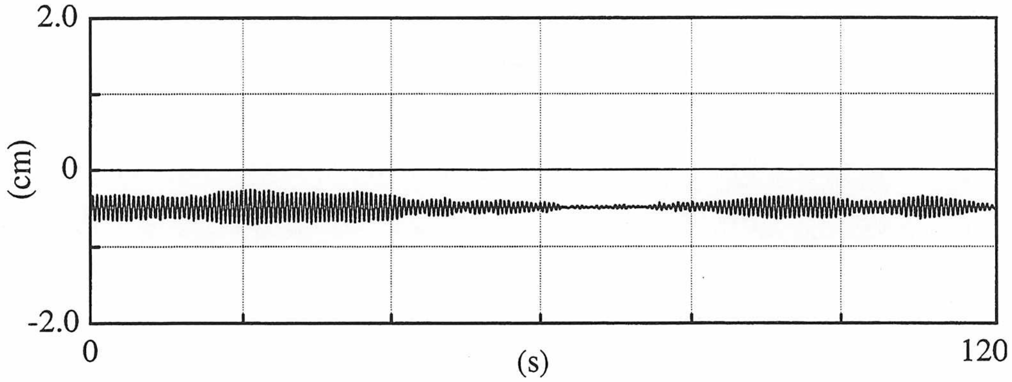


(c) Locus of displacements,

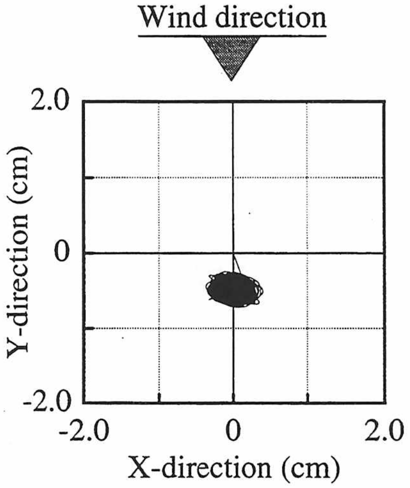
Fig. 5.3.11 Top floor's displacements (Algorithm-2(A)-II, Wind velocity : 5.5 (m/s)).



(a) X-direction (Cross-wind direction),

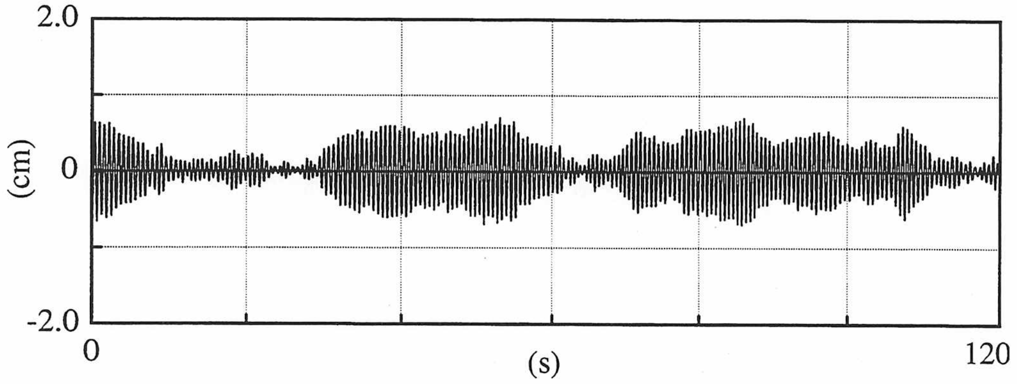


(b) Y-direction (Parallel-wind direction),

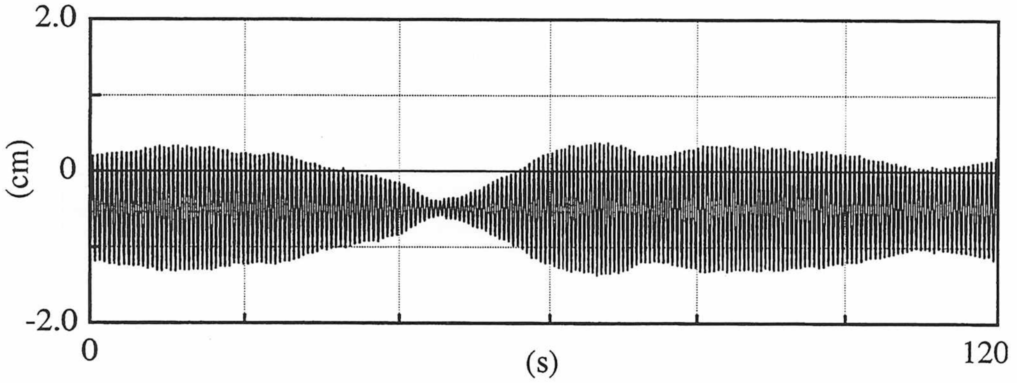


(c) Locus of displacements,

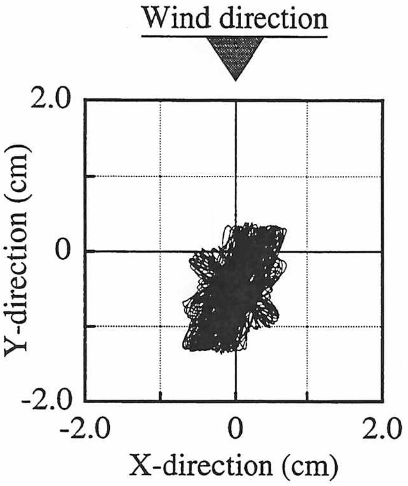
Fig. 5.3.12 Top floor's displacements (Without control, Wind velocity : 8.0 (m/s)).



(a) X-direction (Cross-wind direction),

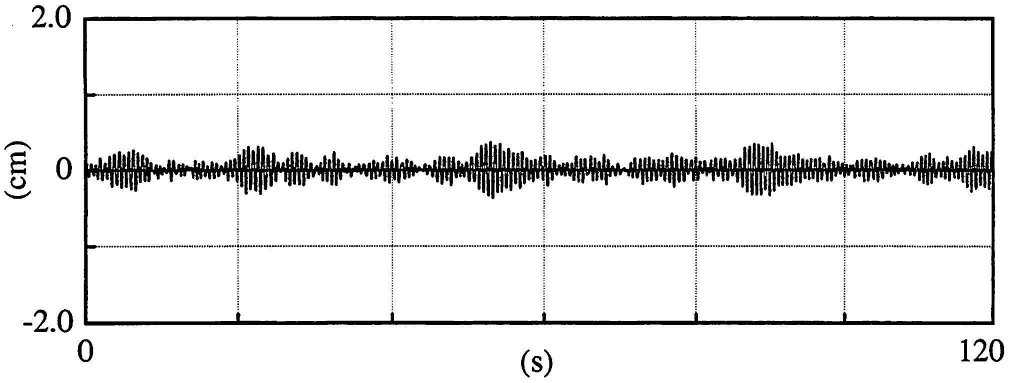


(b) Y-direction (Parallel-wind direction),

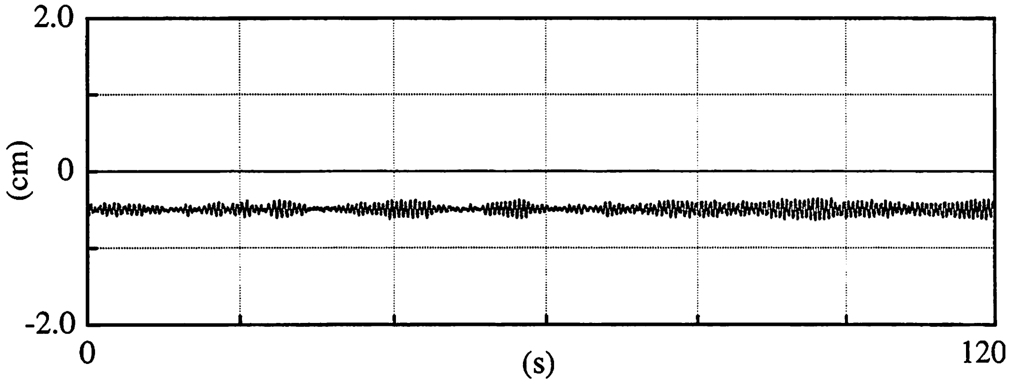


(c) Locus of displacements,

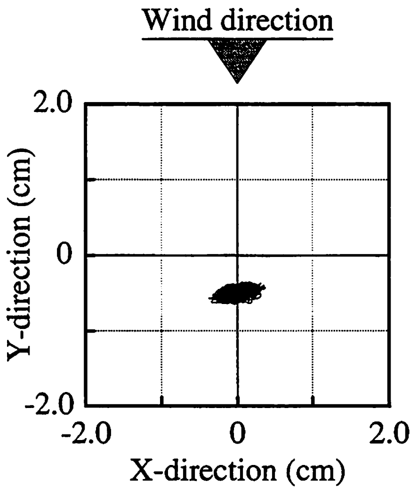
Fig. 5.3.13 Top floor's displacements (Algorithm-2(R)-II, Wind velocity : 8.0 (m/s)).



(a) X-direction (Cross-wind direction),



(b) Y-direction (Parallel-wind direction),



(c) Locus of displacements,

Fig. 5.3.14 Top floor's displacements (Algorithm-2(A)-II, Wind velocity : 8.0 (m/s)).

In those figures, (a), (b) and (c) show the time history on the X-direction (the cross-wind direction), the time history on the Y-direction (the parallel-wind direction) and the locus of the top floor's displacements (during 120 (s)), respectively.

By comparing Figs.5.3.10 and Figs.5.3.11 with Figs.5.3.9, the resonate structural vibrations induced under about 5.5 (m/s) of wind velocity are remarkably reduced by introducing the Control algorithm-2(A)-II on both the cross-wind and the parallel-wind directions. In this case, the controlled responses by using the Control algorithm-2(R)-II may observed as not to be so different from the non-controlled responses on those wind conditions. As the reason of this, since the structural vibrations are appeared as to be comparatively large under those wind velocities, it seems that those non-controlled responses have been already reached to the almost same levels as large as the upper limits of the amplifications which may be actualized by the Control algorithm-2(R)-II.

By comparing Figs.5.3.13 and Figs.5.3.14 with Figs.5.3.12, the structural vibrations induced under about 8.0 (m/s) of wind velocity are remarkably amplified by introducing the Control algorithm-2(R)-II on both the cross-wind and the parallel-wind directions. In this case, the controlled responses by using the Control algorithm-2(A)-II may observed as not to be so different from the non-controlled responses on those wind conditions. As the reason of this, since the structural vibrations are appeared as to be comparatively small under those wind velocities, it seems that those non-controlled responses have been already reached to the almost same levels as small as the lower limits of the reductions which may be actualized by the Control algorithm-2(A)-II.

Through those investigations on the wind tunnel, by introducing the two kinds of variations of the two-directional control algorithm proposed in this section, it may be assured that the quite similar response control effects can be appeared as much as the cases on the large-scaled experimental tests under the natural wind flow. Namely, in those wind tunnel tests, it can be also gained that those control behaviors which are actualized by installing the Control algorithm-2(R)-II and the Control algorithm-2(A)-II are appeared as the inverse control effects for the expected efficiencies on those variations of the newly proposed two-directional control algorithm. To verify those phenomena, the influence of the time delay for spending on the control manipulations of the active fin are evaluated in the following study as the one of the significant possibilities on the mechanical factors which are included on those experimental results.

Study (5.3) - 3 :

There are very interesting phenomena that are found out through the previous studies in this section. By introducing the newly proposed two-directional control algorithm of the active fin system, it is assured that both of the cross-wind and the parallel-wind responses are reduced or amplify at the same time on both of the natural wind tests and the wind tunnel tests. However, the significant problems are remained to solve why those control effects which are observed on those experimental tests are inverted from the primary control efficiency which are expected on those two-kinds of variations of the two-directional control algorithm for aiming for the reductions or the amplifications of the structural vibrations. Accordingly, discussions may be begun to assume that those control effects may be depended on the time delay effects which are requested for the growth of the wind forces by accompanying to rotating operations to change the configurations of the active fin by on-line.

For this conditions, the fluctuations of the control effects based on the differences of the control time intervals Δt_σ which are supposed on each control time step for the on-line control manipulations are evaluated on the wind tunnel. The new structural model on the CTAC system are also used for those investigations. Two kinds of structural properties are prepared on this structural model as shown in Table 5.3.2. The values of the natural periods on the sway movements for those two kinds of the conditions are equal on both of the X-direction and the Y-direction.

Table 5.3.2 Properties of the structural model.

		Stiffness (kgf/cm)	Weight (kgf)	Natural period (s)
Model-1	1st	9.9	33.0	0.62
	2nd	11.0	33.0	0.23
Model-2	1st	9.9	43.0	0.77
	2nd	11.0	47.0	0.28

By replacing the volume of every mass of the structural model, the experimental evaluations are executed for two kinds of conditions of the natural periods of the structural model and those two kinds of conditions of the structural model are called as the Model-1 and the Model-2 in the following study. Active control tests by introducing the Control algorithm-2(R)-II and the Control algorithm-2(A)-II are operating under the two kinds of the 'manipulating velocity' of the active fin by supposing as 200 (rpm : round per minute) and 100 (rpm). Those two kinds of the values of the manipulating velocity are corresponding to the operations of the active fin as that the 'manipulating time' (Δt_d) for 180° of the single rotation by the stepping motor are supposed as $\Delta t_d = 0.15$ and 0.30 (s), respectively. Under those two kinds of manipulating velocity of the active fin, the variations of the control time interval Δt_σ are evaluated as the parameters. In which the control time interval Δt_σ are subjected by $\Delta t_\sigma \geq \Delta t_d$, when the manipulating time is supposed by $\Delta t_d = 0.15$ (s), the control time intervals are evaluated on the cases by $\Delta t_\sigma = 0.15, 0.2, 0.3, 0.4$ and 0.6 (s), and when the manipulating time is supposed by $\Delta t_d = 0.30$ (s), the control time intervals are evaluated on the cases by $\Delta t_\sigma = 0.3$, 0.4 and 0.6 (s) (on the cases by using the Model-2, the case by $\Delta t_\sigma = 1.0$ (s) is additionally evaluated).

In the following discussions, the fluctuations of the control effects according to the variations of the control time intervals are evaluated by using the indicate which is defined as the displacements controlled factor in the Section 4.2. In those evaluations, the displacements are indexed to the top floor's responses. In which, two components of the displacements of the top floor on the X-direction and the Y-direction of the structural model are denoted as x_2 and y_2, respectively. Accordingly, the displacements controlled factors are introduced as $DRMS(x_2)$ and $DRMS(y_2)$. Those indicates are defined as follow,

$$DRMS(x_2) = x_{rms,2} / x'_{rms,2} \ , \qquad (5.3.3a)$$

$$DRMS(y_2) = y_{rms,2} / y'_{rms,2} \cdot \qquad (5.3.3b)$$

In which, $x_{rms,2}$ and $y_{rms,2}$ are defined as the controlled RMS (root mean square) responses of the top floor's displacements on the X-direction and the Y-direction, respectively, and $x'_{rms,2}$ and $y'_{rms,2}$ are defined as the non-controlled RMS responses of the top floor's displacements on the X-direction and the Y-direction, respectively. Those quantities are calculated for the measured data during 120 (s) of the observing times. The experimental examinations are also operated for the two kinds of conditions of the laminar wind flow which are measured as the wind velocities of about 5.5 (m/s) and about 8.0 (m/s) on the wind tunnel.

Figs.5.3.15 and Figs.5.3.16 show the fluctuations of the displacements controlled factors (which are evaluated for the top floor's displacements of the structural model) for the cases by using the Model-1 and are corresponding to the controlled responses by introducing the Control algorithm-2(R)-II and the Control algorithm-2(A)-II, respectively. Figs.5.3.17 and Figs.5.3.18 show the fluctuations of the displacements controlled factors for the cases by using the Model-2 and are corresponding to the controlled responses by introducing the Control algorithm-2(R)-II and the Control algorithm-2(A)-II, respectively. In those figures, (a) and (b) are corresponded to the control effects on the X-direction (the cross-wind direction) and the Y-direction (the parallel-wind direction), respectively. The solid lines plotted by the symbols ● and ◆ are corresponded to the conditions for 5.5 (m/s) and 8.0 (m/s) of the wind velocities, respectively, and the broken lines which is indicated as $DRMS(x_2) = 1.0$ or $DRMS(y_2) = 1.0$ show the non-controlled responses. The denotation Λ which is mentioned on the horizontal axes in those figure is defined as the 'manipulation frequency' which is corresponded to the ratio of the control time step Δt_σ with the first natural periods of the structural model T_1 and this quantity is expressed by $\Lambda = \Delta t_\sigma / T_1$.

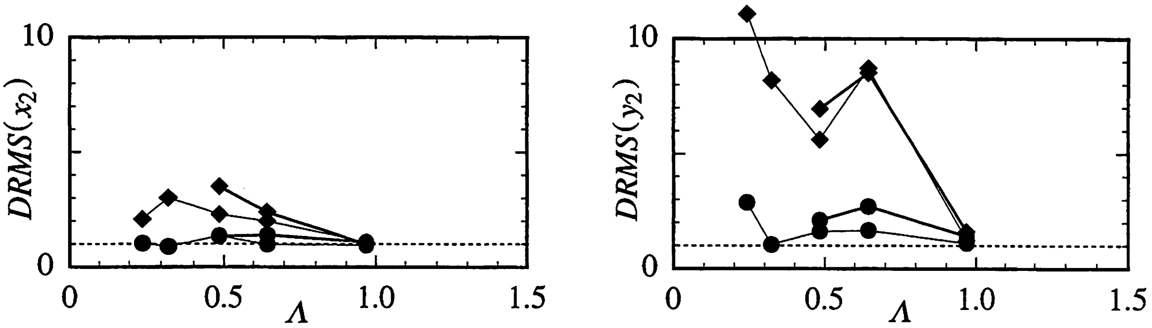
By macroscopically considering for Figs.5.3.15 and Figs.5.3.17, the following three tendencies to the control effects may be pointed under the installations of the Control algorithm-2(R)-II.

Point-1.1) When the control time interval Δt_σ are supposed as that the manipulation frequency Λ are allocated to be over the value of about 0.2, it may be observed that the controlled responses are enlarged. In which, the control effects to amplify the structural responses may be explicitly actualized under 8.0 (m/s) of the wind velocity. As the reason of this, since the non-controlled structural vibrations under this condition of the wind velocity are comparatively small, it may be considered that the amplifying effects are remarkably appeared by the control manipulations.

Point-1.2) When the control time interval Δt_σ are supposed as approaching to or exceeding the first natural period of the structural model, namely, when the manipulation frequency Λ are reached to or surpassed about 1.0, it may be observed that the control effects resulted from the control manipulations are not be almost appeared.

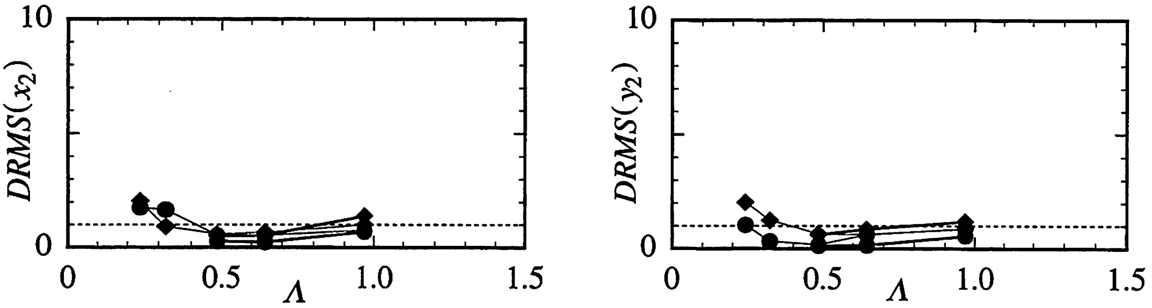
Point-1.3) When the control time interval Δt_σ are supposed as that the manipulation frequency Λ are allocated below the value of about 0.2, it may be considered that the controlled responses are reduced. This tendency can be barely evaluated in the cases by using the Model-2 (in

Wind velocity 5.5 (m/s) : —●— : $\Delta t_d = 0.30$, —●— : $\Delta t_d = 0.15$.
Wind velocity 8.0 (m/s) : —◆— : $\Delta t_d = 0.30$, —◆— : $\Delta t_d = 0.15$.



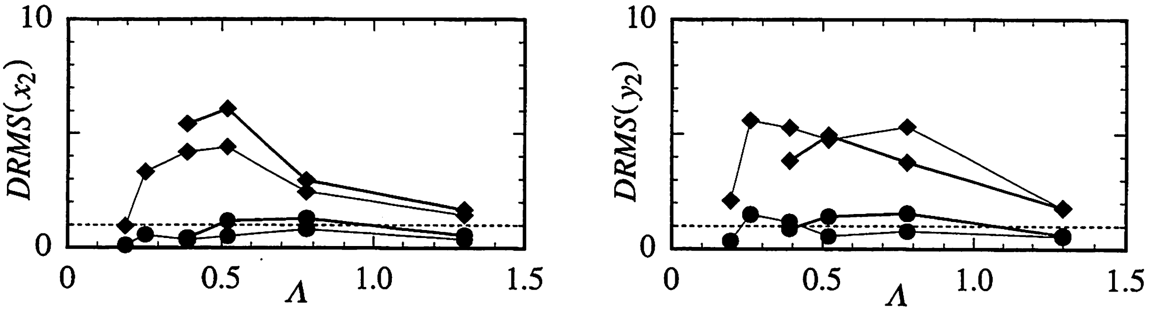
(a) X-direction (Cross-wind direction), (b) Y-direction (Parallel-wind direction),

Fig. 5.3.15 Control effects by using the Control algorithm-2(R)-II (Model-1).



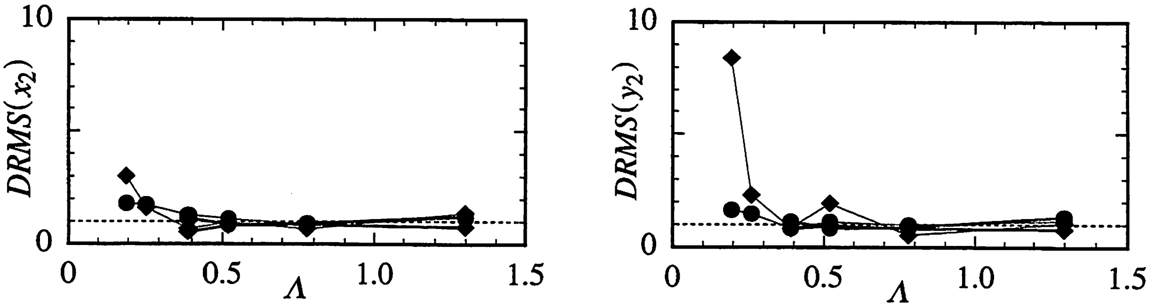
(a) X-direction (Cross-wind direction), (b) Y-direction (Parallel-wind direction),

Fig. 5.3.16 Control effects by using the Control algorithm-2(A)-II (Model-1).



(a) X-direction (Cross-wind direction), (b) Y-direction (Parallel-wind direction),

Fig. 5.3.17 Control effects by using the Control algorithm-2(R)-II (Model-2).



(a) X-direction (Cross-wind direction), (b) Y-direction (Parallel-wind direction),

Fig. 5.3.18 Control effects by using the Control algorithm-2(A)-II (Model-2).

which, such value of the manipulation frequency can not be actualized in the cases by using the Model-1 because of the limitation of the manipulating time interval of the active fin) and it seems that the control effects of the Control algorithm-2(R)-II may be sensitively inverted on the vicinity of this boundary of Λ.

It may be assured that those behaviors on the installations of the Control algorithm-2(R)-II according to the difference of the control time interval Δt_{σ} are equally appeared on both of the parallel-wind and the cross-wind directions and also equally appeared on both of the Model-1 and the Model-2.

On the other hand, by macroscopically considering for Figs.5.3.16 and Figs.5.3.18, the following three tendencies to the control effects may be pointed under the installations of the Control algorithm-2(A)-II.

Point-2.1) When the control time interval Δt_{σ} are supposed as that the manipulation frequency Λ are allocated to be over the value of about 0.3, it may be observed that the controlled responses are reduced. The similar tendencies may be observed under both of the wind velocities of 5.5 (m/s) and 8.0 (m/s).

Point-2.2) When the control time interval Δt_{σ} are supposed as approaching to or exceeding the first natural period of the structural model, namely, when the manipulation frequency Λ are reached to or surpassed about 1.0, it may be observed that the control effects resulted from the control manipulations are not be almost appeared. This tendency may be common with the cases by using the Control algorithm-2(R)-II as mentioned in the Point-1.2.

Point-2.3) When the control time interval Δt_{σ} are supposed as that the manipulation frequency Λ are allocated below the value of about 0.3, it may be observed that the controlled responses are amplified. It may be evaluated that the control effects of the Control algorithm-2(A)-II are also sensitively inverted on the vicinity of this boundary of Λ.

As much as the cases by using the Control algorithm-2(R)-II, it may be assured that those behaviors on the installations of the Control algorithm-2(A)-II according to the difference of the control time interval Δt_{σ} are equally appeared on both of the parallel-wind and the cross-wind directions and also equally appeared on both of the Model-1 and the Model-2.

As the common tendencies for the Control algorithm-2(R)-II or the Control algorithm-2(A)-II, it may be assured that the control effects based on those control algorithms (which are mentioned as from the Point-1.1 to the Point-1.3 for the cases on the Control algorithm-2(R)-II or mentioned as from the Point-2.1 to the Point-2.3 for the cases on the Control algorithm-2(A)-II) may be significantly depended on the manipulation frequency Λ. Namely, it may be considered that the control efficiencies by introducing the Control algorithm-2(R)-II or the Control algorithm-2(A)-II are subjected by the influences of the difference of the control time interval Δt_{σ} rather than the difference of the manipulating time Δt_{d}. Thorough those evaluations, the significant characteristics for the newly proposed two-directional control algorithms may be appeared as that both of the Control algorithm-2(R)-II and the Control algorithm-2(A)-II are inverted there expected control efficiencies by supposing the manipulation frequency Λ as to be exceeded from about 0.2 to about 0.3 and those time interval of the manipulation frequency Λ may be evaluated as to be corresponded to the dime delay of about 1/4 for the first natural period of the structural model. At this point, as the considerations for the previous experimental tests in this section, since the values of the manipulation frequency Λ are evaluated as to be about 0.27 on the large-scaled tests (in the Study (5.3)-1) and evaluated as to be about 0.48 on the wind tunnel tests (in the Study (5.3)-2), it may be assured that both of those values of the manipulation frequency have been allocated on the range which the control effects as mentioned in the Point-1.2 or the Point-2.2 may be actualized.

As concluding remarks in this section, to improve the control efficiencies of the multi-directional response control by using the active fin system, the new type of the two-directional response control algorithm is proposed. By considering the compensative wind force vectors on the wind resistant forces acting on the fin, the very simple form of the expressions of the two-directional control algorithm are composed. Two kinds of variations of this control algorithm are prepared as to reduce and to amplify the structural responses, respectively. At first, the large-scaled experimental tests are executed on the large-scaled experimental structure under the natural wind flow to evaluate this newly proposed two-directional control algorithm. As a result, although the control effects as to reduce or to amplify the structural responses which are appeared on both of the cross-wind and the parallel-wind direction are actualized by each installation of those two kind of variations of the control algorithm, those controlled behaviors are gained as to be inverted for the expected control efficiencies on each variation of those two kinds of control algorithms. To verify those experimental results from the large-scaled structure, the wind tunnel tests are executed. For this aim, two-directional vibrative structural model are newly developed on the CTAC system. By using this new structural model, the reappearances of those large-scaled experimental results are examined. Moreover, by executing the additional wind tunnel tests which are considered for the differences of the natural periods of the structural model and the control time intervals for manipulating the active fin, it may be considered that those inverted control effects are significantly subjected on the time delay spent to change the configurations of the active fin.

5. 4 Verification of multi-directional control algorithms

Through the evaluations in the Section 5.3, it may be assured that the control effects by introducing the newly proposed two-directional control algorithms (which are expressed as the Control algorithm-2(R)-II and the Control algorithm-2(A)-II) are significantly subjected to the time delays for the control manipulations. So that, when the Control algorithm-2(R)-II and the Control algorithm-2(A)-II are installed under the conditions that the control time intervals are supposed as exceeding about 1/4 of the first natural periods of the experimental structure, it may be observed that the control effects by using the active fin system are appeared as to be inverted those expected control efficiencies which should be fundamentally provided on each of those two kinds of two-directional control algorithms. Those phenomena are observed for both operations on the large-scaled experimental tests and on the wind tunnel tests. At this point, the significant interests are appeared, namely, it may be pointed that the control effects by introducing the previous type of the two-directional control algorithms which are proposed as the Control algorithm-2(R) and the Control algorithm-2(A) in the Section 5.2 are observed as that the expected control efficiencies are at least appeared on the cross-wind direction regardless that those control manipulations are also operated under the conditions of the same value of the control time intervals. Accordingly, it seems that the Control algorithm-2(R) and the Control algorithm-2(A) are evaluated as to be more insensitive for the time delays on the control manipulations than the Control algorithm-2(R)-II and the Control algorithm-2(A)-II.

In this section, discussions may be begun to verify and evaluate for the differences of the control operations based on those two kinds of control methods which are mentioned as the Control algorithm-2(R) and the Control algorithm-2(A) and which are mentioned as the Control algorithm-2(R)-II and the Control algorithm-2(A)-II, under the considerations for the time delays on the control manipulations. On the following discussions, those two kinds of two-directional response control methods are called as the 'Version-1' (which is corresponding to the control method mentioned in the Section 5.2) and the 'Version-2' (which is corresponding to the control method mentioned in the Section 5.3) for convenience to distinguish each other. As mentioned on the Section 5.2 and the Section 5.3, the active control tests by using each of those two kinds of control methods are executed on the large-scaled experimental structure. By considering those large-scaled experimental results, it may be observed that the structural vibrations are mostly appeared as to be drawn the elliptical locus under the natural wind flow. As the reason of this, it may be considered that the both of the first natural periods of the orthogonal directions which are specified as the X-direction and the Y-direction on the experimental structure are comparatively close. So that, the similar tendencies are also observed on the experimental results through the wind tunnel tests which are executed on the newly developed CTAC structural model in the Section 5.3. Accordingly, it may be reasonable that the transitions of the configurations of the active fin are evaluated for the elliptic motion of the structural vibrations. In the following discussions, verifications for those two kinds of the control methods for the two-directional response control are operated by supposing two typical cases that the elliptic motion of the structural vibrations are appeared as to be comparatively close to the flat locus and as to be comparatively close to circular locus.

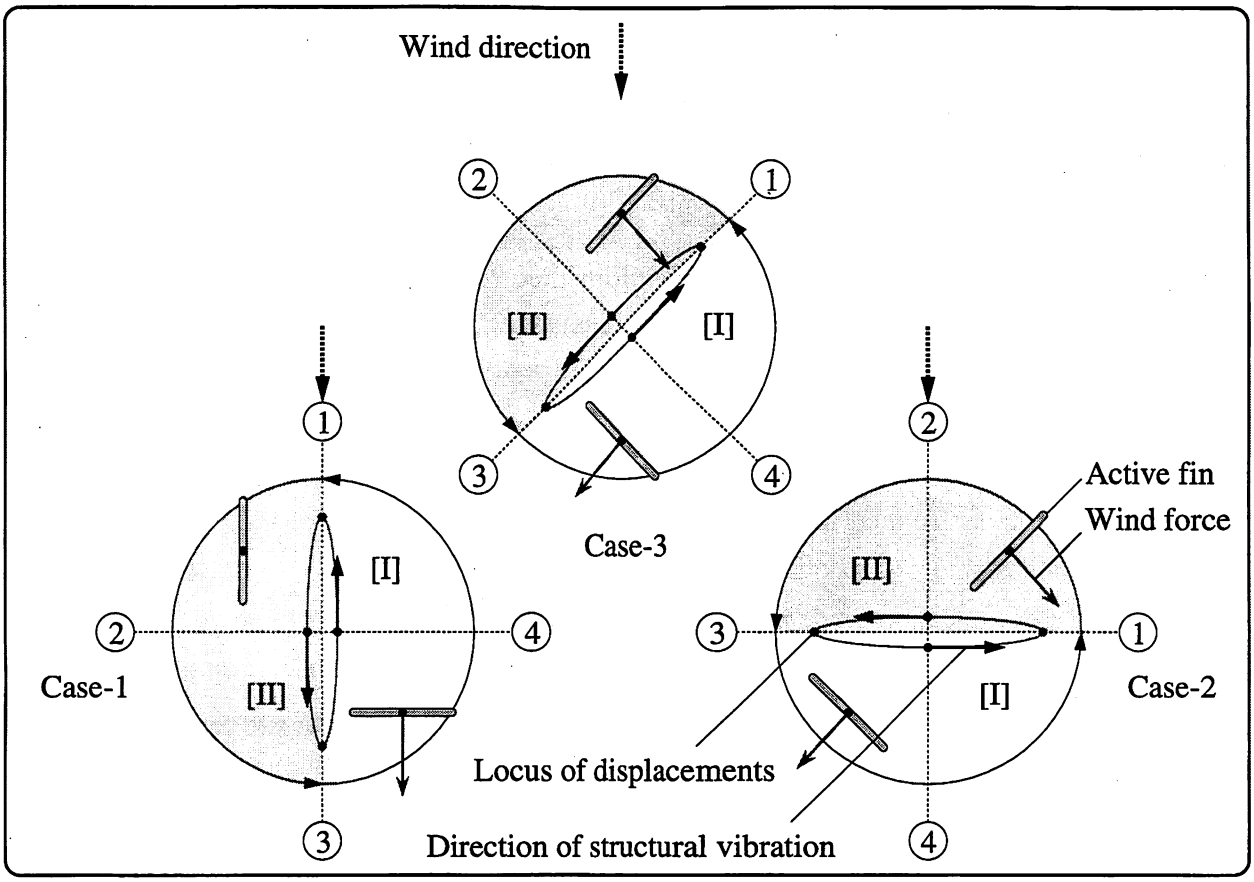
Study (5.4) - 1 :

At first, under the one of the typical conditions that the structural vibrations are appeared as to be comparative flatness of elliptic motion, the control manipulations by introducing those two kinds of control methods may be verified. Figs.5.4.1 and Figs.5.4.2 show the controlled conflagrations of the active fin according to the variations of the directions of the structural vibrations by introducing the Control algorithm-2(R) and the Control algorithm-2(A) of the Version-1 of the two-directional control method, respectively. In those figures, (a) and (b) are corresponded to the cases which is not considered any time delays and which is considered the time delay of 1/4 of the interval for the first natural periods of the experimental structures (namely, the influences for the manipulation frequency Λ as to be 0.25 is considered), respectively. In those figures, three kinds of cases as that the major directions of the structural vibrations are appeared on the parallel-wind direction (Case-1), the cross-wind direction (Case-2) and the middle of those directions (Case-3) are considered, and the rotational direction of the locus of the displacements are assured as to be counter clockwise.

