A Study on the Seismic Disaster Risk Assessment for Buildings under Construction in Urban Areas ～Safety Study Method on Column-to-column Temporary Joints of Steel Structures～

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The urban earthquake disaster prevention can also be applied to the buildings under construction whose studies are not enough to be conducted in general. Therefore, we started the study by noticing that the column-to-column joints under construction in steel structures are sometimes in unsafe temporary state. As the first step of this study, we conducted the bending/shearing experiments about the erection pieces of a column-to-column temporary joints and compared the results of this experiment with the ones of the numerical analysis (FEM model). Our final target is to develop the FEM model of whole temporary structures with those column-to-column joints.

Key words：Urban disaster prevention, Earthquake, Building under construction, Steel structure, Temporary joint

1. INTRODUCTION

There exist in urban areas both completed buildings and buildings under construction whose part is in temporary condition. However, the number of the studies on earthquake resistance of buildings under construction is small. We think that the further consideration for urban earthquake disaster prevention should be taken to the buildings under construction.

In case of steel structure buildings, the structural state changes the most during the steel frame construction process and one of the structurally unsafe situations is when the column-to-column joints are in temporary situation.

Fig. 1 shows the procedure from erection work of steel columns to joint welding work in construction (as example) . Photo 1 shows an example of the column-to-column temporary joints using “Temporary adjustment devices for erection”. “Temporary adjustment devices for erection” are temporary tools that connect the erection pieces of the lower and upper columns that have already been fixed at shop, and that can adjust the position and level of steel column without using of wires. Several manufacturers have developed various types of “Temporary adjustment devices for erection”, and they are used as standard devices in steel frame construction. Recently, reflecting the current situation where the requirements on construction periods and cost are severe, the steelwork of buildings under construction tends to proceed to the further processes and to keep more temporary joints longer.

The current method to examine the seismic safety of column-to-column temporary joints is only to calculate and verify statistically the strength of the temporary joints of two columns, and it is inadequate for the examining method applied to buildings after completion. However, if we can make modeling of the column-to-column temporary joints, which reproduces characteristics of the building under construction, it will be possible to apply the same seismic response analysis for verification of seismic strength of completed buildings to the buildings under construction.

The purpose of this study is to conduct bending/shearing experiments of erection pieces that constitute column-to-column temporary joints of a steel structure building under construction and to make highly reproducible FEM model for the numerical analysis.

