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Fatigne Behavior of Connection Plate between Main Girder and Cross Beam in Composite Plate Girder

Kohsuke HORIKAWA *, Shinji MATSUMOTO ** and Masahiko KITAZAWA ***

Abstract

Since urban freeway bridges were opened for traffic more than twenty years ago, there have been so many reports on the necessity of repairing cracks and deformation. For an example, the cracks at the connection plate between girder and lateral distribution cross beam are reported, and also the cracks at the connection plate between girder and sway bracings for composite plate girders. The investigation for the cracks, the establishment of repair and reinforcement method, and the feedback to the design standard specifications are now urged and many discussions are in progress in many places. In this research, we would like to find out one of the effective solutions by fabricating the test girders with the previous design and with present design, investigating the effects of the total rigidity of the girder upon the fatigue crack and comparing and discussing the proposed structural details.

KEY WORDS: (Fatigue Crack) (Highway Bridge) (Web Gap Plate)

1. Introduction

Since urban freeway bridges were opened for traffic more than twenty years ago, there have been so many reports on the necessity of repairing cracks and deformations.[1)2)] For an example, the cracks at the connection plate between girder and lateral distribution cross beam are reported, and also the cracks at the connection plate between girder and sway bracings for composite plate girders. In the United States such cracks are the worst case of all the simillar damages which is called "Fatigue crack due to web gap".[3)] The web gap means the small gaps between top flange of the girder and the end of the transverse stiffners, and the small gaps between cross beam bracket and web plate for the main girder.

The investigation for the cracks, the establishment of repair and reinforcement method, and the feedback to the design standard specifications are now urged and many studies are in progress in many places. As one of the investigation, finite element method is used in detail stress analysis.[4)]

In Japan, many cracks were found at the reinforced concrete slab for the plate girders which were built between 1965 and 1975. By the investigation, the spacing of main girder : l = 3.85 m and the thickness of reinforced concrete slab : d = 18 cm have been changed to the spacing of the main girder : l = 2.85 m and the thickness of reinforced concrete slab : d = 25 cm respectively. As a result, the standard specification have been revised and applied to the bridge design up to today. Accordingly the former is called "previous design", and the latter "present design".

The cracks at connection plate have been reported also on the previous design only and any cracks have not been reported on the present design. On the reports of the stress analysis, there is the difference of total rigidity for the bridge: in the case of previous design, the stress is bigger than that of present design and the location of the cracks is found at the same stress points of the previous design. As a result, a few new methods for the connection plate have been proposed.[4)]

In this research, we would like to find out one of the effective solutions by fabricating the test girders with the previous design and with present design, investigating the effects of the total rigidity of the girder upon the fatigue crack and comparing and discussing the proposed structural details.

2. Design of Test Girder and Test Method

(1) Outline of Test

The flow chart of tests are shown in **Fig. 1.** The cause of the fatigue crack due to web gap has been considered the effect for the neck swing of the top flange of the girder and the relative displacement between the girders.

In the first step, the main cause of fatigue crack due to web gap has been investigated. As the first step the test girders were designed with A and B type, which were expected to test the neck swing effect (test 1) for test girder A-1 (see **Fig. 2**), and the relative displacement effect (test

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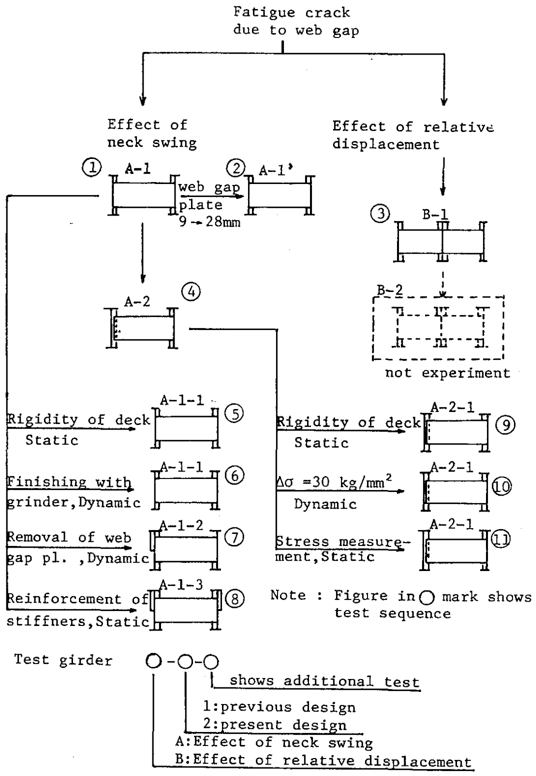


Fig. 1 Flow chart for tests.

3) for test girder B-1 (see **Fig. 3**). The Wide Flange Shape equivalent to the rigidity of deck is fastened with High Strength Bolts to the A type test girder, and the test load was loaded at the center of the Wide Flange Shape. For B type test girder, the rigidity ratio for deck and cross beam : deck/cross beam ≒ 1/100, which was so small that rigidity of the deck was neglected, and the test load was loaded at center of intermediate girder.