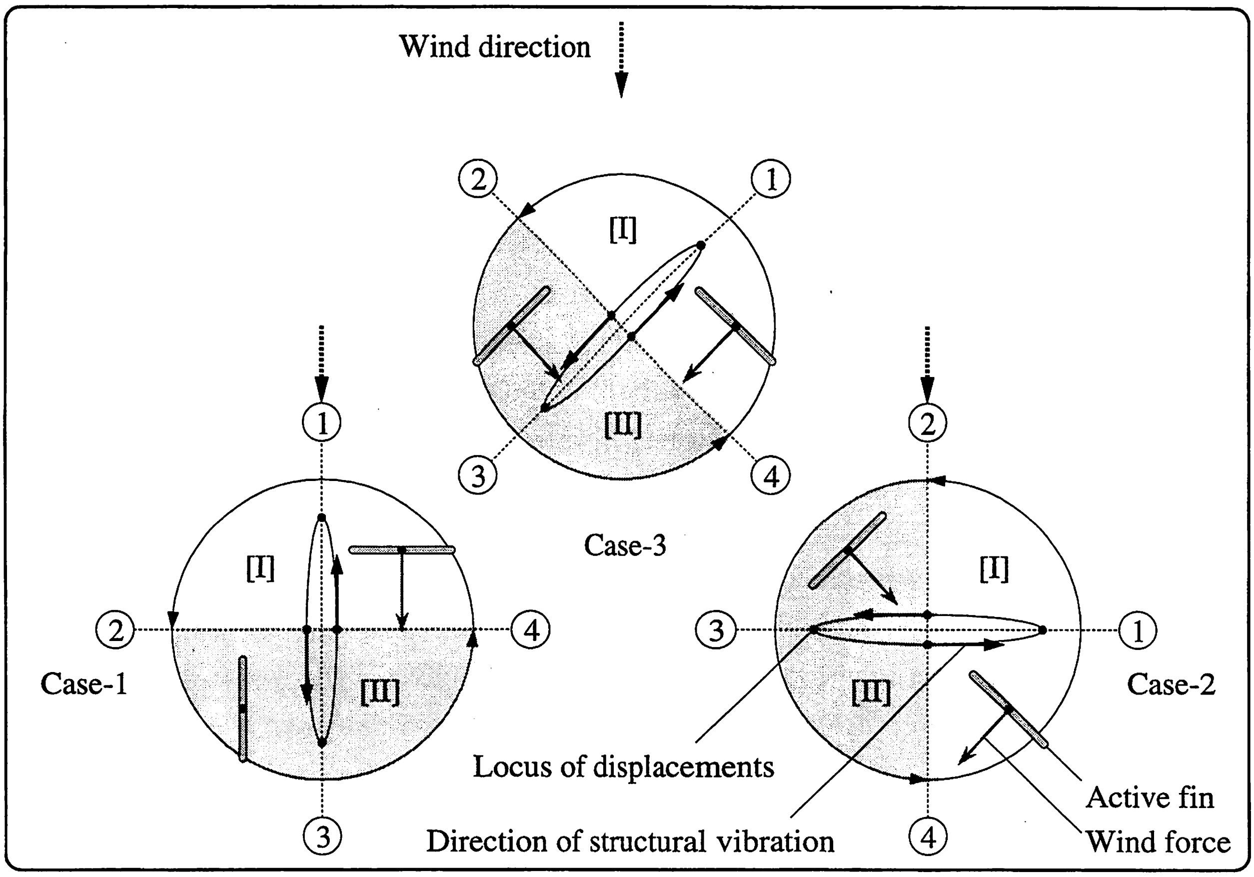
As seen in Figs.5.4.1 and Figs.5.4.2, the states of the structural vibrations specified by the symbols ② and ④ are corresponded to the instances as that the maximum velocities may be appeared and the states of the structural vibrations specified by the symbols ① and ③ are corresponded to the instances as that the orientations of velocities for the major directions may be inverted. In which, it may be regarded that the orientations of the structural vibrations on the duration from the state ③ to the state ① (called as the 'Duration-1') are almost same and that the orientations of the structural vibrations on the duration from the state ① to the state ③ (called as the 'Duration-2') are also almost same. Two kinds of configurations of the active fin (which are appeared on the interval [I] and on the interval [II]) are supposed according to two kinds of the major orientations of velocities by every cases of three kinds of the major directions of the structural vibrations. When the Case-1 is supposed (the major directions of the structural vibrations are appeared on the parallel-wind direction), the closed mode and the open mode may be allocated on those intervals [I] and [II], respectively. When the Case-2 is supposed (the major directions of the structural vibrations are appeared on the cross-wind direction), the leftward mode and the rightward mode may be allocated on those intervals [I] and [II], respectively. When the Case-3 is supposed (the major directions of the structural vibrations are appeared on the middle of those directions), the leftward mode and the rightward mode may be allocated on those intervals [I] and [II], respectively.

The following four items may be pointed as the considerations for the control manipulations based on the Version-I of the two directional control method under the condition as that the structural vibrations are appeared as like to the single-directional motion.

Point-1.1) As seen in Figs.5.4.1 (a), the interval [I] and the interval [II] that the positioning of the active fin may be held on the fixed configurations may be consistent with the Duration-1 and

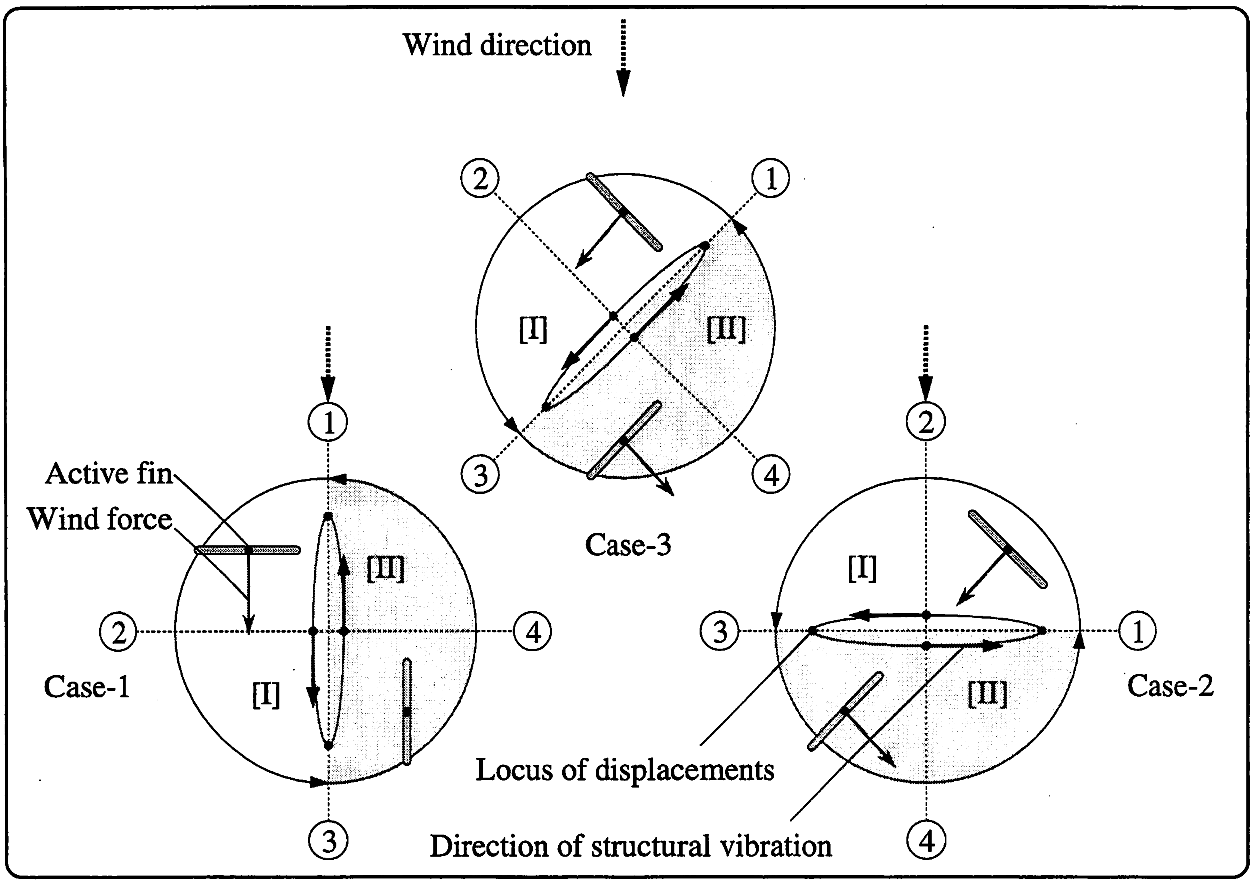


(a) Configurations of the active fin (any time delays are not considered),

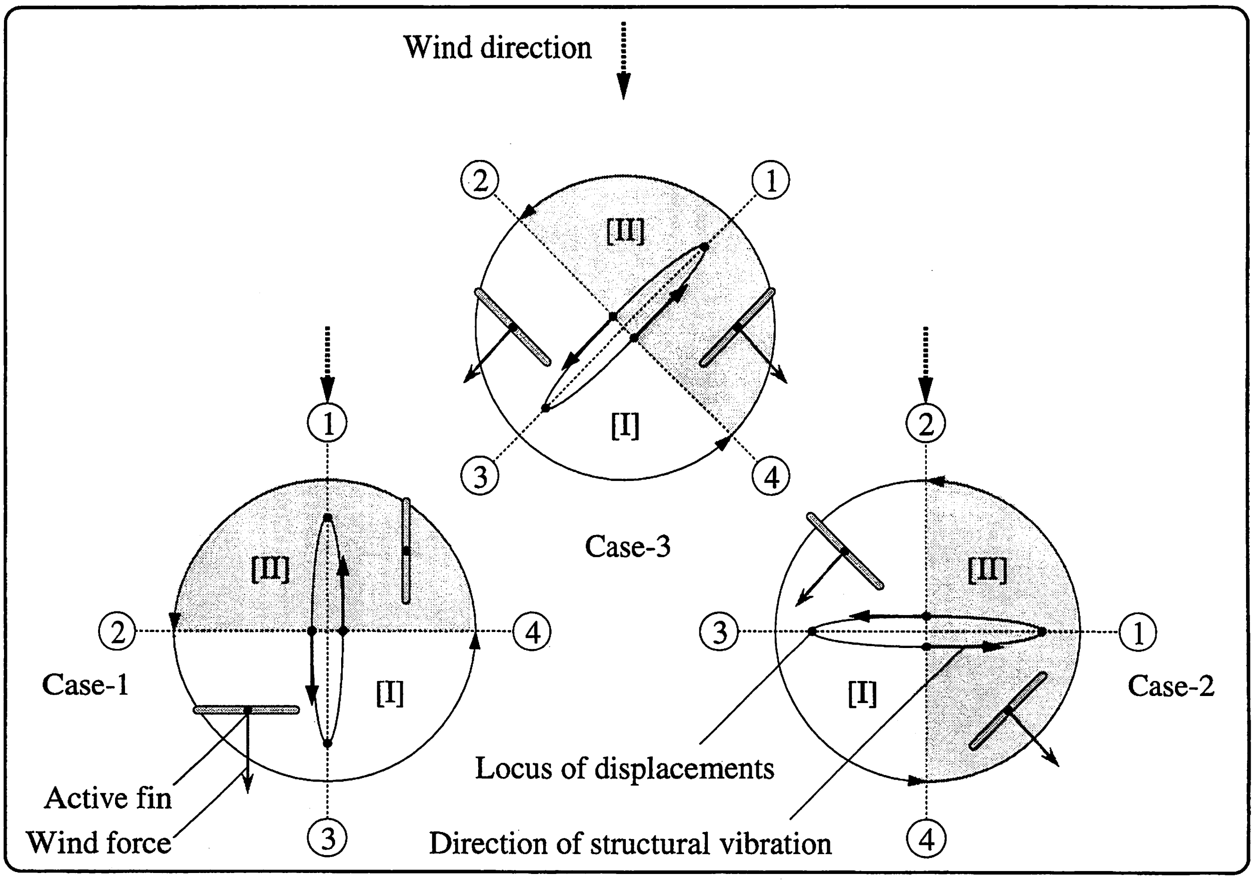


(b) Configurations of the active fin (time delays by $\Lambda = 1/4$ are considered),

Fig. 5.4.1 Manipulations on the Control algorithm-2(R) under flatness of elliptic motion.

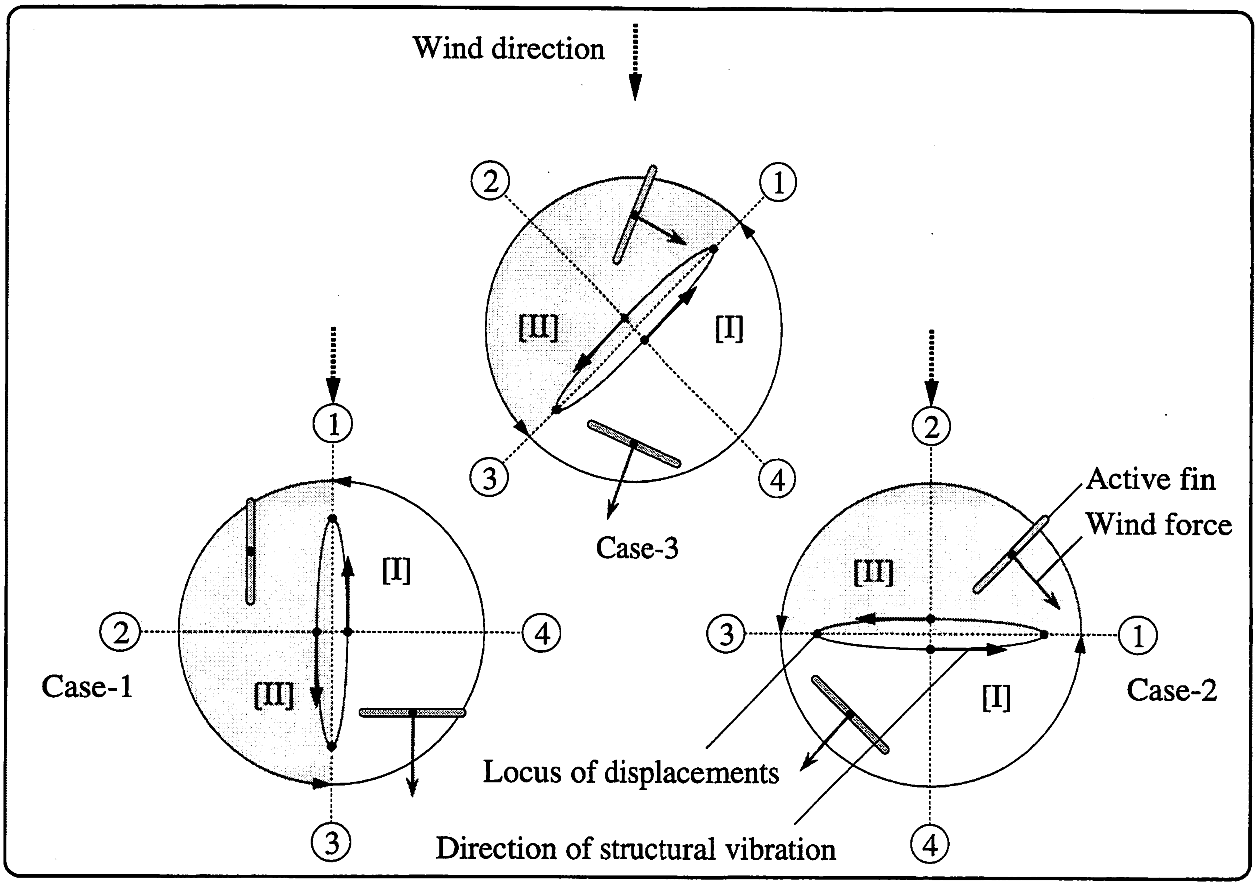


(a) Configurations of the active fin (any time delays are not considered),

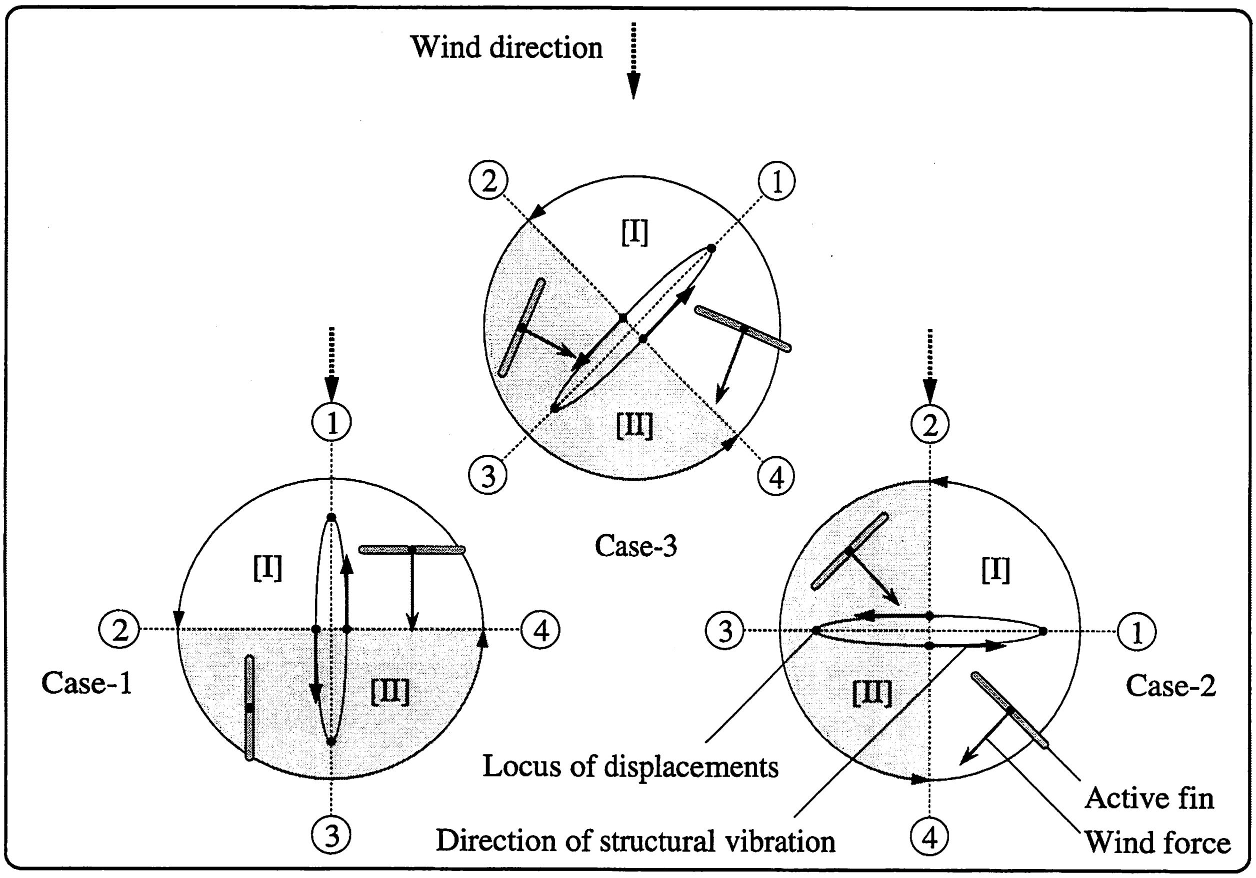


(b) Configurations of the active fin (time delays by $\Lambda = 1/4$ are considered),

Fig. 5.4.2 Manipulations on the Control algorithm-2(A) under flatness of elliptic motion.

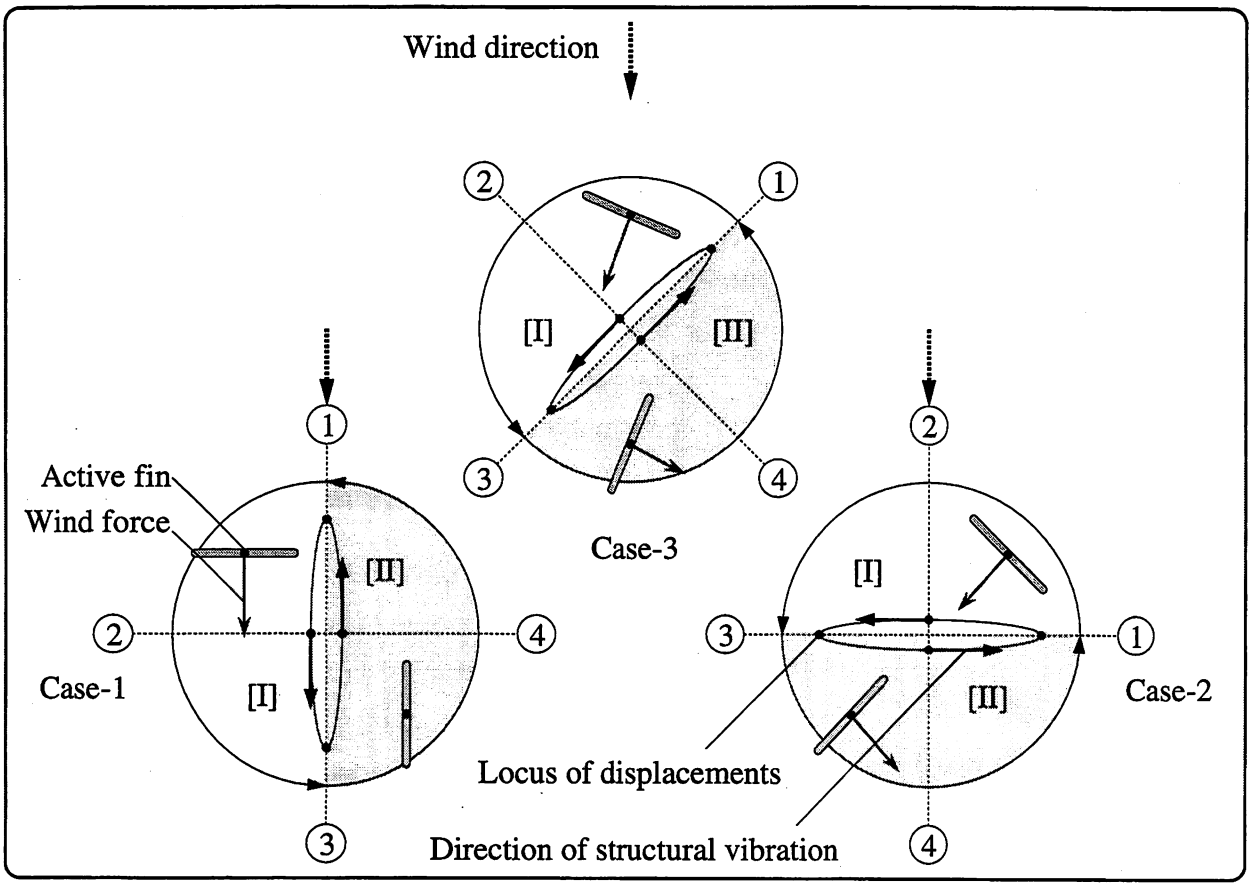


(a) Configurations of the active fin (any time delays are not considered),

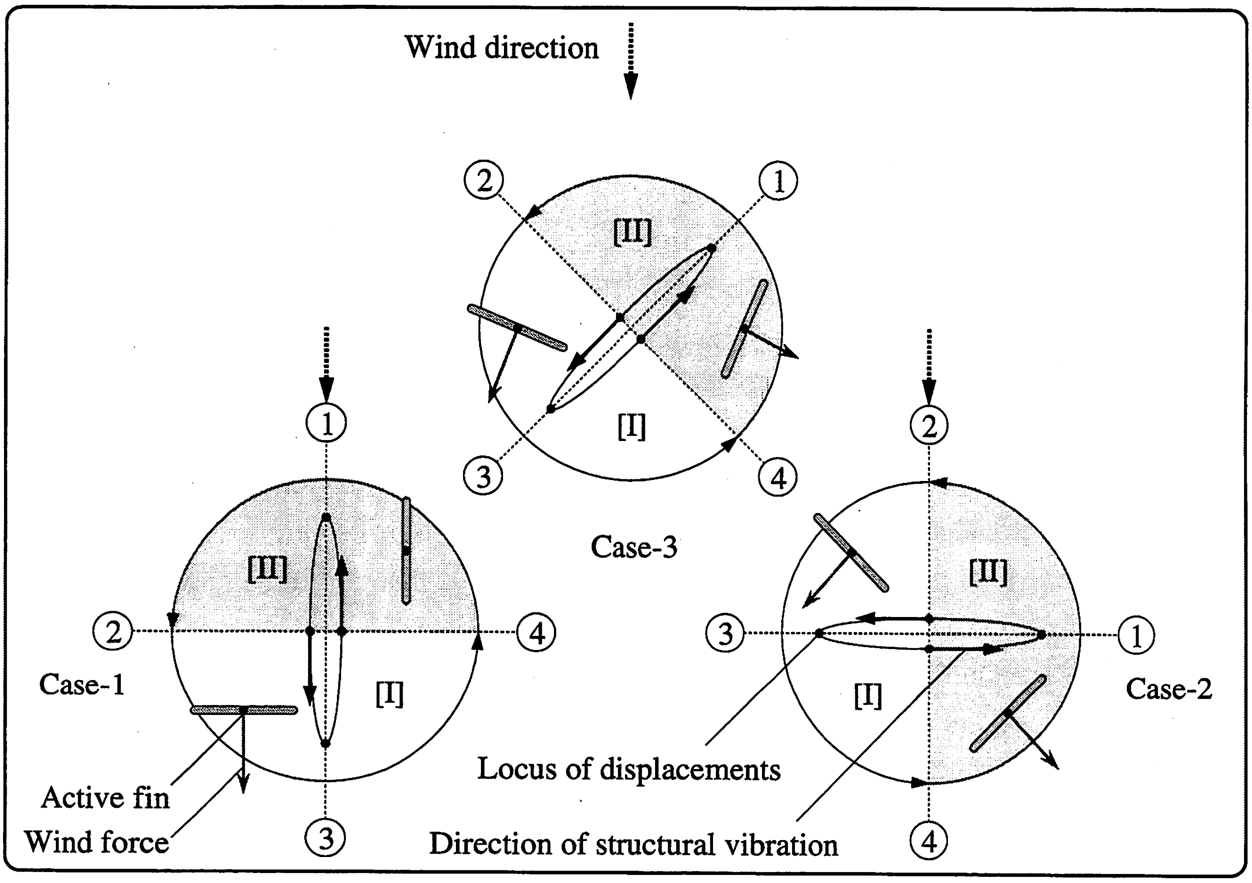


(b) Configurations of the active fin (time delays by $\Lambda = 1/4$ are considered),

Fig. 5.4.3 Manipulations on the Control algorithm-2(R)-II under flatness of elliptic motion.



(a) Configurations of the active fin (any time delays are not considered),



(b) Configurations of the active fin (time delays by $\Lambda = 1/4$ are considered),

Fig. 5.4.4 Manipulations on the Control algorithm-2(A)-II under flatness of elliptic motion.

the Duration-2, respectively. Namely, when any time delays are not considered, it may be pointed that the configurations of the active fin are changed by every instances as that the major orientations of the structural vibrations are inverted. Accordingly, the control manipulations based on the Control algorithm-2(R) of the Verson-1 of the two-directional control method for two cases as that the major directions of the structural vibrations are appeared on the parallel-wind direction (Case-1) and the cross-wind direction (Case-2) may be evaluated as to be equality with the Control algorithm-P1(R) and the Control algorithm-C1(R) based on the single-directional control method mentioned in the Section 5.1 and Section 5.2, under the condition as that the structural vibrations are appeared as like to the single-directional motion.

Point-1.2) As seen in Figs.5.4.1 (b), under the conditions which are considered for the control time intervals as that the manipulation frequency Λ is supposed to be 0.25, the interval [I] and the interval [II] are allocated as to be included the time delay of about 1/4 for the first natural periods of the experimental structures from the Duration-1 and the Duration-2, respectively. Accordingly, it may be pointed that the configurations of the active fin are changed by every instances as that the major orientations of the structural vibrations are grown to the maximum states. However, it seems that those time delays may not cause the inversions of the control effects from the reductions to the amplifications for the structural vibrations on the Control algorithm-2(R). Because, by considering the experimental results on the single-directional active control tests in the Section 5.1 and Section 5.2, it may be pointed that the expected reducing effects for the controlled responses are observed on the wind tunnel tests by using the Control algorithm-P1(R) and the Control algorithm-C1(R) under the conditions which are included the similar values of the time delays.

Point-1.3) As seen in Figs.5.4.2 (a), the interval [I] and the interval [II] that the positioning of the active fin may be held on the fixed configurations may be consistent with the Duration-2 and the Duration-1, respectively. When any time delays are not considered, the control manipulations based on the Control algorithm-2(A) for two cases as that the major directions of the structural vibrations are appeared on the parallel-wind direction (Case-1) and the cross-wind direction (Case-2) may be evaluated as to be equality with the Control algorithm-P1(A) and the Control algorithm-C1(A) based on the single-directional control method mentioned in the Section 5.1 and Section 5.2, under the condition as that the structural vibrations are appeared as like to the single-directional motion.

Point-1.4) As seen in Figs.5.4.2 (b), since the interval [I] and the interval [II] are allocated as to be included the time delay of about 1/4 for the first natural periods of the experimental structures from the Duration-2 and the Duration-1, respectively. However, it also seems that those time delays may not cause the inversions of the control effects from the amplifications to the reductions for the structural vibrations on the Control algorithm-2(A).

At this point, even if the major directions of the structural vibrations are supposed as like the Case-3, it seems that the configurations of the active fin allocated by the Control algorithm-2(R) or the

Control algorithm-2(A) may be enough to be effective for reducing or for amplifying the structural vibrations under the condition as that the time delays of about 1/4 for the first natural periods of the experimental structures are considered. Because, when the structural vibrations are appeared as like to the single-directional motion and when any time delays are not considered on the Case-3, the control manipulations to change the configurations of the active fin may be always operated at the instances that the major orientations of the structural vibrations are inverted as like to both of the Case-1 and the Case-2. Accordingly, even if the influences for the control time intervals as that the manipulation frequency Λ is supposed to be 0.25 are considered on the Case-3, it may be regarded that the allocations of the adequate configurations of the active fin are also warranted until the instances that the major orientations of the structural vibrations are grown to the maximum states.

Study (5.4) - 2 :

On the other hand, under the conditions that the structural vibrations are appeared as to be comparative flatness of elliptic motion, the control manipulations by introducing the Version-2 of the control methods may be verified. Figs.5.4.3 and Figs.5.4.4 show the controlled configurations of the active fin according to the variations of the directions of the structural vibrations by introducing the Control algorithm-2(R)-II and the Control algorithm-2(A)-II of the Version-2 of the two-directional control method, respectively. In those figures, (a) and (b) are corresponded to the cases which is not considered any time delays and which is considered the time delay of 1/4 of the interval for the first natural periods of the experimental structures, respectively. In those figures, three kinds of cases as that the major directions of the structural vibrations are appeared on the parallel-wind direction (Case-1), the cross-wind direction (Case-2) and the middle of those directions (Case-3) are also considered, and the rotational direction of the locus of the displacements are assured as to be counter clockwise.

In Figs.5.4.3 and Figs.5.4.4, the states of the structural vibrations specified by the symbols ② and ④ are corresponded to the instances as that the maximum velocities may be appeared and the states of the structural vibrations specified by the symbols ① and ③ are corresponded to the instances as that the orientations of velocities for the major directions may be inverted. When it may be assured that the major orientations of the structural vibrations may be approximately regarded as to be two kinds, the configurations of the active fin are supposed as to be approximately regarded to two kinds (those are appeared on the interval [I] and on the interval [II]) by every cases from the Case-1 to the Case-3.

By comparing Figs.5.4.3 with Figs.5.4.1, and by comparing Figs.5.4.4 with Figs.5.4.2, when the Case-1 (the major directions of the structural vibrations are appeared on the parallel-wind direction) or the Case-2 (the major directions of the structural vibrations are appeared on the cross-wind direction) is supposed, it may be pointed that the control manipulations based on the Version-2 of the two-directional control method are evaluated as to be equality to the control manipulations based on the Version-1. When the Case-3 is supposed (the major directions of the structural vibrations are appeared on the middle of those directions), it may be evaluated that the more effective arrangements of the wind forces for the parallel-wind components of the structural vibrations may be considered on the Version-2 of the two-directional control method rather than the Version-1. Because the middle configuration between the leftward mode and the closed mode is allocated on the interval [I] and the middle configuration between the rightward mode and the open mode is allocated on the interval [II], and the turnings of the volumes of the drag of the wind forces are also actualized. Namely, when the structural vibrations are appeared as like to the single-directional motion, it may be regarded that the allocations of the control effects by introducing the Control algorithm-2(R)-II and the Control algorithm-2(A)-II of the Version-2 of the two-directional control method are also appeared as to able to actualize the expected control efficiencies as much as the control manipulations by the Version-1 of the control method, even if the influences for the control time intervals as that the manipulation frequency Λ is supposed to be 0.25 are considered.

In those verifications for the two kind of the two-directional control methods under the assumptions as that the structural vibrations are appeared as to be comparative flatness of elliptic motion, it may be assured that the inversions of the expected control effects for the Version-2 of the control method are not appeared under the considerations for the influence of the time delays on the control manipulations which is supposed by $\Lambda = 0.25$. Moreover, it may be evaluated that the remarkable differences between the Version-1 and the Version-2 of the control methods are not also pointed. At this point, by considering that both of the large-scaled experimental results for the Version-1 and the Version-2 of the two-directional control methods (as mentioned in the Section 5.2 and the Section 5.3) are observed as to be subjected on the same conditions of the control time intervals as that the manipulation frequency Λ is supposed to be about 0.27. So that, it may be evaluated that the inversions of the expected control effects for the Version-2 of the control method should be appeared under the time delays on the control manipulations by $\Lambda = 0.25$, and accordingly, it may be pointed that the other significant factors should be latently existed.

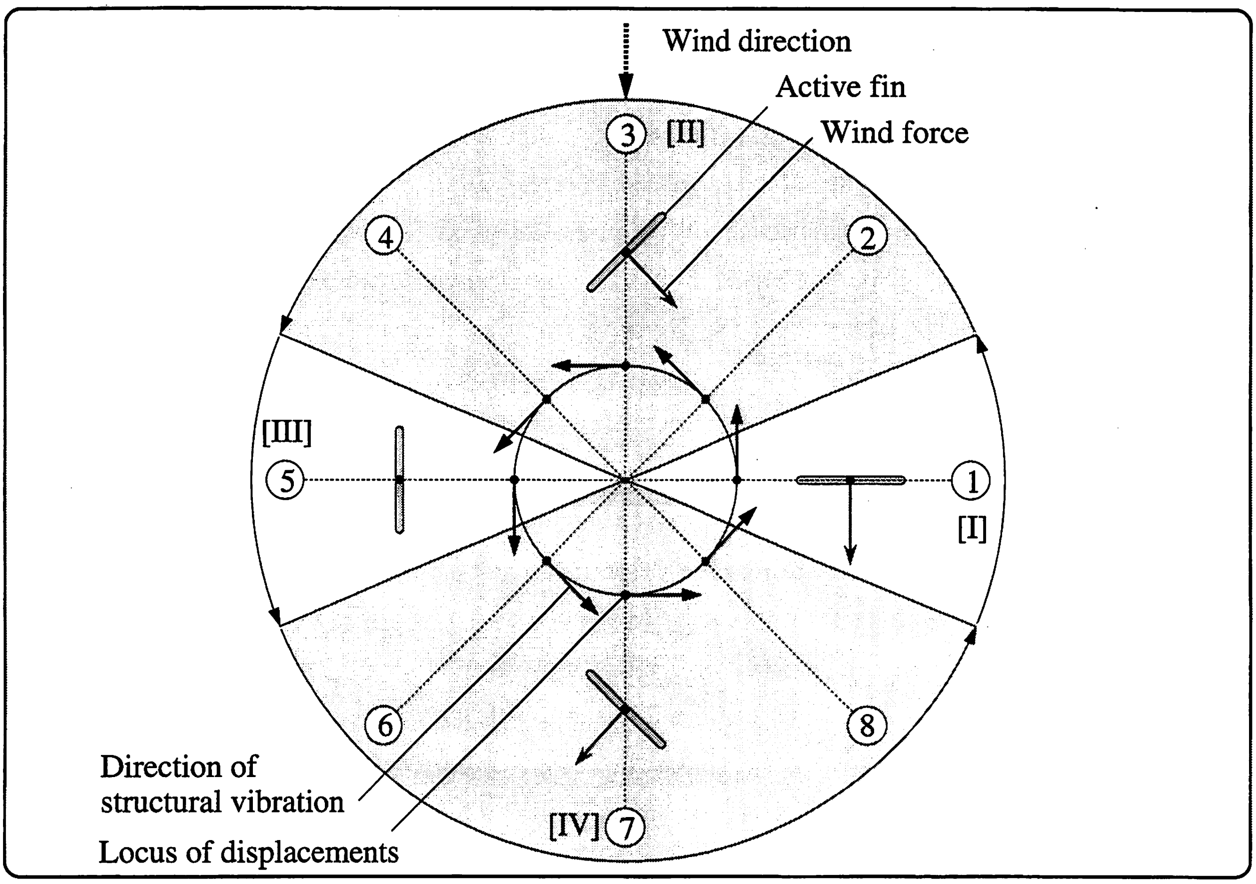
Study (5.4) - 3 :

As the another one of the typical conditions that the structural vibrations, under the condition that the elliptic motions of the experimental structure are appeared as to be close to the circular locus, the control manipulations by introducing those two kinds of control methods may be verified. Figs.5.4.5 and Figs.5.4.6 show the controlled configurations of the active fin according to the variations of the directions of the structural vibrations by introducing the Control algorithm-2(R) and the Control algorithm-2(A) of the Version-1 of the two-directional control method, respectively. In those figures, (a) and (b) are corresponded to the cases which is not considered any time delays and which is considered the time delay of 1/4 of the interval for the first natural periods of the experimental structures (namely, the influences for the manipulation frequency Λ as to be 0.25 is considered), respectively. In those figures, the circular locus of the structural vibrations are considered and the rotational direction of the locus of the displacements are assured as to be counter clockwise.