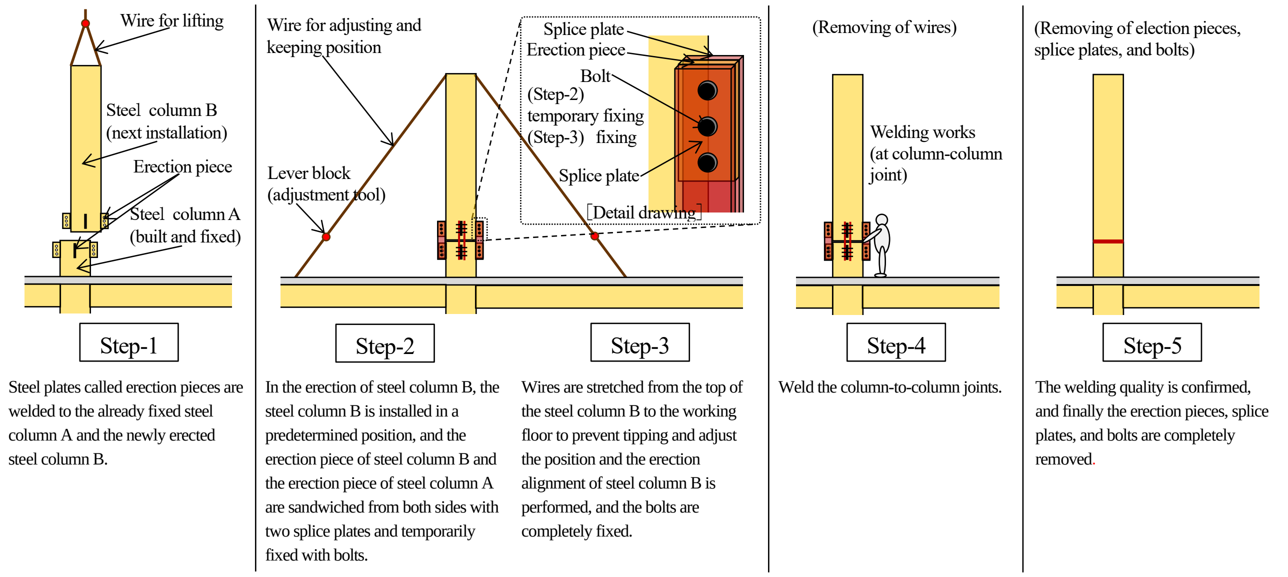


Fig. 1 The procedure from erection work of steel columns to joint welding work in construction (as example)

The previous studies on the simulation of structural joints of buildings are as follows,

- Brian Uy et al.[1] studied and developed the methods for joints (column-to-column, beam-to-beam, floor-to-beam) with removable steel structures and composite structures, and conducted numerical simulation verification of the plastic domain.
- Mizushima et al.[2] simulated the seismic response of a large-scale steel structure that caused a joint rupture using a detailed finite model.

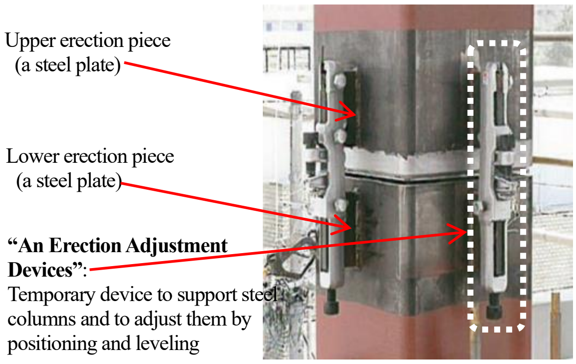


Photo. 1 An example of the column-to-column temporary joints using "Temporary adjustment devices for erection"

As listed above, there are many studies of the permanent structural joints (welded joint, high-strength bolt joint, etc.). On the other hand, this study focuses on simple temporary joints composed of "Temporary adjustment devices for erection" (refer to Photo 1) and such a kind of the joint is not applied to the "permanent" structure of the buildings.

In addition, it is also the study that considers loading conditions such as large loads and dynamic loads similar to those required for permanent structures, which are not naturally required for temporary structures. Ushio et al.[3] focused on the mast joints of temporary heavy lifting equipment and studied it, but his target is different from this studies' scope.

2. CONTENTS OF STIUDY

(1) Bending and shearing experiments

a) Experimental equipment and loading method

Fig. 2 shows an examination model and the experimental setup of the bending/shearing experiment of the erection pieces. The experiment simulates this examination model. The static horizontal load assumed as seismic force is supported by all erection pieces this examination model, and it is replaced to the vertical load to an erection piece in the experimental.

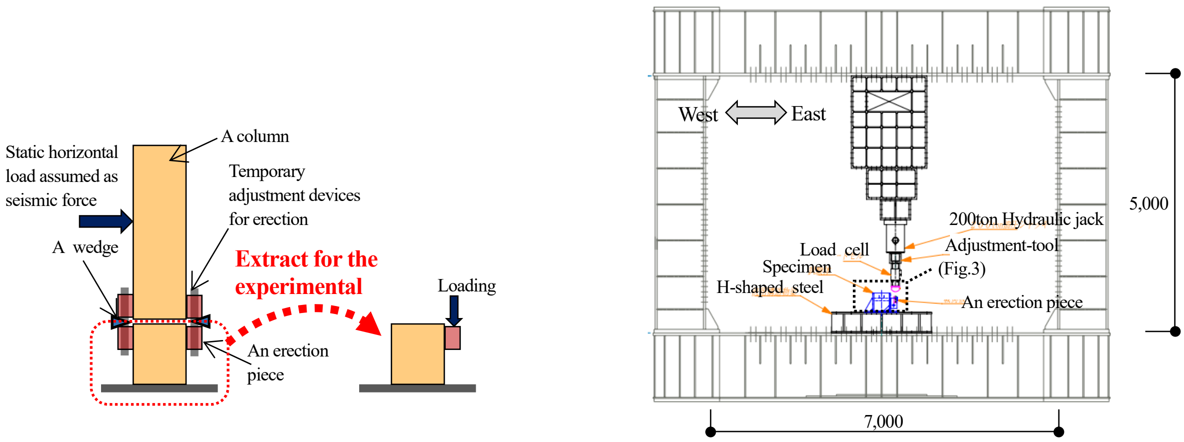
Fig. 3 shows details and measuring plan of the specimen, and Table 1 shows the material test results of SM490A used for the specimen. The test piece of the erection piece is PL-130×200×22 (SM490A) and is jointed by partial penetration welding to the steel pipe □-350×350×22 (BCP-325) which is the square steel pipe column. A base plate is welded to the bottom of the steel pipe and the base plate is fixed with bolts to the H-shaped steel of the base.