As the second step, test began from bigger effect case, where A-2 test girder designed by present design (see **Fig. 4**) was fabricated and tested because in the results of the first step tests, the cracks were found for A-1 test girder while no cracks for B-1 test girder (test 3). If the relative displacement effect had been bigger than neck swing effect, the additional test (B-2 test girder) would

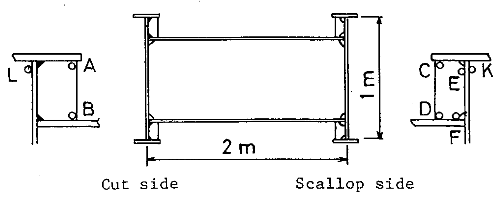


Fig. 2 A-1 test girder.

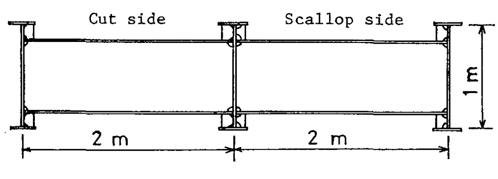


Fig. 3 B-1 test girder.

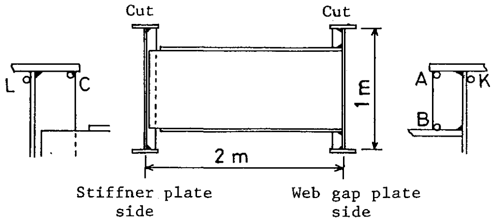


Fig. 4 A-2 test girder.

have took place, but as a result of the first step test, neck swing effect was bigger than the relative displacement effect, so that B-2 test was canceled.

The additional tests were required to confirm the effects of incidental factors. By changing the thickness of the web gap plate from 9 mm to 28 mm, the fatigue test took place because the crack were found at test 1. This additional test is called test (2) and the test girder for the test (2) was named A-1′.

Then by turning the A-1 test girder upside-down, finishing the toe for the web gap plates with round grinders, which is called A-1-1 test girder and the following tests took place. For A-1-1 test girder static loading test took place using three different kind of Wide Flange Shape (test 5), to find the relations between the rigidity of Wide Flange Shape (deck rigidity), deflection angle of Wide Flange Shape and the magnitude of stress on the web gap palte. The next fatigue test took place on A-1-1 test girder with the size of Wide Flange Shape 100 × 200 ($I = 1840\ cm^4$) (test 6); in this case to find the effect of the bead finish of the weld, that A-1 test girder have not been finished with grinders.

To prevent the fatigue crack due to web gap, test (7) took place by removing one side web gap plate and by reinforcing the other with the stiffners (A-1-2 test girder). In test (8), to find the effect of the reinforced stiffner, both sides of web gap plate are reinforced (A-1-3 test girder), because in test (7) the effect of the removal of the web gap plate was so large that the effect of the reinforcing with the stiffner could not been found.

Turning A-2 test girder upside-down, which was named A-2-1 test girder. For A-2-1 test girder, test (9) took palce the same static load test as test (5). From test (1) to test (9), we have had some results : when the stress range $\Delta\sigma$ is more than $40\ kg/mm^2$, the crack are found, and if the stress range is less than $16.8\ kg/mm^2$ (the maximum stress under which the cracks are not found), the cracks are not found. Then we have had some questions about the effect of the stress between $16.8\ kg/mm^2$ and $40\ kg/mm^2$. Test (10) took place by arranging the test loading to $\Delta\sigma = 30\ kg/mm^2$ at the corner of the web gap plates to solve the questions.

The next arguments were about the difference of stress between tested web gap plates and those for actual bridges which have been discussed from the first step of the test.[5] As one of the solution toward the question, we thought effective was to set the strain gauge. Test (11) took place by setting as many strain gauges as possible at the corner of the web gap plates.

(2) Design for Test Girder

Two types (A and B) of test girders were planned and designed in accordance with two different design standards. One is previous design standard and the other present design. The difference between both standards are shown in **Table 1**. All the test girders are of Bridge length = 1m, Girder spacing = 2m, and Girder depth = 1m, and the Moment of inertia for decks and cross beam is changed for each standard.

Table 1 Difference of previous and present design.

Items	Standard specification	
	Previous design	Present design
d (cm)	18	25
l (m)	3.85	2.85

d: Thickness of reinforced concrete slab
l: Spacing of main girder

1) Rigidity of Deck

The rigidity of deck for the test girders were decided to be equal deflection angles at A point of **Fig. 5** to the actual bridge. The effective width of deck is 100 cm. To assume the simple beam, when the point load is loaded at center between the girders, the deflection angle for the deck at point A are expressed in θ. When the deflection angle for actual bridge are expressed in θ_p, and the deflection angle for the test girder are expressed in θ_e, the moment of inertia of the deck for the test girders are decided so as to $\theta_p = \theta_e$. The Wide Flange Shape approximately equivalent to the above mentioned moment of inertia are adopted as the deck for test girder.

2) Rigidity of Cross Beam

The rigidity of cross beam for test girder were decided so that the ratio of the deflection for intermediate girder ; δ to the span ; 1, which = $\delta/1$ were equal to the test girder and actual bridge (**Fig. 6**).

3) Test Load

For A type, as shown in **Fig. 7 (a)**, when the unit travelling load is moved on the transverse direction, the maximum deflection angle : θ_{max} are obtained. Assuming that test girders are simple beam, when the point load is loaded at center of the Wide Flange Shape, the point load that gives deflection angle θ_{max} is obtained. Then the test load is decided by the above mentioned procedure. For B type, as shown in **Fig. 7 (b)**, when the unit travelling load is moved on the transverse direction, the test load is decided by maximum reactions for intermediate girder.