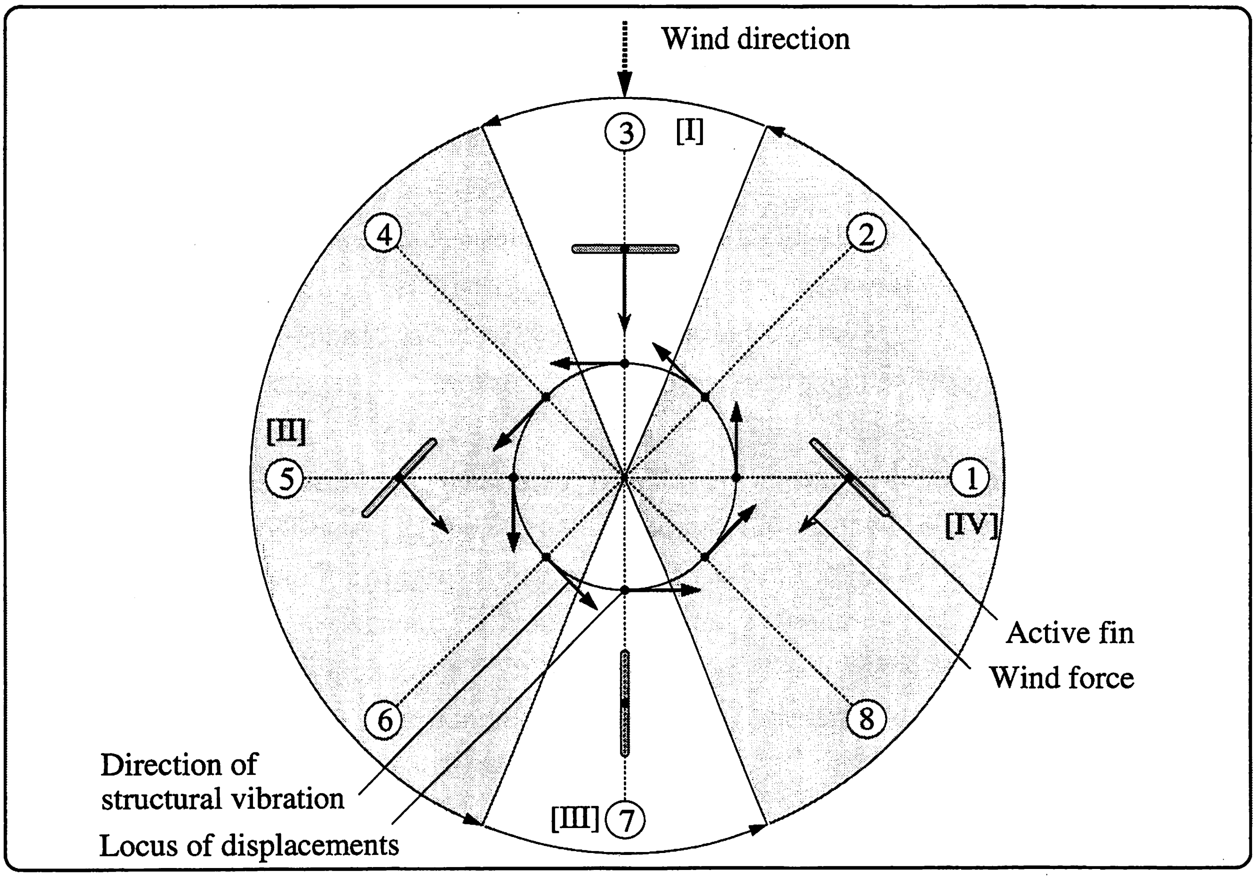
As seen in Figs.5.4.5 and Figs.5.4.6, the states of the structural vibrations specified by the symbols ① and ⑤ are corresponded to the instances as that the orientations of the velocities may be appeared as to be allocated on the windward and the leeward to the wind direction, respectively. When the instances as that the sign of the components of velocities for those parallel-wind directions may be inverted are considered, the states of the structural vibrations specified by the symbols ⑦ and ③ are corresponded to the instances as that the parallel-wind components of velocities may be changed from the leeward to the windward and from the windward to the leeward. Similarly, the states of the structural vibrations specified by the symbols ③ and ⑦ are corresponded to the instances as that the orientations of the velocities may be appeared as to be allocated on the leftward and the rightward (which are faced to the windward), respectively. When the instances as that the sign of the components of velocities for those cross-wind directions may be inverted are considered, the states of the structural vibrations specified by the symbols ① and ⑤ are corresponded to the instances as that the cross-wind components of velocities may be changed from the rightward to the leftward and from the leftward to the rightward. In which, it may be pointed that the orientations on the parallel-wind components of the structural vibrations on the duration from the state ⑦ to the state ③ (called as the 'Duration-P1') are the windward and that the orientations of the structural vibrations on the duration from the state ③ to the state ⑦ (called as the 'Duration-P2') are the leeward. Similarly, it may be pointed that the orientations on the cross-wind components of the structural vibrations on the duration from the state ① to the state ⑤ (called as the 'Duration-C1') are the leftward to the wind direction and that the orientations of the structural vibrations on the duration from the state ⑤ to the state ① (called as the 'Duration-C2') are the rightward to the wind direction. By introducing the Control algorithm-2(R) and the Control algorithm-2(A) based on the Version-1 of the two-directional control method, four kinds of the configurations of the active fin may be allocated according to the variations of the structural vibrations as shown in Figs.5.4.5 and Figs.5.4.6, namely, the closed mode, the rightward mode, the open mode and the leftward mode may be configured on the intervals [I], [II], [III] and [IV], respectively.

The following five items may be pointed as the considerations for the control manipulations based on the Version-1 of the two-directional control method under the condition as that the structural vibrations are appeared as like to the circular motion.

Point-2.0) As the common tendencies which are evaluated by considering Figs.5.4.5 and Figs.5.4.6, it may be specified that the intervals [II] and [IV] (that the positioning of the active fin may be held on the fixed configurations of the rightward mode and the leftward mode, respectively) are arranged as to become larger than the intervals [I] and [III] (that the positioning of the active fin may be held on the fixed configurations of the closed mode and the open mode, respectively). Namely, the configured timings for the leftward mode and the rightward mode are tuned as to be encroached forward by terminating the allocations for the open mode and the closed mode. Accordingly, when the time delays are considered, it may be evaluated that the control manipulations based on the Version-1 of the two-directional control method are provided margins for controlling the responses on the cross-wind direction, however that those manipulations are severe for controlling the responses on the parallel-wind direction.

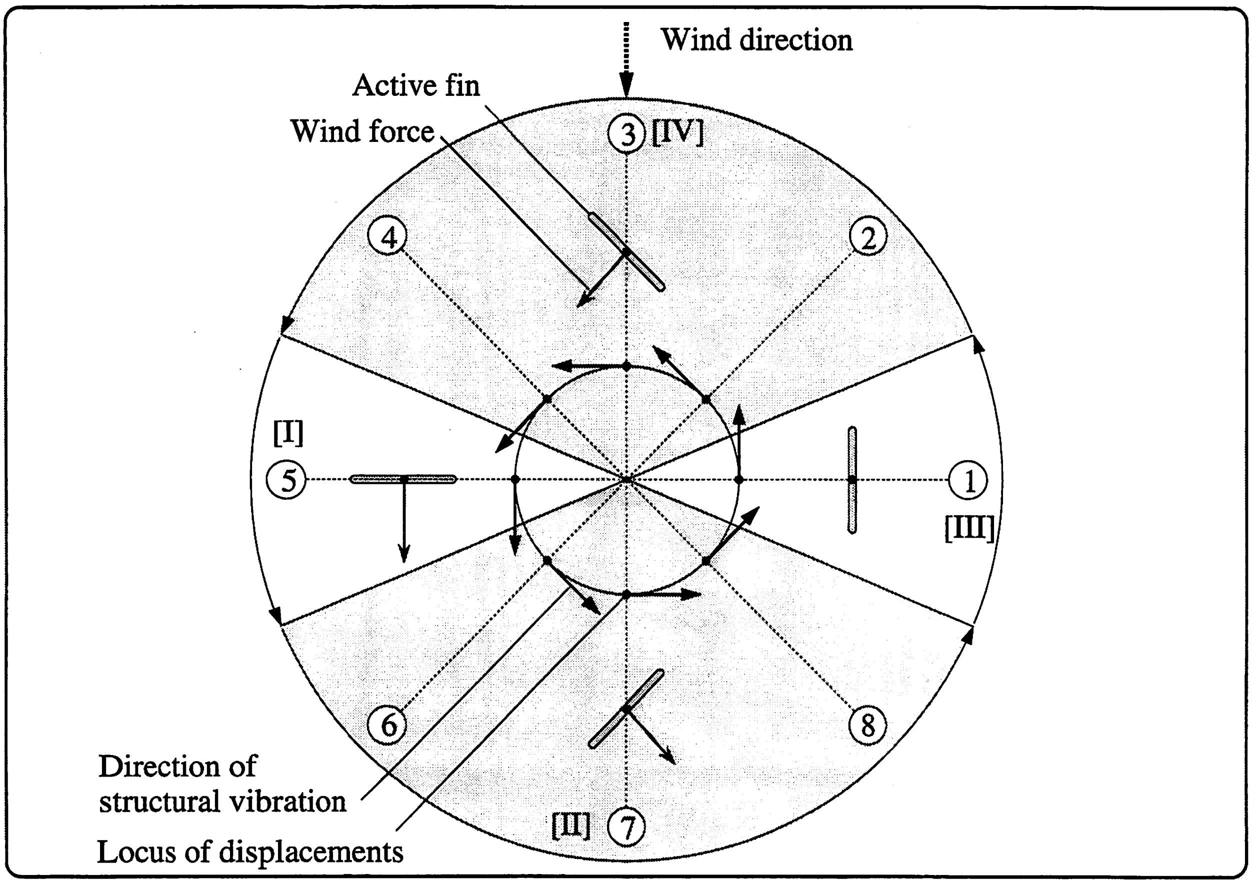


(a) Configurations of the active fin (any time delays are not considered),

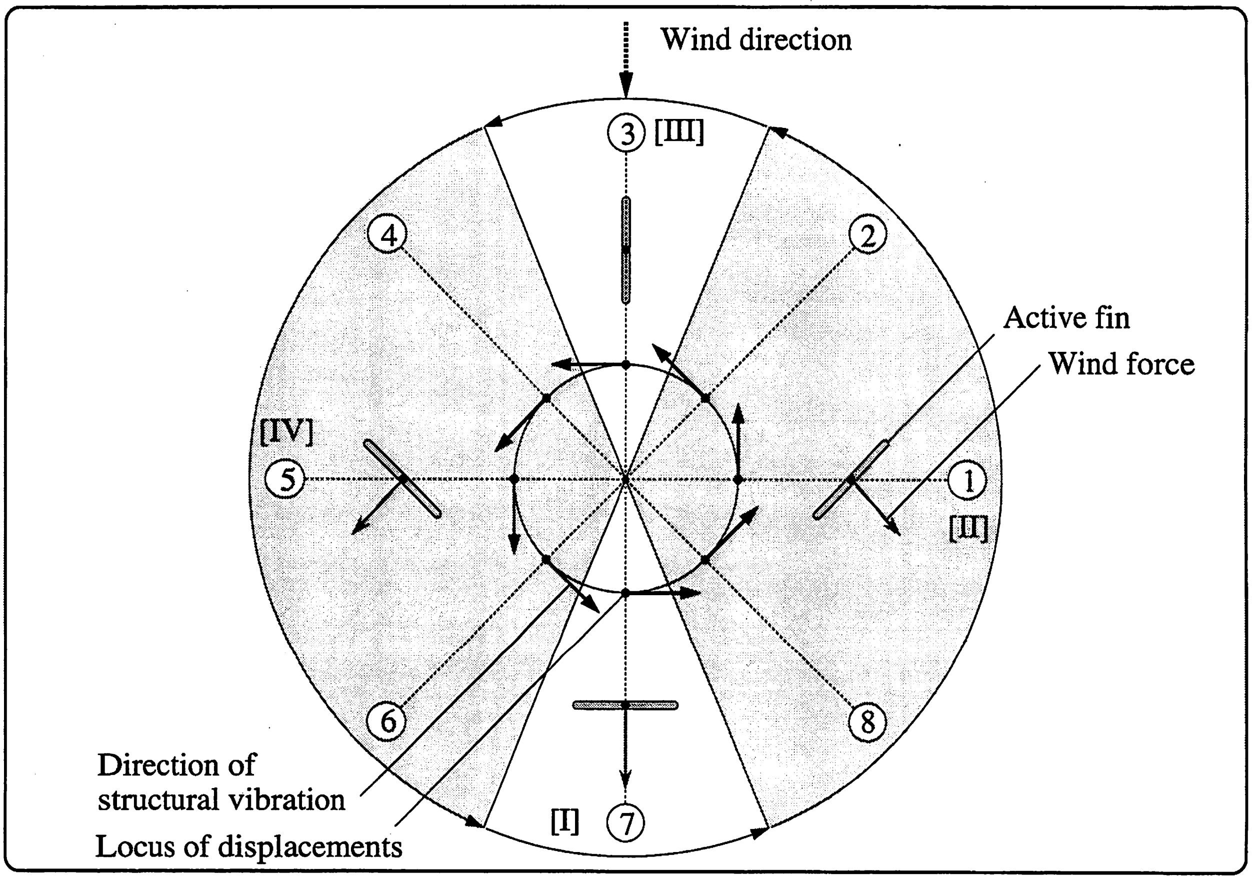


(b) Configurations of the active fin (time delays by $\Lambda = 1/4$ are considered),

Fig. 5.4.5 Manipulations on the Control algorithm-2(R) under circular motion.

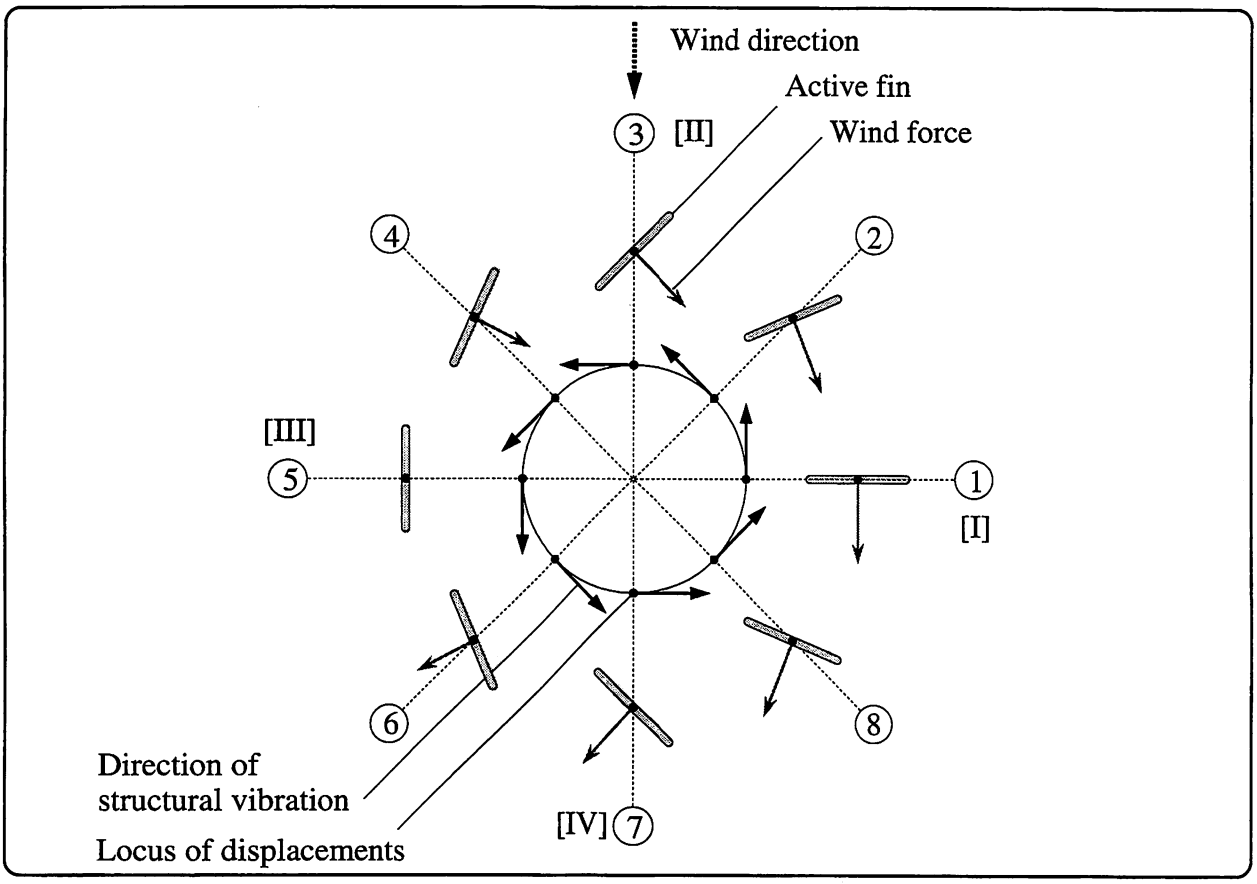


(a) Configurations of the active fin (any time delays are not considered),

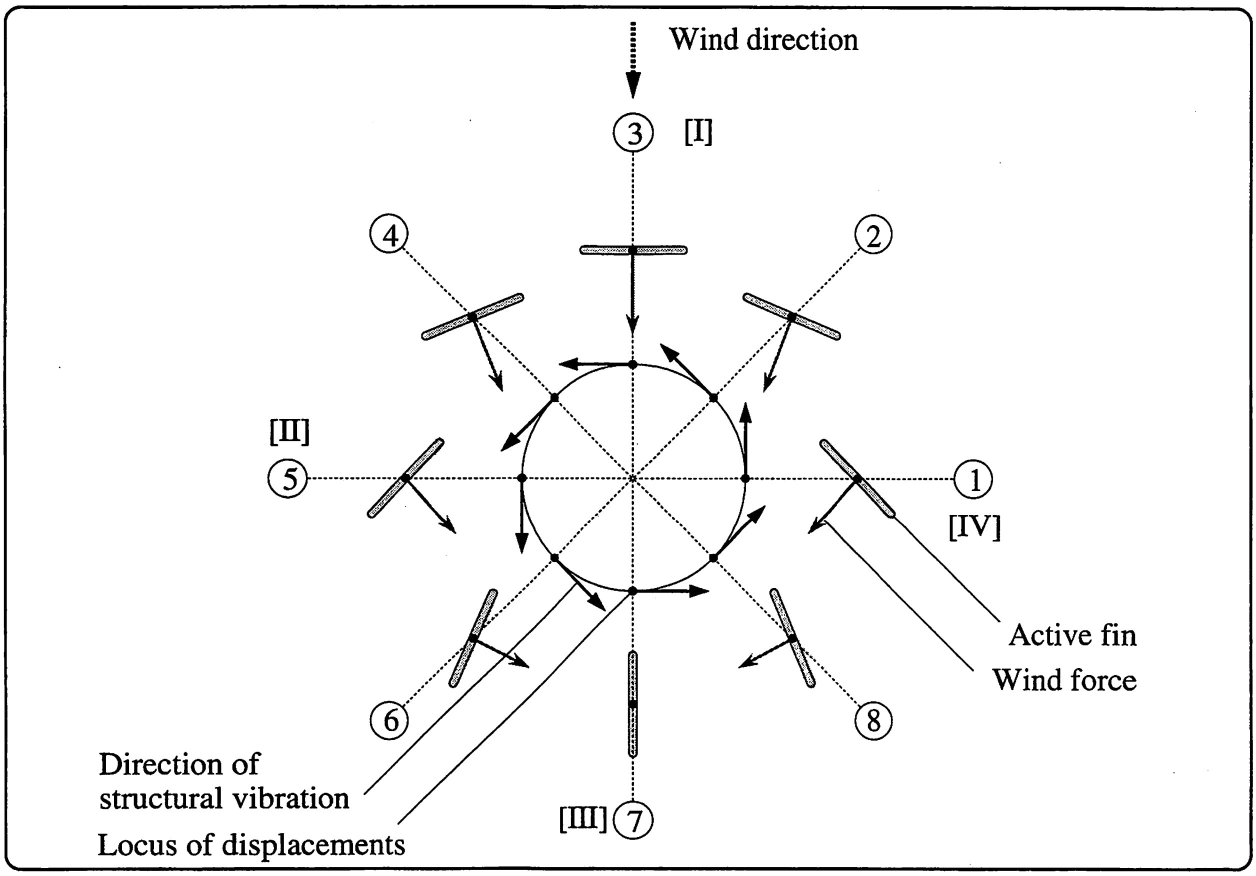


(b) Configurations of the active fin (time delays by $\Lambda = 1/4$ are considered),

Fig. 5.4.6 Manipulations on the Control algorithm-2(A) under circuler motion.

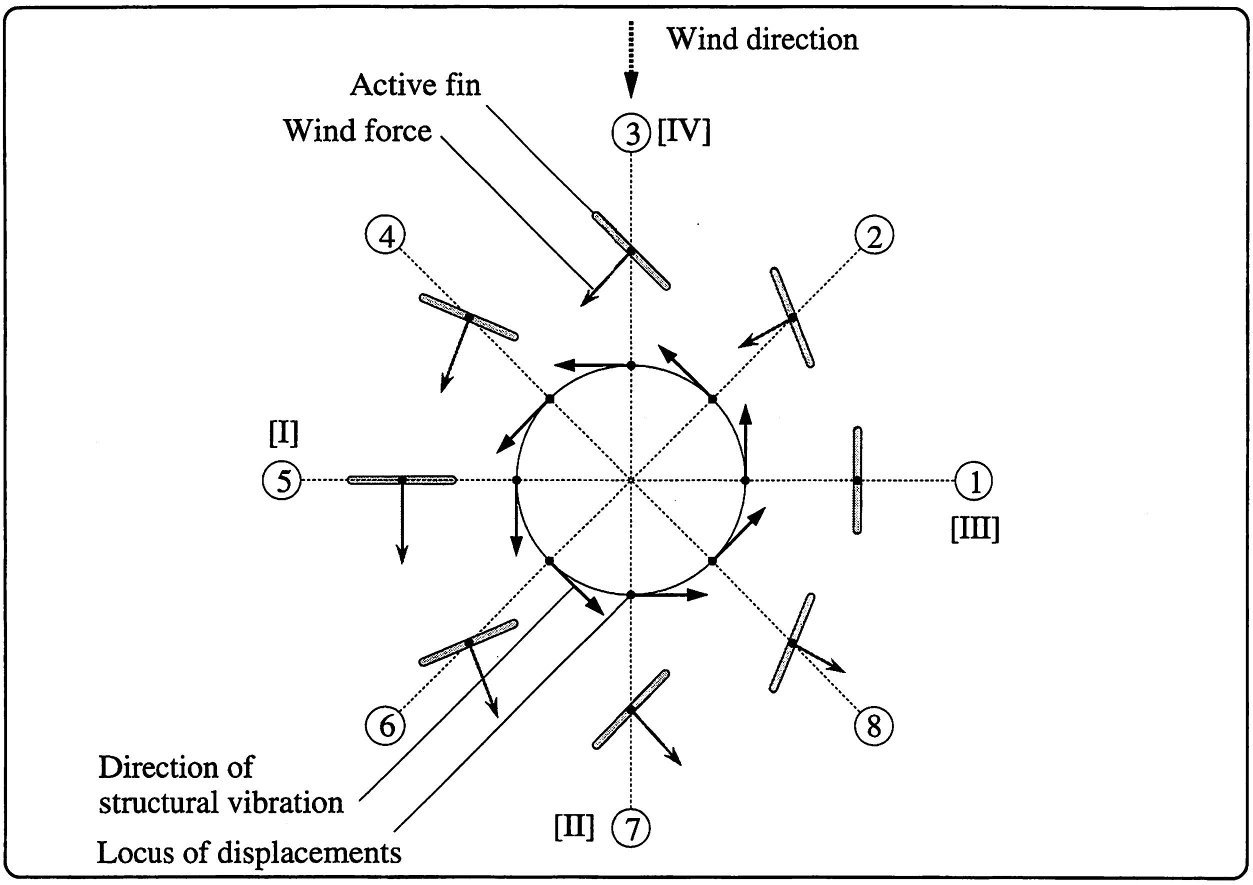


(a) Configurations of the active fin (any time delays are not considered),

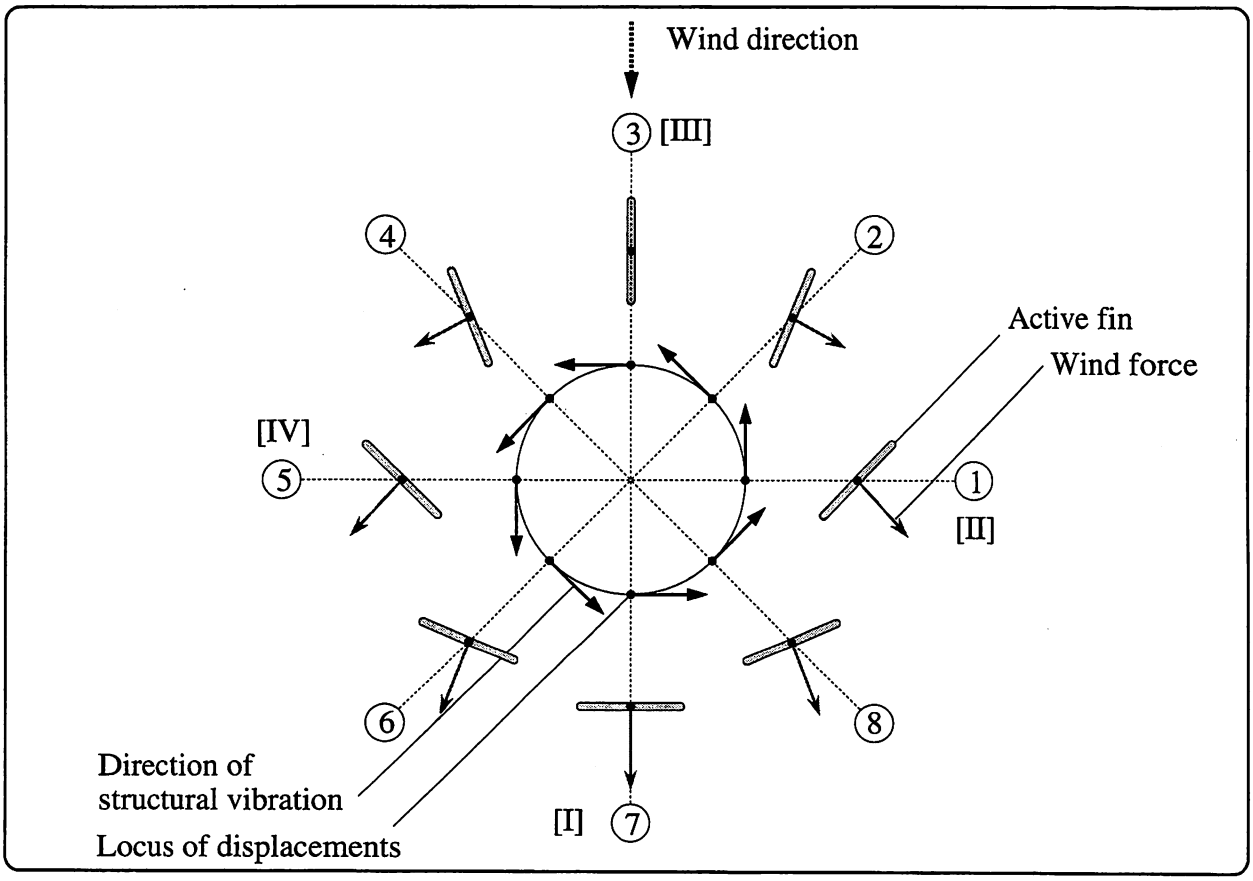


(b) Configurations of the active fin (time delays by $\Lambda = 1/4$ are considered),

Fig. 5.4.7 Manipulations on the Control algorithm-2(R)-II under circuler motion.



(a) Configurations of the active fin (any time delays are not considered),



(b) Configurations of the active fin (time delays by $\Lambda = 1/4$ are considered),

Fig. 5.4.8 Manipulations on the Control algorithm-2(A)-II under circuler motion.

Point-2.1) As seen in Fig.5.4.5 (a) under the considerations for the Point-2.0, the intervals [II] and [IV] may be allocated as to be almost consistent with the Duration-C1 and the Duration-C2, respectively. At this point, since the intervals [I] and [III] may be only appeared as to be allocated on the narrowed durations as that the parallel-wind components of the structural velocities have been grown to a certain extent of volumes, it seems that those corresponded configurations as the open mode and the closed mode may not be affected by the primary efficiencies, but may be functioned as the neutral configurations for transformations between the leftward mode and the rightward mode. Accordingly, it may be evaluated that the primary control effects by introducing the Control algorithm-2(R) based on the Version-1 of the two-directional control method are appeared as the reductions of the cross-wind structural vibrations.

Point-2.2) As seen in Fig.5.4.5 (b), under the conditions which are considered for the control time intervals as that the manipulation frequency Λ is supposed to be 0.25, the interval [I] and the interval [III] are dragged on the every narrowed durations as that the orientations of the parallel-wind components of the structural velocities are inverted from the windward to the leeward and from the leeward to the windward, respectively. At this time, it may be explicitly considered that those configured positionings of the active fin which are allocated as to be the closed mode and the open mode are not be taken effects to reduce the structural responses on the parallel-wind directions, because that those configured positionings are arranged as to be opposite for the manipulations to cancel the structural vibrations. As the compensations for those handicaps, the beginnings of the intervals [II] and [IV] may be allocated as to become almost close to the immediate timings after that the cross-wind components of the structural velocities have been grown to the maximum volumes on the leftward and on the rightward, respectively. At this point, by comparing this figure with the Case-2 in Figs.5.4.1 (b), even if the structural vibrations are appeared as like to the circular motion, it seems that the control manipulations for the cross-wind direction can be kept the almost equality operations with the cases as that the structural vibrations are appeared as like to the single-directional motion. Accordingly, by considering for the Point-1.2 on the Study (5.4)-1, it seems that only the control effects on the cross-wind directions by introducing the Control algorithm-2(R) may be regarded as to be able to reduce the structural vibrations under the considerations for those time delays.

Point-2.3) As seen in Figs.5.4.6 (a) under the considerations for the Point-2.0, the intervals [II] and [IV] may be allocated as to be almost consistent with the Duration-C2 and the Duration-C1, respectively. By taking notice with the similar tendencies for the Point-2.1, since the intervals [I] and [III] may be also evaluated as to be functioned as the neutral configurations for transformations between the leftward mode and the rightward mode, it may be considered that the primary control effects by introducing the Control algorithm-2(A) based on the Version-1 of the two-directional control method are appeared as the amplifications of the cross-wind structural vibrations.

Point-2.4) Similarly, as seen in Figs.5.4.6 (b), under the conditions which are considered for the control time intervals as that the manipulation frequency Λ is supposed to be 0.25, the interval [I] and the interval [III] may be allocated as to be the closed mode and the open mode are not be taken effects to amplify the structural responses on the parallel-wind directions. On the other hand, since the beginnings of the intervals [II] and [IV] may be allocated as to become almost close to the immediate timings after that the cross-wind components of the structural velocities have been grown to the maximum volumes on the rightward and on the leftward, respectively, it seems that only the control effects on the cross-wind directions by introducing the Control algorithm-2(A) may be regarded as to be able to enlarge the structural vibrations under the considerations for those time delays.

Through those verifications for the Version-1 of the two-directional control method, when the structural vibrations are supposed to be appeared as the circular locus, it may be evaluated that the configured positionings of the active fin which are allocated by the Control algorithm-2(R) or the Control algorithm-2(A) become only to be effective for reducing or for amplifying the structural vibrations on the cross-wind direction under the condition as that the time delays of about 1/4 for the first natural periods of the experimental structures are considered. Because, even if the structural vibrations are appeared as like to the circular motion, the control manipulations to change the configurations of the active fin may be almost operated as to be transformed only between the leftward mode and the rightward mode at the instances that the orientations of the cross-wind components of the structural vibrations are inverted under the conditions that any time delays are not considered. And also, when the influences for the control time intervals as that the manipulation frequency Λ is supposed to be 0.25 are considered, it may be regarded that the allocations of the adequate configurations of the active fin for controlling the cross-wind responses are warranted until the instances that the cross-wind components of the structural vibrations are grown to the maximum states. Accordingly, it may be regarded that the observed phenomena on the experimental results by introducing the Version-1 of the two-directional control method which are mentioned on the Section 5.2 (that those control effects are appeared as to be reduced or amplified only the cross-wind responses) are significantly subjected to both of the influences of the time delays for the control manipulations and the circular locus of the structural vibrations.

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On the other hand, under the conditions that the structural vibrations are appeared as to be close to the circular locus, the control manipulations by introducing the Version-2 of the control methods may be verified. Figs.5.4.7 and Figs.5.4.8 show the controlled configurations of the active fin according to the variations of the directions of the structural vibrations by introducing the Control algorithm-2(R)-II and the Control algorithm-2(A)-II of the Version-1 of the two-directional control method, respectively. In those figures, (a) and (b) are corresponded to the cases which is not considered any time delays and which is considered the time delay of 1/4 of the interval for the first natural periods of the experimental structures (namely, the influences for the manipulation frequency Λ as to be 0.25 is considered), respectively. In those figures, the circular locus of the structural vibrations are considered and the rotational direction of the locus of the displacements are assured as to be counter clockwise. By introducing the Control algorithm-2(R)-II and the Control algorithm-2(A)-II based on the Version-2 of the two-directional control method, various kinds of configurations of the active fin may be allocated according to the variations of the structural vibrations as shown in Figs.5.4.7 and Figs.5.4.8. In those figures, the representative states of the structural vibrations are specified by the symbols from ① to ⑧, and especially, the cases which are configured the closed mode, the rightward mode, the open mode and the leftward mode by introducing the Control algorithm-2(R)-II and the Control algorithm-2(A)-II are shown as the instances [I], [II], [III] and [IV], respectively. When the control time intervals of the active fin system are tuned as that the manipulation frequency Λ is supposed to be 0.25, the configurations of the active fin may be changed by every manipulated time instances by every intervals of the 1/4 of the first natural periods of the experimental structures, namely, four kinds of configurations may be appeared by every single cycle of the structural vibrations and every configurations may be held for 1/4 cycle of the structural vibrations.