The H-shaped steel is fixed with bolts to the steel frame that constitutes the experimental equipment. The loading area of the specimen is the top surface of the erection piece and extends within 60mm from the edge of the surface (Fig. 3). And after pre-loading of 50kN, monotonic loading is applied in one vertical direction to the maximum displacement (7mm or 15mm) using a hydraulic jack. Three displacement gauges for measuring vertical displacement are installed, and vertical displacement of side surface of the erection pieces measured by DV-C (Fig. 3) is adopt as vertical displacement of the specimen. Because its displacement gauge is installed to the specimen directly.

The main purpose of this experiment is to confirm the strength of the erection piece, and the average value of Three same specimens should be evaluated.

Table 1 The material test results of SM490A used for the specimen

Material	Yield strength	Tensile strength	Young's modulus
SM490A	346(N/mm^2)	522(N/mm^2)	1.99×10^5(N/mm^2)



[An examination model] **[The experimental setup]**

Fig. 2 An examination model and the experimental setup of the bending/shearing experiment of the erection pieces

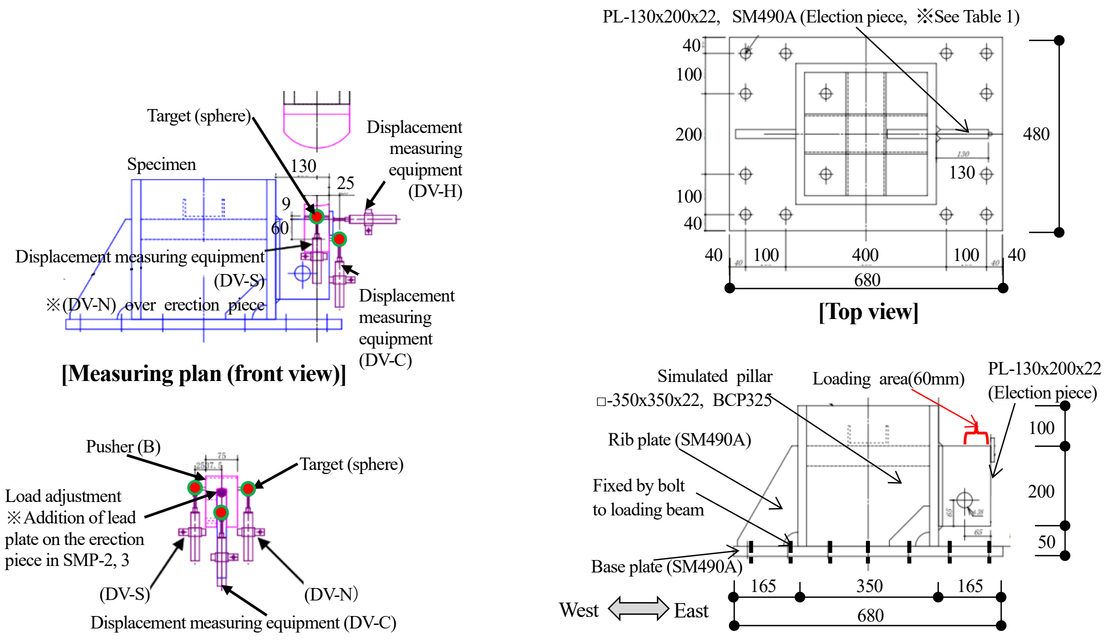


Fig. 3 Details and measuring plan of the specimen

b) Result of experimental

Table 2 shows the initial stiffness and yield strength (loading of 0.2% proof stress) list of each specimen (DV-C). Fig. 4 shows the relationship diagram between the applied load and vertical displacement of side surface of the erection pieces (DV-C), and Photo 2 shows the broken specimen SMP-3 after loaded. The results are as follows,

- The yield strength of the three specimens has little variation (σ =9kN) and their average value is 557kN. It is more than the designed strength 413(kN).
- The initial stiffness of the three specimens has little variation (σ =5kN/mm) and their average value is 253kN.

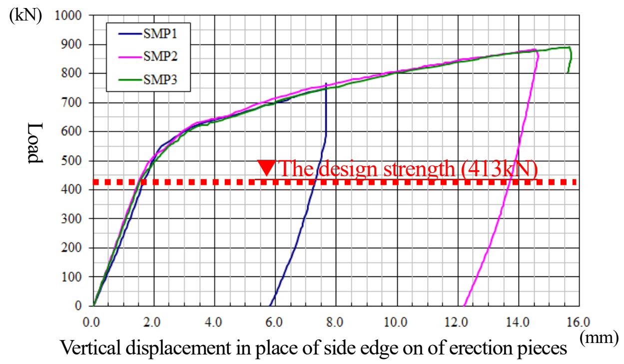


Fig. 4 The relationship diagram between the applied load and vertical displacement of side surface of the erection pieces (DV-C)

[From south side] [Top surface]