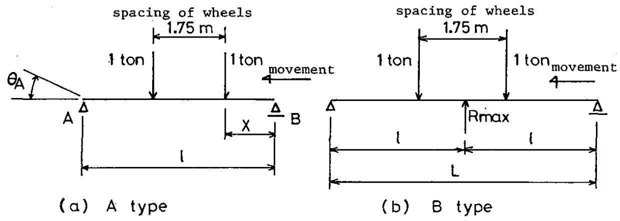


Fig. 7 Movement of unit travelling load.

4) Detail for Test Girder

The details of web gap plates for test girder A-1 are arranged using both scallop and cut-and-weld (see Fig. 2). For scallop, the radius are 35 mm, where the round weld are done. For cut-and-weld, the corner cut size is 10 mm, where are filled up by welds. For the test girder A-1 to be repaired (A-1′), the web gap plates of 28 mm thickness are arranged using cut-and-weld for both sides. The "corner" indicates top and bottom of free edge for the web gap plates. For easy to comparison of the results for test in A type test girder, the marks for gauge position were Rame (see Fig. 2 and 4). For the test girder A-2, transverse stiffners are fastened to the web plate of the cross beam with High Strength Bolts in one side, and the cross beam is welded to web plate of the main girder as test girder A-1 in other side. The details of web gap plates are arranged using the cut-and-weld for both sides (see Fig. 4). For the test girder B-1, the web gap plates are fabricated symmetrically to top and bottom, and left and right, the details of which are arranged using both scallop and cut-and-weld. The cross beam are welded directly to web plate (see Fig. 3).

(3) Fatigue Test

The fatigue test took place under the load controlled three points bending. Electro-hydro servo controlled fatigue test machine (P_{max} = 20^{ton}, δa = 30 mm) was used. The support spans are of 2m for A type, and 4m for

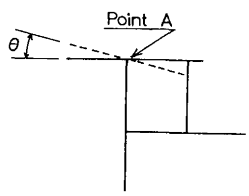


Fig. 5 Deflection angle of deck.

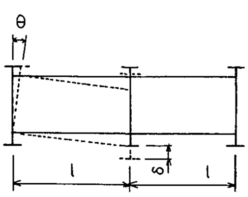


Fig. 6 Deflection angle due to relative displacement for main girder.

Table 2 Loading conditions

Test girder	Load range (ton)	Speed of loading (Hz)
A-1	1-13.8	1 - 2
B-1	1-13.4	3 - 5
	1-19.0	3 - 5
A-2	1-11.0	4 - 5
	1-19.0	4 - 5
A-1-1	1-13.8	1 - 3
A-1-2	1-13.8	1
A-2-1	1-12.0	1 - 3

B type. The loads and loadings speed are shown in Table 2. The maximum load for fatigue test are minimum load P = 1^{ton} plus test load obtained in section 3).

The length for crack was measured by visual method using penetrant for liquid penetrant. The length of the crack were measured from free edge of the web gap plate.

3. Results of Test and Discussion

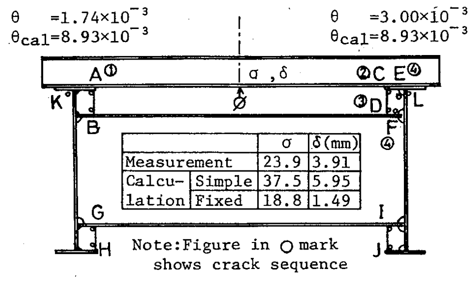
(1) Comparison of Neck Swing Effects and Effects for Relative Displacement

In this section the comparison are made to the effects for neck swing (test 1) and relative displacement for web gap plates (test 3) on fatigue. On the experimental feature for type A and B, the two mechanisms for fatigue effect due to the web gap plate were assumed as follows : The test girders type A were assumed that the cross beam with large amount of rigidity than that of deck was hardly followed to the deflection angle of the deck (neck swing), while the top flange which was connected to the deck in stiffness is easily followed to the deck. Therefore the high local stress were occurred at the corner of web gap plate.

On the other hand test girder type B were that the cross beam was affected the bending deformation due to the relative displacement between the main girders, which so the web gap plates were resisted by the deck that high local stress were found at web gap plate. For the test it was intended to get that high local stress at the shaded parts in **Fig. 9**.

The results of stress measurement for test (1) and test (3) are shown in Fig. 8 and Fig. 9. For the results of fatigue test, the cracks were found in five points A, C, D, E, F for A-1 test girder. On the other hand no cracks were found even which the initial loads (13.4^{ton}) and increased loads 19^{ton} for B-1 test girder. The stress for the corner of web gap plates were that $\Delta\sigma = 47.$ kg/mm^2 at point A and $\Delta\sigma = 40.9$ kg/mm^2 at point C for A-1 test girder. The results of this test are agree well with the theoretical results for the stress analysis report.[4] The crack were found at the point of high stress zone. On the other hand for test girder B-1 of which the maximum stress (at gauge number 15) were $\Delta\sigma = 11.5$ kg/mm^2, and that was approximately 1/4 of the test girder A-1. Although the loads were increased up to 19 ton, the stress was $\Delta\sigma = 16.4$ kg/mm^2 at the same point. From the result of the calculations of the deflection angle it was imagined that the stress at web gap plate would become more high for type A rather than type B. The results of the calculation of the deflection angle shows that $\theta = 8.48 \times 10^{-3}$rd for test girder A-1, and $\delta/l = 3.88 \times 10^{-4}$ rd for test girder B-1.

