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Compressive Characteristics of Box Columns Repaired by Heating and Pressing†

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Abstract

Correction by heating and pressing is used as a method of repair for steel structures damaged by local buckling, but the effect of correction by heating and pressing on mechanical behavior of steel members is not elucidated sufficiently. So to examine the compressive characteristics of box columns corrected by heating and pressing, a series of experiments was carried out. Local buckling was generated in the virgin column by compressive loads and it was corrected by heating below the A_1 transformation temperature and then pressing. A compressive experiment for the corrected columns was performed and the results of the experiment were compared with that in the virgin situation. The stiffness in the axial direction of the corrected column decreased and the out-of-plane displacement at the ultimate situation increased compared to those in the virgin situation. This was because of the irregularity of the column's height due to correction of the panels. In the case that the irregularity was leveled by lathing, they were controlled and kept as those of the virgin columns. In any case the ultimate strength of the box column corrected by heating and pressing was not lower than that in the virgin situation.

KEY WORDS: (Repair) (Correction by Heating and Pressing) (Buckling) (Ultimate Strength) (Box Column)

1. Introduction

When steel members of large structures, for example, bridge piers and plate girders, are damaged by fire, traffic accident or natural disaster such as earthquakes, it is required that the damaged infrastructures are quickly repaired so as to keep flowing the traffic of the emergency (ambulances or fire engines) services and transportation of aid goods. Correction by heating and pressing is one of the effective methods of temporary repair for the steel members, when damage is mainly small, because it can be performed on site and it is no need of new members for repair. Actually, in the Hyogoken-nambu earthquake (1995), local buckling deformations of many steel members were rapidly corrected by heating and pressing on site[1].

However, when correcting large deformations such as buckling, the effect of correction by heating and pressing on the strength of members is unknown. So it is necessary to confirm safety and reliability of the members corrected by heating and pressing.

A series of tests and their simulations is conducted in order to elucidate the effects of correction by heating and pressing on the compressive characteristics of steel cruciform columns[2), 3)]. In this paper, a series of experiments for steel box columns which have different shapes from the cruciform columns is carried out to elucidate the effect of correction by heating and pressing on the compressive characteristics of the box columns.

A compressive experiment for the virgin columns is carried out at first. Through the experiments, out-of-plane deformation is generated by local buckling. The local buckling from compressive loads is corrected by heating below the A_1 transformation temperature and then pressing. Finally, they are compressed again. Based on the results of each compressive experiment, the characteristics of the box column repaired by heating and pressing are revealed.

2. Compressive experiment for the virgin box columns

2.1. Test specimen

Specimens are box columns with square cross-section. The number of specimens is two. **Figure 1** shows the shape and dimensions of the specimen. The material is SM490Y, whose mechanical properties obtained by a tensile test are shown in **Figure 2**. The thickness is t=6(mm), the height is a=700(mm) and breadth is b=400(mm). The size of the specimen is