By comparing Figs.5.4.7 with Figs.5.4.5, and by comparing Figs.5.4.8 with Figs.5.4.6, when the structural vibrations are supposed as to be the circular motions, the explicit differences between the control manipulations based on the Version-1 and the Version-2 of the two-directional control methods may be found out. As seen in Fig.5.4.7 (a), when the states ①, ③, ⑤ and ⑦ are supposed to be allocated as the timings for the control manipulations, the closed mode, the rightward mode, the open mode and the leftward mode may be configured at those instances, respectively. However, by comparing this specified case with the Case-1 and the Case-2 which are mentioned on Figs.5.4.3 (a) on the Study (5.4)-2, it may be pointed that the configured timings for those positionings of the active fin by supposing the circular motion of the structural vibrations have been allocated by the delays of 1/4 cycle of the structural vibrations although any time delays are not considered. At this point, the significant differences of the control manipulations on the Control algorithm-2(R)-II between the cases that the structural vibrations are appeared as like to the single-directional motion and as like to the circular motions may be assured. Accordingly, it may be evaluated the time delays of 1/4 cycle of the structural vibrations are latent on the control manipulations on the Control algorithm-2(R)-II by that the structural vibrations are appeared as to be close to the circular motions.

As seen in Fig.5.4.7 (b), when the time delays of 1/4 of the first natural periods are considered under the conditions as that the structural vibrations are supposed as like to the circular motions, it may be regarded that any configurations of the active fin may be allocated as to be affected amplifying the structural vibrations because that the total influences as the time delays which are estimated by the circular motions and by the manipulating time intervals are almost appeared as the 1/2 of the first natural periods of the experimental structures. By the other words, since the closed mode and the open mode of the active fin may be dragged at the instances as that the parallel-wind components of the structural vibrations are inverted from the windward to the leeward and from the leeward to the windward, respectively, and the leftward mode and the rightward mode may be dragged at the instances as that the cross-wind components of the structural vibrations are inverted from the rightward to the leftward and from the leftward to the rightward, respectively, it may be considered that any configurations of the active fin may be allocated for amplifying the structural vibrations by introducing the Control algorithm-2(R)-II.

As seen in Fig.5.4.8 (a), when the states ①, ③, ⑤ and ⑦ are also supposed to be allocated as the timings for the control manipulations, the open mode, the leftward mode, the closed mode and the rightward mode may be configured at those instances, respectively. Similarly, by comparing this specified case with the Case-1 and the Case-2 which are mentioned on Figs.5.4.4 (a) on the Study (5.4)-2, the significant differences of the control manipulations on the Control algorithm-2(A)-II between the cases that the structural vibrations are appeared as like to the single-directional motion and as like to the circular motions may be also assured. Namely, it may be regarded that the time delays of 1/4 cycle of the structural vibrations are latent on the control manipulations on the Control algorithm-2(A)-II by that the structural vibrations are appeared as to be close to the circular motions.

Accordingly, as seen in Fig.5.4.8 (b), when the time delays of 1/4 of the first natural periods of the experimental structure are considered under the conditions as that the structural vibrations are supposed as like to the circular motions, the closed mode and the open mode of the active fin may be dragged at the instances as that the parallel-wind components of the structural vibrations are inverted from the leeward to the windward and from the windward to the leeward, respectively, and the leftward mode and the rightward mode may be dragged at the instances as that the cross-wind components of the structural vibrations are inverted from the leftward to the rightward and from the rightward to the leftward, respectively. So that, it may be also considered that any configurations of the active fin may be allocated for reducing the structural vibrations by introducing the Control algorithm-2(A)-II.

Through those verifications for the Version-2 of the two-directional control method, when the structural vibrations are supposed to be appeared as the circular locus, it may be evaluated that the positionings of the active fin allocated by the Control algorithm-2(R)-II or the Control algorithm-2(A)-II are configured as to be included the time delays of 1/4 for the first natural periods of the experimental structures even if any manipulating time interval are not considered. Because, although it may be regarded that any one of the positionings of the active fin which are allocated according to the orientations of the structural vibrations by every manipulating instance may be configured at the state as that the structural vibration has been already grown to the maximum volume on this specified orientation, in the sense of the most effective timings, this specified configuration of the active fin should be appeared at the instance that the component of the structural vibrations on this orientation are inverted. However, this instance are always appeared at the 1/4 for the first natural periods of the experimental structures before the manipulating timings. Accordingly, when the influences for the control time intervals as that the manipulation frequency Λ is supposed to be 0.25 are considered under those conditions which are supposed by the circular motions, it may be regarded that the 1/2 of the time delays for the experimental structures are appeared. By the reasons of those, it may be regarded that the experimental results by introducing the Control algorithm-2(R)-II or the Control algorithm-2(A)-II based on the Version-2 of the two-directional control method which are mentioned on the Section 5.3 (that those control effects are appeared as to be inverted those expected control efficiencies) are also significantly subjected to both of the influences of the time delays for the control manipulations and the circular locus of the structural vibrations.

Accordingly, by those verifications from the Study (5.4)-1 to the Study (5.4)-4, it may be regarded that the actualized control effects by introducing those two-kinds of two-directional control methods are characterized by the difference whether the structural vibrations are appeared as to be the comparatively flat locus or as to be close to the circular locus. On the meanings of those, it may be considered that those two kinds of two-directional control methods are provided enough effectiveness as the wind-resistant response controllers for any wind flows which are supposed on any directions under the condition that the structural vibrations are appeared as the flatness locus as to be close to the single-directional motions, even if the control time intervals as that the manipulation frequency Λ is supposed to be 0.25 are considered.

However, it seems that the influence which are cause by the circular locus of the structural vibrations may not be avoidable factor as far as that the multi-directional response control are operated. At this point, if the compensated control manipulations as that the time delay effects which are subjected to the circular locus of the structural vibrations are cancelled those influences can be operated, it may be considered that the control effects by introducing the those two kinds of those two-directional response control method can be improved as to be provided equal effectiveness as well as the cases that the structural vibrations are appeared as to be close to the single-directional motions. When the structural vibrations are comparatively appeared as to be simple harmonic elliptic motions, by estimating the acceleration responses as the factor which can predict the orientations of the future structural vibrations, it seems that the configured positionings of the active fin at the any control time steps may be dragged forward as to cancelling those influences of the time delay effects caused from the circular locus of the structural vibrations. Since it may be considered that the orientations of the velocities and the accelerations of the structural response are appeared almost orthogonally under the circular motion of the structural vibrations, by considering the orientation of the acceleration responses as the additional referential items, at least, a certain extents of the orientation of the structural velocities at the future within 1/4 of the first natural period of the experimental structure may be able to be predicted.

For this aim, the 'direction of structural vibrations' are regarded as the predicted orientations of the top floor's velocity on the two-directional response control methods. By using two components of the top floor's structural velocities on the X-direction and the Y-direction, and by using two components of the top floor's structural accelerations on the X-direction and the Y-direction, the predicted structural velocities by introducing on the two-directional control manipulations are defined as follow.

$$\hat{\dot{x}}_2\,(\sigma + \Delta t_p) = \dot{x}_2\,(\sigma) + \ddot{x}_2\,(\sigma) \cdot \Delta t_\pi \ ,$$

$$\hat{\dot{y}}_2\,(\sigma + \Delta t_p) = \dot{y}_2\,(\sigma) + \ddot{y}_2\,(\sigma) \cdot \Delta t_\pi \ . \tag{5.4.1}$$

In which, those expressions are mentioned for the two-directional vibrative structural model on the CTAC system, $\dot{x}_2\,(\sigma)$ and $\ddot{x}_2\,(\sigma)$ mean the top floor's velocity and acceleration on the X-direction, respectively, and $\dot{y}_2(\sigma)$ and $\ddot{y}_2(\sigma)$ mean the top floor's velocity and acceleration on the Y-direction, respectively. Those quantities are corresponded to the structural responses which are measured and calculated via the sensors equipped on the structural model at the σ-th control time step (σ is assigned as the integer number) and Δt_p means a time intervals for the response predictions. The volume and the direction of the predicted top floor's velocity are computed as $\hat{\zeta}_r$ (cm/s) and $\hat{\theta}_r$, respectively. In which, $\hat{\theta}_r$ ($-180° < \hat{\theta}_r \leq 180°$) is corresponded to the angle which is indicated with the X-direction of the structural model as the reference axis. By introducing the λ rounds of monitoring time by every control time interval Δt_σ, $E(\hat{\zeta}_r)$ and $E(\hat{\theta}_r)$ are also calculated on the computer as the averaged quantities.

Study (5.4) - 5 :

The wind tunnel tests are operated by introducing the Version-2 of the two-directional control method. Because, since the control effects which are observed on the previous experimental tests on both of the large-scaled experimental structure and the wind tunnel are explicitly deteriorated as the controlled phenomena which are inverted the expected control efficiencies by introducing two kinds of control algorithms based on the Version-2 of the two-directional control method, it may be considered that the control effects by introducing the response predictions are appeared as that those inversions are fixed to the expected control efficiencies if those additional manipulations are effective and if the verifying considerations on this section are proper. Namely, if the control effects by observing at this study are appeared as that the structural vibrations are reduced and amplified by using the Control algorithm-2(R)-II and the Control algorithm-2(A)-II, respectively, it may be reached to the confirmations for the verified results as that the circular locus of the structural vibrations may be significantly affected as to be dominant on the control performances for the two-directional response control methods which are proposed on the previous sections.

Accordingly, two kinds of the Version-2 of the two-directional response control method, are installed by the following compositions.

Control algorithm-2(R)-II' :

If $\hat{\zeta}_r \leq \zeta_{r,min}$ or $\zeta_w \leq \zeta_{w,min}$ ***then*** , keeping before positioning,
else if $\phi_{fw} = (1/2) \cdot \hat{\phi}_{rw}$.

Control algorithm-2(A)-II' :

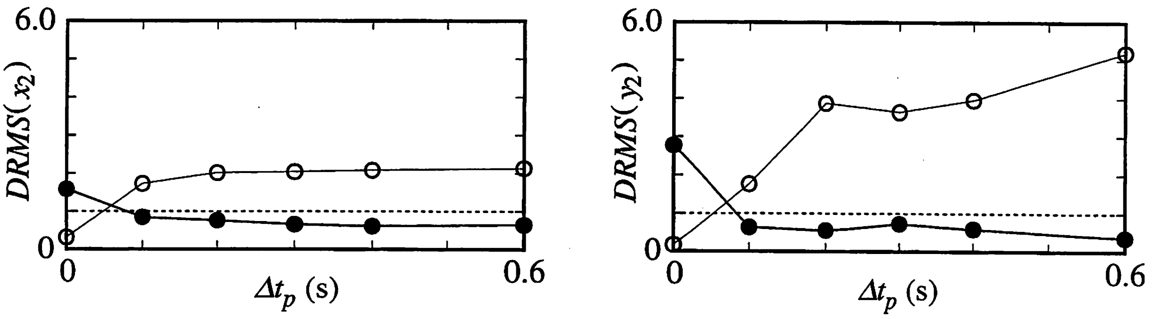
If $\hat{\zeta}_r \leq \zeta_{r,min}$ or $\zeta_w \leq \zeta_{w,min}$ ***then*** , keeping before positioning,
else if $\phi'_{fw} = (1/2) \cdot \hat{\phi}_{rw}$.

In which, $\hat{\phi}_{rw}$ is corresponded to the windage angle of the structural vibrations which are referred to the wind flow as the estimative indicates to express the Version-2 of the two-directional control method, this quantity is defined by $\hat{\phi}_{rw} = E(\hat{\theta}_r) - E(\theta_w)$. On the wind tunnel tests, $E(\theta_w)$ is used as the constant value ($E(\theta_w) = -90°$) which are determined by the allocations of the structural model.

By using the Control algorithm-2(R)-II' and the Control algorithm-2(A)-II' of the Version-2 of the two-directional control methods which are introduced the response predictions, the wind tunnel tests are executed on the new structural model on the CTAC system. The structural properties are adopted as the conditions of the Model-1 which are mentioned on Table 5.3.2 in the Section 5.3. Those experimental examinations are operated for the laminar wind flow which are measured as the wind velocities of about 5.5 (m/s) on the wind tunnel. The control effects on the Control algorithm-2(R)-II' and the Control algorithm-2(A)-II' are examined by that the predicting time interval Δt_p are supposed as 0, 0.1, 0.2, 0.3, 0.4, 0.6 (s). In which, when the time interval is supposed by $\Delta t_p = 0$ (s), since any response predictions may not be operated, the introduced control algorithms for the two-directional response control become equal to the Control algorithm-2(R)-II and the Control algorithm-2(A)-II. The control time interval Δt_σ is supposed as 0.3 (s).

Fig.5.4.9 (a) and Fig.5.4.9 (b) show the fluctuations of the displacements controlled factors $DRMS(x_2)$ on the X-direction and $DRMS(y_2)$ on the Y-direction (which are evaluated for the top floor's displacements of the structural model) according to the difference of the predicting time intervals Δt_p , respectively. In those figure, the solid lines which are plotted by the symbols ● and O are corresponded to the controlled responses by installing the Control algorithm-2(R)-II' and the Control algorithm-2(A)-II', respectively, and the broken lines which is indicated as $DRMS(x_2) = 1.0$ or $DRMS(y_2) = 1.0$ are shown the non-controlled responses.

—●— : Control algorithm-2(R)-II, —○— : Control algorithm-2(A)-II.



(a) X-direction (Cross-wind direction), (b) Y-direction (Parallel-wind direction),

Fig. 5.4.9 Control effects by introducing the response predictions.

As seen in Figs.5.4.9, by introducing the response predictions under the conditions that the predicting time Δt_p is supposed as to be over 0.1 (s), it may be observed that the control effects are appeared as to be reduced by using the Control algorithm-2(R)-II' and as to be amplified the Control algorithm-2(A)-II', respectively. When the response predictions are not operated (namely, $\Delta t_p = 0$ (s)) , since control operations on those two kinds of control algorithms may be equal to the original

Version-2 of the two-directional control method, it may be assured that those controlled responses are appeared as to be inverted from the expected control efficiencies by every those two kinds of control algorithms.

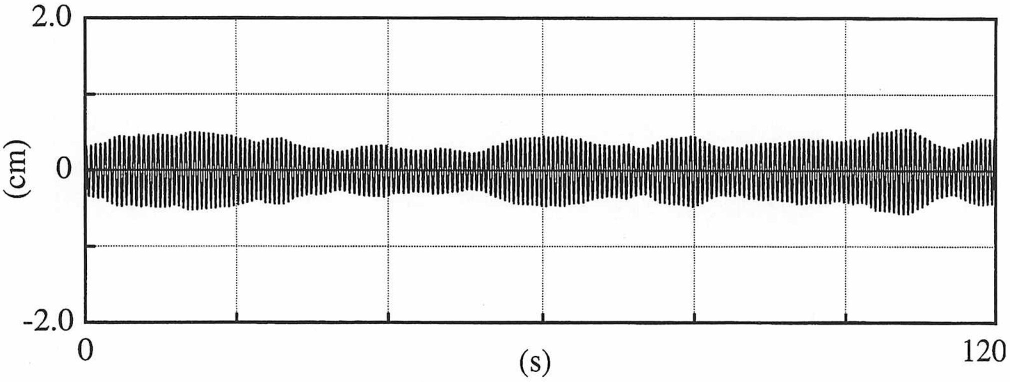
Those experimental results are also evaluated from the comparisons for the time histories and the locus of the displacements of the top floor. Figs.5.4.10 show the non-controlled displacements of the top floor. Figs. 5.4.11 and Figs.5.4.12 show the controlled displacements of the top floor by introducing the Control algorithm-2(R)-II and the Control algorithm-2(A)-II, respectively (namely, those control manipulations mentioned on Figs. 5.4.11 and Figs.5.4.12 are corresponded to the cases as that the predicting time interval is supposed by $\Delta t_p = 0$ (s) on the Control algorithm-2(R)-II' and the Control algorithm-2(A)-II'). Figs. 5.4.13 and Figs.5.4.14 show the controlled displacements of the top floor by introducing the Control algorithm-2(R)-II' and the Control algorithm-2(A)-II' under the conditions by the predicting time interval $\Delta t_p = 0.3$ (s), respectively. In those figures from Figs.5.4.9 to Figs.5.4.14, (a), (b) and (c) are corresponded to the time history on the X-direction (the cross-wind direction), the time history on the Y-direction (the parallel-wind direction) and the locus of the top floor's displacements (during 120 (s)), respectively.

By comparing Figs.5.4.11 and Figs.5.4.12 with Figs.5.4.10, it may be observed that the structural vibrations are amplified by introducing the Control algorithm-2(R)-II on both the cross-wind and the parallel-wind directions and reduced by introducing the Control algorithm-2(A)-II on both the cross-wind and the parallel-wind directions, respectively. Namely, when any response predictions are not operated, it may be assured that those controlled responses by using the Control algorithm-2(R)-II and the Control algorithm-2(A)-II are inverted from their expected control efficiencies. On the other hand, by comparing Figs.5.4.13 and Figs.5.4.14 with Figs.5.4.10, by introducing the response predictions as that the predicting time interval is supposed by $\Delta t_p = 0.3$ (s), it may be observed that the structural vibrations are reduced by introducing the Control algorithm-2(R)-II' on both the cross-wind and the parallel-wind directions and amplified by introducing the Control algorithm-2(A)-II' on both the cross-wind and the parallel-wind directions, respectively.

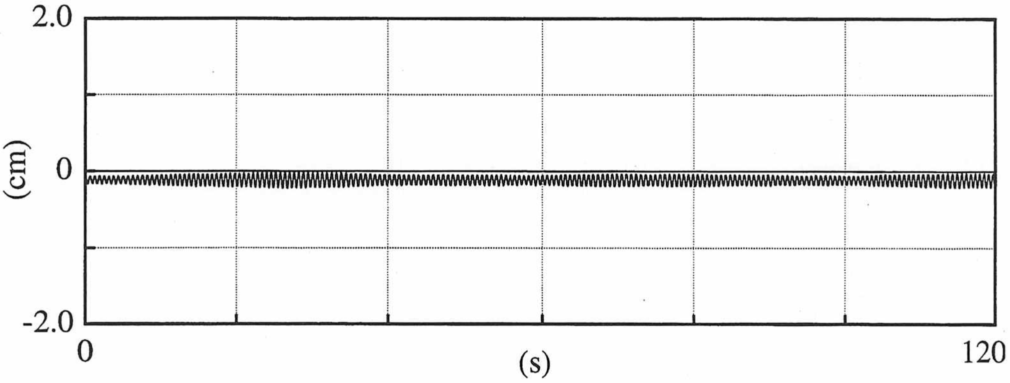
Through those active control tests on the wind tunnel, by introducing the response predictions on the Version-2 of the two-directional control method, it may be assured that the structural vibrations on both of the cross-wind direction and the parallel-wind direction can be effectively reduced and amplified by installing the Control algorithm-2(R)-II' and the Control algorithm-2(A)-II', respectively. Accordingly, since it seems that those operations of the response predictions may be affected to cancel the influence which are caused by the circular locus of the structural vibrations, those verified results may be reached to the considerations that the control effects of those two-directional response control methods are explicitly changed their expected control efficiencies under the conditions that the structural vibrations are close to the comparatively circular locus on the elliptic motions.

As concluding remarks in this section, the control manipulations for two kinds of two-directional response control methods which are proposed in the Section 5.2 and the Section 5.3 are verified under the considerations for the time delays which are caused by the manipulating time intervals to change the positionings of the active fin. Through those verifications, it may be assured that the control effects by introducing those two kinds of two-directional response control methods are significantly subjected to both of the influences of the time delays for the control time intervals and the circular locus of the structural vibrations. Namely, when the Version-1 of the two-directional response control method are introduced, controlled responses are appeared as to be only effective for the cross-wind direction. And when the Version-2 of the two-directional response control method are introduced, controlled responses are appeared as to be inverted those expected control efficiencies. Those experimental results may not be able to be explained until by considering for the influences which are caused from the circular locus of the structural vibrations as the additional factor on the time delays for the manipulating time intervals.

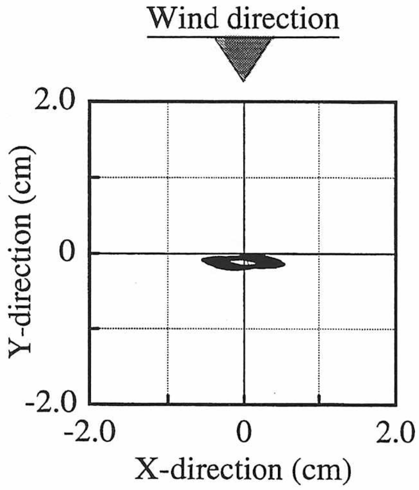
Moreover, to experimentally confirm that the time delay effects caused by structural vibrations as to be close to the circular locus may affects as the significant influences as to change the control effects for the two-directional response control operations, by introducing the response predictions as to cancel the influence for the circular locus of the structural vibrations, the wind tunnel tests by using the two-directional structural model are executed. This confirmations are examined on the Version-2 of the two-directional response control method, because it may be regarded that those influences can be explicitly evaluated whichever the control effects by introducing the response predictions can be operated as the expected control efficiencies on every two kinds of control algorithms or not. As a result, it is assured that those control operations by introducing the response predictions on the Version-2 of the two-directional response control method may be improved as that the expected control efficiencies can be actualized. So that, it may be confirmed that the control effects of those two-directional response control methods are explicitly changed their expected control efficiencies under the conditions that the structural vibrations are close to the comparatively circular locus on the elliptic motions.



(a) X-direction (Cross-wind direction),

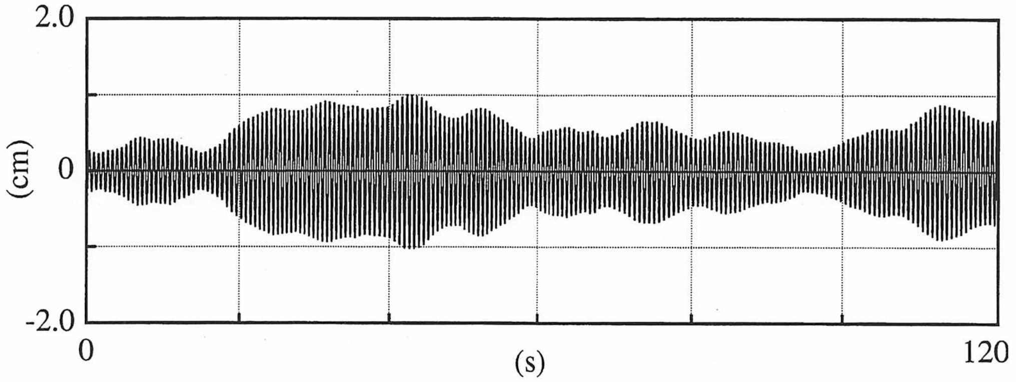


(b) Y-direction (Parallel-wind direction),

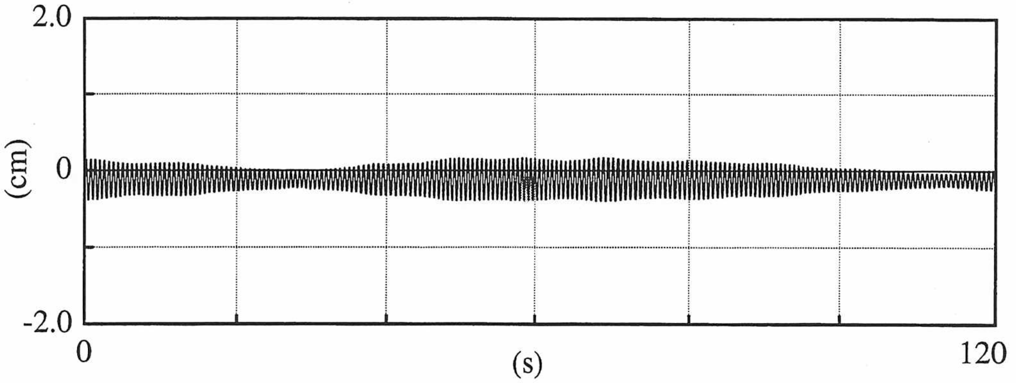


(c) Locus of displacements,

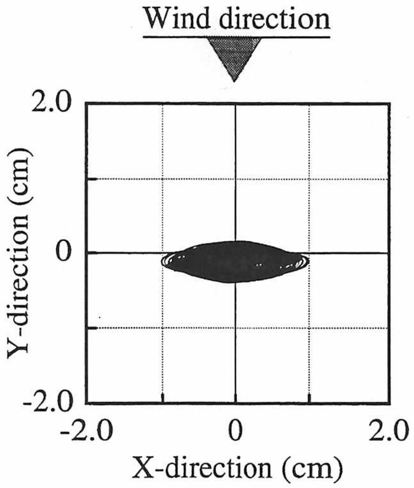
Fig. 5.4.10 Top floor's displacements (Without control).



(a) X-direction (Cross-wind direction),

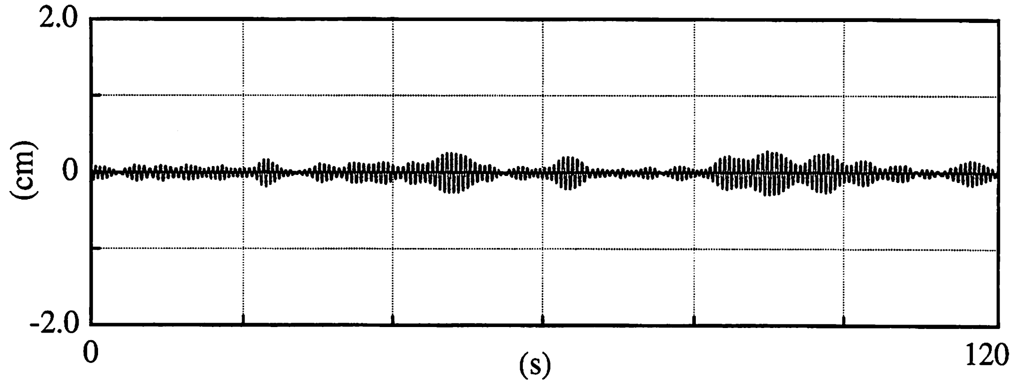


(b) Y-direction (Parallel-wind direction),

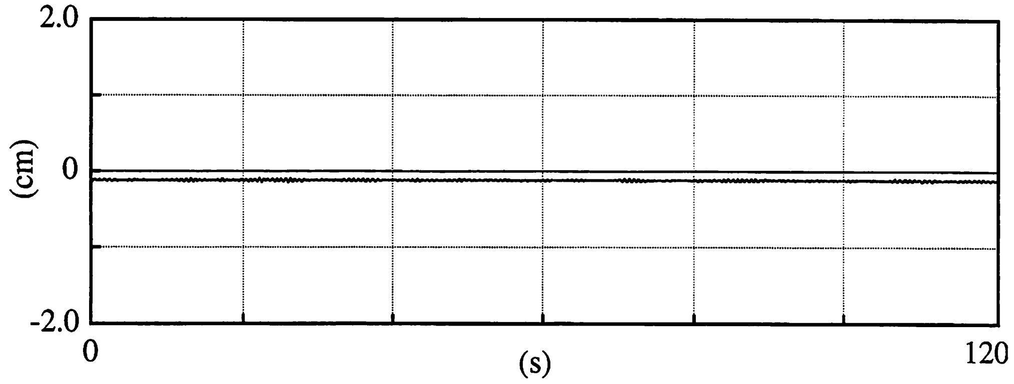


(c) Locus of displacements,

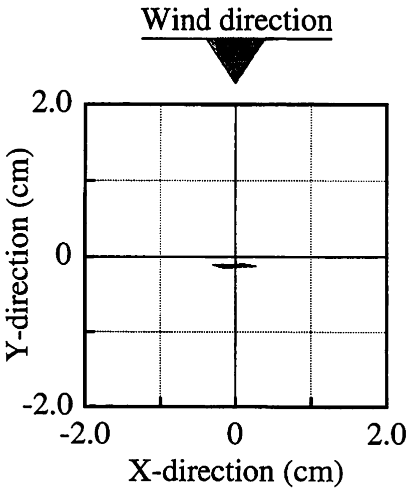
Fig. 5.4.11 Top floor's displacements (Control algorithm-2(R)-II, $\Delta t_p = 0$ (s)).



(a) X-direction (Cross-wind direction),

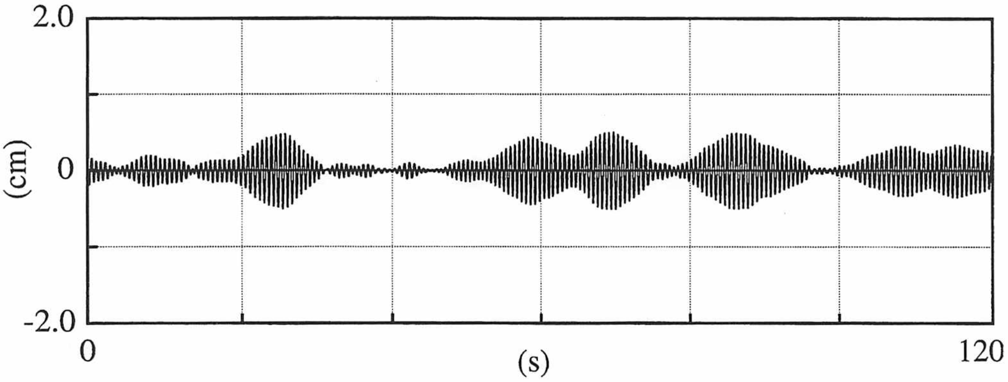


(b) Y-direction (Parallel-wind direction),

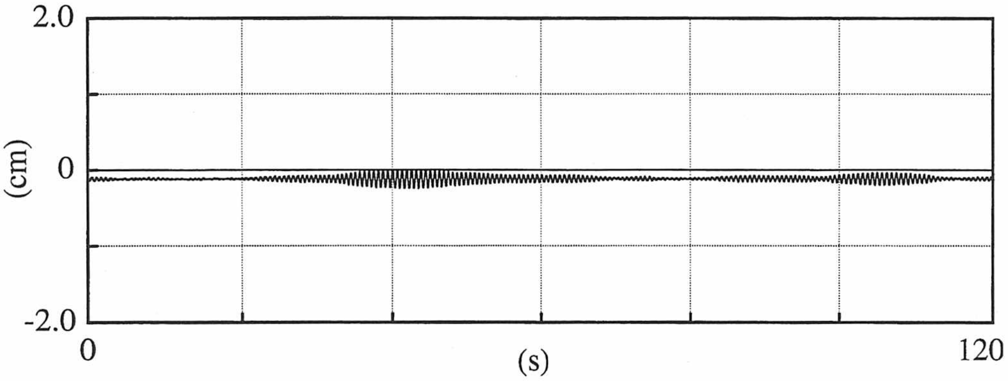


(c) Locus of displacements,

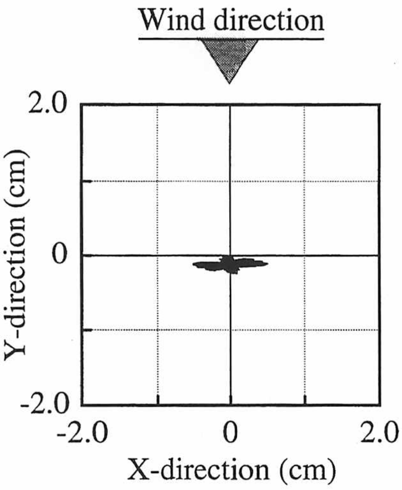
Fig. 5.4.12 Top floor's displacements (Control algorithm-2(A)-II, $\Delta t_p = 0$ (s)).



(a) X-direction (Cross-wind direction),

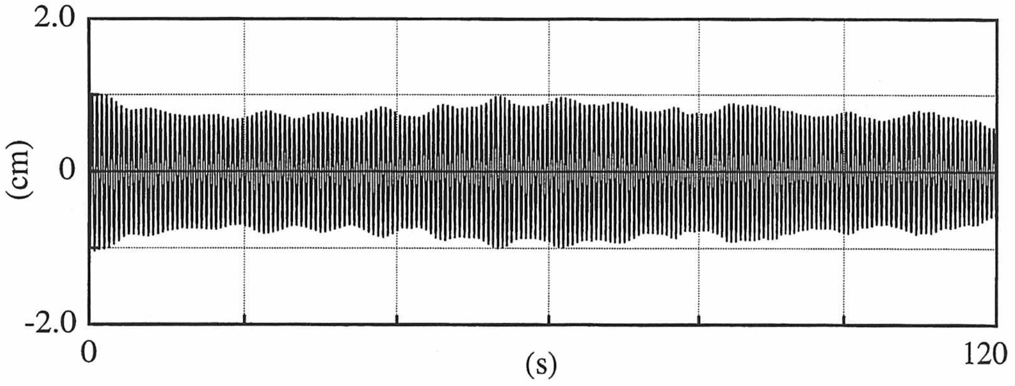


(b) Y-direction (Parallel-wind direction),

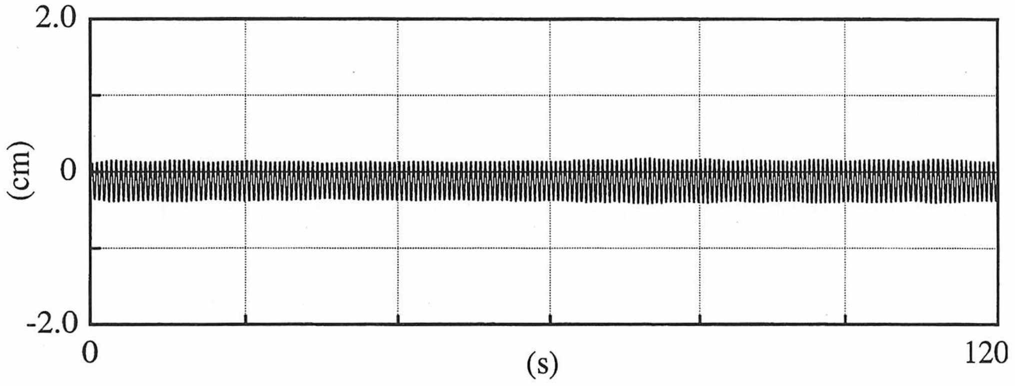


(c) Locus of displacements,

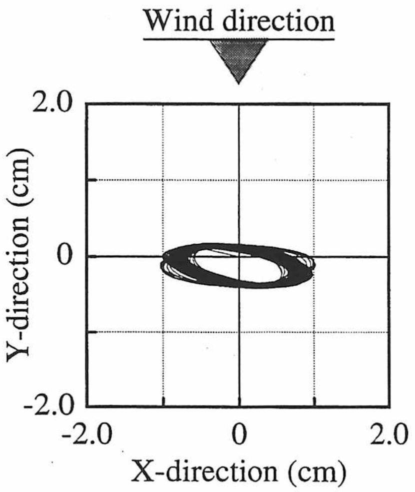
Fig. 5.4.13 Top floor's displacements (Control algorithm-2(R)-II', $\Delta t_p = 0.3$ (s)).



(a) X-direction (Cross-wind direction),



(b) Y-direction (Parallel-wind direction),



(c) Locus of displacements,

Fig. 5.4.14 Top floor's displacements (Control algorithm-2(A)-II', $\Delta t_p = 0.3$ (s)).