From the above we must consider that the reason of the fatigue crack for web gap plate will be the neck swing effect for top flange of main girder.

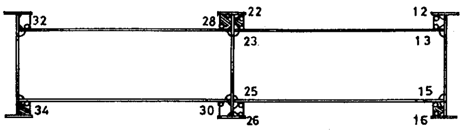


		σ	δ(mm)
Measurement		23.9	3.91
Calcu-	Simple	37.5	5.95
lation	Fixed	18.8	1.49

Gage No.	Δσ Measurement	Δσ Calculation[4]	Gage No.	Δσ Measurement
A	47.3	47.5	G	11.4
B	23.0	16.3	H	13.9
C	40.9	47.5	I	-
D	5.7	16.3	J	15.1
E	13.1	20.0	K	13.1
F	20.1	27.5	L	15.7

Δσ : Stress range (kg/mm^2)

Fig. 8 Results of stress measurement for A-1 test girder (Pmax = 13.8 ton).



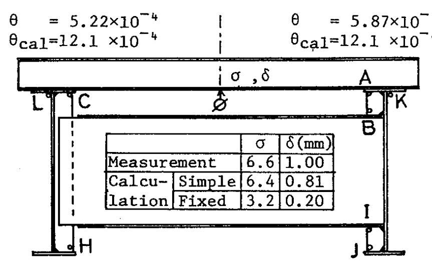
Gage No.	Δσ	Gage No.	Δσ	Gage No.	Δσ
12	0	22	3.0	28	4.6
13	0.2	23	5.4	30	3.0
15	11.5	25	3.9	32	3.7
16	6.7	26	0.3	34	6.9

Δσ : Stress range (kg/mm^2)

Fig. 9 Results of stress measurement for B-1 test girder (Pmax = 13.4 ton).

(2) Comparison for Previous Design Standard and Present Design Standard

The comparison are made to the test (1) and test (4) which were the designed and fabricated to the test girder A-1 for previous design standard, and to the test girder A-2 for present design standard. The results of stress measurements for test (4) and shown in **Fig. 10** and the results of test (1) were shown in Fig. 9. As the results of the fatigue test, the cracks were found at five points in early stage of test for test girder A-1, but the crack were not found that applied number of cycles were up to 2



		σ	δ(mm)
Measurement		6.6	1.00
Calcu-	Simple	6.4	0.81
lation	Fixed	3.2	0.20

Gage No.	Δσ	Gage No.	Δσ	Gage No.	Δσ
A	9.1	H	1.6	K	1.9
B	3.7	I	2.3	L	1.9
C	4.9	J	3.2		

Δσ : Stress range (kg/mm^2)

Fig. 10 Results of stress measurement for A-2 test girder (Pmax = 11.0 ton).

$\times 10^6$, in both of the initial loadings (11 ton) and the increased loads (19 ton) for the test girder A-2.

The comparison of deflection angle for test girder A-1 and A-2 are shown in **Fig. 11**. For test girder A-2, the deflection angle are plotted at the initial loadings. At Fig. 11, the slope for each line indicates the rigidity of the deck, the steeper the slope is, shows the smaller rigidity of the deck. The slope for test girder A-1 were 0.21 $\times$ 10^{-6} rd/kg for the scallop side and 0.15 $\times$ 10^{-6} rd/kg for the cut side. On the other hand the slope was 0.05 $\times$ 10^{-6} rd/kg for test girder A-2 which was 3 ~ 4 times increasing of the rigidity. From the results the stress range at the corner for A-2 test girder were $\Delta\sigma = 9.1$ kg/mm^2 at point A and $\Delta\sigma = 4.9$ kg/mm^2 at point C, which was reduced in remarkable to A-1 test girder.

For the next stage, the static load was took place with changing the rigidity of deck, that is moment of inertia of Wide Flange Shape for test (5) and test (9). The results at each test for the load and deflection angle are shown in **Fig. 12**. In the figure the larger slope in the right and left end of main girder are shown. From the results of test, the more increasing of rigidity for deck, the less deflection angle are born, as the results it is admitted that the stress at the corner of web gap plates are reduced. The relations between the deflection angle for top flange plates of main girder and the stress (at point A and C) for the corner of web gap plate are shown in **Fig. 13**.

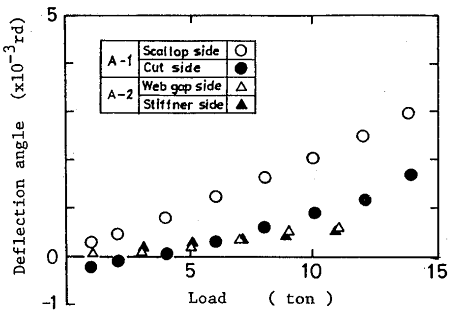


Fig. 11 Comparison of deflection angle for A-1 and A-2 test girder.

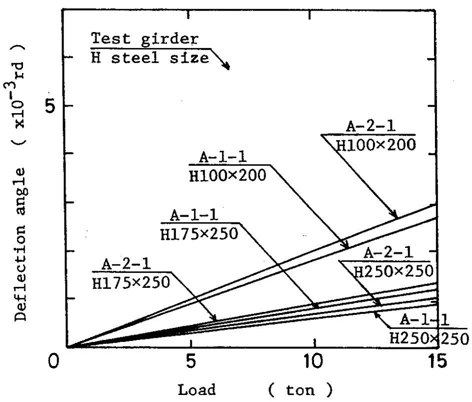


Fig. 12 Comparison of deflection angle for test girder with changing the rigidity of deck.