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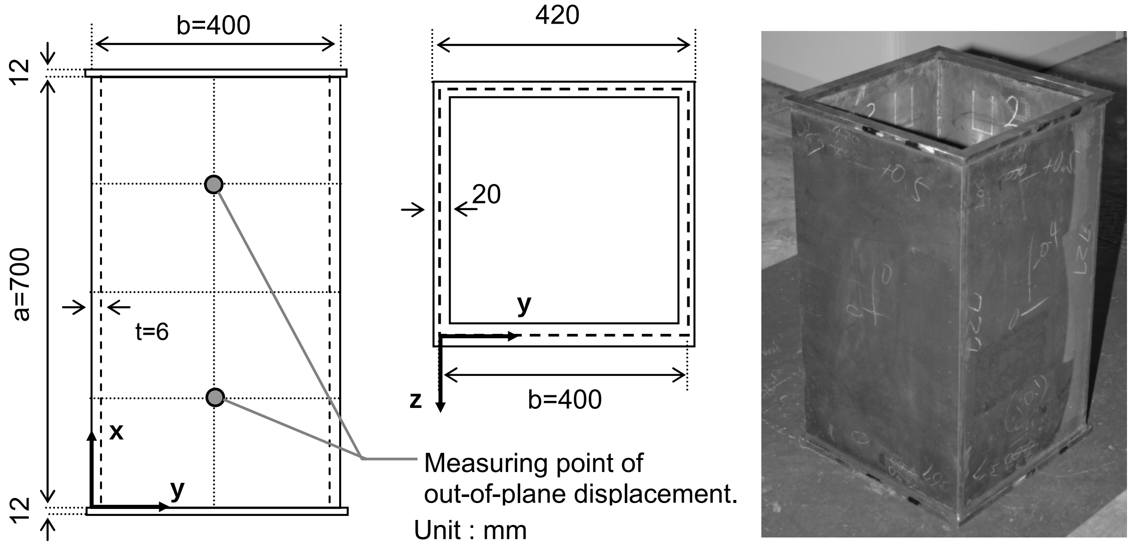


Fig. 1 Square cross-section box column.

decided by considering that the cross-section of the specimen is required to be enough wide to allow the workability of correction by heating and pressing. Thick steel plate (12mm) is welded at the top and bottom of the column in order that compressive loads act uniformly on the specimen.

A slenderness parameter is calculated by Eq.(1), λ_P is 1.40.

$$\lambda_P = \frac{1}{\pi}\sqrt{\frac{12(1-\nu^2)}{k}}\sqrt{\frac{\sigma_Y}{E}}\frac{b}{t} \tag{1}$$

Here, the buckling factor is k=4.0, which is decided by the simply supported condition[4].

It is confirmed that the initial deflection of the panels is below 1.0-1.5mm in the out-of-plane direction.

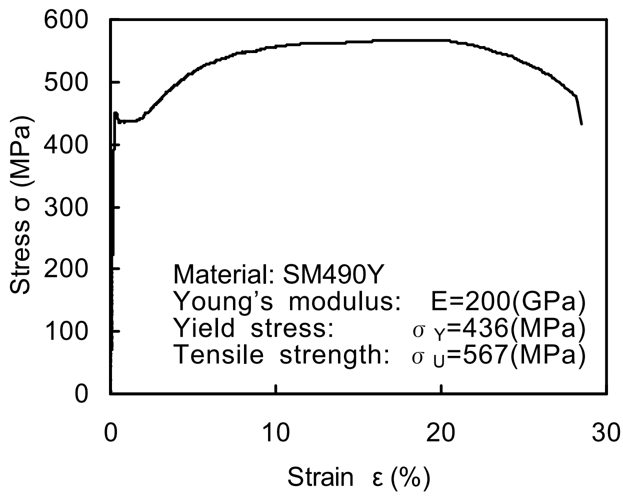


Fig. 2 Stress-strain curve.

2.2. Compressive experiment

A compressive experiment for the virgin specimens is carried out. Monotonic compressive loads are gradually increased and reach a maximum load, that is, the ultimate situation.

Figure 3 shows a buckling mode after the compressive experiment. The buckling mode of each specimen is one cycle of a sine curve, and it is symmetric with respect to the central point in the axial direction. **Figure 4** shows a relation between load and vertical displacement and Figure 5 shows a relation between load and out-of-plane displacement. The out-of-plane displacement is measured at the peak points of the buckling mode (x=175 and 525, y=200 and z=200(mm); referring to Fig. 1 and Fig. 3). Because the behavior of out-of-plane displacement at eight measuring points is almost the same, the average of these absolute values is shown in **Fig. 5** as the out-of-plane displacement, w.