5. 5 Evaluation of aerodynamics on wind forces and improvement of multi-directional control algorithm

The two kinds of the multi-directional response control methods on the active fin system (which are proposed as the Version-1 and the Version-2 of the two-directional response control methods) are verified under the considerations for the time delays in the Section 5.4. The controlled responses by introducing the Control algorithm-2(R) and the Control algorithm-2(A) based on the Version-1 of the two-directional control method are appeared as to be only effective on the cross-wind direction, and the controlled responses by introducing the Control algorithm-2(R)-II and the Control algorithm-2(A)-II based on the Version-2 of the two-directional control method are appeared as to be inverted from the expected control efficiencies. The fundamental factors which are affected for those controlled behaviors have been discussed in the previous sections. Through those evaluations for the control manipulations of the active fin, it may be assured that the control effects by introducing those two kinds of the two-directional response control methods are significantly subjected to both of the influences of the time delays which are accompanied for the control manipulations and which are caused by the circular locus of the structural vibrations. Those verified considerations are also confirmed by operating the wind tunnel tests in the Section 5.4. So that, by introducing predictions of the future structural velocities from the acceleration responses, it may be assured that the controlled responses by introducing the Control algorithm-2(R)-II and the Control algorithm-2(A)-II based on the Version-2 of the two-directional control method can be actualized as to be regained their expected control efficiencies. At this point, by considering as that those additional installations of the response predictions may be affected as to cancel the influences which are caused by the circular locus of the structural vibrations, it seems that those operations by using the response predictions may indicate the one of the solutions to improve the control efficiencies of the two-directional response control methods which are proposed as the Version-1 and the Version-2, in the sense that the time delays are always existed as the unavoidable factors to manipulate the active fin system. However, it may be considered that those kinds of operations may not be always effective in the sense of the practical use, because that the wind-induced responses under the natural wind flows or the turbulent artificial wind flow may not be warranted as to be always appeared as the harmonic simple structural vibrations. Especially, it seems that the response predictions by evaluating the acceleration responses may be difficult to be functioned as to be able to exactly forecast the future structural velocities under the conditions that the high-frequency responses are significantly appeared.

In this section, discussions may be begun to find out the another solutions to improve the control efficiencies for the multi-directional wind-resistant response control by installing the active fin system under the considerations for the time delay effects which are caused by the circular locus of the multi-directional structural vibrations. At this point, the deteriorations of the control effects of the active fin system based on the two kinds of the control methods (which are specified as the Version-1 and the Version-2) may be occurred by the time delays which are requested for the control manipulating time intervals, and those requested time intervals are superposed on those time delay effects which are appeared by the circular locus of the structural vibrations. So that, through the previous verifications in the Section 5.4, it may be considered that the control operations by introducing any one of the previous two kinds of the two-directional control methods are enough effectively actualized on the following conditions.

Condition-1) Even if the manipulating time intervals are supposed as to be close to 1/4 of the first natural periods of the experimental structure, it can be regarded that the structural vibrations are appeared as to be almost close to the single directional motions.

Condition-2) Even if the structural vibrations are appeared as to be almost close to the circular locus of the elliptic motions, it can be regarded that those time delay effects which are caused by the circular locus of the structural vibrations can be canceled by the additional operations based on the response predictions.

Since it seems that some kinds of the structural buildings may be designed as that the dominant vibrations are restricted on the specified single direction, the Condition-1 can be satisfied on those kinds of buildings. In this case, the installations of either the Version-1 or the Version-2 of the two-directional response control algorithms may be considered as to be enough available in the practical meanings that the wind-resistant response control manipulations can be effectively operated even if any directions of the wind flow on the horizontal plane are supposed. For instance, whichever the wind directions are appeared as to be parallel or orthogonal to the dominant structural vibrations, the positionings of the active fin may be automatically related to the adequate set of the configurations to control the parallel-wind vibrations or to control the cross-wind vibrations by installing any one of those two kinds of two-directional response control methods. However, those kinds of the structural buildings which can warrant the Condition-1 should be considered as the quite limited buildings among the whole of the structural constructions. In the practical sense, it should be considered that the influence which are caused by the circular locus of the structural vibrations as supposed on the Condition-2 may be unavoidable factor when the general sense of the two-directional wind-resistant response control systems are synthesized by installing the active fin. Accordingly, those additional operations of the response predictions which are requested on the Condition-2 are introduced as to aim to cancel the time delay effects caused by the circular locus of the structural vibrations. Of course, as the attentions to the previous verifications in the Section 5.4, it has been pointed that the control operations based on the Condition-2 may not be provided enough applicability for the practical installations, because that the control operations by introducing the response predictions for the wind-induced responses may be regarded as to be difficult to actualized on the practical conditions under the natural wind flows or the turbulent artificial wind flow.

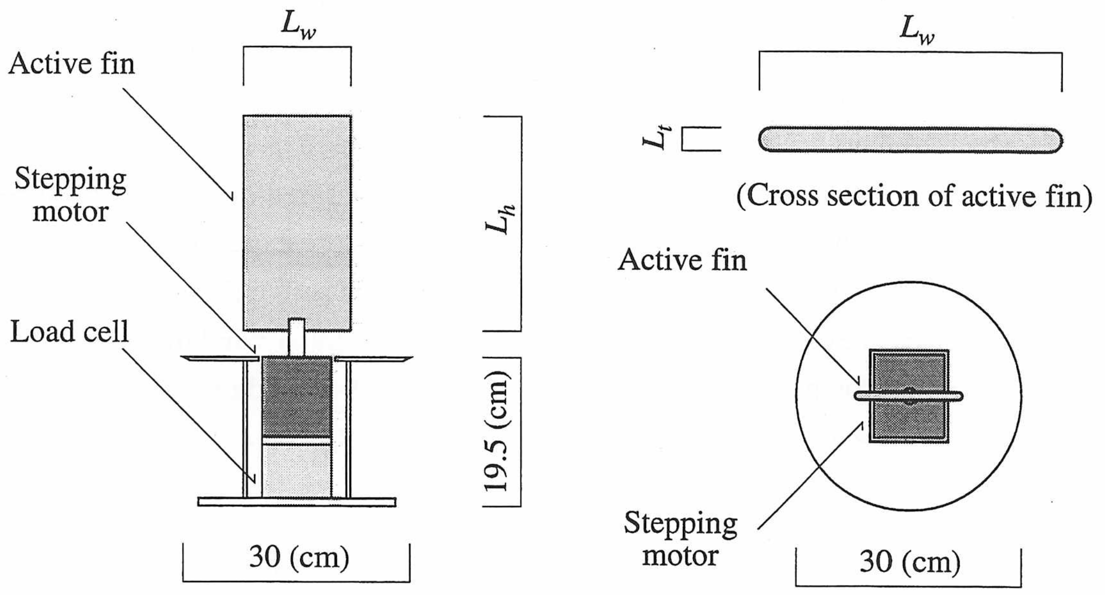
On the other hand, it may be pointed that the installations of the response predictions in the Condition-2 are also based on the considerations as that the manipulating time intervals to control the active fin can not be reduced by the mechanical restrictions of the control devices. In the previous active control tests (which are operated as the investigations for the Version-1 and the

Version-2 of the two-directional response control methods), since the values of the manipulating time intervals are synthesized from the conditions as that the rotating range for the positionings of the active fin are defined from the θ_f = -90° to θ_f = 90° (namely, the 180° of the rotations within the manipulating time intervals should warranted as the maximum manipulation of the active fin), the control time interval is requested as to be 0.3 (s). On the installations of the Version-1 and the Version-2 of the two-directional response control methods, since those influences for the time delays by accompanying to the manipulating time intervals may be also considered as to be unavoidable factor as much as the influences of the circular locus of the structural vibrations, it may be regarded that the installations of the response predictions are also affected as the substitute operations to also aim to recover for the influences the time delays related to the control time intervals. From those meanings, the value of the control time intervals may be synthesized as the allowable margin to be able to cover the manipulating time intervals for any transformations of the active fin. It may be considered that the significant clues to improve the two-directional response control methods are specified on the Condition-2. Namely, when the other kinds of the control manipulations which can make those rotating ranges for the positionings of the active fin narrow may be proposed instead of the operations of the response predictions, it can be considered that the manipulating time intervals are reduced. Accordingly, discussion may be reached to the constructions of the new type of the two-directional response control operations which can be satisfied the following condition.

Condition-3) Even if the structural vibrations are appeared as to be almost close to the circular locus of the elliptic motions, it can be regarded that the time delays to be requested as the control time intervals can be reduced (in which, the control time intervals should be allocated as the allowable margin to be able to cover the manipulating time intervals for any transformations of the active fin).

At this point, the further significant interests which should be considered to confirm whether the Condition-3 can be actualize or not may be arisen. Namely, even if the manipulating time intervals can be reduced in the sense that any kinds of the manipulations to change the positionings of the active fin are allocated as not to be exceeded any control time intervals, it has not been confirmed whether the growth of the wind resistant forces which are generated on the active fin can be overtaken for those reduced manipulating time intervals or not. Since both of the previous two kinds of the two-directional control methods (which are corresponded to the Version-1 and the Version-2 of the two-directional response control methods), are introduced by based on only the quasi-static states of the wind resistant forces acting on the fin, those problems are not considered for the constructions on those control methods.

To make assure those problems and to take a walk for the reconstructions of the other kinds of the control method for the two-directional response control, the aerodynamic properties of the wind forces under the transitional states by rotating the active fin are investigated through the wind tunnel tests. For this aim, the testing apparatus to evaluate the wind forces acting on the fin is developed as shown in Figs.5.5.1, and the outlook of this testing apparatus is shown in Photo.5.5.1.



(a) Front view, (b) Top view,

Fig. 5.5.1 Testing apparatus to evaluate the wind forces.

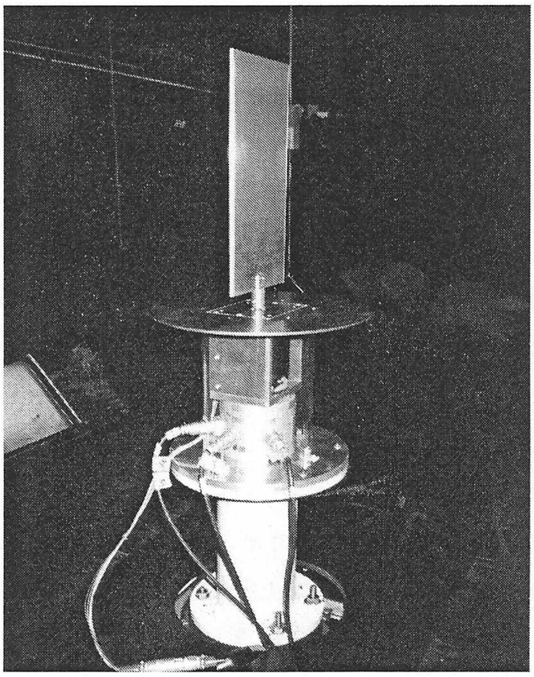


Photo. 5.5.1 Outlook of the testing apparatus.

By installing a load cell which is inserted to the pedestal of the active fin, the wind forces which are generated according to the configurations of the active fin are measured under the laminar wind flow on the wind tunnel. As seen in Fig.5.5.1 (a), this testing apparatus is equipped as that the part of the rotor fin is allocated over the base line of the wind tunnel and the parts of the stepping motor and the load cell are hide away below the base line of the wind tunnel. To avoid the influence for the disturbance of the wind flow on the boundary at vicinity of the base line of the wind tunnel, the larger sized testing plate than the small-scaled active fin which is used on the previous wind tunnel tests are adopted for those evaluative studied, namely, 28.3 (cm) height ($= L_h$), 14.1 (cm) width ($= L_w$) and 0.5 (cm) thickness ($= L_t$) of the active fin are used as seen in the Figs.5.5.1.

In the following discussions, the wind forces which are measured on this testing apparatus are evaluated by introducing the dimensionless indicates as that those experimental results can be directly applied to the syntheses for both order of the small-scaled active fin and the large-scaled active fin. Drag forces (the components of the wind forces to the parallel-wind direction) $F_D^* \ (\phi_{fw})$ (kgf) and lift forces (the components of the wind forces to the cross-wind direction) $F_L^* \ (\phi_{fw})$ (kgf) are evaluated by using wind force coefficients $C_D^* \ (\phi_{fw})$ and $C_L^* \ (\phi_{fw})$ as defined from the following expressions.

$$C_D^* \ (\phi_{fw}) = F_D^* \ (\phi_{fw}) \,/\, (A_{max} \cdot q_H) \,, \quad C_L^* \ (\phi_{fw}) = F_L^* \ (\phi_{fw}) \,/\, (A_{max} \cdot q_H) \,, \qquad (5.5.1)$$

in which,

$$q_H = (1\,/\,2) \cdot \rho \cdot V_H{}^2 \,, \ A_{max} = L_w \cdot L_h \,. \qquad (5.5.2)$$

In those expressions, q_H (kgf / cm^2) means the dynamic pressure, ρ (kgf · s^2 / cm^4) means the air density and V_H (cm/s) means the wind velocity. A_{max} (cm^2) is corresponded to the maximum volume of the projected area of the active fin and ϕ_{fw} means a projected angle of the active fin to the wind flow. The differences between the 'quasi-static' states and the transitional states of wind forces are estimated in the following studies. Those wind tunnel tests are executed under the laminar flow of 10 (m/s) of the wind velocity. In which, since the value of the air density is estimated about 0.125×10^{-8} (kgf · s^2 / cm^4), the dynamic pressure q_H (kgf / cm^2) which is corresponding to 10 (m/s) (= 1000 (cm/s)) of the wind velocity is evaluated about 6.25×10^{-8} (kgf/cm^2). The wind force coefficients $C_D^* \ (\phi_{fw})$ and $C_L^* \ (\phi_{fw})$ are defined for the 'quasi-static' states as that the wind forces are converged for the fixed projected angle of the active fin. Accordingly, when the time-dependent fluctuations of those wind force coefficients according to the transformations of the active fin are considered, the following denotations are introduced to express those quantities. Let denote $F_D\,(t)$ and $F_L\,(t)$ (kgf) as the drag and the lift of wind forces under the transitional states at a certain time instance t, the wind force coefficients $C_D\,(t)$ and $C_L\,(t)$ under the transitional states are defined from the following expressions.

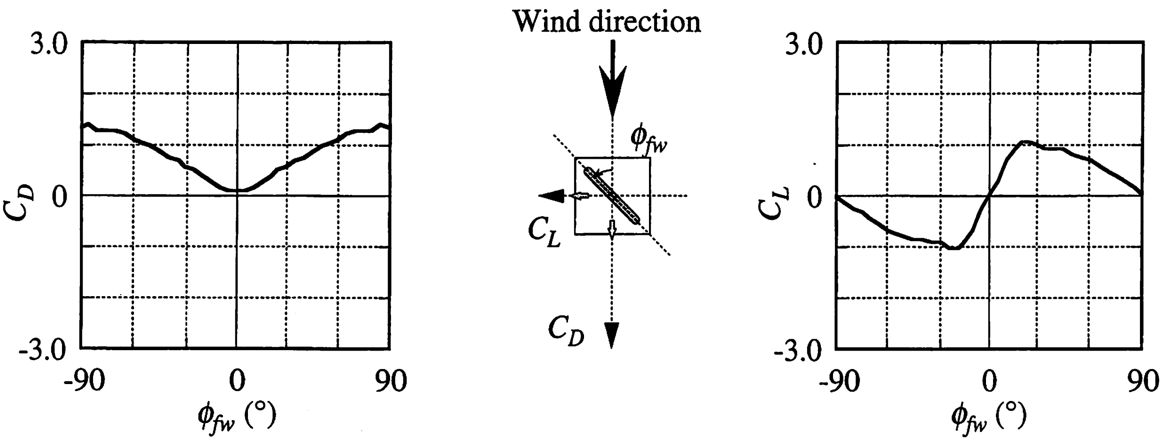
$$C_D \ (t) = F_D\,(t) \,/\, (A_{max} \cdot q_H) \,, \ C_L\,(t) = F_L\,(t) \,/\, (A_{max} \cdot q_H) \,, \qquad (5.5.3)$$

When any transformations of the active fin should be explicitly specified on those transitional states of the wind force coefficients $C_D\ (t)$ and $C_L\ (t)$, those quantities are described as $C_D\,(t,\ \phi_{fw}^0\ ,\ \phi_{fw}^f\ )$ and $C_L\,(t,\ \phi_{fw}^0\ ,\ \phi_{fw}^f\ )$. In which, ϕ_{fw}^0 means the initial positionings of the active fin at $t = t_0$, and ϕ_{fw}^f means the transformed positionings of the active fin by any single step of turnings. If the continuous turnings are supposed, those expressions are described as $C_D\,(t,\ \phi_{fw}^0\ ,\ *\ )$

and $C_L(t,\ \phi^0_{fw}\ ,*)$. In the following discussions, unless those conditions of the transformations are requested as to be specified explicitly, $C_D(t)$ and $C_L(t)$ are simply used as the denotations for those transitional states of the wind force coefficients.

Study (5.5) - 1 :

At first, the steady state of wind force conditions according to the projected angle of the active fin are measured. Those results are evaluated as the quasi-static characteristics of the coefficients of drag and lift of wind forces (which are related to the projected angle ϕ_{fw} of the active fin) and are shown in Fig.5.5.2 (a) and (b), respectively.



(a) Drag of the wind forces,

(b) Lift of the wind forces,

Fig. 5.5.2 Quasi-static states of the wind forces acting on the fin.

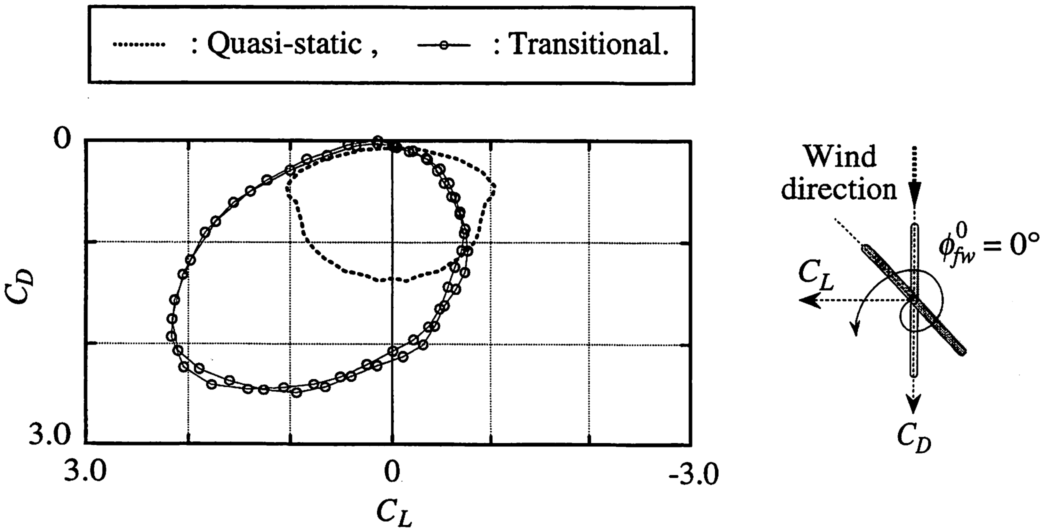


Fig. 5.5.3 Locus of the wind force vectors under the transitional states (Continuous left turn).

Those properties of the wind forces are regarded as the converged wind-resistant forces related to the fixed positionings of the active fin under the wind flow which are blowing by the fixed wind velocity on the fixed directions, and also have been already mentioned on Fig.5.2.3 in the Section 5.2. The previous response control methods which are evaluated from the Section 5.1 to the Section 5.3 are constructed by based on those quasi-static states of the wind forces. As the next step, to evaluate for the aerodynamic properties of the wind forces acting on the fin, the wind forces under the transitional state due to the continuous rotations of the active fin are measured. On this examination, the active fin is operated with 100 (rpm; round per minute) of the rotating velocity. This value of the rotating velocity is corresponded to the 180° of turning of the active fin by 0.3 (s), namely, this value is adopted as the same quantities for the rotating velocity which is operated on the control manipulations on the active fin in the previous active control tests.

Fig.5.5.3 shows the locus of the wind force vectors under the transitional state (which is operated by the continuous left (CCW) turning of the active fin). In this figure, the fluctuations of the wind force vectors according to the continuous left turning of the active fin are mentioned as the solid lines with the dot-pointed states by every 0.01 (s). The broken curve is corresponded to the quasi-static state of the wind force vectors by evaluating from the properties of the wind forces which are mentioned on Figs.5.5.2. As seen in Fig.5.5.3, it may be observed that the wind force vectors under the transitional states become the elliptic locus and are expanded to the left side on the horizontal plane. When the active fin is turned to the right (CW), the corresponded locus of the wind force vectors may be leaned to the right side as to be in symmetry with this figure. Those phenomena are explained as the '*Magnus* effects' for the thin plates.

By considering for those characteristics of the transitional states of the wind force vectors, it may be assured that the remarkable differences from the quasi-static states of the wind forces are appeared on the growth mechanism of the wind force vectors which are significantly subjected by the rotating motions of the active fin. Namely, when the *Magnus* effects are considered on the control manipulations of the active fin system, the transitional wind forces may be explicitly enlarged on the single side of the horizontal plane according to the rotating direction of the active fin, and the wind forces may not be appeared as to be symmetry as like to the quasi-static locus of the wind forces. Accordingly, since it seems that the influences of the *Magnus* effects are regarded as to subjected by the rotating directions to change the configurations of the active fin, it may be considered that those growth mechanism of the wind force vectors may not become as to be able to utilized on the response control method of the active fin system until the rotating directions of the active fin are carefully introduced as the additional evaluative item. For this aim, in the following discussions, the characteristics of the growth mechanism of the wind force vectors by accompanying to the single step of turnings of the active fin which are corresponded to any control manipulations by every control time steps are investigated as the preparations to reconstruct the new type of the two-directional response control method which are based on the evaluations for the *Magnus* effects.

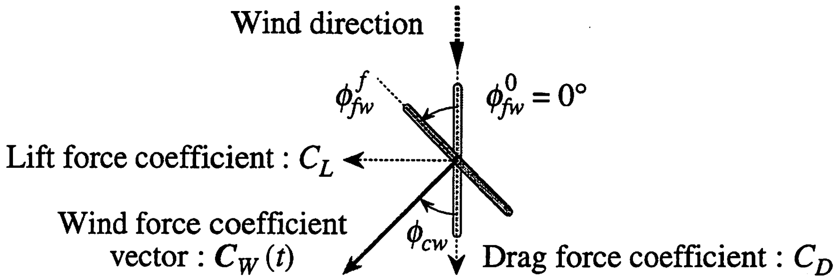
***Study (5.5) - 2a* :**

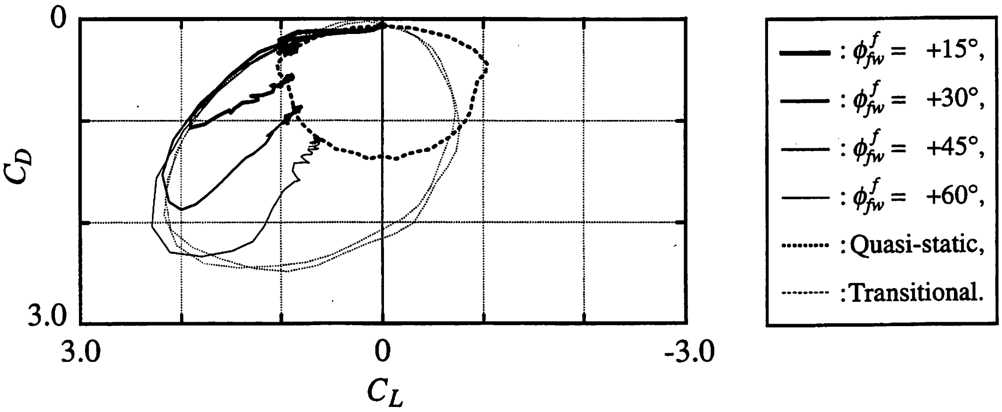
To make assure the transitional properties of the wind forces which are generated according to the single step of turnings of the active fin, the wind tunnel tests are executed. By operating those studies, it may be expected that the growth mechanism of the wind force vectors which are actualized at any instances to be changed the configurations of the active fin can be determinately estimated. Those evaluative wind tunnel tests are also examined for 10 (m/s) of the laminar wind flow, the transitional properties of the wind forces are measured under the conditions as that the active fin is operated with 100 (rpm) of the rotating velocity.

Figs.5.5.4 shows the locus of wind force vectors for the single step of left (CCW) turnings of the active fin from ϕ_{fw}^{0} = 0° to any one of ϕ_{fw}^{f} = +15°, ···, +165° which are supposed by every 15° of division. Those locus of the wind force vectors which is related to the transformation of the positionings for the projected angles of the active fin are mentioned by the solid lines on those figures. And also, the transitional states of the wind forces (which are generated by the continuous left (CCW) turnings of the active fin) and the quasi-static states of the wind force vectors are illustrated by the thin and fat broken lines on those figures, respectively. By observing those figures, when the positioning angle ϕ_{fw}^{f} are supposed as to be +30° or larger, it may be assured that the influence caused by the *Magnus* effects are similarly appeared on the growth of the wind forces by accompanying to the single step of rotating of the active fin as much as the transitional states which are corresponded to the continuous turnings of the active fin. As the considerations from those locus of the wind force vectors which are generated by the single step of turnings, the following analyzations may be pointed : "At first, the growth of the wind force vectors may be traced the backbone curve of the transitional states (which is observed as the aerodynamic locus in the continuous turning of the active fin under the same rotating direction by the same turning velocity), after then those wind force vectors may be moved to the state which are allocated under the quasi-static conditions".

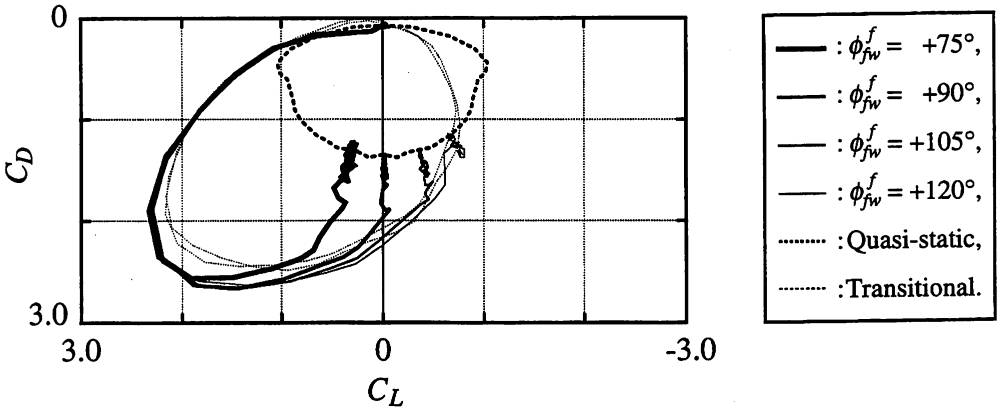
The time histories for the growth of those wind forces which are corresponded to each case mentioned in Figs.5.5.4 are also investigated. For this aim, by denoting $\boldsymbol{C_W}(t)$ (= $\{C_D(t)\ C_L(t)\}$) as the vectors of the wind force coefficients under the transitional states, the floating directions and the floating volumes of the wind forces are defined as the orientations and the size of the vector $\boldsymbol{C_W}(t)$. Accordingly, since the floating directions of the wind force coefficient vectors are regarded as the same with the directions of the wind force vectors, those quantities are expressed by the angle difference of the wind forces from the wind flow ϕ_{cw}. And the floating volumes of the wind forces are represented as the norm of the wind force coefficient vectors by the denotations $|\boldsymbol{C_W}(t)|$. Figs.5.5.5 show the floating directions of the wind forces (which are corresponded to the fluctuations of ϕ_{cw}) and Figs. 5.5.6 show the floating volumes of the wind forces (which are corresponded to the fluctuations of $|\boldsymbol{C_W}(t)|$).

As seen in those figures, it may be observed that the time delays from about 0.05 (s) to about 0.3 (s) are required for the growth of the wind forces on the single step of turnings of the active fin from ϕ_{fw}^{0} = 0° to any one of ϕ_{fw}^{f} = +15°, ···, +165°. At this point, it may be considered that those results from Figs.5.5.5 and Figs.5.5.6 can present the solutions for the significant problems which have been remained on the considerations for the control manipulations in the previous experimental tests. Namely, as mentioned at the beginnings in this section, those problems are pointed as whether the previous active control tests may be operated as that the growth of the wind resistant forces which are generated on the active fin can overtake to the manipulating time intervals or not. By

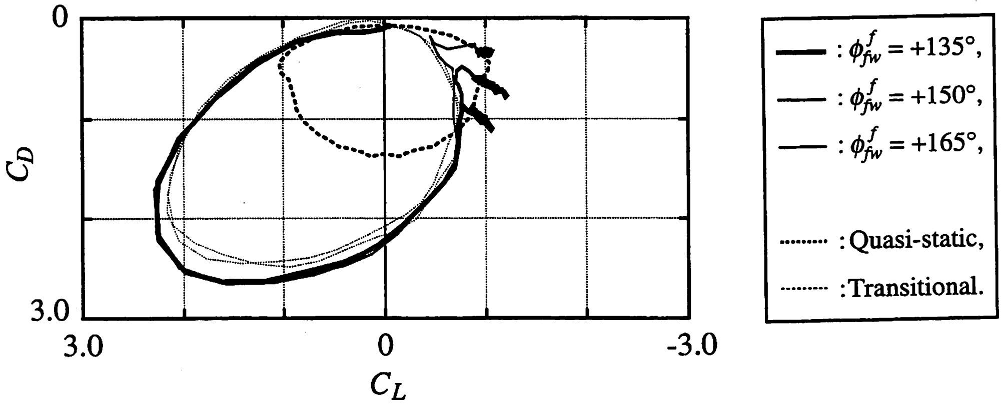




(a) ϕ_{fw}^{f} = +15°, +30°, +45° and +60°,

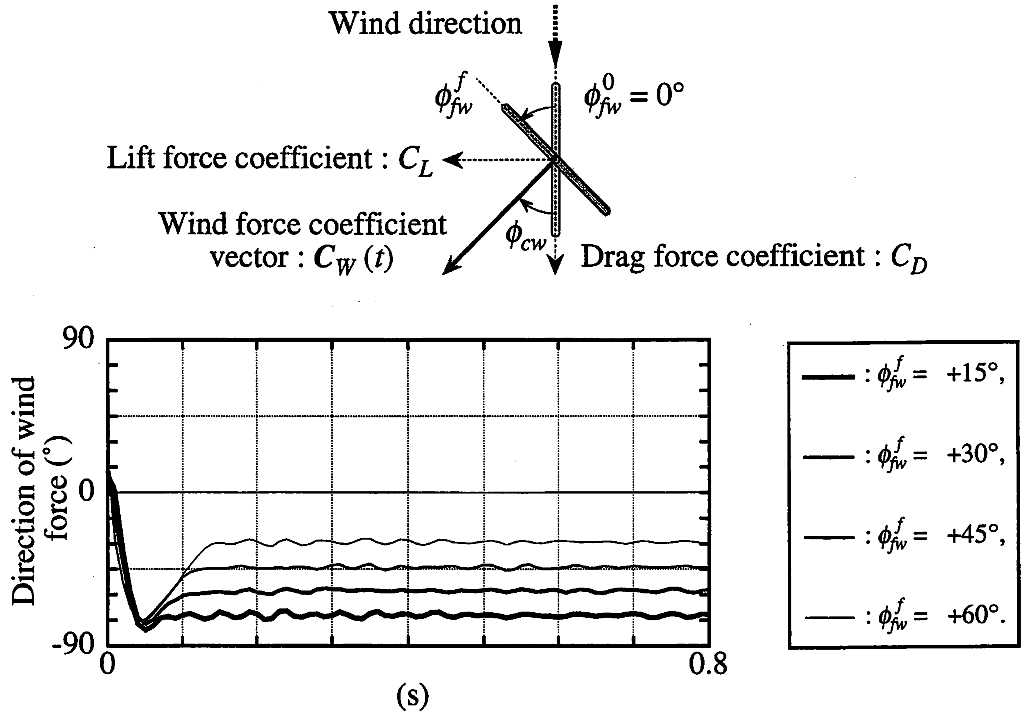


(b) ϕ_{fw}^{f} = +75°, +90°, +105° and +120°,

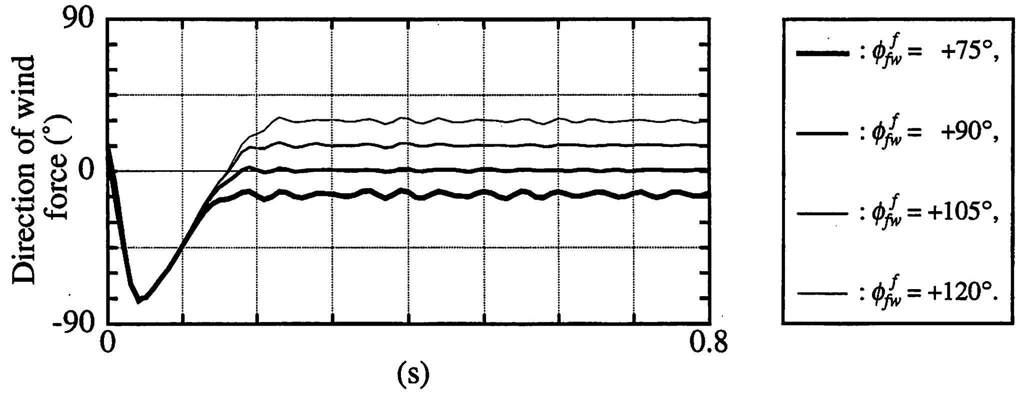


(c) ϕ_{fw}^{f} = +135°, +150° and +165°,

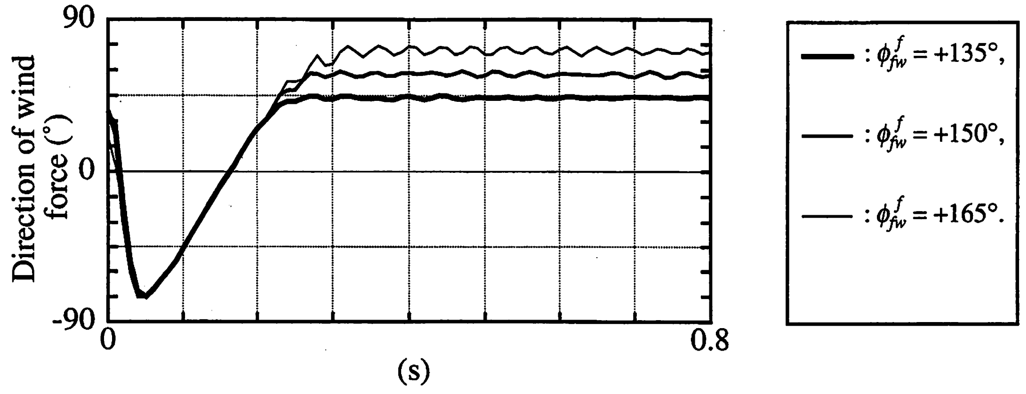
Fig. 5.5.4 Locus of wind force coefficients for various kinds of single step left (CCW) turnings from ϕ_{fw}^{0} = 0°.