Photo 2 The broken specimen SMP-3 after loaded

Table 2 The initial stiffness and yield strength (loading of 0.2% proof stress) list of each specimen (DV-C)

Name	Unit	SMP-1	SMP-2	SMP-3	Average μ	Deviation σ	Design strength※3
The initial stiffness※1	(kN/mm)	250	250	260	253	5	---
The yield strength※2	(kN)	570	550	550	557	9	413

※1 : The initial stiffness: the slope of the straight line connecting the origin and the proportional limit (experiment: at 2 mm, FEM: at 1 mm) in the load-displacement graph.
※2 : The yield strength (loading of 0.2% proof stress): the applied load at the intersection of the straight line with the initial stiffness passing through the X-intercept of the displacement corresponding to 0.2% of the erection piece's length in the load-displacement graph
※3 : Design strength: The applied load value corresponding to the upper limit of allowable stress.

(2) Verification by numerical analysis

a) Outline of the numerical analysis

Ansys LS-DYNA R11 (Rev.134719 (double precision version)) is used for numerical analysis.

Fig. 5 shows a schematic diagram of the numerical analysis model of the experiment. The shape and size of specimen is same as experimental. Fig. 7 shows detail of the components of the numerical experiment. Table 3 shows the components and material properties of the numerical experiment. The target model covered by the numerical analysis is the portion from the 200-ton jack of the test machine in the upper part to the base plate of the steel pipe column fixed to H-shaped steel with bolts in the lower part. The tester mount and pusher (A) are spliced by a pin joint. Pusher (A), pusher(B) and loading adjustment are spliced as roller joints. Fig. 6 shows the setting conditions of the numerical analysis. The loading stroke by tester mount moves only vertical. The load is applied by forcibly displacing the upper end of the pusher(A) vertically downward, as in the experiment. The maximum amount of displacement is 10 mm. Baseplate is fixed on loading beam fully.

The model is a solid elements type. The measurement point is same as the position of DV-C on experimental.