The two specimens differ from each other at the unloading point in order to make the difference of the degree of out-of-plane deformation. Specimen A is unloaded when the load decreases to 95% of the ultimate

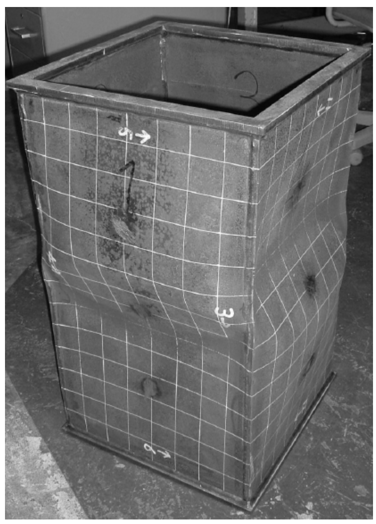


Fig. 3 Mode of local buckling (Virgin: Specimen B).

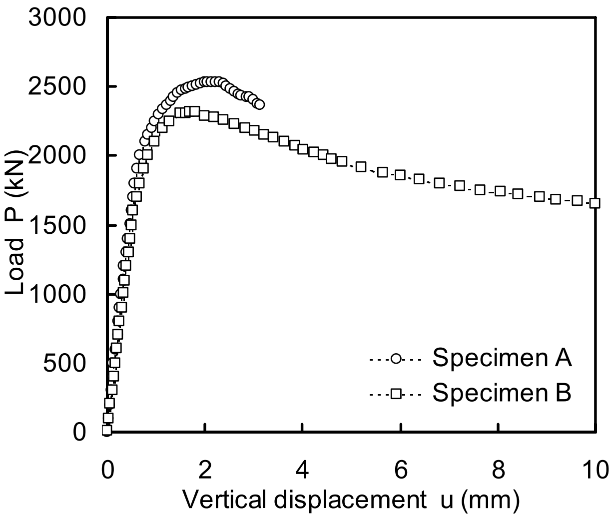


Fig. 4 Relation between load and vertical displacement (Virgin).

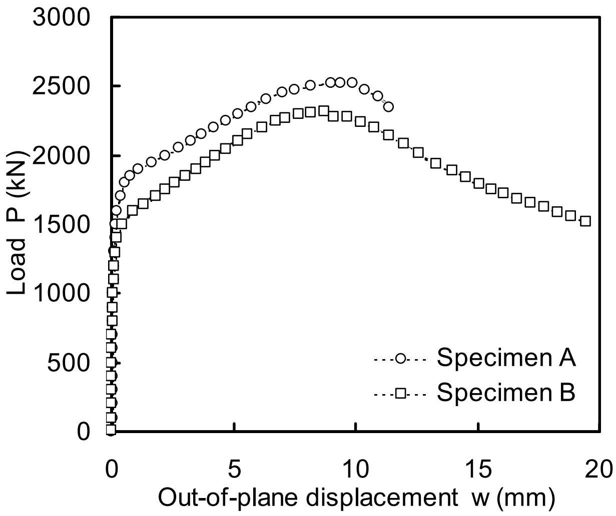


Fig. 5 Relation between load and out-of-plane displacement (Virgin).

strength (maximum load). On the other hand, specimen B is unloaded when the load decreases to 70% of the ultimate strength. In the case of specimen A, the absolute value of out-of-plane deformation at the peak point of the sine curve is about 10mm. In the case of specimen B, that is about 20mm.

No crack is observed in the welds after the experiments.

3. Correction by heating and pressing

Correction by heating and pressing is performed at the local buckled parts of the specimens by compressive loads. The procedure of the correction is as follows. At first the local buckled part is heated by a gas burner and then pressed through a thick steel plate by a pressing machine. Then a jig with a frame shape is used as a support for the reaction force, which resembles the actual work on site such as the correction without dismantling the damaged members.

Heating temperature (550-650 degrees centigrade) is below the A_1 transformation temperature (about 720 degrees centigrade) in order to prevent changes in the microstructure of the steels[5]. **Figure 6** shows the procedure for the correction by heating and pressing.