(a) ϕ_{fw}^{f} = +15°, +30°, +45° and +60°,

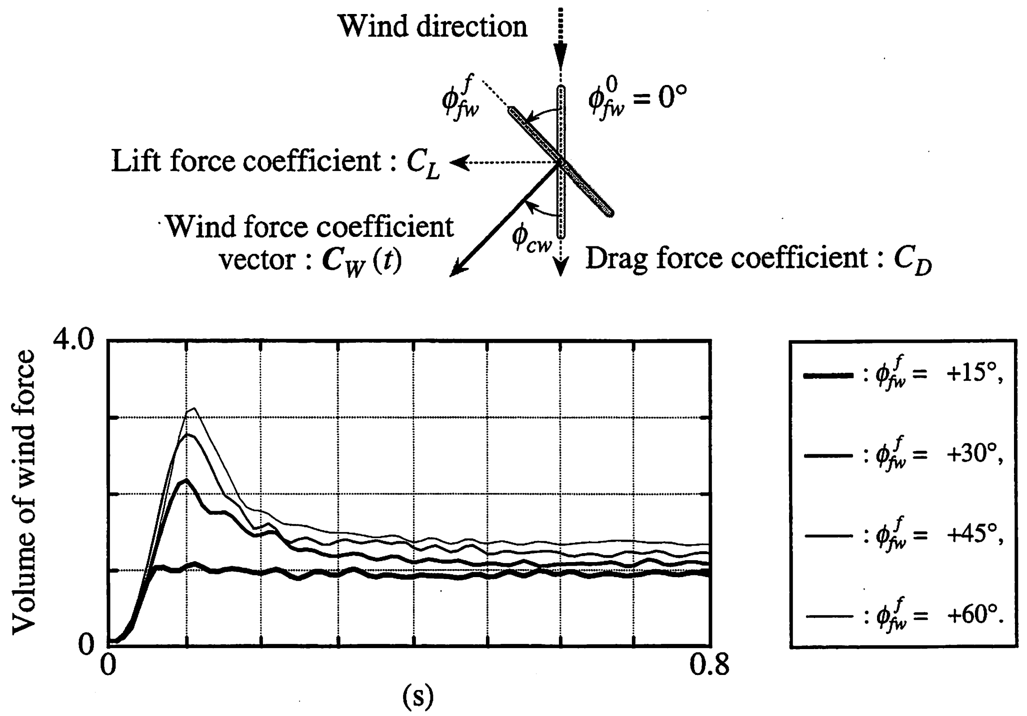


(b) ϕ_{fw}^{f} = +75°, +90°, +105° and +120°,

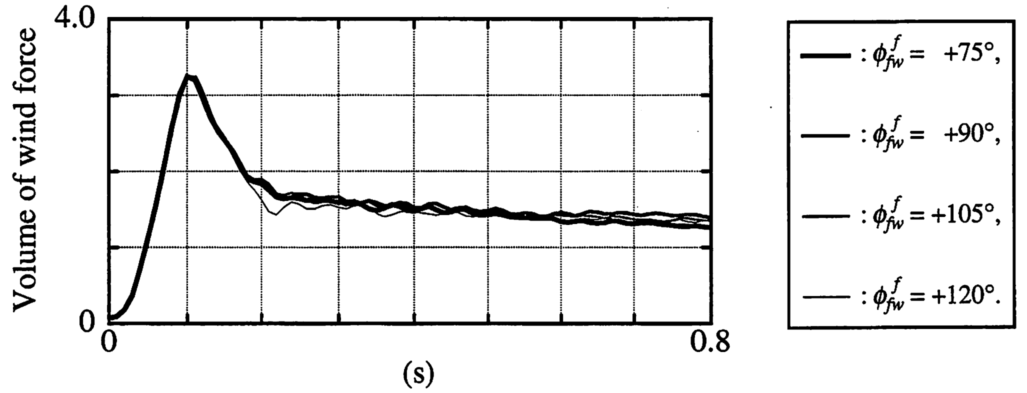


(c) ϕ_{fw}^{f} = +135°, +150° and +165°,

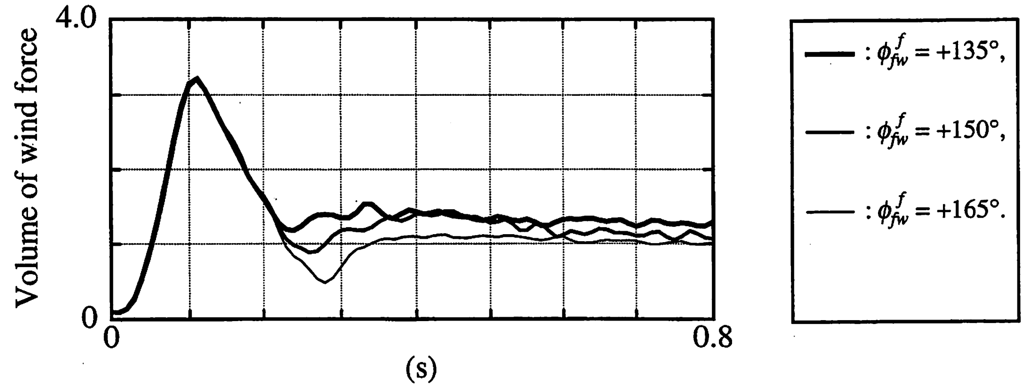
Fig. 5.5.5 Time histories of directions of wind force coefficient vectors (ϕ_{cw}) for various kinds of single step left (CCW) turnings from ϕ_{fw}^{0} = 0°.



(a) ϕ_{fw}^{f} = +15°, +30°, +45° and +60°,



(b) ϕ_{fw}^{f} = +75°, +90°, +105° and +120°,



(c) ϕ_{fw}^{f} = +135°, +150° and +165°,

Fig. 5.5.6 Time histories of volumes of wind force coefficient vectors ($|\boldsymbol{C}_W(t)|$) for various kinds of single step left (CCW) turnings from ϕ_{fw}^{0} = 0°.

considering those figures, even if the 180° of the rotations are supposed as the maximum transformation of the active fin, it may be also evaluated that about 0.3 (s) of the time delays are spent as the time intervals for the growth of the wind force vectors. Accordingly, it can be confirmed that the manipulating time intervals which are supposed in the previous experimental tests by introducing both of the two kinds of the two-directional control methods (which are corresponded to the Version-1 and the Version-2 of the two-directional response control methods) have been allocated as not to intercept the transitional states for the growth of the wind force vectors.

As the further significant characteristics on the transitional states of the wind forces which can be evaluated from Figs.5.5.6, for any manipulations by excepting the case for the single step of turning of the active fin from ϕ_{fw}^{0} = 0° to ϕ_{fw}^{f} = +15°, the 'converged' time intervals for the growth of the wind forces (which are evaluated as the durations until the wind forces can be regarded as to be almost converged to the volumes for the quasi-static states in the Figs.5.5.6) may be observed as the almost same values which are specified to about 0.3 (s) due to the influences caused by the *Magnus* effects. On the other hand, it may be found that the another advantageous properties are produced by those aerodynamic effects. Namely, as seen in Figs.5.5.6, the timings as that the maximum volumes are appeared along the growth procedures of the wind forces may be evaluated as to be about 0.1 (s) in the equal for any manipulations as to be subjected to the influences by the *Magnus* effects.

Under the considerations for those transitional properties of the wind forces, when the Condition-3 (which are proposed as the clue to construct the new type of the two-directional response control operations) are reviewed, it may be regarded as to be difficult to satisfy the condition as that the control time intervals should be reduced. Because, although the control time intervals can be reduced by restricting the maximum range of the transformations of the active fin, those conditions may be only satisfied in the meanings that those values are allocated as to be able to cover the any manipulating time intervals. For instance, when the maximum rotating motion among any control manipulations of the active fin are supposed as to be 90°, the manipulating time intervals for 90° of the transformations are reduced as to be 0.15 (s). However, in the another meanings as that the control time interval should be also allocated as not to intercept the growth of the wind forces, this specified value can not satisfy those requirements for the control time intervals. As evaluated from Figs.5.5.6, even if the transformations of the active fin are narrow and the manipulating time intervals which are spent to complete the single step of operations can be reduced, the converged time intervals can not be reduced under the influences by the *Magnus* effects. Accordingly, it may be regarded that 0.3 (s) of control time intervals can not be reduced in the meanings that any control manipulations should be operated as not to intercept the growth of the wind forces at any control time steps.

Therefore, when those experimental results are considered from the another view point, the advantageous to be positively evaluated for the *Magnus* effects as the another clues for constructing the other kinds of the two-directional response control method of the active fin system may be appeared. As seen in Figs.5.5.5, it is assured that the directions of the wind force vectors are converged within about 0.1 (s) of the time intervals under the single step of turnings within +45° from ϕ_{fw}^{0} = 0°. For instance, as seen in Fig.5.5.5 (a) and Fig.5.5.6 (a), in the cases that the control manipulations as to change the configurations of the active fin from the open mode to the leftward mode or the rightward mode are supposed, time intervals for the growth of the directions of the wind forces may be regarded as to be about 0.1 (s) and larger control forces than the quasi-static states may be produced by accompanying to the rotating motions of the active fin. Accordingly, when the transitional states of the wind forces are evaluated as to be separated to the 'direction-converged' states and the 'volume-converged' states, the converged time intervals may be considered as to have double sides of the stages which are supposed as the 'direction-converged' time intervals (as that the wind force vectors may be regarded as to be reached to the same orientation for the quasi-static states), and the 'volume-converged' time intervals (as that the wind forces may be regarded as to be reached to the same volumes for the quasi-static states). Explicitly, even if the influences by the *Magnus* effects are considered, the 'direction-converged' time intervals may be regarded as to be able to be reduced by that the transformations of the active fin are narrow and that the manipulating time intervals which are spent to complete the single step of operations are also reduced. Accordingly, by replacing the following conditions with the Condition-3, the discussions for the constructions of the new type of the two-directional response control operations may be continued.

Condition-4) Even if the structural vibrations are appeared as to be almost close to the circular locus of the elliptic motions, it can be regarded that the time delays to be requested on the manipulating time intervals can be reduced and that the direction-converged time intervals for any manipulations are taken care as to be equally reduced (in which, the control time intervals should be allocated as the allowable margin to be able to cover both of the manipulating time intervals and the direction-converged time intervals for any transformations of the active fin).

It seems that the reconstructions of the new kinds of the two-directional response control method for the active fin system under the Condition-4 may be regarded as to be based on the positive utilizations of the *Magnus* effects for the control operations. At this point, to actualize the Condition-4, the another significant properties which are related to the *Magnus* effects should be considered. When the continuous turning motions are supposed on the active fin, the transitional states of the wind force vectors may be allocated as the elliptic locus which are mentioned as the solid lines in Fig.5.5.3, and the directions which are appeared as the expansions of the volumes of the wind forces from the quasi-static states are determined by evaluating for the rotating velocity and the rotating direction of the active fin. However, when the single step of turnings of the active fin are supposed, the further conditions may be required for generating those overshooting properties which are subjected to the *Magnus* effects. Namely, the overshooting phenomena along to the growth mechanism of the wind forces are only appeared when the transformations of the active fin are included the specified interval as that the active fin are moved from the smaller projected angle than the 'stalled angle' to the larger projected angle than the 'stalled angle'. In which, the 'stalled angle' is corresponded to the positioning of the active fin as that the increase of the lift of the wind forces along to the increments of the projected angle of the active fin from the minimum state (ϕ_{fw} = 0°) has been reached to the maximum value, as seen in Fig.5.5.2 (b), the stalled angle of the active fin may be evaluated as to be about 20° (in the following discussions, this value as the stalled angle of the active fin are expressed as ϕ^{*}_{fw}). For instance, when the single step of the left (CCW) turnings of the active fin are supposed, the overshooting phenomena caused by the *Magnus* effects may be appeared only on the case as that the transformations of the active fin are passed the stalled angle of the active fin on the left side plane (namely, the overshooting of the wind forces may be actualized only when the vicinity of the left side of the stalled angle of the active fin ($\phi_{fw} = +\phi^{*}_{fw}$) are included on those transformations of the active fin). Accordingly, to utilize the *Magnus* effects for the operations for wind-resistant response control, it seems that the turning direction of the active fin and the allocations of the stalled angle on the transformations of the active fin may be additionally required as the evaluative items for the control methods.

By the way, in the previous active control tests, it may be regarded that the *Magnus* effects are also affected to the control effects which are actualized by the control manipulations based on the Version-1 and the Version-2 of the two-directional response control method. However, it seems that the influences by those aerodynamical effects of the wind forces appeared on the active fin under the transitional states may not be so sensitively observed on the previous experimental tests for both of the Version-1 and the Version-2 of the control methods. As the reason for this, since it may be pointed that those two kinds of the previous control methods may composed as to be significantly subjected to the quasi-static wind force conditions which are allocated as the converged states, it may be pointed that the turning direction of the active fin are not considered as the significant item for the control manipulations. Accordingly, it seems that the controlled responses by introducing those two kinds of the two-directional control methods may be enough explained by considering for the quasi-static characteristics of the wind forces acting on the fin and by evaluating the transitional conditions of the wind forces as to be simply regarded the time delay effects as reviewing on the Section 5.4.

It seems that discussions have been reached at the stage to be able to be concretely considered for the 'Version-3' of two-directional response control method of the active fin system. Those considerations may be begun to talk about what kinds of configurations of the active fin at every control time steps are allocated according to the both states of the structural vibrations and the wind directions, at the same time, what kinds of transformations of the active fin to change those configurations are operated at any control time instance.

By considering for the fundamental theory for the response control by using the active fin system again, it may be remembered that "the tunings of the drag of the wind forces are utilized to the response control for the parallel-wind direction and the tunings of the lift of the wind forces are utilized to the response control for the cross-wind direction". At this point, when the single-directional response control operations are evaluated, the positionings for the open mode and the closed mode may be classified to the configurations to control responses on the parallel-wind direction and the positionings for the leftward mode and the rightward mode may be classified to the configurations to control responses on the cross-wind direction. Under those classifications to those two kinds of the set of the configurations of the active fin, by considering for the transformations between the open mode and the closed mode and by considering for the transformations between the leftward mode and the rightward mode, those response control operations by using the active fin system may be also regarded as that "the tunings of the volumes of the wind forces are mainly affected to the response control for the parallel-wind direction and the tunings of the orientations of the wind forces are mainly affected to the response control for the cross-wind direction". Accordingly, when the influences of the *Magnus* effects for those transformations of the active fin are considered, it seems that the *Magnus* effects may be regarded as to be effectively utilized only for the control operations on the cross-wind directions.

When the structural vibrations are appeared as the two-directional motions, it may be reasonable that the two-directional response control operations may be constructed by base on those fundamental theory of the single-directional response control operations of the active fin system. Although both of the previous two kinds of the two-directional response control methods have been constructed as to satisfy those conditions which are proposed for the single-directional response control operations, the following differences between the Version-1 and the Version-2 of the two-directional response control methods may be pointed. The Version-1 of the two-directional response control method may be composed by that the typical four kinds of the configurations of the active fin which are introduced on the single-directional response control operations are allocated according to the judgements whether the structural vibrations are dominantly appeared on the parallel-wind direction or on the cross-wind direction. Accordingly, the control operations by the Version-1 may be regarded as to be the switching between the parallel-wind response control and the cross-wind response control. On the other hand, as the compositions of the Version-2 of the two-directional response control method, since any transformations of the active fin may be complemented by that the neutral positionings among those typical four kinds of the configurations of the active fin are introduced, those switching operations may be regarded as not to be explicitly appeared.

Therefore, when the conditions to be utilized the *Magnus* effects for the response control operations are considered, the preparations of the explicit switching operations as supposed on the Version-1 of the two-directional response control method may be requested as the significant item to construct the Version-3 of the two-directional response control method. Because, it seems that the overshooting of the wind forces caused by the *Magnus* effects may be effectively utilized only in the sense of the tuning of the orientations of the wind forces as the control operations on the cross-wind directions. From those meanings, the explicit classifications whether the parallel-wind or the cross-wind response control are aimed by every control manipulations at any control time instance may be required (in the following discussions, those classifications are called as the 'prioritized class on the parallel-wind' response control and the 'prioritized class on the cross-wind' response control, respectively), and accordingly, it may be convenient that the configurations of the active fin which are adopted on the Version-3 of the two-directional response control method are restricted to the four kinds positionings which are the open mode, the closed mode, the leftward mode and the rightward mode in the sense as to be agreed to such classifications. Because, it may be explicitly regarded that the set of the open mode and the closed mode are adjusted to the prioritized class on the parallel-wind response control, and that the set of the leftward mode and the rightward mode are adjusted to the prioritized class on the cross-wind response control. At this point, as the final preparations for the composing to the Version-3 of the two-directional response control method, it may be significant to make assure that the transitional properties by accompanying to the transformations between any two kinds of the positionings among those specified four types of the configurations of the active fin. For this aim, the following experimental studies on the wind tunnel tests as the additional investigations for the Study (5.5)-2a are executed by using the testing apparatus to evaluate the wind forces as seen in Figs.5.5.1.

Study (5.5) - 2b :

In this study, the transitional properties of the wind forces which are generated according to the single step of turnings of the active fin are also evaluated by the wind tunnel tests. The following specified cases of the single step of turnings are investigated as to be consider for every kinds of transformations among the four kinds of the configurations of the active fin (in which, those cases are represented as the transformations of the projected angle of the active fin ϕ_{fw}) :

Case-1) The left turning from ϕ_{fw}^{0} = 0° to ϕ_{fw}^{f} = +45° and the right turning from ϕ_{fw}^{0} = +45° to ϕ_{fw}^{f} = 0°; the transformations between the open mode and the leftward mode are supposed (indirectly, the transformations between the open mode and the rightward mode are also evaluated in this case).

Case-2) The left turning from ϕ_{fw}^{0} = -45° to ϕ_{fw}^{f} = +45° and the right turning from ϕ_{fw}^{0} = +45° to ϕ_{fw}^{f} = -45°; the transformations between the rightward mode to the leftward mode are supposed (in which, those transformations are the mirror symmetry for the wind direction each other),

Case-3) The left turning from ϕ_{fw}^{0} = 0° to ϕ_{fw}^{f} = +90° and the right turning from ϕ_{fw}^{0} = +90° to ϕ_{fw}^{f} = 0°; the transformations between the open mode and the closed mode are supposed (indirectly, the transformations between the open mode and the closed mode by the inverted turnings are also evaluated in this case),

Case-4) The left turning from ϕ_{fw}^{0} = +45° to ϕ_{fw}^{f} = +90° and the right turning from ϕ_{fw}^{0} = +90° to ϕ_{fw}^{f} = +45°; the transformations between the leftward mode and the closed mode along the smaller pass are supposed (indirectly, the transformations between the rightward mode and the closed mode along the smaller pass are also evaluated in this case),

Case-5) The left turnings from ϕ_{fw}^{0} = -45° to ϕ_{fw}^{f} = +90° and the right turning from ϕ_{fw}^{0} = +90° to ϕ_{fw}^{f} = -45°; the transformations between the rightward mode and the closed mode along the larger pass are supposed (indirectly, the transformations between the leftward mode and the closed mode along the larger pass are also evaluated in this case),

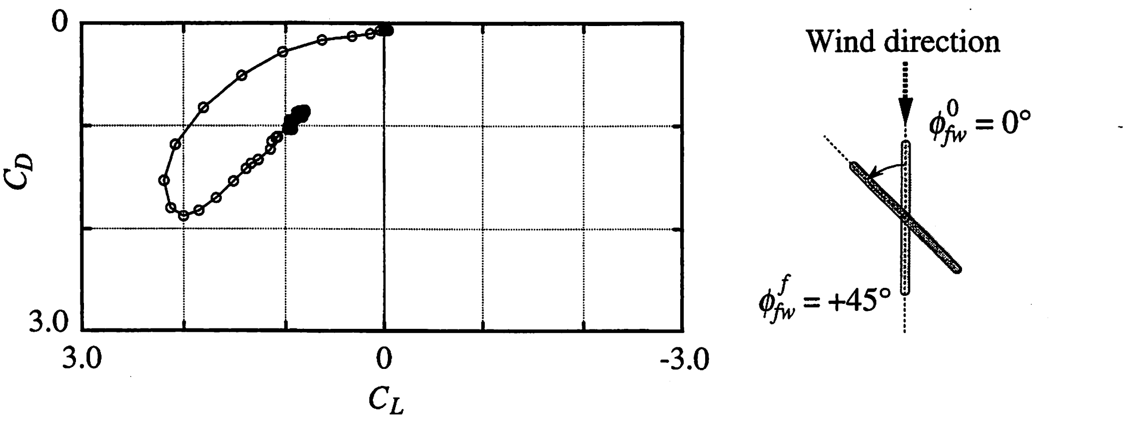
Those evaluative wind tunnel tests are also examined for 10 (m/s) of the laminar wind flow, the transitional properties of the wind forces are measured under the conditions as that the active fin is operated with 100 (rpm) of the rotating velocity.

Figs.5.5.7.1 and Figs.5.5.7.2 show the transitional states of the wind force vectors for the left turning from ϕ_{fw}^{0} = 0° to ϕ_{fw}^{f} = +45° (Case-1a) and the right turning from ϕ_{fw}^{0} = +45° to ϕ_{fw}^{f} = 0° (Case-1b), respectively. Figs.5.5.8.1 and Figs.5.5.8.2 show the transitional states of the wind force vectors for the left turning from ϕ_{fw}^{0} = -45° to ϕ_{fw}^{f} = +45° (Case-2a) and the right turning from ϕ_{fw}^{0} = +45° to ϕ_{fw}^{f} = -45° (Case-2b), respectively. Figs.5.5.9.1 and Figs.5.5.9.2 show the transitional states of the wind force vectors for the left turning from ϕ_{fw}^{0} = 0° to ϕ_{fw}^{f} = +90° (Case-3a) and the right turning from ϕ_{fw}^{0} = +90° to ϕ_{fw}^{f} = 0° (Case-3b), respectively. Figs.5.5.10.1 and Figs.5.5.10.2 show the transitional states of the wind force vectors for the left turning from ϕ_{fw}^{0} = +45° to ϕ_{fw}^{f} = +90° (Case-4a) and the right turning from ϕ_{fw}^{0} = +90° to ϕ_{fw}^{f} = +45° (Case-4b), respectively. Figs.5.5.11.1 and Figs.5.5.11.2 show the transitional states of the wind force vectors for the left turning from ϕ_{fw}^{0} = -45° to ϕ_{fw}^{f} = +90° (Case-5a) and the right turning from ϕ_{fw}^{0} = +90° to ϕ_{fw}^{f} = -45° (Case-5b), respectively. In those figures from Figs.5.5.7 to Figs.5.5.11, (a) is corresponded to the locus of wind force vectors (which are mentioned as the solid lines with the dot-pointed states by every 0.01 (s)) and (b) is corresponded to the time histories for the growth of those wind forces (which are mentioned as the floating directions and the floating volumes of the wind forces by the solid lines and the broken lines, respectively).

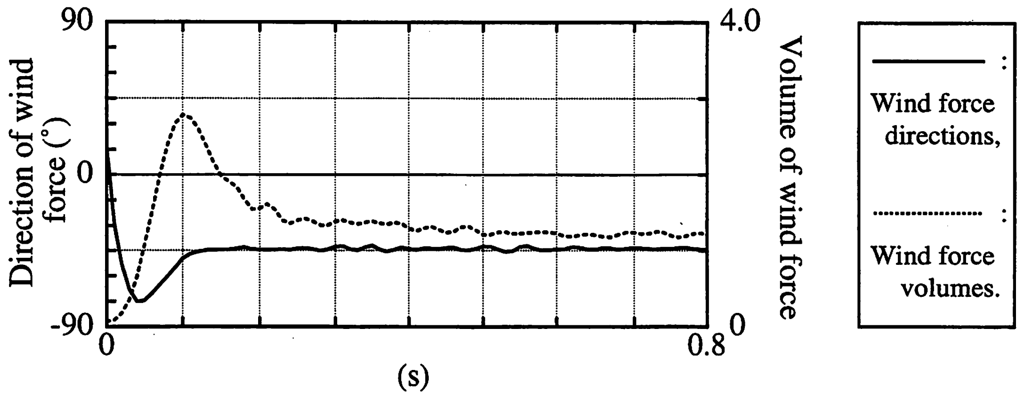
By evaluating for those experimental results, the following five items may be pointed out by every five kinds of cases as the estimations for the significant clues to decide the fundamental frame of the Version-3 of the two-directional control method.

Point-1) By considering the fluctuations for floating volumes as seen in Figs.5.5.7.1 (Case-1a) and Figs.5.5.7.2 (Case-1b), the overshooting of the wind forces by the *Magnus* effects may be observed on the left turning from ϕ_{fw}^{0} = 0° to ϕ_{fw}^{f} = +45° and may not be appeared on the right turning from ϕ_{fw}^{0} = +45° to ϕ_{fw}^{f} = 0°. Those two kinds of single step of turnings are corresponded to the transformations from the open mode to the leftward (or rightward) mode and the transformations from the leftward (or rightward) mode to the open mode, respectively. Since the switching between the different prioritized classes are supposed in the Case-1, both of two kinds of transformations may be regarded as to be able to be effectually adjusted for this aim. In both of the Case-1a and the Case-1b, while 45° of the rotating angle of the active fin are supposed (namely, the manipulating time interval are allocated as to be 0.075 (s)), the direction-converged time intervals for both of cases may be evaluated as about 0.1 (s) (in which, although the oscillations of the direction of the wind forces may be observed in Fig.5.5.7.2 (b), it may be depended on the difficulty to exactly measure those direction of the wind forces on the state ϕ_{fw}^{0} = 0°, accordingly, the direction-converged time in this case are regarded as to be equal to the volume-converged time).

Point-2) By considering the fluctuations for floating volumes as seen in Figs.5.5.8.1 (Case-2a) and Figs.5.5.8.2 (Case-2b), the overshooting of the wind forces by the *Magnus* effects may be observed on both of the left turning from ϕ_{fw}^{0} = -45° to ϕ_{fw}^{f} = +45° and the right turning from ϕ_{fw}^{0} = +45° to ϕ_{fw}^{f} = -45°. Those two kinds of single step of turnings are corresponded to the transformations between the leftward mode and the rightward mode. Since the tunings of the orientations of the wind forces on the same prioritized class on the cross-wind response

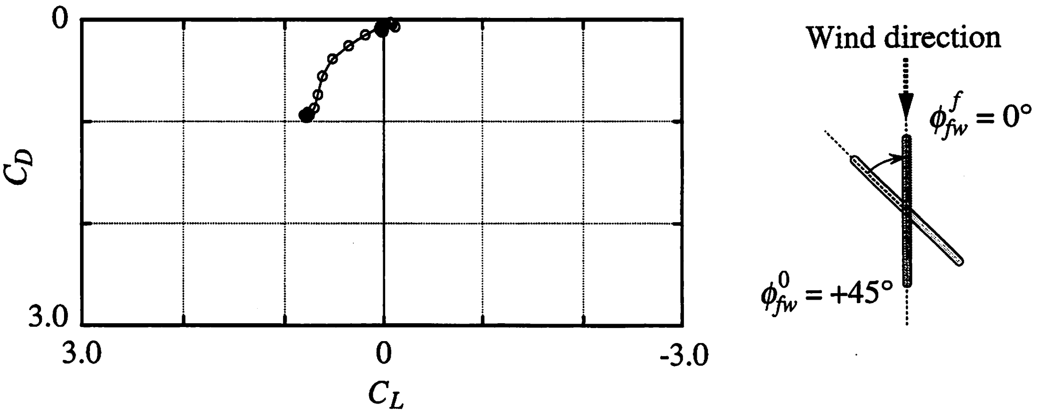


(a) Locus of the wind forces,

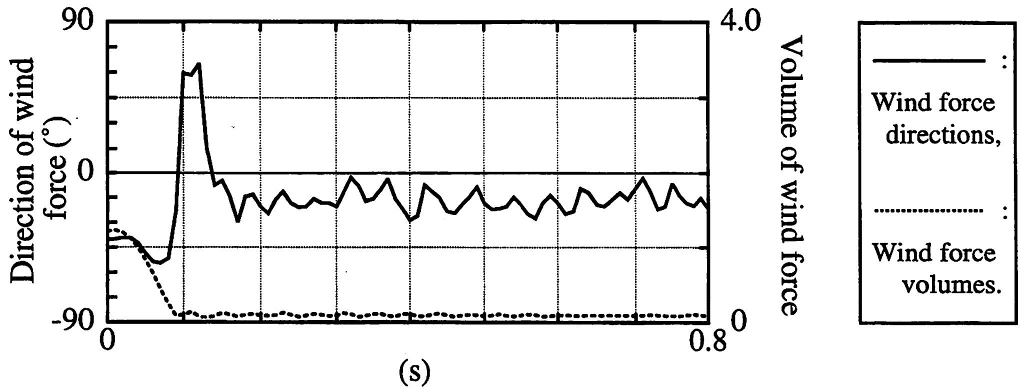


(b) Time histories of the dierctions and the volumes of the wind forces,

Fig. 5.5.7.1 Transitional states for the left turning from ϕ_{fw}^0 = 0° to ϕ_{fw}^f = +45° (Case-1a).

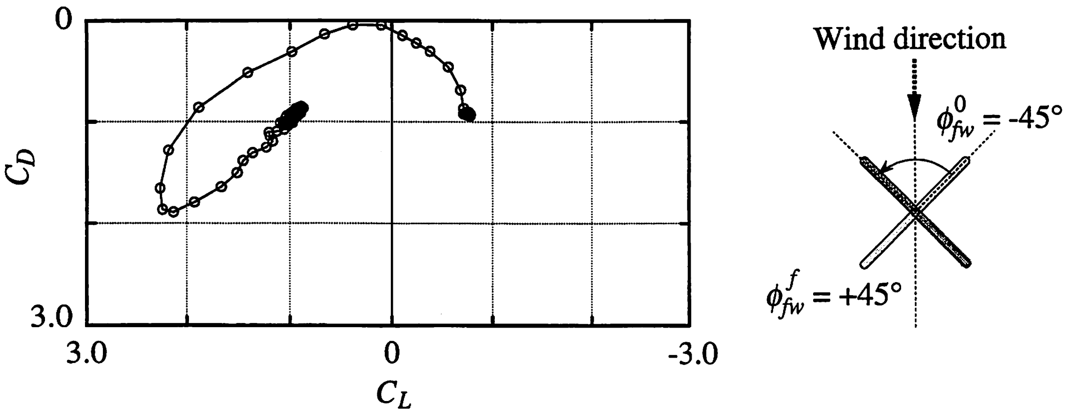


(a) Locus of the wind forces,

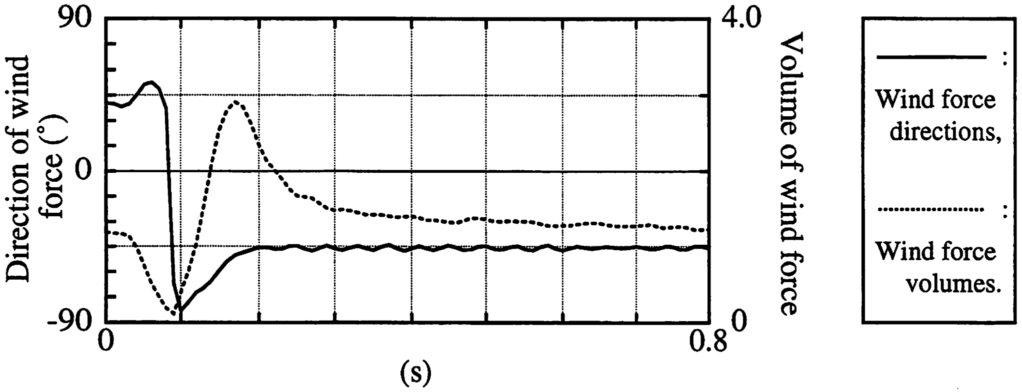


(b) Time histories of the dierctions and the volumes of the wind forces,

Fig. 5.5.7.2 Transitional states for the right turning from ϕ_{fw}^0 = +45° to ϕ_{fw}^f = 0° (Case-1b).

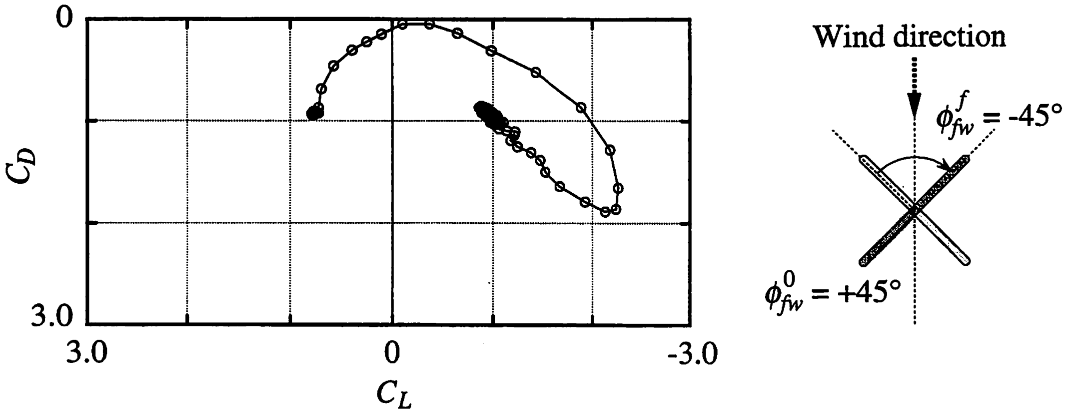


(a) Locus of the wind forces,

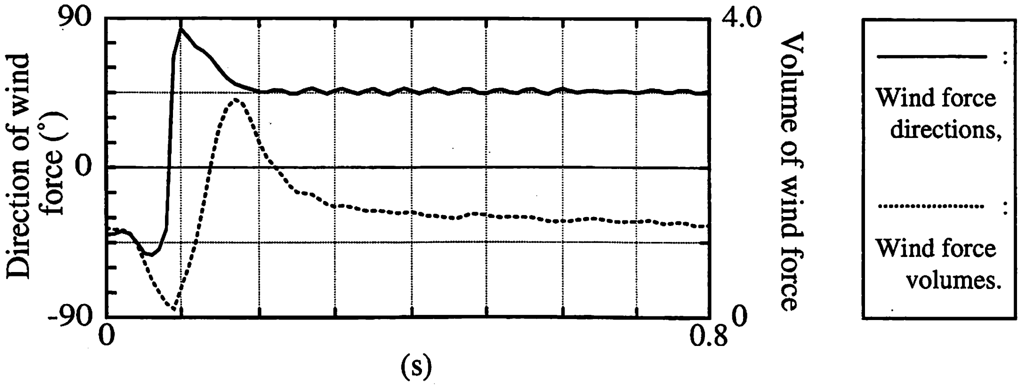


(b) Time histories of the dierctions and the volumes of the wind forces,

Fig. 5.5.8.1 Transitional states for the left turning from ϕ_{fw}^0 = -45° to ϕ_{fw}^f = +45° (Case-2a).

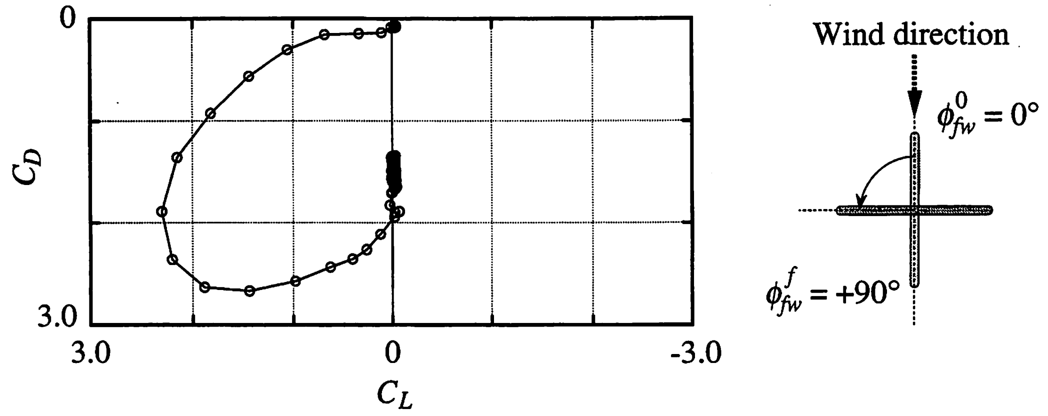


(a) Locus of the wind forces,

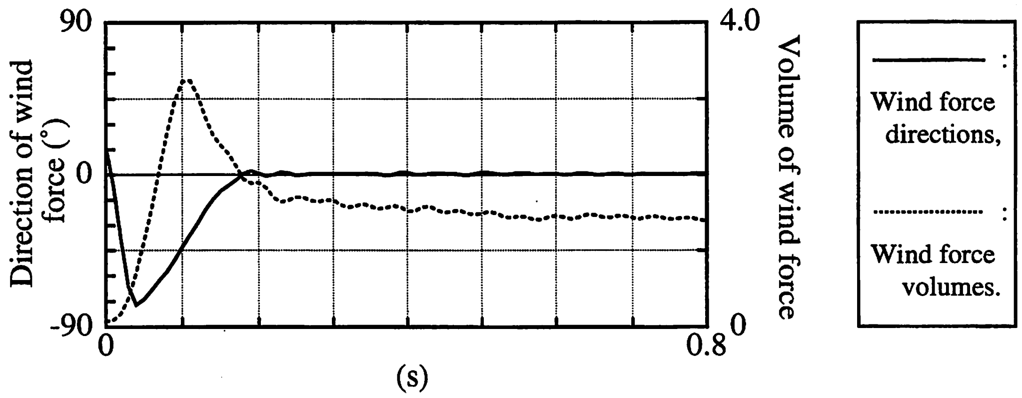


(b) Time histories of the dierctions and the volumes of the wind forces,

Fig. 5.5.8.2 Transitional states for the right turning from ϕ_{fw}^0 = +45° to ϕ_{fw}^f = -45° (Case-2b).