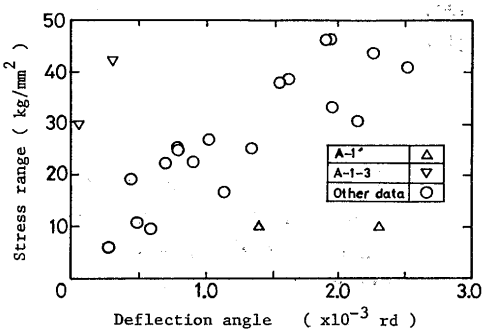


Fig. 13 Relation between deflection angle and stress at the corner.

In the figure all points of the test results are shown. Although some exception exist, the tendency are found by the figure that the deflection angle become bigger the stress at the corner of the web gap plate are increased, except the test results of test girder A-1′ and A-1-3. It is considered that the stress are reduced approximately to 1/4 ~ 1/5 because of increment of the thickness for the web gap plate to 28 mm, and also the rigidity of the top flange of main girder were increased against to the Wide Flange Shape due to the reinforcement by two stiffners for test girder A-1-3. It was considered that the cracks were initiated for that the stress at the corner of the web gap plates were increased because of the less rigidity of the deck for test girder A-1, which was designed previous design standard.

(3) Comparison of S-N Curve and Other Design Standard

As the results of the fatigue tests the cracks were found on the test girder that were A-1, A-1-1, A-1-2 and A-2-1. The results were plotted on the figure which were expressed the relations of the stress range $\Delta\sigma$ and number of cycles N. **Figure 14** are shown with the numbers of cycles when the cracks were found initially. For the comparison of the test, the Fatigue Design Specifications (joint detail E)[6] by Society of Steel Construction of Japan (JSSC for short), Japan Steel Railway Bridge Standard (joint detail C) (JNR), and British Standard BS 5400, part 10 (joint detail F_2) (BS) were shown in Fig. 14. In Fig. 14 the results of this test were longer lives than the other three standards. This was considered that the average stress at the corner were compression. On the

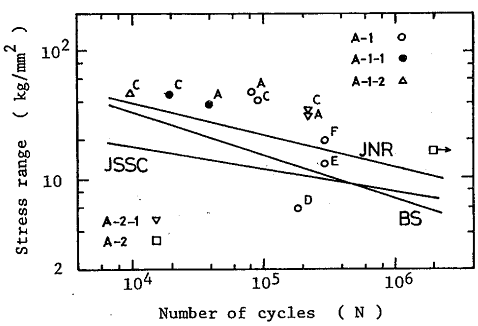


Fig. 14 Results of fatigue test.

Fatigue Design Specification by JSSC it is indicated that the effect of the safety factor should be considered to the effect which the crack growth are reduced with increasing of compression even if under the same stress range, because of reducing of average stress. The slope k for this results of the test, the other data of the slope k and the coefficient of material m are shown in **Table 3**. The point D, E and F were omitted to obtain the slope k from the results of the tests. Because the points around the scallop E and F were too worth of the visual form at the toe of bead compared with the corner points A and C, and that the tension stress were governed at points E and F as noted in section (6). The value k = 0.185 are in good agreement with the value which of the Fatigue Design Specification by JSSC and Institute of Civil Engineering for Ministry of Construction.[7] From the S-N curve obtained by the tests, the fatigue stress range at the number of cycles of 2×10^6 was $\Delta\sigma = 21$ kg/mm^2.

Table 3 Comparison of slop k.

Reference		k	m
This test data		0.185	5.41
Other data	JSSC (E) [6]	0.18	(5.56)
	PWRI report[7]	(0.186)	5.376
	JNR (C)	(0.25)	4
	BS 5400 (F_2)	(0.33)	3

(4) Crack growth and Arrest of Crack

The observation was made to the extension of the cracks. The results were shown in **Fig. 15**. For the extension of crack at point A in test girder A-1-1 shown in Fig. 15 the crack growth are found in three categories which are the range of rappid extension, the range of very slow growth and the range of arrest finally. The crack growth rates were calculated according to the above three categories. As the results, the rates for the range of rapid growth were the order of 10^{-4} mm/cycle and the next range were the order of 10^{-5} mm/cycle and range of arrest were the order of 10^{-6} mm/cycle.

The stress range $\Delta\sigma$ and the length of cracks at the final of fatigue test are shown in **Fig. 16**. A point which was the maximum stress range within the point that cracks were not found was shown in the figure ($\Delta\sigma$ =16.8 kg/mm^2 at point A for A-2 test girder). In the figure the points of the solid mark are shown that the cracks seemed to arrest, which the order of crack growth rate were 10^{-6} mm/cycle. And for open mark it is indicated that the cracks were still seemed to growing. It seems the tendency to which if the stress range are increased the final crack is long. The average stress at point D were tension and all other cracks were born at compression zone. The average stress from external loading are compression at the corner of the web gap plates. In case of existence of tension residual stress at the corner of web gap plates the total stress are increased to the average stress. On the other hand, as crack growth goes further, residual stress is released, then average stress becomes small. Consequently the cracks were thought to arrest.