It is intended that the out-of-plane deformation is corrected below the acceptable value decided in the Specifications for Highway Bridges in Japan[6]. Initial deflection in the out-of-plane direction is set below b/150; b is the breadth of a plate (b=400(mm)). In the case of this specimen, b/150=2.67mm. **Figure 7** shows the results of measurements of the out-of-plane deformation in each specimen after the correction. Because all four panels have the same tendency, the measurement result of only one panel is shown. The out-of-plane deformation remaining in the specimen after the correction is called residual imperfection. Although the residual imperfection is a little larger than the initial deflection in the virgin situation (1.0-1.5mm) and the acceptable value (2.67mm), each specimen can be corrected without cracks in the welds regardless of the magnitude of out-of-plane deformation generated by compressive loads.

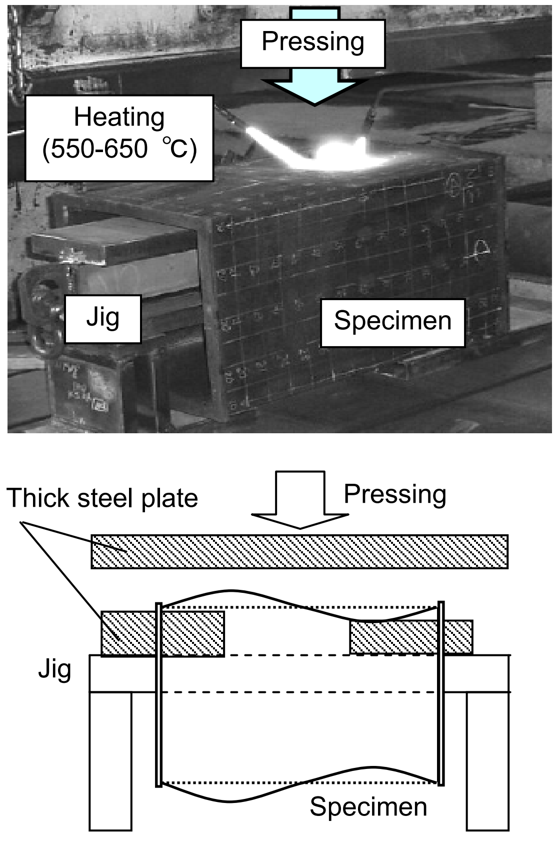
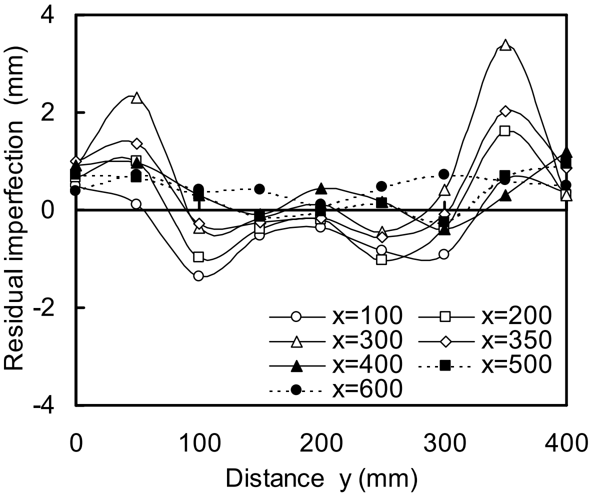
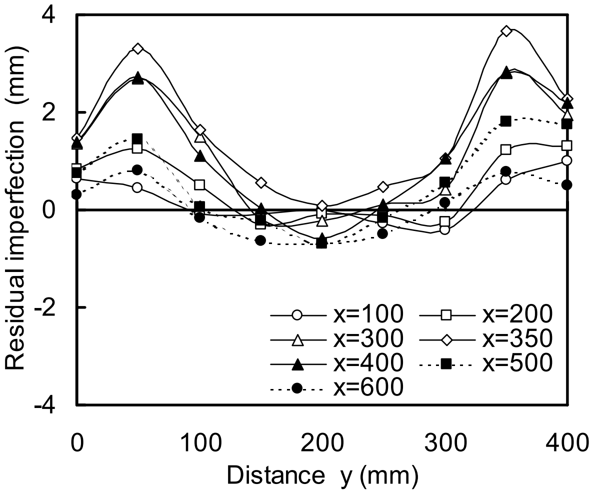


Fig. 6 Correction by heating and pressing.