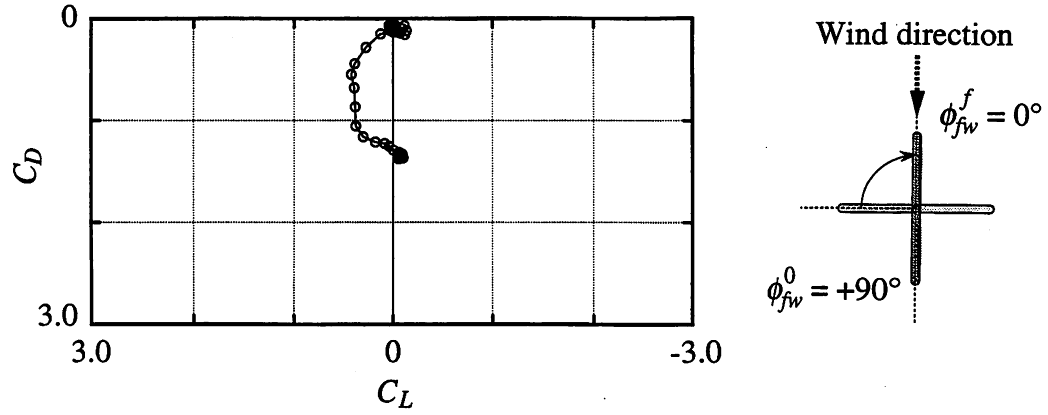


(a) Locus of the wind forces,

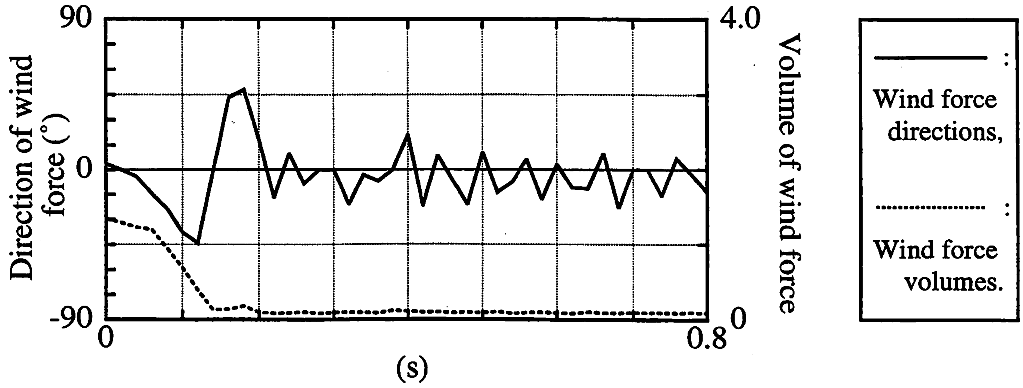


(b) Time histories of the dierctions and the volumes of the wind forces,

Fig. 5.5.9.1 Transitional states for the left turning from ϕ_{fw}^{0} = 0° to ϕ_{fw}^{f} = +90° (Case-3a).

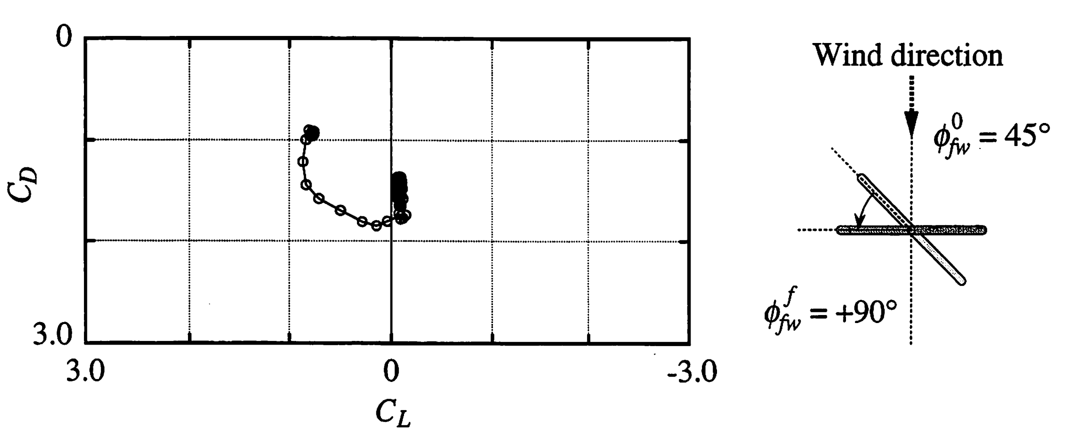


(a) Locus of the wind forces,

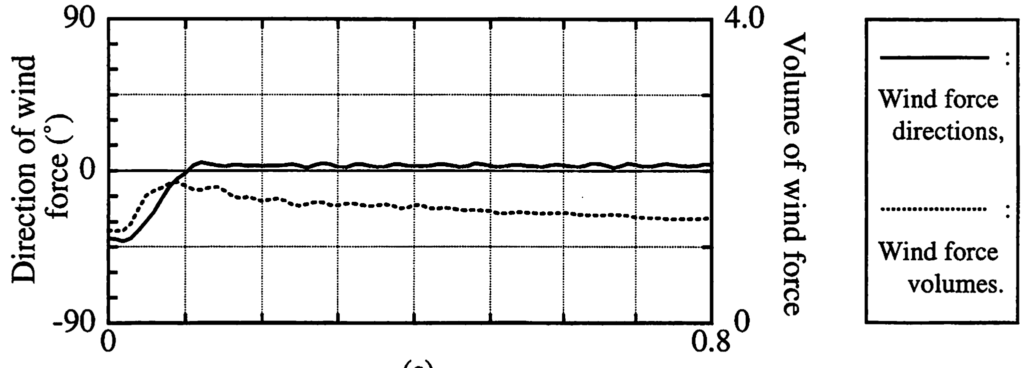


(b) Time histories of the dierctions and the volumes of the wind forces,

Fig. 5.5.9.2 Transitional states for the right turning from ϕ_{fw}^{0} = +90° to ϕ_{fw}^{f} = 0° (Case-3b).



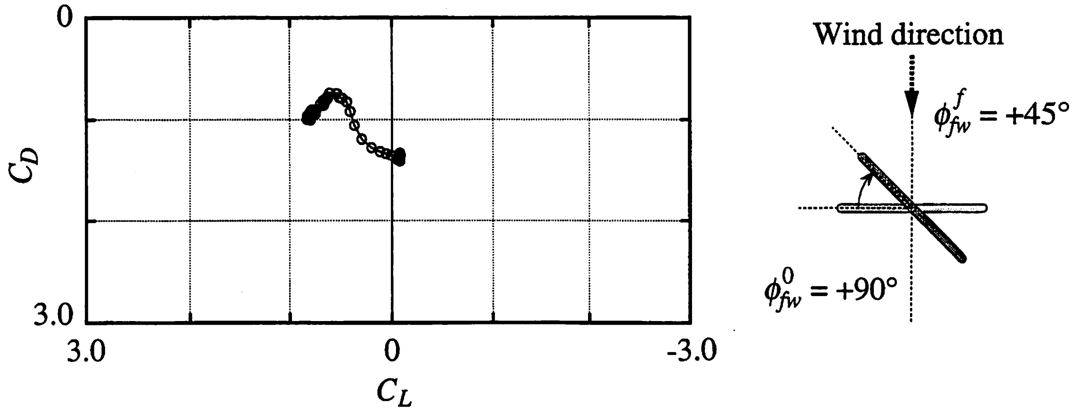
(a) Locus of the wind forces,



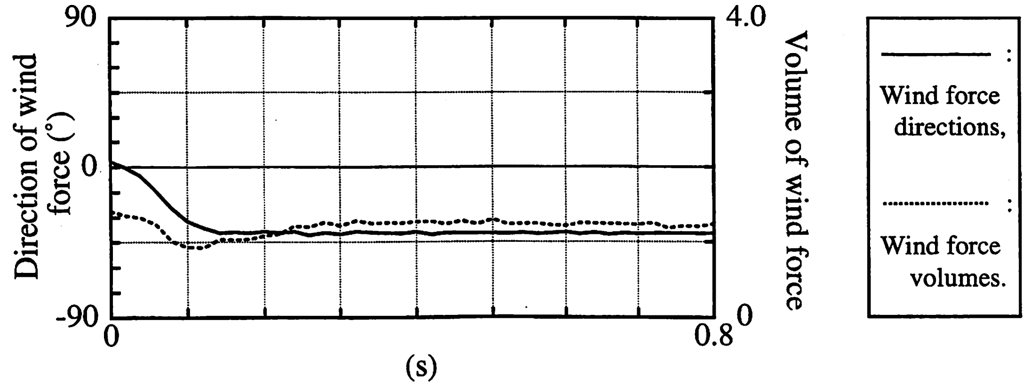
(s)

(b) Time histories of the dierctions and the volumes of the wind forces,

Fig. 5.5.10.1 Transitional states for the left turning from ϕ_{fw}^0 = +45° to ϕ_{fw}^f = +90° (Case-4a).



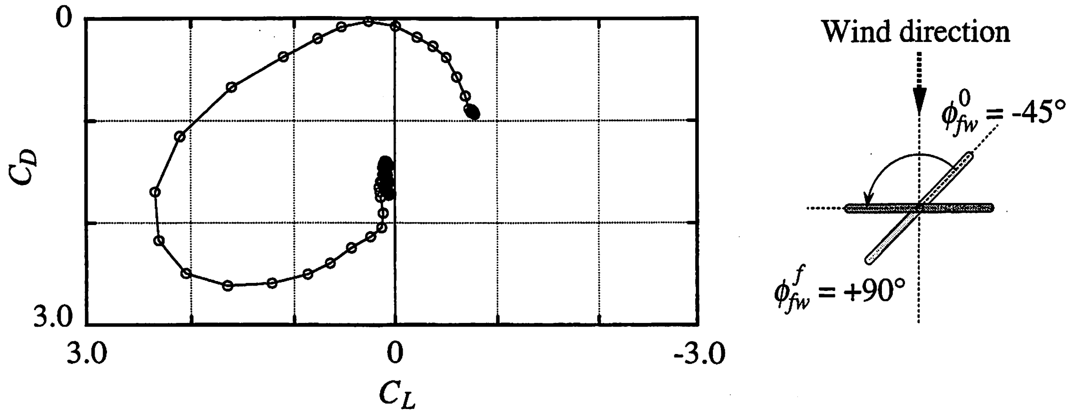
(a) Locus of the wind forces,



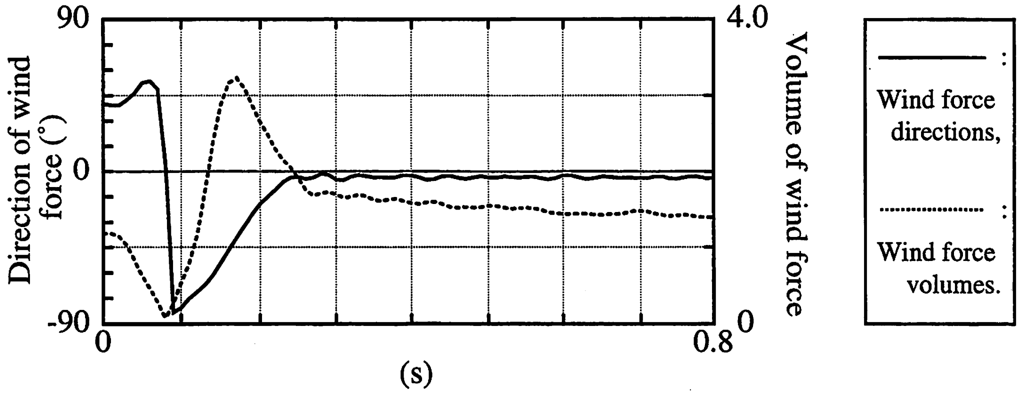
(s)

(b) Time histories of the dierctions and the volumes of the wind forces,

Fig. 5.5.10.2 Transitional states for the right turning from ϕ_{fw}^0 = +90° to ϕ_{fw}^f = +45° (Case-4b).

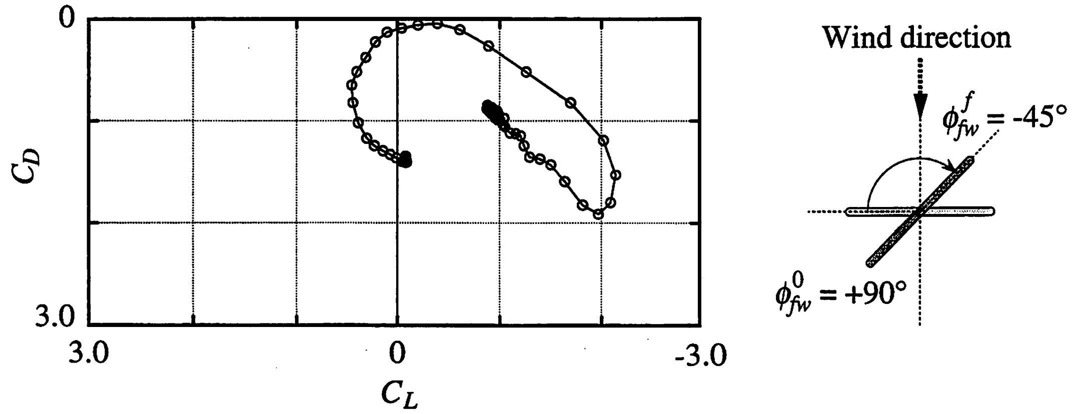


(a) Locus of the wind forces,

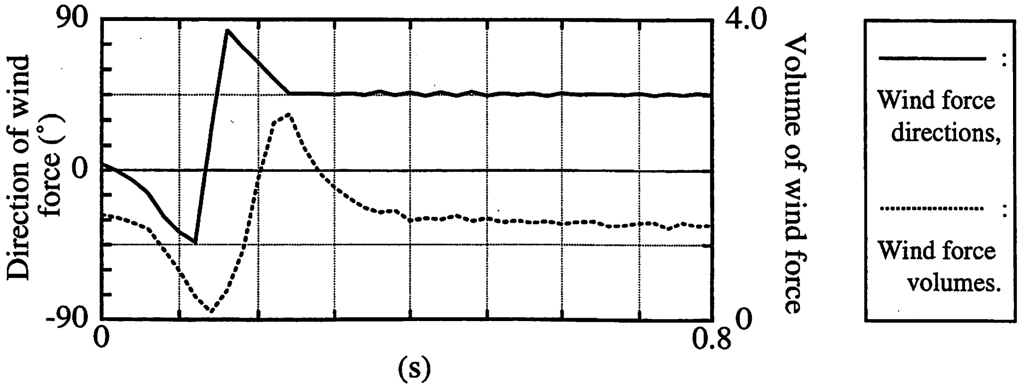


(b) Time histories of the dierctions and the volumes of the wind forces,

Fig. 5.5.11.1 Transitional states for the left turning from ϕ_{fw}^0 = -45° to ϕ_{fw}^f = +90° (Case-5a).



(a) Locus of the wind forces,



(b) Time histories of the dierctions and the volumes of the wind forces,

Fig. 5.5.11.2 Transitional states for the right turning from ϕ_{fw}^0 = +90° to ϕ_{fw}^f = -45° (Case-5b).

control are supposed in the Case-2, both of two kinds of transformations may be regarded as to be able to be effectually adjusted for this aim. In both of the Case-2a and the Case-2b, while 90° of the rotating angle of the active fin are supposed (namely, the manipulating time interval are allocated as to be 0.15 (s)), the direction-converged time intervals for both of cases may be evaluated as about 0.17 (s).

Point-3) By considering the fluctuations for floating volumes as seen in Figs.5.5.9.1 (Case-3a) and Figs.5.5.9.2 (Case-3b), the overshooting of the wind forces by the *Magnus* effects may be observed on the left turning from ϕ_{fw}^{0} = 0° to ϕ_{fw}^{f} = +90° and may not be appeared on the right turning from ϕ_{fw}^{0} = +90° to ϕ_{fw}^{f} = 0°. Those two kinds of single step of turnings are corresponded to the transformations from the open mode to the closed mode and the transformations from the closed mode to the open mode, respectively. In the Case-3, the tunings of the volumes of the wind forces on the same prioritized class on the parallel-wind response control are requested. Although the transformations on the later case as the Case-3b may be regarded as to be able to be effectually adjusted for this aim, the undesired overshooting of the wind forces by the *Magnus* effects are accompanied to the transformations on the first case as the Case-3a. In both of the Case-3a and the Case-3b, while 90° of the rotating angle of the active fin are supposed (namely, the manipulating time interval are allocated as to be 0.15 (s)), the direction-converged time intervals for the Case-3b may be evaluated as about 0.15 (s) (in which, although the oscillations of the direction of the wind forces may be observed in Fig.5.5.9.2 (b), it may be depended on the difficulty to exactly measure those direction of the wind forces on the state ϕ_{fw}^{0} = 0°, accordingly, the direction-converged time in this case are regarded as to be equal to the volume-converged time), however, the direction-converged time intervals for the Case-3a may be enlarged as to be about 0.2 (s).

Point-4) By considering the fluctuations for floating volumes as seen in Figs.5.5.10.1 (Case-4a) and Figs.5.5.10.2 (Case-4b), the overshooting of the wind forces by the *Magnus* effects may not be appeared on both of the left turning from ϕ_{fw}^{0} = +45° to ϕ_{fw}^{f} = +90° and the right turning from ϕ_{fw}^{0} = +90° to ϕ_{fw}^{f} = +45°. Those two kinds of single step of turnings are corresponded to the transformations from the leftward (or rightward) mode to the closed mode and the transformations from the closed mode to the leftward (or rightward) mode along the smaller pass, respectively. In the Case-4, the switching between the different prioritized classes are requested. Although the transformations on the first case as the Case-4a may be regarded as to be able to be effectually adjusted for this aim, the desired overshooting of the wind forces by the *Magnus* effects are not generated on the transformations on the later case as the Case-4b. In both of the Case-4a and the Case-4b, while 45° of the rotating angle of the active fin are supposed (namely, the manipulating time interval are allocated as to be 0.075 (s)), the direction-converged time intervals for both of cases may be evaluated as about 0.1 (s).

Point-5) By considering the fluctuations for floating volumes as seen in Figs.5.5.11.1 (Case-5a) and Figs.5.5.11.2 (Case-5b), the overshooting of the wind forces by the *Magnus* effects may be observed on both of the left turnings from ϕ_{fw}^{0} = -45° to ϕ_{fw}^{f} = +90° and the right turning from $\phi_{fw}^{0} = +90°$ to $\phi_{fw}^{f} = -45°$. Those two kinds of single step of turnings are corresponded to the transformations from the rightward (or leftward) mode to the closed mode and the transformations from the closed mode to the rightward (or leftward) mode along the larger pass, respectively. In the Case-5, the switching between the different prioritized classes are also requested. Although the transformations on the later case as the Case-5b may be regarded as to be able to be effectually adjusted for this aim, the undesired overshooting of the wind forces by the *Magnus* effects are accompanied to the transformations on the first case as the Case-5a. By evaluating with the Point-4 under the considerations for the effective utilizations of the *Magnus* effects, it may be requested as the control operations as that the smaller pass should be allocated for the transformations from the leftward / rightward mode to the closed mode and that the larger pass should be allocated for the transformations from the closed mode to the leftward / rightward mode. In both of the Case-5a and the Case-5b, while 135° of the rotating angle of the active fin are supposed (namely, the manipulating time interval are allocated as to be 0.225 (s)), the direction-converged time intervals for both of cases may be enlarged as to be about 0.25 (s).

Through those evaluations for each case study, it may be pointed that the most of the negative factors which influenced to the two-directional response control operations are appeared on the cases of the transformations which are related to the closed mode. As mentioned on the Point-3, the undesired influences by the *Magnus* effects for the transformations from the open mode to the closed mode (as corresponding to the Case-3a) may be accompanied as the unavoidable factors. By comparing this case with the other cases which are supposed by the same rotating angle of the active fin, it may be pointed the further negative factors as that the larger direction-converged time intervals are spent on the Case-3a. Moreover, when the cases by mentioned on the Point-4 and the Point-5 (which are also specified as to be related to the closed mode) are considered, the larger pass should be selected for the transformations from the closed mode to the leftward / rightward mode (as corresponding to the Case-5b) as the requirements to utilize the *Magnus* effects. In this case, explicitly, the control operations can not be escaped from the time delays by accompanying to the larger direction-converged time intervals.

As the solutions for those problems, it may be reached to the eliminations of the closed mode from the set of the configurations of the active fin to compose the two-directional response control operations. When the closed mode is not supposed on the positionings of the active fin, it may be regarded that only the Case-1 and the Case-2 are evaluated for any transformations of the active fin. As the estimations on the Point-1 and the Point-2, it may be assured that any cases of the transformations of the active fin (which are supposed by the Case-1 and the Case-2) can be effectually adjusted for any situations based on the considerations for the prioritized classes of the control operations. Moreover, since the direction-converged time intervals for the Case-1 can be evaluated about 0.1 (s) for 0.075 (s) of the manipulating time interval and the direction-converged time intervals for the Case-2 can be evaluated about 0.17 (s) for 0.15 (s) of the manipulating time interval, those values of the direction-converged time intervals may be estimated as to be enough to satisfy the

Condition-4 which are supposed to reconstruct the new version of the two-directional response control method as to be able to provide enough effectiveness under the time delay effects by the circular locus of the structural vibrations. At this point, by considering the experimental results for the Case-4, it may be regarded that the disadvantage by uninstalling the closed mode at the prioritized class on the parallel-wind direction are quite small. Because, for the conditions as that the tunings of the volumes of the wind forces are requested in this case, the volumes of the drag of the wind forces may be regarded as to be enough large by introducing the leftward mode or the rightward mode as much as the volumes of the drag of the wind forces by the closed mode. Accordingly, it seems that the installations of the closed mode can be also replaced by holding the positionings of the active fin to the leftward mode or the rightward mode.

As the final stage to construct the Version-3 of the two-directional response control method, discussions may be moved to the considerations as how to control the *Magnus* effects, namely, as how to allocate the timings to be generated the overshooting states caused by the *Magnus* effects. Under the conditions that the structural vibrations are appeared as to be close to the circular locus, it may be reasonable to consider that the dominant directions are moved between the parallel-wind and the cross-wind directions by every 1/4 of the single cycle of the structural vibrations. Namely, for the windage angle of the structural vibrations ϕ_{rw}, those dominant orientations of the structural vibrations may be classified as to be the 'leeward-dominant area' by $\{\phi_{rw} \mid -45° < \phi_{rw} < 45°\}$, the 'leftward-dominant area' by $\{\phi_{rw} \mid -135° < \phi_{rw} < -45°\}$, the 'windward-dominant area' by $\{\phi_{rw} \mid -180° < \phi_{rw} < -135°, 135° < \phi_{rw} < 180°\}$ and the 'rightward-dominant area' by $\{\phi_{rw} \mid 45° < \phi_{rw} < 135°\}$. When the configurations of the active fin are allocated as that the leeward-dominant area and the windward-dominant area are related to the prioritized class on the parallel-wind response control and as that the leftward-dominant area and the rightward-dominant area are related to the prioritized class on the cross-wind response control, any transformations of the active fin may be compose the concrete shape of the Version-3 of the two-directional response control method. Accordingly, the control manipulations which are proposed as the Version-3 of the two-directional response control method are appeared as the following two kinds of descriptions (which are corresponded to the two kinds of control algorithms to reduce or to amplify the structural vibrations :

"To reduce the structural vibrations,
when the leeward-dominant area is moved to the left / rightward-dominant area,
the active fin is turned from the open mode to the right / leftward mode,
when the left / rightward-dominant area is moved to the leeward-dominant area,
the active fin is turned from the right / leftward mode to the open mode,
after the left / rightward-dominant area is moved to the windward-dominant area,
at the instance as that the cross-wind orientations of structural vibrations are changed,
the active fin is turned from the right / leftward mode to the left / rightward mode".

"To amplify the structural vibrations,
when the windward-dominant area is moved to the left / rightward-dominant area,

the active fin is turned from the open mode to the left / rightward mode,
when the left / rightward-dominant area is moved to the windward-dominant area,
the active fin is turned from the left / rightward mode to the open mode,
after the left / rightward-dominant area is moved to the leeward-dominant area,
at the instance as that the cross-wind orientations of structural vibrations are changed,
the active fin is turned from the left / rightward mode to the right / leftward mode".

In which, the 'structural vibration' means the orientation of the top floor's velocity vector of the structure, and the 'wind flow' means the orientation of the wind flow from windward to leeward. At this point, from the evaluations in the Study (5.5)-2b, it may be confirmed that the *Magnus* effects can be always affected as to effectually adjusted to the final positionings at any single step of the transformations of the active fin by limiting the set of the configurations active fin as to be the open mode, the leftward mode and the rightward mode. Accordingly, when the single cycle of the structural vibrations may be separated as that the adequate one of the configurations of the active fin which are related to the windage angle of the structural vibrations ϕ_{rw}, this Version-3 of the two-directional control method can also be expressed by simple compositions (so that, it may be warranted that any transformations which are specified on the descriptions as mentioned above may be automatically actualized under the expressions as follows).

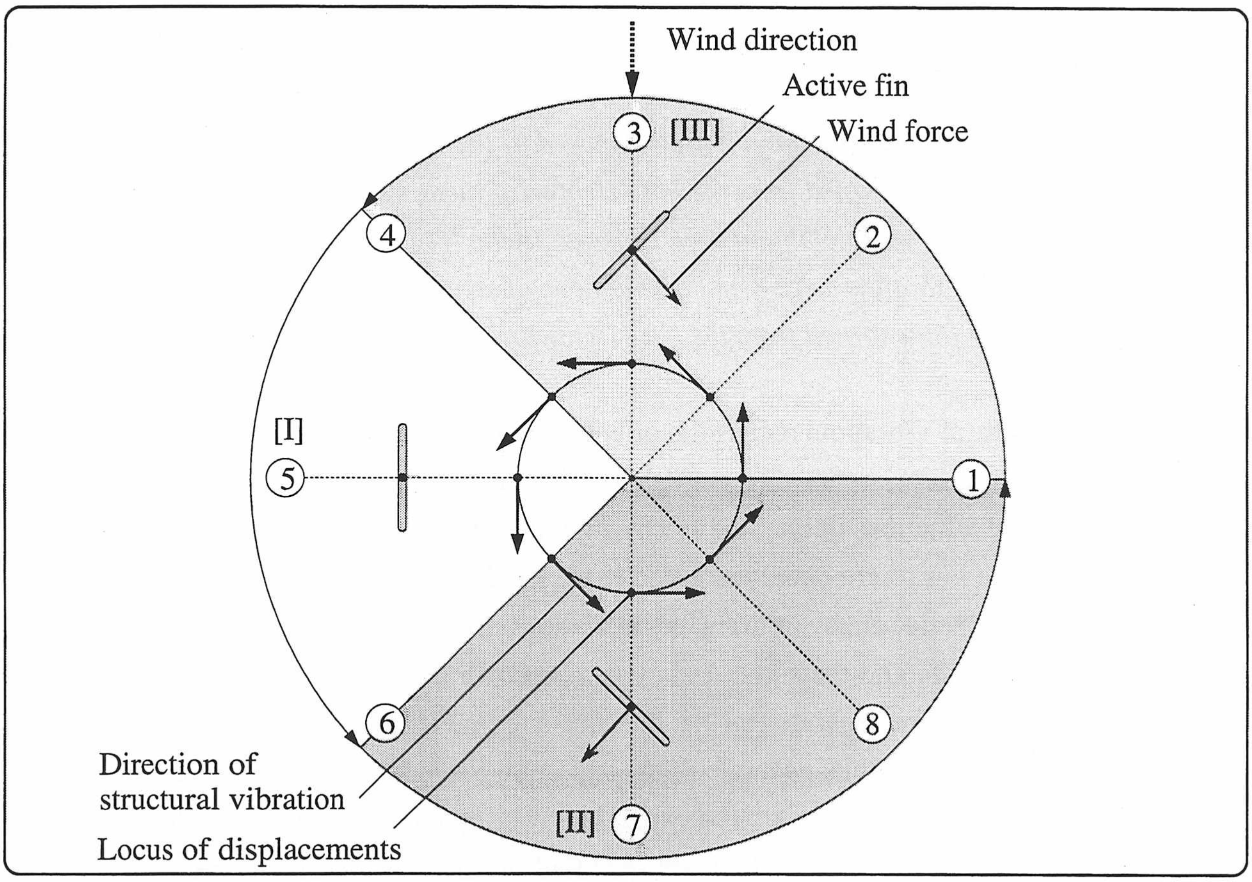
Control algorithm-2(R)-III :

If	ζ_r	$\leq$	$\zeta_{r,\,min}$ or	$\zeta_w \leq \zeta_{w,\,min}$,
				then , keeping before mode,
else if	$\lvert \phi_{rw} \rvert$	$\leq$	45°,	***then*** , open mode,
else if	ϕ_{rw}	$<$	-45°,	***then*** , rightward mode,
else if	ϕ_{rw}	$>$	45°,	***then*** , leftward mode.

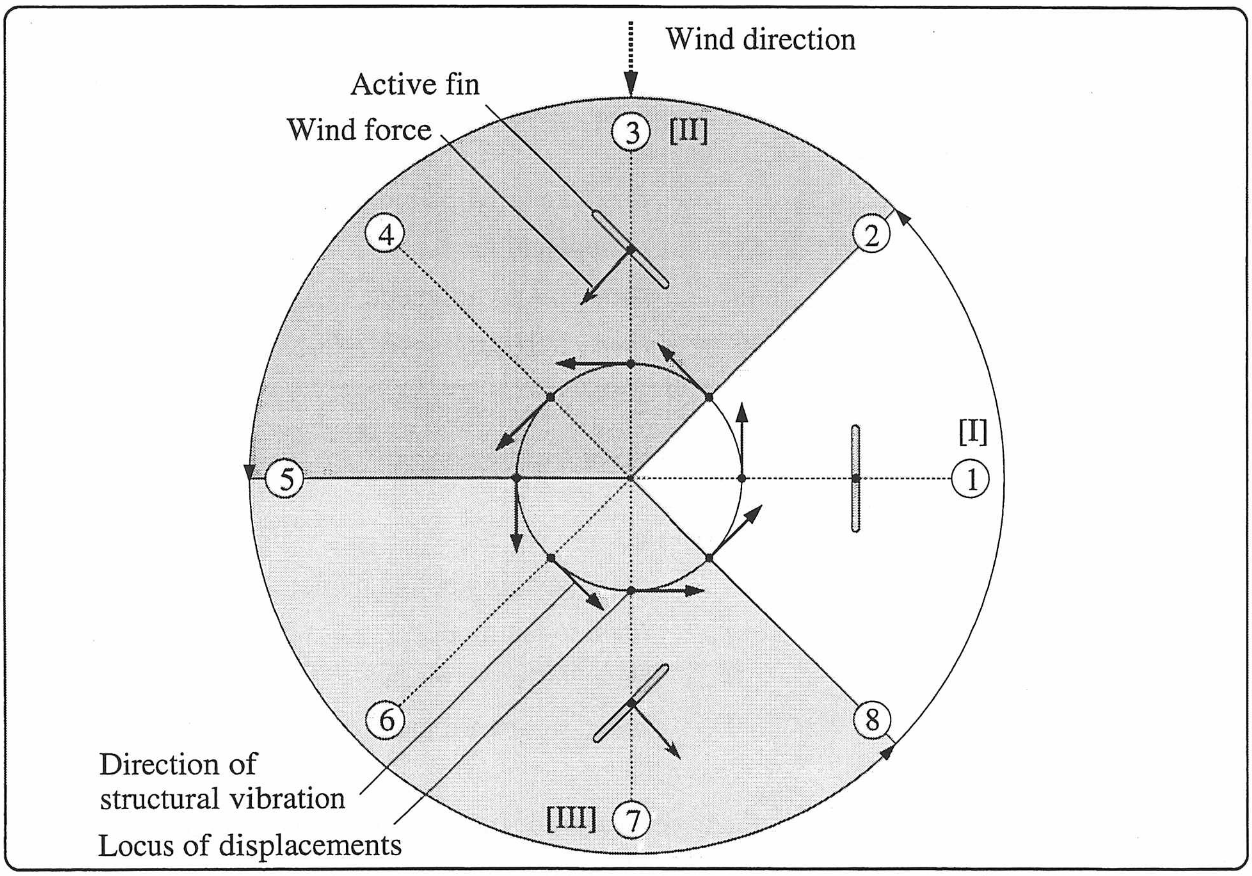
Control algorithm-2(A)-III :

If	ζ_r	$\leq$	$\zeta_{r,\,min}$ or	$\zeta_w \leq \zeta_{w,\,min}$,
				then , keeping before mode,
else if	$\lvert \phi_{rw} \rvert$	$\geq$	135°,	***then*** , open mode,
else if	ϕ_{rw}	$<$	0°,	***then*** , leftward mode,
else if	ϕ_{rw}	$>$	0°,	***then*** , rightward mode.

In which, $\zeta_{r,\,min}$ and $\zeta_{w,\,min}$ are used as the trigger level for the volumes of the structural responses and the wind velocities, respectively. Those two kinds of control algorithms based on the Version-3 of the two-directional control method are also illustrated as shown in Figs.5.5.12. In those figures, (a) and (b) are corresponded to the control manipulations by introducing the Control algorithm-2(R)-III and the Control algorithm-2(A)-III based on the Version-3 of the two-directional response



(a) Configurations of the active fin on the Control algorithm-2(R)-III,



(b) Configurations of the active fin on the Control algorithm-2(A)-III,

Fig. 5.5.12 Control manipulations based on the Version-3 of the control method.

control methods under the conditions that the structural vibrations are appeared as to be close to the circular locus, respectively (in those figures, the counter clockwise movements of the structural vibrations are represented).

As seen in Figs.5.5.12, the representative states of the structural vibrations are specified by the symbols from ① to ⑧, and especially, the states of the structural vibrations specified by the symbols ① and ⑤ are corresponded to the instances as that the orientations of the velocities may be appeared as to be allocated on the windward and the leeward to the wind direction, respectively, and the states of the structural vibrations specified by the symbols ③ and ⑦ are corresponded to the instances as that the orientations of the velocities may be appeared as to be allocated on the leftward and the rightward to the wind direction, respectively. By introducing the Version-3 of the two-directional control method, three kinds of the configurations of the active fin may be allocated according to the windage angle of the structural vibrations ϕ_{rw}, namely, the open mode, the leftward mode and the rightward mode may be configured on the intervals [I], [II] and [III], respectively.