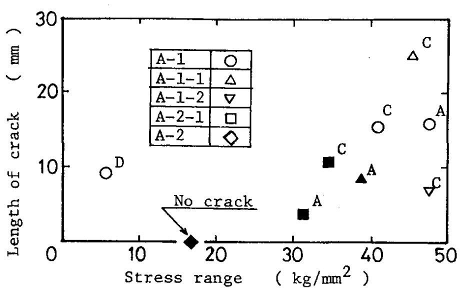


Fig. 16 Relation between length of crack and stress range.

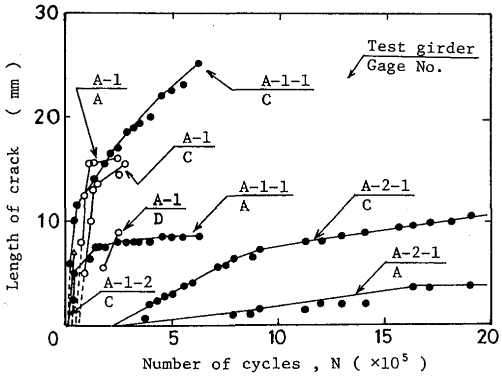


Fig. 15 Relation between length of crack and number of cycles.

(5) Effects to Thicker Plate for Web Gap Plates

Though the cracks were found in early stage to the thickness of web gap plates 9 mm for test girder A-1, on the other hand the cracks were not found to the increased plate 28 mm up to number of 2×10^6 cycles for test girder A-1′. In this case, the stress at the corner of web gap plates were reduced from 47.3 kg/mm^2 to 10.3 kg/mm^2 at point A, and 40.9 kg/mm^2 to 9.3 kg/mm^2 at point C, as the results reduction of the stress for A-1′ test girder were approximately 1/4 ~ 1/5. But as the reduction of stress the deflection angle are not reduced. The reasons of stress reduction are considered that effects of the increment of the thickness of plates for about three times.

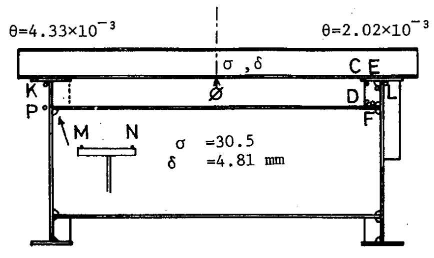
According to the reports for the stress analysis the stress were reduced to 1/3 to increment of the thickness of web gap plates from 9 mm to 27 mm, which were well agreed with the test results.[8] From the above the thicker plate are considered to the effective method.

(6) Effects to Weld Bead Finish

The cracks were found at the five points of A, C, D, E, F to the test girder A-1 which were not finished to the weld bead. On the other hand, for test girder A-1-1 which were finished by stick sanders the cracks were found only at the corner points of A and C, but no cracks were found at points D, E and F. It seems to effective where the stress range are higher than 40 kg/mm^2 the bead finishing will not be effected, but at the lower stress range will be effective. To comparison of around the scallop points E, F and corner points A, C the high stress concentrations were considered because of sharp angles at weld toe at points E and F. Therefore the stress became high the cracks born and the cracks also were born under the low stress which measured with gauge. As the results the bead finishing for those points is considered to be effective.

(7) Effects to Removal of Web Gap Plates

The results of stress measurements for test (7) are shown in **Fig. 17**. As the results of the fatigue test for test girder A-1-2, the cracks were found at point of C for web gap plate and at web-to-flange fillet weld of main girder for the removal of the web gap plates. The stress range (at point C) of the web gap plate, the stress (at points K and L) of the fillet weld for main girder and slope which indicated the rigidity of the deck are shown in **Table 4**. From Table 4 the deflection angle at the side of removal to web gap plate were increased to about two times comparing to A-1-1 test girder, and that the stress at web-to-flange fillet weld of main girder (point K) were 39.6 kg/mm^2 in tension side which was very high value. The cracks at the fillet weld for main girder were initiated in earlier stage of the tests affected by the above reason. The tensile stress 20 kg/mm^2 was found at the points (points M and N), for fillet weld for the top flange of cross beam because of which the large out-of-plane deformations were found at around the center of web plate and top flange cross beam where the web plates were the removal side of web gap plate. Although



Gage No.	Δσ	Gage No.	Δσ	Gage No.	Δσ
C	47.4	F	14.6	M	22.0
D	30.0	K	39.6	N	19.9
E	3.4	L	8.6	P	19.1

Δσ : Stress range (kg/mm^2)

Fig. 17 Results of stress measurement for A-1-2 test girder (Pmax = 13.8 ton).

Table 4 Deflection angle and stress at the corner.

Test girder	Position	Slope (×10^{-6}rd /kg)	Deflection angle (×10^{-3}rd)	Δσ (kg/mm^2) at corner	Δσ (kg/mm^2) at fillet weld
A-1-1	Scallop side	0.18	2.59	45.4	20.2
	Cut side	0.14	1.78	38.9	6.6
A-1-2	Stiffner plate side	0.19	2.02	47.4	8.6
	Web gap plate side	0.31	4.33	-	39.6

Slope = Deflection angle(rd) / Load(kg)
Δσ : Stress range

the cracks were not found at points M and N by the tests the possibility for crack initiation would be considered the same points.