When correcting the out-of-plane deformation, the center of the panel is expanded in the axial direction



(a) Specimen A.



(b) Specimen B.

Fig. 7 Result of measurement of residual imperfection.

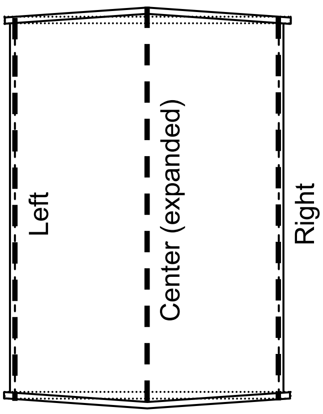


Fig. 8 Measuring position of column's height.

(referring to **Figure 8**). Although the deformation around the center part can be corrected sufficiently, it is difficult to correct the deformation around the corner part. If the deformation is forced to correct perfectly, there is a possibility of occurrence of cracks near the welds. As a result, due to the difference of expansion between the center and the corner part, an irregularity of the column's height is generated in each specimen. The difference of this height is 4-5mm. After the correction, the thick plate at the top and bottom of only specimen B is lathed and leveled. **Table 1** shows the results of measurement for the column's height. The position of measurement is shown in Fig. 8.

Table 1 Result of measurement of column's height.

	Specimen A (Without leveling)		
	Left	Center	Right
Panel 1	716	719.5	717
Panel 2	716	719.5	716.5
Panel 3	716	719.5	716.5
Panel 4	717	720	716
	Specimen B (Before leveling)		
	Left	Center	Right
Panel 1	713	715	713
Panel 2	713	717	715
Panel 3	715	717	712.5
Panel 4	712.5	718	713
	Specimen B (After leveling)		
	Left	Center	Right
Panel 1	708	709	708.5
Panel 2	708.5	708.5	709
Panel 3	709	708.5	709
Panel 4	709	710	708

4. Results and consideration

4.1. Compressive experiment for the columns corrected by heating and pressing

A compressive experiment for the specimens after the correction is performed. Both specimens A and B reach to the ultimate situation without occurrence of cracking at the welds as well as the virgin situation. No crack can be observed in the welds after the experiment.

Figure 9 shows a buckling mode after the compressive experiment. The buckling mode under

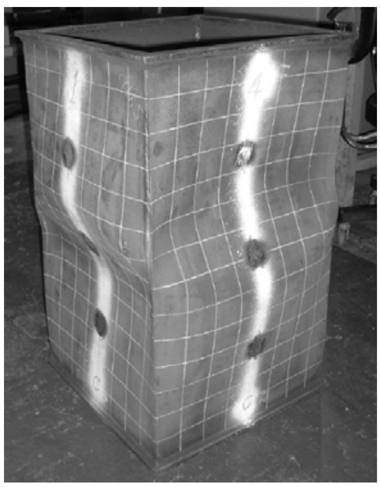


Fig. 9 Mode of local buckling (Corrected: Specimen B).

compressive loads is the same as that in the virgin situation. The mode is one cycle of a sine curve.

Figure 10 shows the relation between load and vertical displacement and **Figure 11** shows the relation between load and out-of-plane displacement, which is defined in the same way as for the virgin compressive experiment. Open symbol is the result of the virgin specimens and solid symbol is that of the corrected specimens.