Table 3 The components and material properties of the numerical experiment

Name of the components		Material	Mass density (ton/mm^3)	Young's modulus (N/mm^2)	Poisson's ratio	Yield stress (N/mm^2)
Pusher (A), Pusher (B) ※1		S45C	7.89×10^9	2.06×10^5	0.3	490.0
Loading adjustment		rigid body	7.89×10^9	2.06×10^5	0.3	---
Specimen	Erection piece※2	SS490	7.89×10^9	1.99×10^5	0.3	345.7
	Steel pipe column, baseplate etc. ※1	SS400	7.89×10^9	2.04×10^5	0.3	284.8

※1 : elastoplastic body (Bilinear) ※2 : Elasto-plastic model which is input stress-strain relationship as point sequences

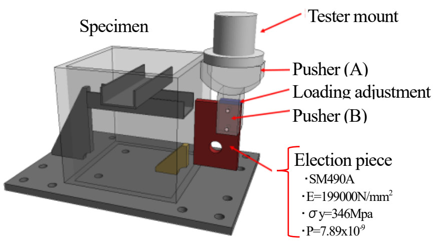


Fig. 5 A schematic diagram of the numerical analysis model of the experiment

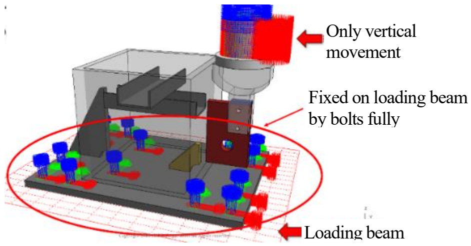


Fig. 6 The setting conditions of the numerical analysis

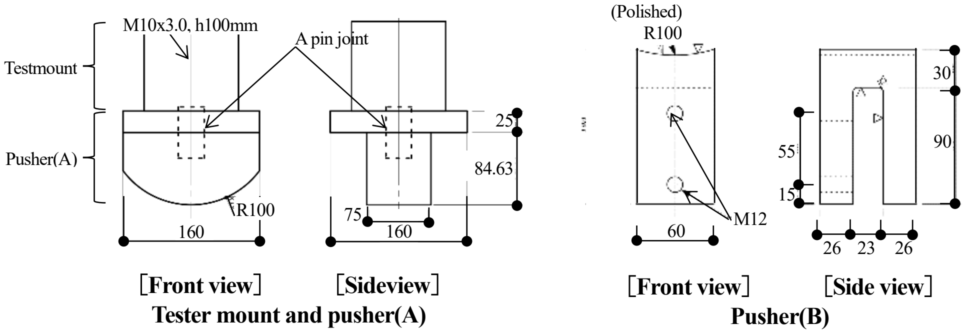


Fig. 7 Detail of the components of the numerical experiment

b) Result of the verification by the numerical analysis

Fig. 8 shows the relationship between applied load and vertical displacement of the side surface of the erection piece calculated by the numerical analysis and the result obtained by the experiment for comparison. Table 4 shows a comparison of initial stiffnesses and yield strength between the results of the numerical analysis and the experiment. The results are evaluated as follows,

- The yield strength of the numerical model is 545(kN). The ratio of the yield strength of the numerical model to the experimental average is 0.98. It can be said highly reproducible.
- The initial stiffness of the numerical model is 420(kN/mm). The ratio of the yield strength of the numerical model to the experimental average is 1.66. It cannot be said highly reproducible.
- The load-displacement relationship in the nonlinear region of the numerical analysis result also shows the same trend as the experiment result.

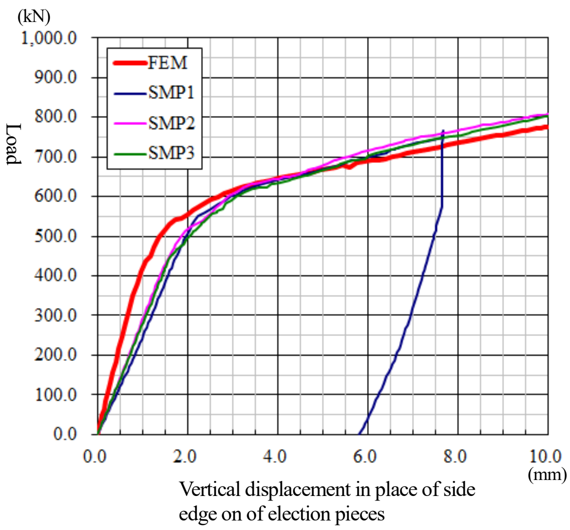


Fig. 8 The relationship between applied load and vertical displacement of the side surface of the erection piece calculated by the numerical analysis and the result obtained by the experiment for comparison