As seen in Fig.5.5.12 (a), by installing the Control algorithm-2(R)-III, three kinds of transformations of the active fin are operated at the instance which are allocated on the states of the structural vibrations ④, ⑥ and ①. When the structural vibrations are passed the states ④ or ⑥, the active fin may be manipulated as to be turned from the rightward mode to the open mode or as to be turned from the open mode to the leftward mode, respectively. By considering for the Point-1 which are evaluated for Case-1 on the Study (5.5)-2b, the manipulating time intervals and the direction-converged time intervals for both of those two kinds of transformations are warranted as to be 0.075 (s) and about 0.1 (s), respectively. Accordingly, when the first natural periods of the target structures are supposed as to be over about 0.6 (s), it seems that the value of the manipulating time interval may be allocated as that those transformations can be completed by reaching to the states ⑤ and ⑦, and that the time delays of the direction-converged time from those states may be evaluated as to be quite small. When the structural vibrations are passed the state ①, the active fin may be manipulated as to be turned from the leftward mode to the rightward mode. By considering for the Point-2 which are evaluated for Case-2 on the Study (5.5)-2b, the manipulating time intervals and the direction-converged time intervals for this transformations are warranted as to be 0.15 (s) and about 0.17 (s), respectively. Accordingly, when the first natural periods of the target structures are also supposed as to be over about 0.6 (s), it seems that the value of the manipulating time interval may be allocated as that this transformation can be completed by reaching to the state ③, and that the time delays of the direction-converged time from this state may be evaluated as to be quite small. At the same time, it may be confirmed that the volumes of the wind forces have been kept as the drag by the leftward mode up to the state ①. It may be reached to the significant efficiencies of the Control algorithm-2(R)-III as follow : "when the core states of the windward-dominant area, the leftward-dominant area, the leeward-dominant area and the rightward-dominant area (in which, those states may be specified as the states ①, ③, ⑤ and ⑦, respectively) are considered, the volume of drag of the wind forces are increased or decreased on the states ① or ⑤ which is also regarded as the core of prioritized class on the parallel-wind response control, respectively, and that the orientations of lift of the wind forces are leaned to the right or the left on the states ③ or ⑦ which is also regarded as the core of the prioritized class on the cross-wind response control, respectively".

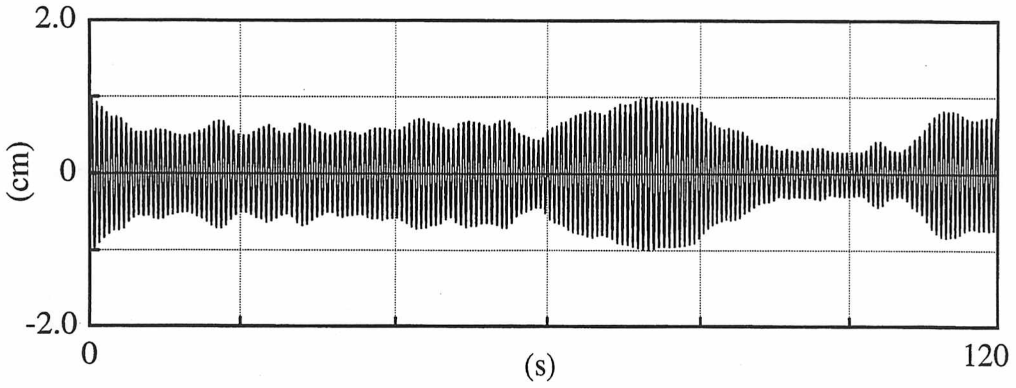
The similar discussions may be also operated for the Control algorithm-2(A)-III by evaluating for Fig.5.5.12 (b). As the difference between this figure and Fig.5.5.12 (a), it may be pointed that three kinds of transformations of the active fin are operated at the instance which are allocated on the states of the structural vibrations ②, ⑤ and ⑧. Accordingly, when the structural vibrations are passed the states ⑧ or ②, the active fin may be manipulated as to be turned from the rightward mode to the open mode or as to be turned from the open mode to the leftward mode, respectively, and when the structural vibrations are passed the state ⑤, the active fin may be manipulated as to be turned from the leftward mode to the rightward mode. To sum up, it may be also reached to the significant efficiencies of the Control algorithm-2(A)-III as follow : "when the core states of the windward-dominant area, the leftward-dominant area, the leeward-dominant area and the rightward-dominant area (in which, those states may be specified as the states ①, ③, ⑤ and ⑦, respectively) are considered, the volume of drag of the wind forces are <u>decreased or increased</u> on the states ① or ⑤ which is also regarded as the core of prioritized class on the parallel-wind response control, respectively, and that the orientations of lift of the wind forces are leaned to the <u>left or the right</u> on the states ③ or ⑦ which is also regarded as the core of the prioritized class on the cross-wind response control, respectively". Namely, it may be assured that the control operations by the Control algorithm-2(A)-III are evaluated as to be completely inverted from the control operations by the Control algorithm-2(R)-III.

As the final study in this section, the control effects by installing the Control algorithm-2(R)-III and the Control algorithm-2(A)-III based on the Version-3 of the two-directional response control method are investigated by operating the active control tests on the wind tunnel.

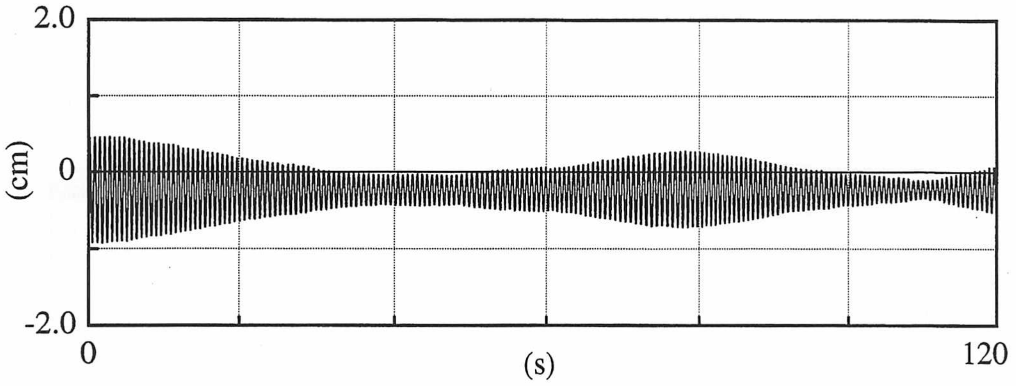
Study (5.5) - 3 :

The wind tunnel are executed on the new structural model on the CTAC system to investigate for the effectiveness of the Control algorithm-2(R)-III and the Control algorithm-2(A)-III of the Version-3 of the two-directional response control method. The structural properties for those wind tunnel tests are adopted as the conditions of the Model-1 which are mentioned on Table 5.3.2 in the Section 5.3. The active response control tests are operated under the laminar wind flows which are measured as the wind velocities of about 6.5 (m/s) on the wind tunnel. Figs.5.5.13 show the non-controlled displacements of the top floor. Figs. 5.5.14 and Figs.5.5.15 show the controlled displacements of the top floor by introducing the Control algorithm-2(R)-III and the Control algorithm-2(A)-III, respectively. In those figures from Figs.5.5.13 to Figs.5.5.15, (a), (b) and (c) are corresponded to the time history on the X-direction (the cross-wind direction), the time history on the Y-direction (the parallel-wind direction) and the locus of the top floor's displacements (during 120 (s)), respectively.

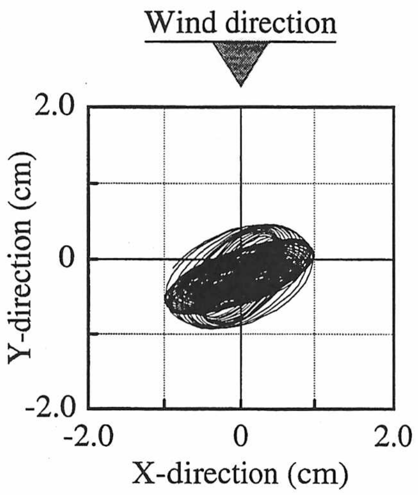
By comparing Figs.5.5.14 and Figs.5.5.15 with Figs.5.5.13, it may be assured that the effective reductions of the structural vibrations are observed by introducing the Control algorithm-2(R)-III on both the cross-wind and the parallel-wind directions and that the effective amplifications of the



(a) X-direction (Cross-wind direction),

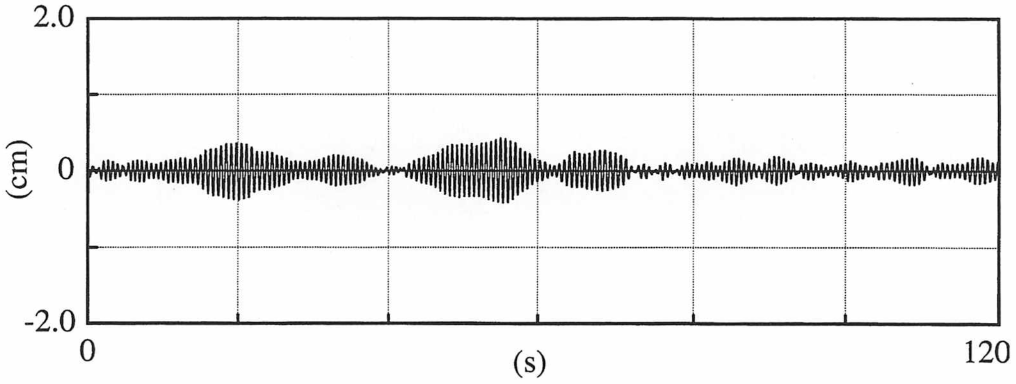


(b) Y-direction (Parallel-wind direction),

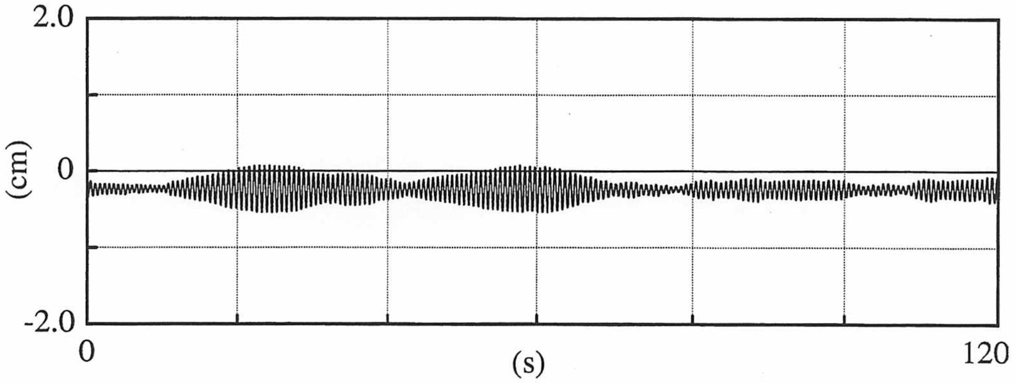


(c) Locus of displacements,

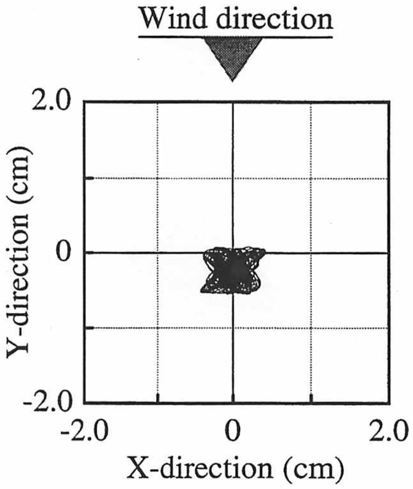
Fig. 5.5.13 Top floor's displacements (Without control).



(a) X-direction (Cross-wind direction),

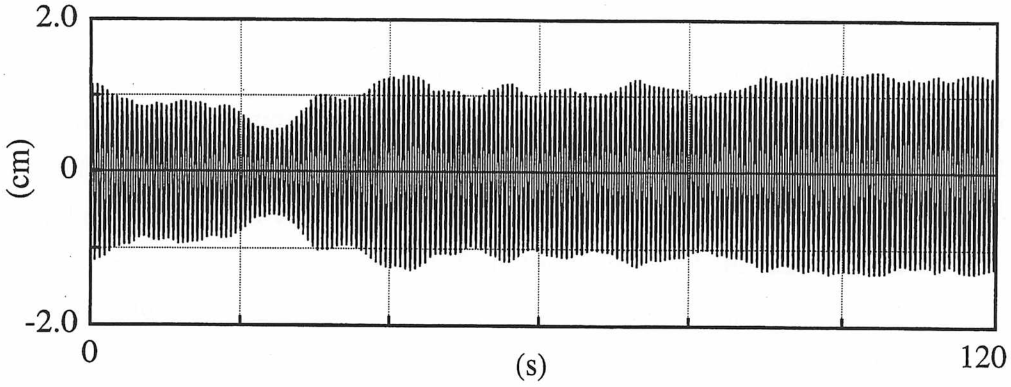


(b) Y-direction (Parallel-wind direction),

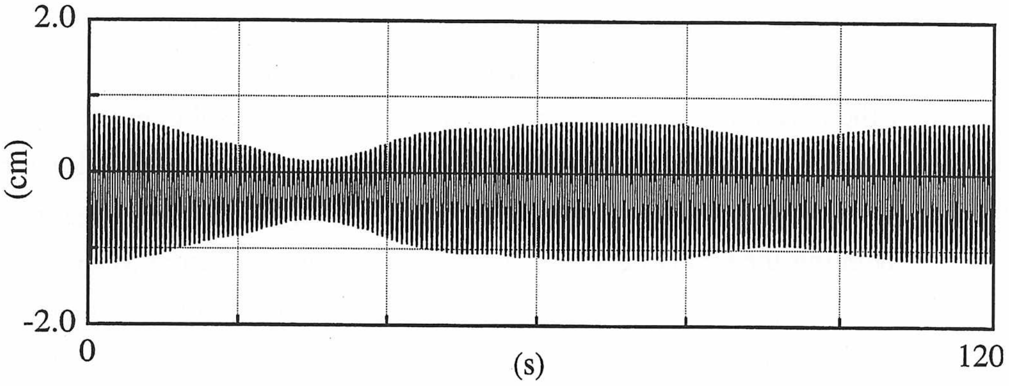


(c) Locus of displacements,

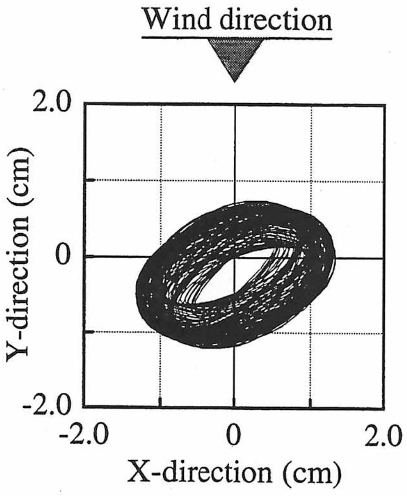
Fig. 5.5.14 Top floor's displacements (Control algorithm-2(R)-III).



(a) X-direction (Cross-wind direction),



(b) Y-direction (Parallel-wind direction),



(c) Locus of displacements,

Fig. 5.5.15 Top floor's displacements (Control algorithm-2(A)-III).

structural vibrations are observed by introducing the Control algorithm-2(A)-III on both the cross-wind and the parallel-wind directions, respectively. On those active control tests on the wind tunnel, it may be considered that the structural vibrations are appeared as the elliptic motions to be close to the circular locus as observed on the non-controlled responses in Fig.5.5.13. Accordingly, since it may be regarded that those control manipulations by introducing the Version-3 of the two-directional response control method are effectually affected as to control the wind-induced structural vibrations, namely, that the expected control efficiencies on those two kinds of installations as the Control algorithm-2(R)-III and the Control algorithm-2(A)-III (which are supposed as to be reduced or amplified the structural vibrations) can be actualized under the influences which are caused by the circular locus of the structural vibrations.

As concluding remarks in this section, to improve the control efficiencies for the multi-directional wind-resistant response control by installing the active fin system under the considerations for the time delay effects which are caused by the circular locus of the multi-directional structural vibrations, the Version-3 of the two-directional response control method are newly introduced. This new version of the control method is constructed by evaluating for the transitional states of the wind forces. Namely, the mechanisms on the growth of the wind forces by accompanying the rotating motions of the active fin are effectually installed on the control operations, and those efficiencies are taken care for the compositions on this newly proposed two-directional response control method. For this aim, the aerodynamic properties of the wind forces are investigated on the wind tunnel by introducing the newly developed testing apparatus to measure for the transitional states of wind forces. Through those evaluations for the transitional wind force characteristics, it is arisen that the *Magnus* effects may be allocated as the significant factor to be affected to the control manipulations of the active fin. By investigating for the influences caused by *Magnus* effects in detail and by considering for the control manipulations as to be able to effectually utilize those aerodynamic properties of the transitional wind forces, the concrete shape of the Version-3 of the two-directional response control method is constructed. As a result from those preparatory evaluations, it may be reached to the compositions of the Version-3 of the two-directional response control method as the quite simple control operations which are based on the transformations of the active fin among only three kinds of configurations by the open mode, the leftward mode and the rightward mode.

To experimentally investigate for the fundamental effectiveness of this newly proposed Version-3 of the two-directional response control method, the wind tunnel active control tests are also executed. Two kinds of the control algorithms which are introduced as to be aimed to reducing or amplifying the structural vibrations are proposed as the Control algorithm-2(R)-III and the Control algorithm-2(A)-III based on the Version-3 of the control method. As a result, under the conditions as that the structural vibrations are appeared as to be close to the circular locus, it is assured that the remarkable reductions of the amplifications can be actualized by installing Control algorithm-2(R)-III and the Control algorithm-2(A)-III, respectively. So that, it may be regarded that the Version-3 of the response control algorithm can be provided enough efficiencies as multi-directional wind-resistant response control method.

5. 6 Concluding remarks

Through the considerations in this chapter, the developments and the investigations for the active fin system which is proposed as the new type of the wind-resistant active response controller. The active fin system is designed as to be able to utilize the wind forces acting on the fins as the effective forces for controlling the wind-induced structural vibrations. At first, to evaluate the fundamental efficiencies of this kind of active control system, the pilot model of the control device of the active fin is developed for the wind tunnel tests. The basic installations and estimations of the active fin system are executed by using the three-stories of structural model on the CTAC standard system in the Section 5.1. The single-directional response control tests for the parallel-wind direction by using this pilot type of control device of active fins are executed by installing the very simple control algorithm. As a results, by evaluating the top floor's velocities as the state of the structural vibrations and by selecting the conflagrations of the active fin to the open mode or the closed mode according to the direction of the structural vibrations, it is assured that the effective response controls are actualized on the parallel-wind direction by introducing the active fin system.

In the Section 5.2, discussions are expanded to the multi-directional response control by using the active fin system. For this aim, the control device of the active fin is newly designed as to be provided the efficiencies which can utilize both of the drag and the lift of wind forces acting on the fin, even if any directions of the wind flow on the horizontal plane are supposed. At first, this newly designed control device of the active fin is evaluated on the wind tunnel tests. The single-directional response control tests on the parallel-wind direction are executed and the reappearance of the control effects which are assured on the previous experimental tests are examined. Moreover, by considering the characteristics of the lift of the wind forces generated on the active fin, the single-directional response control algorithm for the cross-wind direction is constructed. By executing the wind tunnel tests, it is assured that this new model of the active fin can also operate the effective response controls on the cross-wind direction. As the next step of the Section 5.2, the large-scaled experimental tests are executed on the large-scaled experimental structure. The newly designed active fin is introduced as the large-scaled control device of the active fin. To operate the multi-directional response control on this large-scaled experimental structure, the two-directional response control method (which are specified as the Version-1 of control method) is proposed by superposing the two type of the single-directional response control algorithm for the parallel-wind and the cross-wind directions. Under the strong natural wind flow, the large-scaled active response control tests are operated. As a result, by using the two-directional control method which is proposed in this section, it is assured that the effective response control are almost actualized on the cross-wind direction, however, that the control effects on the parallel-wind direction may not be appeared.

To improve the efficiencies of the active fin system for operating the multi-directional response control, discussions in the Section 5.3 are begun to talk from that the control algorithm for the two-directional response control is reconsidered and reconstructed. By considering the offset of the wind force vector generated by the active fin, the new type of the two-directional control method (which are specified as the Version-2 of control method) is proposed. At first, to evaluate this newly proposed control algorithm, the large-scaled experimental tests are executed. Those experimental tests are investigated from the two kinds of operations as that the response controls are manipulated as to reduce and amplify the structural vibrations. As a result, it is assured that the structural responses appearing on both of the cross-wind and the parallel-wind directions are effectively reduced or amplified by installing each one of those two kinds of operations, however, that those experimental results are inverted from the expected control efficiencies by every two kinds of operations. To make assure those controlled behaviors by introducing this new type of the two-directional control method on the wind tunnel tests, on the later half of this section, the new type of the structural model which are provided the two-directional motions on the horizontal plane are developed and introduced for the CTAC-based evaluative tests. By executing the active control tests on this new structural model, it may be confirmed that the similar controlled behaviors by using the Version-2 of the two-directional control method can be also reappeared on the wind tunnel. Moreover, by executing the additional wind tunnel tests which are considered for the various conditions of the natural periods of the structural model and the control time intervals for manipulating the active fin, it is assured that those inverted control effects which are observed on the controlled behaviors by the Version-2 of the control method are significantly subjected on the time delay spent to change the conflagrations of the active fin.

In the Section 5.4, to find out the fundamental factors which are subjected on the control operations and the control effects by introducing the Version-1 and the Version-2 of the two-directional response control methods of the active fin system, the verifications of those two kinds of the control methods are evaluated in detail. On those verifications, two kinds of the typical cases of the structural vibrations are considered, namely, those cases are supposed as that the structural vibrations may be appeared as the comparatively flatness of the elliptic motions (which are considered as to be almost close to the single-directional motions) and as the structural vibrations may be appeared as to be close to the circular locus of the elliptic motions. When the structural vibrations are supposed as the flatness of the elliptic motions, the control manipulations by introducing both of the Version-1 and the Version-2 of those two kinds of the two-directional response control methods may be evaluated as to be almost equality, and the control efficiencies may be considered as to be provided enough effectiveness under the considerations for the time delays which are accompanied to the control time intervals. However, when the structural vibrations are supposed as to be close to the circular locus, it is assured that the significant differences between the Version-1 and the Version-2 of the two-directional response control methods are appeared. Namely, it is found that the controlled behaviors which are observed on the previous experimental tests (as mentioned in the Section 5.2 and the Section 5.3) may be explained under the conditions as that the structural vibrations are considered as to be close to the circular locus. Accordingly, through those verifying evaluations for the control manipulations of the active fin, it is assured that the control effects by introducing those two kinds of the two-directional response control methods are significantly subjected to the complexed factors which are resulted from both of the influences of the time delays by accompanied to the control manipulations and by caused on the circular locus of the structural vibrations. To experimentally confirm those verifying considerations, the wind tunnel tests are also executed. For this aim, the additional operations on the two-directional response control manipulations are introduced as the response predictions by evaluating the acceleration responses, and those operations are installed as to be cancelled the time delay effects caused by the circular locus of the structural vibrations. The wind tunnel active control tests are operated for the cases as to be targeted the Version-2 of the two-directional control method which is additionally introduced the response predictions. As a result, the inversions of the expected control efficiencies of the two kinds of the control algorithm based on the Version-2 of the two-directional response control method can be effectively regained due to the additional installations of the response predictions. By considering those controlled responses which are observed on the wind tunnel tests, it is confirmed that the control efficiencies of the Version-2 of the two-directional control method are significantly affected by the circular locus of the structural vibrations.

As the further investigations to overcome the time delay effects caused by the circular locus of the structural vibrations and accompanied to the control manipulations to transform the configurations of the active fin, the two-directional response control operations are reconstructed by evaluating for the transitional states of the wind forces in detail. Because, it is considered that the response predictions are not always effective in the practical meanings as that the wind-induced responses under the natural wind flows or the turbulent artificial wind flow may not be always appeared as the harmonic simple structural vibrations. In the Section 5.5, aerodynamic wind force effects which are induced by rotating operations of the active fins are measured on the wind tunnel tests and dynamic properties of the wind resistant forces acting on the fins may be assured as the mechanism based on the *Magnus* effects. By estimating for those aerodynamic wind force effects and by considering for the effectual utilizations of the *Magnus* effects, the Version-3 of the two-directional control method is composed. As the installations of this newly proposed response control method, the two kinds of control algorithm which are aimed to reduce and amplify the structural vibrations are introduced. Through the wind tunnel active control tests, it is assured that remarkable reductions and the amplifications of the two-directional structural vibrations are actualized as the control effects which are expected for each control operation by every two kinds of the control algorithms based on the Version-3 of the two-directional control method.

As the summary of the studies in this chapter, it may be pointed that the active fin system can be introduced as the effective wind-resistant response controller by considering the following items.

(1) When the single-directional structural vibrations are appeared on the parallel-wind direction, those wind-induced structural responses can be controlled effectively by manipulating the configurations of the active fin as that the volume of the drag of the wind forces are tuned according to the parallel-wind orientations of the structural vibrations related to the wind flow by on-line. Those control operations may be actualized as only the transformations of the active fin between the open mode and the closed mode.

(2) When the single-directional structural vibrations are appeared on the cross-wind direction, those wind-induced structural responses can be also controlled effectively by manipulating the

configurations of the active fin as that the orientations of the lift of the wind forces are tuned according to the cross-wind orientations of the structural vibrations related to the wind flow by on-line. Those control operations may be actualized as only the transformations of the active fin between the leftward mode and the rightward mode.

(3) Under the considerations for the multi-directional wind flows on the horizontal plane, the multi-directional response control operations as the superpositions of the single-directional response control manipulations for the parallel-wind and the cross-wind directions are requested. Those superpositions may be composed from the two kinds of different way. When the switchings between the prioritized class on the parallel-wind and the cross-wind directions are considered, the Version-1 of the two-directional response control method is composed as the sequences to allocate the discrete positionings as to be the open / closed modes for the prioritized class of the parallel-wind direction and the leftward / rightward modes for the prioritized class of the cross-wind direction according to the relations for the directions between the structural vibrations and the wind flows. When the continuous correspondences of the configurations of the active fin according to the relations for the directions between the structural vibrations and the wind flows are considered, the Version-2 of the two-directional response control method is composed as the sequences to regulate the continuous positionings of the active fin.

(4) When the structural vibrations are supposed as to be dominantly appeared on only the specified single-directions for any wind flows from any directions, both of the control operations by installing the Version-1 and the Version-2 of the two-directional response control methods may be evaluate as to be almost similar and both of the control efficiencies may be considered as to be effective for both the parallel-wind and the cross-wind structural vibrations. Because, both of those two-directional control methods are composed as the superpositions of the single-directional response control manipulations for the parallel-wind and the cross-wind directions.

(5) Under the conditions as that the dominant directions of the structural vibrations are not supposed and as that the elliptic motions of the structural vibrations are appeared as to be close to the circular locus, the control effects by installing the Version-1 of the two-directional response control methods are deteriorated, namely, the controlled responses may be appeared as to be effectually affected only on the cross-wind direction.

(6) When the control manipulations based on Version-2 of the control method are also operated under the conditions as that the structural vibrations are appeared as to be close to the circular locus of the elliptic motions, the control effects may be appeared as to be inverted on both of the parallel-wind and the cross-wind directions, namely, the controlled responses by introducing the two kinds of the control algorithms based on the Version-2 which are aimed to reduce or to amplify the structural vibrations may be affected to the amplifications or the reductions of the structural responses. As the reason for those differences between the controlled responses by using the Version-1 and the Version-2, the influences caused by that the control manipulations are discretized by the comparatively large control time intervals may be pointed as to be sensitively subjected to the cases on the Version-2. Accordingly, as the compositions for the two-directional response control method, the advantage to prepare the allocations of the discretized configurations

of the active fin by evaluating for the prioritized classes according to the relations for the directions between the structural vibrations and the wind flows may be considered .

(7) By evaluating for the transitional states as the growth of the wind forces by accompanying to the transformations of the active fin, the *Magnus* effects are also appeared as the significant factors which are affected to the control effects on the multi-directional response control operations. When the effectual utilizations of those aerodynamic properties caused by the *Magnus* effects are considered, the estimations of the transforming pass and the rotating orientations to change the configurations of the active fin should be requested on the control manipulations. When the positionings of the active fin are limited into three kinds by the open mode and the leftward / rightward mode, it is found that effectual generations or ungenerations of the *Magnus* effects may be automatically actualized and the Version-3 of the two-directional response control method are composed from those considerations. Even if the structural vibrations are appeared as to be close to the circular locus, it is assured that the control effects by installing the Version-3 of the two-directional response control methods are appeared as to be actualized the expected efficiencies.

Those significant items which are appeared through the discussions and considerations in this chapter may be regarded as very attractive for the practical installations of the wind-resistant active response control systems by using the active fin, and also, the sufficient investigations for the syntheses of the control manipulations by utilizing the wind forces may be mentioned from those case studies. As the further progressions to continue those evaluations for the active fin system, it is suggested that the considerations for the syntheses of the size of the active fin or the investigations for the control operations as the multi-devices systems (which are installed as the multi-located active fins on the single story to control the rotational components of the structural vibrations or as the multi-located active fins on the plural stories to improve the control performances) may be pointed out as the interested items.

5. 7 References

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* 実務者のための建築物風洞実験ガイドブック.

6 Conclusion

As the summary of this study, the fundamental and the applicative installations of the CTAC system are introduced through the researches and the discussions on the previous chapters. The CTAC system are proposed as the standard evaluative testing apparatus to investigate and verify the common sense of the 'effectiveness' on the various kinds of structural response control systems through the procedures by 'mutual benchmark evaluations'. To produce the systematic structural response control syntheses, significance for those fundamental concepts on the evaluative systems are briefly discussed as the introductions of this study with the backgrounds that the structural designs have been taken a progress to the structural response control designs.

By reviewing the technical progress as that various kinds of structural response control techniques have been introduced on the structural engineering fields and as that a lot of practical response controlled buildings have been actually constructed, the essential characteristics of those response control systems are classified from the mechanical and the theoretical view points, and also, the effectual meanings which are produced to the traditional structural designs are investigated with installations of those advanced techniques. At the same time, the general meanings of the active structural response control systems are widely discussed and the future possibilities for the structural response controlled building constructions are considered from the view point of the applications of those active response control techniques. Namely, in the Chapter 2, this study are taken into a course to pioneering the applicable installations of the active response control technique by starting from those recent technical trend in the structural engineering field.

The concrete shapes of this study are assigned as the operations of the standard evaluative researches for the active structural response control systems through the developmental investigations of the CTAC system in the Chapter 3. The basic configurations and the basic efficiencies of the CTAC system are composed as the standard evaluative testing apparatus by considering the significance to operate the mutual benchmark evaluations for enabling the systematic syntheses of the structural response control systems. The fundamental meanings of the CTAC-based evaluative researches are pointed on preparations of the evaluative interfaces for various kinds of the structural response control systems. And also, by executing the preliminary check for the CTAC-based experimental apparatus through the shaking table tests and the wind tunnel tests, the basic capacities and the adequate operative conditions on the CTAC system are investigated as the starting points to the following researches. On the following two chapters, the standard evaluating investigations for the aseismic response control systems and the wind-resistant response control systems are introduced as the typical two kinds of the applicative researches by using the CTAC system.

In the Chapter 4, the CTAC-based evaluative researches for the aseismic active response control systems are operated through the trials to find out the adequate installations and the applications of the newly proposed aseismic response controllers. Namely, the quasi-optimizing control method is introduced and investigated. The basic package of this quasi-optimizing control method is supposed under predictions of the structural responses for the limited numbers of the pre-provided patterns of the discretized control forces, and the regulations of the structural behaviors are very simply operated by referring the digital-indexes. The parametric benchmark evaluations are executed by using the three-stories of the CTAC standard structural model which are equipped the active braces on every stories, and the following significant remarks are pointed as the effectual items to introduce the quasi-optimizing control method for controlling the seismic structural vibrations :

(1) By considering the practical applicability of the quasi-optimizing control method for the active control systems with multi-devices, the supplemental algorithms to reduce the load of the CPU on the quasi-optimizing procedures are proposed as the multi-layer searching algorithms by introducing the searching sequence according to the relative priorities of the control devices.
(2) Under the considerations for the effective arrangements of capacities of control devices on the multi-located system and the responsibilities of those multi-control devices, the lumped-node control force system which are introduced as the para-systems of control forces for the active braces installed on every inter-stories are regarded as to be effective to actualize reductions of responses.
(3) To utilize the quasi-optimizing control method as the aseismic response controllers under the considerations for the variations of the external input levels, the set of the trial control forces which are synthesized as the geometric fractional division type can be effectually applied for this aim.

In the Chapter 5, the CTAC-based evaluative researches for the wind-resistant active response control systems are operated through the trials to find out the adequate installations and the applications of the newly proposed wind-resistant response controllers. Namely, the active fin systems are developed and examined. The active fin system is designed for effectively utilizing the aerodynamic effects of the wind forces acting on the fin to control the wind-induced structural vibrations. For effectually operating those researches on the active fin system, the other two kinds of the CTAC-based standard structural models are also introduced, the one is the two-directional motions type of the testing model on the wind tunnel and the another one is the large-scaled experimental structural building on the tests under the natural wind flow. Through the experimental benchmark evaluations on the wind tunnel and the large-scaled experimental facilities, the following significant remarks are pointed as the effectual items to introduce the active fin system for controlling the wind-induced structural vibrations :

(1) When the single-directional structural vibrations are appeared on the parallel-wind direction, those wind-induced structural responses can be controlled effectively by manipulating the configurations of the active fin as that the volumes of the drag of the wind forces are tuned according to the parallel-wind orientations of the structural vibrations by related to the wind flow by on-line. Those control operations may be simply actualized by only the transformations of the active fin between the open mode and the closed mode.

(2) When the single-directional structural vibrations are appeared on the cross-wind direction, those wind-induced structural responses can be also controlled effectively by manipulating the configurations of the active fin as that the orientations of the lift of the wind forces are tuned according to the cross-wind orientations of the structural vibrations by related to the wind flow by on-line. Those control operations may be simply actualized by only the transformations of the active fin between the leftward mode and the rightward mode.

(3) When the multi-directional structural vibrations are appeared on the horizontal plane, the transitional states under the growth of the wind forces by accompanying to the transformations of the active fin are pointed as the significant factor which should be evaluated on the control algorithms of the active fin system. By effectually utilizing those aerodynamic transitional properties which are explained as the *Magnus* effects, the effective multi-directional response control can be actualized on the structural control system by installing the active fin.

As the concluding remarks in this study, to construct the effective response control systems for building structures, emphases are put on the importances of introducing the active control techniques and of estimating the reliability and the adequateness on those advanced controllers through the benchmark evaluations. As the basic approaches for those aims, the developmental and applicable examinations of the CTAC system are discussed in detail. By actively utilizing the standard testing apparatus as like the CTAC system in order to operate the mutual benchmark evaluation for the active control systems, the evaluative interfaces for the practical syntheses on the structural response control systems may be systematically prepared according to the actual necessities as like to compare and estimate various kinds of controllers or as like to also develop and apply the new kinds of controllers. The practical meanings of the effectiveness of the active control technologies may not be polished up until overcoming the various problems which are latently existed on the active control systems. Accordingly, the experiment-based evaluations will discover those problems, and the numerical-based evaluations will also support the theoretical considerations to solve those problems. The researches which are introduced in this study have been allocated into the first step to support the further progress on the active control systems for the building constructions, and the author's future researches will be continued to go toward the more practical and effectual applications of active structural response control technologies for the actual building constructions.

7 Publications

7. 1 Official refereed papers for journals or transactions

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