For the side reinforced by stiffner, deflection angle were not so much reduced comparing to A-1-1 test girder and the high stress range of initiation 47.4 kg/mm^2 were found at point C of the corner. As the result the cracks were initiated at point C. The cause of the crack initiation were considered that the rigidity were reduced by removal of the web gap plates and the reinforcement for the stiffner were not effective. The removal of web gap plates is considered little efficiency to prevent the fatigue crack because not only the reduction of total rigidity for removal side but also the other members are affected to worse influences.

(8) Effects for Reinforcement with Stiffners at Both Side of Web Plate

The comparison of deflection angle for test girder A-1-1 and A-1-3 are shown in **Fig. 18**. The effect are not seen to the reinforcement of rigidity because that though the deflection angle are reduced very much the stress at the corner point A are increased from 39.6 kg/mm^2 to 42.8 kg/mm^2, and the stress at point C are reduced from 45.4 kg/mm^2 to 29.8 kg/mm^2. And that from the relation to deflection and stress of center for Wide Flange Shape in test girder A-1-3 the reduction of stress are not so reduced as reduction of deflection angle. Therefore the advantage were not found to the reinforcement of stiffners for test girder A-1-3.

(9) Stresses in Web Gap Plates

The stresses in web gap plates are considered for A-1 test girder. The results for the stress measurement for web gap plate are shown in **Fig. 19**. From Fig. 19 the compressive stress due to the bending moment for the top flange of main girder are governed at the top of web gap plate, especially the compressive stress are very high at free edge (points A and C). And that approaching from the free edge to web plate the complex stress condition are found with sloping of the principle axis. This is also indicated in the results of test (11) (see **Fig. 20**). The tensile stress are high at the bottom of web gap plate which

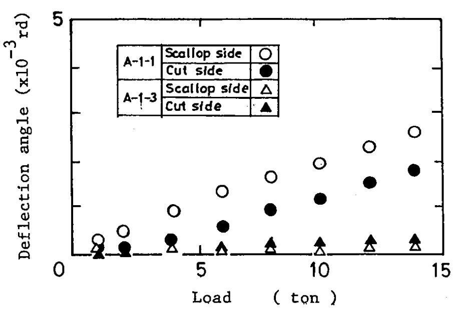


Fig. 18 Comparison of deflection angle for A-1-3 and A-1-1 test girder.

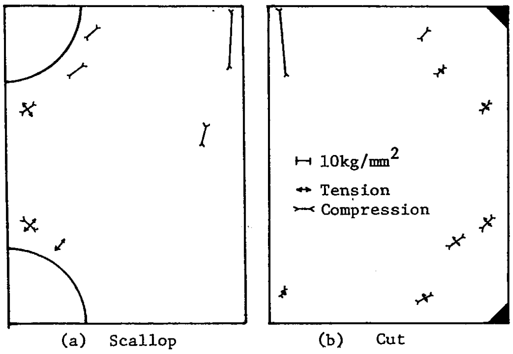


Fig. 19 Results of stress measurement of web gap plate.

tendencies are found in particular at scallop side. The cracks at points D, E and F are seemed to affect the above tensile stress. For the complex stress conditions at web gap plate, the stress are considered due to deformation the rotation of top flange of main girder and the out-of-plane deformation of web plate.

(10) The Stress at the Corner of Web Gap Plate

From the results of test (11), the principal stress diagram at near the corner of web gap plate is shown in **Fig. 20** and the equal stress line diagram is shown in **Fig. 21**. From Fig. 21, the equal stress line are become the denser to approaching to the corner, especially the range of 30 kg/mm^2 to 45 kg/mm^2 are rather dense. They are considered when the stress under the 30 kg/mm^2 the equal stress line are rough and around σ = 20 kg/mm^2 value are indicated the average stress regardless to the corner effects.

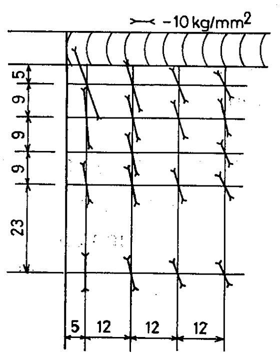


Fig. 20 Results of stress measurement at near the corner.

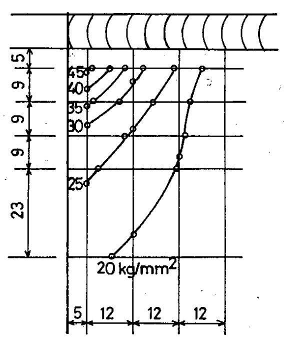


Fig. 21 Equal stress line diagram at near the corner.

(11) Crack at Fillet Weld for Main Girder

The cracks were also found at web-to-flange fillet weld of main girder in some test girders. The length of crack when the crack were found and the stress at the fillet weld are shown in **Table 5**. The cracks were intiated at the toe of fillet weld outside of web plate, which was always just under the Wide Flange Shape. The cracks at the top of

Table 5 Crack of web-to-flange fillet weld of main girder for each test girder.