The ratio (FEM/μ) of the initial stiffness in horizontal direction is 1.78. It is considered that this large difference of the initial stiffness in both direction due to difference of the boundary conditions (the fixed condition) of the baseplate.

Table 4 A comparison of initial stiffness and yield strength between the results of the numerical analysis and the experiment

Name	Unit	FEM	FEM/μ (no unit)	Result of specimen				
				Average(μ)	Deviation(σ)	SMP-1	SMP-2	SMP-3
The initial stiffness※1	(kN/mm)	420	1.66	253	5	250	250	260
The yield strength※2	(kN)	545	0.98	557	9	570	550	550

※1：The initial stiffness: the slope of the straight line connecting the origin and the proportional limit (experiment: at 2 mm, FEM: at 1 mm) in the load-displacement graph.

※2：The yield strength (loading of 0.2% proof stress): the applied load at the intersection of the straight line with the initial stiffness passing through the X-intercept of the displacement corresponding to 0.2% of the erection piece's length in the load-displacement graph

c) Consideration by FEM analysis

Fig. 9 shows the Von Mises stress distribution diagram (contour diagram) obtained from the numerical analysis.

The numerical analysis results show the followings:

・The Von Mises stress increases near the upper loading surface of the erection piece and at the upper and lower ends of the weld connecting the steel pipe and the erection piece.

・The plastic deformation shape of the erection piece by FEM analysis is almost the same as that of the experiment.

・Any stress of the steel pipe does not exceed the maximum stress of the erection piece. In addition, such a safety balance of Von Mises stress (permanent member Von Mises stress < temporary member Von Mises stress) is considered to be very desirable in terms of erection piece design.

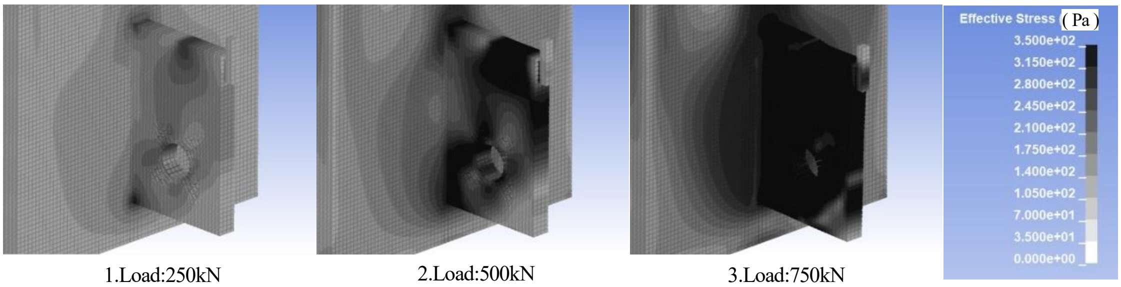


Fig. 9 The Von Mises stress distribution diagram (contour diagram) obtained from the numerical analysis

3. CONCLUSION

In this study, the following findings were obtained.

・Bending/shearing experiments of erection pieces forming the column-to-column temporary joints, were conducted, and the enough strength were confirmed.

・The FEM model of the erection piece and the column can be said to be highly reproducible (with 2% difference from the experimental result) in the yield strength, but their initial stiffness are much defferent.

・It is confirmed that the maximum mises stress of the column can be kept smaller than the maximum mises stress of the erection pieces (= safety design) in this design by FEM numerical analysis.

That the initial stiffness of this FEM model does not fit to result of experimental is one of problems. After understanding this point, utilizing the outcomes of this study, we will develop the model of the whole temporary structures with the column-to-column temporary joints and will develop the method for examining safety of these structures against large earthquakes.

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