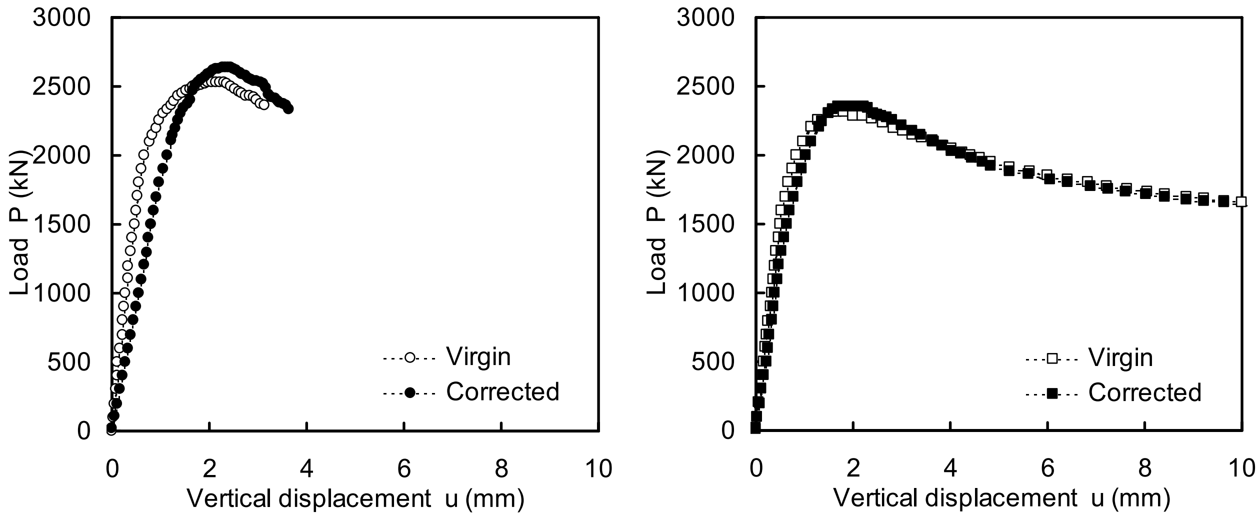
In the case of specimen A after the correction, the slope of the load-vertical displacement diagram is smaller than that in the virgin situation. In other words, the stiffness in the axial direction becomes lower than that in the virgin situation. The out-of-plane displacement is larger than that in the virgin situation under the same load.

In the case of specimen B after the correction, the slope of the load-vertical displacement diagram, which is the stiffness in the axial direction, is almost the same as that in the virgin situation. The behavior of the out-of-plane displacement is almost the same as that in the virgin situation.

The ultimate strengths of both specimens A and B after the correction are not lower compared with those in the virgin situation.

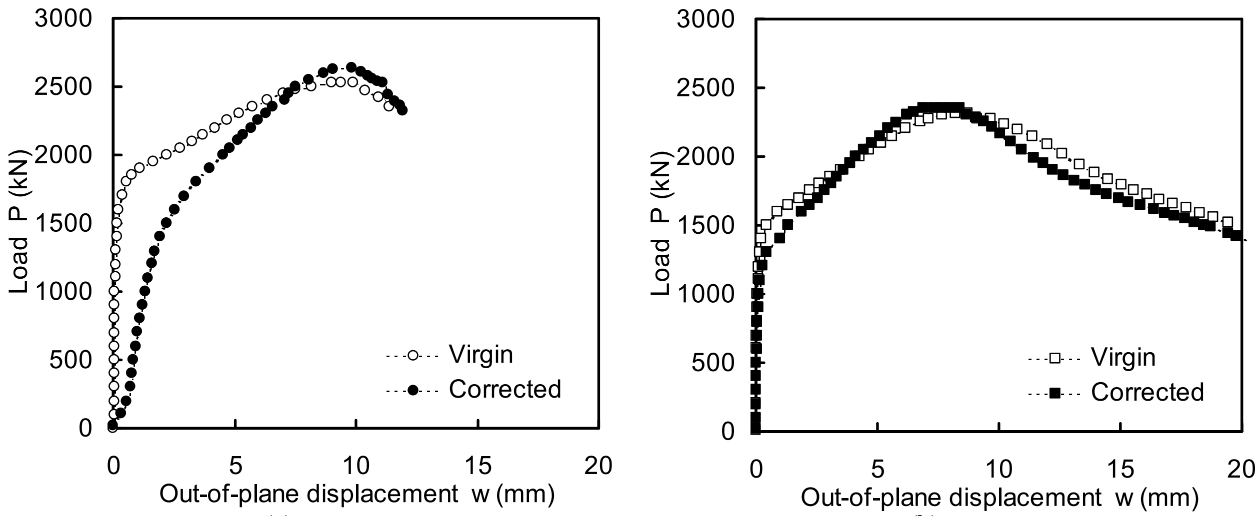
4.2. Effect of correction by heating and pressing on the compressive characteristics of box column