Test girder	Location of crack	Ni ($\times 10^3$)	li (mm)	lf (mm)	$\Delta\sigma$ at fillet weld
A-1	Scallop side ,lower	261	85	238	15.7
	Cut side ,upper	261	95	305	13.1
A-1-1	Cut side ,upper	31	26	132	6.6
	Cut side ,lower	31	27	118	
	Scallop side ,upper	43	15	108	20.2
	Scallop side ,lower	108	41	118	
A-1-2	No web gap pl. side	25	–	–	39.6
A-2-1	Stiffner side ,lower	1630	43	48	14.6
	Web gap pl. side,lower	1630	48	57	10.7
A-2	–	–	–	–	1.9
A-1-3	–	–	–	–	7.0

Ni : Number of cycles when the crack was first detected
li : Length of crack when it was first detected
lf : Length of crack when test finished
$\Delta\sigma$: Stress range (kg/mm^2)

fillet weld toe propagated to the thickness direction for top flange, and the cracks at bottom of fillet weld toe extended in streight across the web thickness. For A-2 test girder which the cracks were not found, the stress range is low at 1.9 kg/mm^2. For the test girder which the cracks were found, the relation between load and deflection angle are shown in **Fig. 22**. In the figure the larger slope were shown for each test girders which has two slopes at left and right main girder. For the comparison the test girder A-2 without cracks and test girder A-1-3 less rotations were shown in the figure. From **Fig. 22** and **Table 5**, when the increments of the slope of line which indicates the rigidity of deck are becomming small, deflection angle increased, and then the stress of fillet weld are increased. For the out-of-plane deformation of web plate, as the rigidity of cross beam and deck are reduced, the deformations are increased.

As the above mentioned, the cracks at fillet weld for main girders are born by large deflection angle of deck and increments of out-of-plane deformation of web. This cracks for web-to-flange fillet weld of the main girders are considered to prevent by increasing of rigidity of the deck. Also, as no fatigue test are done the reinforcements by stiffner for A-1-3 test girder are considered to be effective.

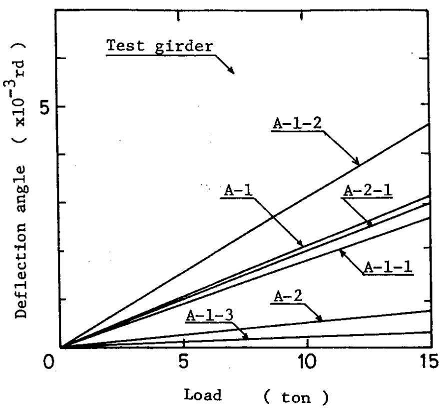


Fig. 22 Comparison of deflection angle for each test girder.

4. Summary

(1) The cracks were initiated for A-1 test girder in order to find the effects for neck swing, while the crack were not found to the initial loads (13.4 ton) and increased loads 19 ton which in order to find the effects for relative displacement for B-1 test girder. From the above, the effects for fatigue crack due to web gaps are considered no to be the effects for relative displacement for main girders, but to neck swing effects for top flange of main girder.

(2) The cracks were born in five points for A-1 test girder which were designed and fabricated by previous design standard. On the other hand the cracks were not found for A-2 test girder, which was designed by present design standard, and which applied loads were the designated initial load and increased loads 19 ton. The cause of crack born are considered the less rigidity of the deck for A-1 test girder comparing to A-2 test girder.

(3) As the results of the fatigue tests the slope k = 0.185 was obtained from S-N lines. The value was close to the value which k = 0.18 of the Fatigue Design Specification by JSSC and m = 5.376 for Institute of Civil Engineering in Ministry of Construction. And from S-N line the fatigue strength were obtained approximately 21 kg/mm^2 for 2×10^6 cycles.

(4) The cracks at the corner (points A and C) of web gap plates are considered to arrest. Because mean stress due to external loads is compression, as extension of the crack the tension residual stress is released and that the mean stress are reduced.

(5) The thickness of web gap plate 9 mm for the cracked A-1 test girder was increased to 28 mm and repaired. As the results the stress at the corner of web gap plates was reduced approximately to 1/4, and the cracks were not found.

(6) To finishing the toe of fillet weld, these were no effect at the large stress range, on the other hand the effect were found at high concentrated stress as the round weld for scallop where the stress range were the less.

(7) For the repair method for removal of web gap plate, which the rigidity of total bridge are reduced much and increasing of deflection angle of top flange for main girders and that the out-of-plane deformation of web are increased in remarkable. Therefore the cracks are born in initial stage at web-to-flange fillet weld of the main girder, and although the cracks were not found by the test at the joint of top flange of cross beam and web plate for main girder the high stress were found and that were the fear about the crack born. The reducing of total rigidity affected worth to the crack born at the other member.

(8) The repair method of reinforcement of stiffners to web plate of main girders was not so effective as expected. The deflection angle reduced but the stress at the corner of web plate were not reduced. On the other hand the stress at the fillet weld for main girder by the effect of reduction of deflection angle are considered to be effective to the fatigue of the fillet weld for the main girder.

(9) For the stress conditions at web gap plates, the compressive stress due to the rotation of top flange are governed at top of the web gap plate, especially high compressive stress were found at the corner. And at those (point A and C) the cracks were found. The tensile stress were increased at the bottom of gap plate, especially in the scallop side the tendency were found. The cracks at round weld at scallop (point E and F) are considered to the effects. The cut-and-weld are better than scallop because the shapes at round welds of the scallop are easily worked in sharp angles.

(10) The clarifications are necessary to the corner stress because the stress are more than 30 kg/mm^2, and dense equivalent stress line are spread around the corner of web gap plates.

(11) The cracks were born at fillet weld of the main girder for some test girders. The cracks are considered the effects to the large deflection angle of deck and large out-of-plane deformation of the web plates. To prevent this crack, it is considered that increment of the rigidity of deck and reinforcement of stiffners to the web plate are effective.

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