In both specimens A and B, the out-of-plane deformation in the four panels generated by the compressive loads can be corrected to nearly the acceptable value of initial deflection. But there is a difference between the two specimens in the point of the irregularity of the column's height.



(a) Specimen A. (b) Specimen B.

Fig. 10 Relation between load and vertical displacement (Virgin and corrected).



(a) Specimen A. (b) Specimen B.

Fig. 11 Relation between load and out-of-plane displacement (Virgin and corrected).

Because specimen A has the irregularity of the column's height (4-5mm), it is probable that the compressive loads do not act uniformly in the experiment after the correction. As a result, in the compressive experiment after the correction, the stiffness in the axial direction is decreased and the out-of-plane deformation is increased under the same loads compared with the virgin situation. On the other hand, in the case of specimen B, because the top and bottom of the column are lathed and leveled, uniform compressive loads probably act on the specimen in the compressive experiment after the correction. Therefore, in the compressive experiment after the correction, the stiffness in the axial direction and the behavior of the out-of-plane deformation are kept the same as those in the virgin situation.

It is clear that the degree of evenness at the top and bottom of the column largely affects the stiffness in the axial direction of the column. This result indicates that it is important, not only to correct the local parts, but also to keep the overall form of the member in correcting the damaged steel structural members.

The ultimate strengths of both specimens A and B after the correction are not lower compared with that in the virgin situation and no crack occurs in the welds after the experiment. This result indicates that the mechanical properties of the steels never deteriorate compared with that in the virgin situation after correction by heating below the A_1 transformation temperature and then pressing.

5. Conclusions

In order to elucidate compressive characteristics of box columns repaired by heating and pressing, a series of experiment was carried out.

The obtained main results are as follows:

A compressive experiment was carried out for the virgin columns:

(1) The out-of-plane deformation (10-20mm) generated by monotonic compressive loads was corrected by heating below the A_1 transformation temperature and then pressing without dismantling the specimen. No cracks occurred in the welds with correction by heating and pressing.

(2) Although the out-of-plane deformation of the panels could be corrected to nearly the acceptable value of the initial deflection, an irregularity (4-5mm) of the column's height occurred due to the correction of the panels.

A compressive experiment was carried out for the columns after the correction:

(3) Because of the irregularity of the column's height, the stiffness in the axial direction of the columns after the correction became lower and the out-of-plane deformation under the same load became larger compared with those in the virgin situation. But they were controlled and kept the same as those in the virgin situation by leveling the irregularity.

(4) Ultimate strength of the columns corrected by heating and pressing was not lower than that in the virgin situation and no crack occurred in the welds during the experiment. It was confirmed that the mechanical properties of the steels did not deteriorate compared with that in the virgin situation with correction by heating below the A_1 transformation temperature and then pressing.

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