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Static Loading Performance of Tubular Joint in Multi-Column Composite Bridge Piers

by

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Abstract

In this study, the bridge pier composed of multi-columns is proposed by using concrete-filled tubes. This structure is expected to be a new structural system to improve the energy absorption capacity under the earthquake. In order to obtain some useful information for reasonable design of the tubular joint in the proposed structure, the loading test of four joint specimens were carried out.

The test result is summarized as follows; (1) Comparing to the design load, the maximum capacities of filled concrete specimen and hollow specimen are 3 times and 5 times higher, respectively. Therefore, it results in an enough safety side. (2) The ultimate deformation in concrete filled tubular specimen is very small because of the stiffened effect by filled concrete. (3) The failure pattern in hollow specimen is local buckling at the steel pipe. In the filling concrete specimen, local buckling did not occur, but cracking in the welded joint occurred. (4) It is confirmed that the composite tubular joint in the proposed structure can be designed enough safely by the present design specification. But it is necessary to consider the reinforcement effect of the filling concrete for a more reasonable design.

Keywords: Concrete filled tubular column, Multi-column composite pier, Diagonal stiffener, Local buckling

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1. Introduction

The Hyogo-ken Nanbu Earthquake left various valuable lessons about the method of earthquake resisting of structures and the earthquake disaster prevention of the society. It is considered that the most remarkable matter is the brittle failure of structures and the tremendous of the following disaster. In order to avoid collapse of structures even if subjected to big ground vibration after the earthquake, the new structure and technology has been developed. The technology standard is also drastically revised from the allowable stress design to the ultimate strength design. In the future, it will be introduced changing from the specification design to performance-based design[1].

In this study, the bridge pier composed multi-column is proposed by using concrete-filled tube, for the aim of retaining the excellent seismic performance and developing the excellent structures in construction. This structure is expected to be a new structural system to improve the energy absorption capacity under the earthquake. In this structure, by attempting lightweight of the substructure with connecting between the main CFT members by the diagonal members, the 3-D (solid) skeleton structure is produced in the higher order indeterminate structure[2),3)]. **Fig.1** shows the image of the proposed multi-column composite bridge piers using concrete filled tubular columns. The effect of the cross-section of the main part of concrete-filled tube for the diagonal member and joint types, on the mechanism of the overall structure is investigated.

In order to obtain some useful information for reasonable design of the joint in

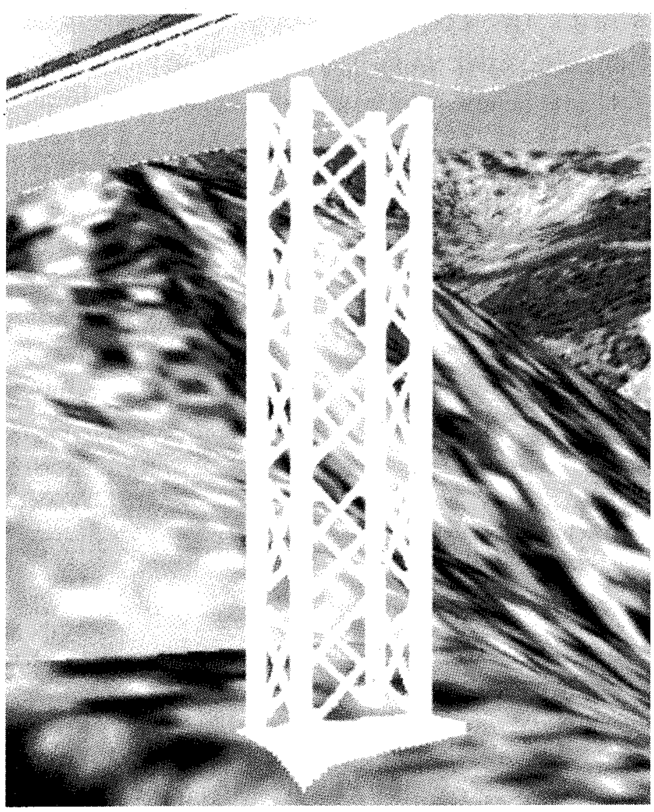

Fig. 1 Multi-Column Composite Bridge Piers

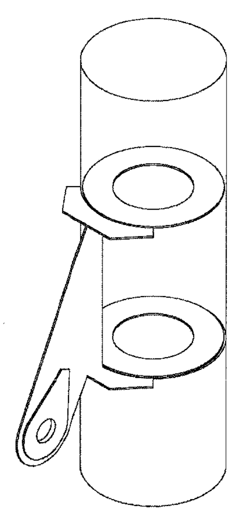

Fig. 2 Outline of Joint

the proposed structure, as shown in **Fig.2**, the loading test was carried out. In the test, the load carrying capacity and deformation property of joint were chosen as the subject of the study.

2. Outline of Test

2.1 Description of specimen

Design stress resultant of the specimen was matched at the test specimen level with the stress resultant between the main member and diagonal stiffener obtained from calculation. The comparison of design stress is shown in **Table 1**.

The real bridge pier was assumed to be 3 spans continuous truss bridge with 70 m height of the bridge pier composed by multi-columns. The effect of filled-concrete in the column and relative stiffness ratio was considered to be the parameter to optimization design of the steel weight. The design stress resultant of test specimen was calculated in accordance with this similarity ratio. The test specimen is modeled from the joint of main member and diagonal stiffener. Four specimens were produced with the parameters such as the existence of filled concrete and the variation of the angle between the main member and diagonal stiffener, which are shown in **Fig.3** and **Table 2**. The steel tube, ring stiffener, gusset-plate and rib are specified as STK400 and SM490A, respectively, in JIS Code. The stiffener was arranged in the same section as the rib. The inner cap on the inside was installed at both ends of the steel pipe, and coming out of the filled concrete was restrained. In the filled concrete, the high flow concrete was used, and the strength at 28 days was approximately 36.3 N/mm^2.

Table 1 Design Section Forces

		Span Direction		Perpendicular Direction to Span	
		Real Pier	Specimen	Real Pier	Specimen
Main Member	Axial Force (kN)	-40300	-2110	-28300	-1480
	Bending Moment (kN·m)	15400	190	7700	100
Diagonal Member	Axial Force (kN)	5330	280	2700	140

Table 2 Specimen Types

Specimen Type	Concrete	Angle between the main member and diagonal member
A-1	Filled	25.2° (Span Direction)
A-2	Hollow	
B-1	Filled	35.2° (Perpendicular Direction to Span)
B-2	Hollow	

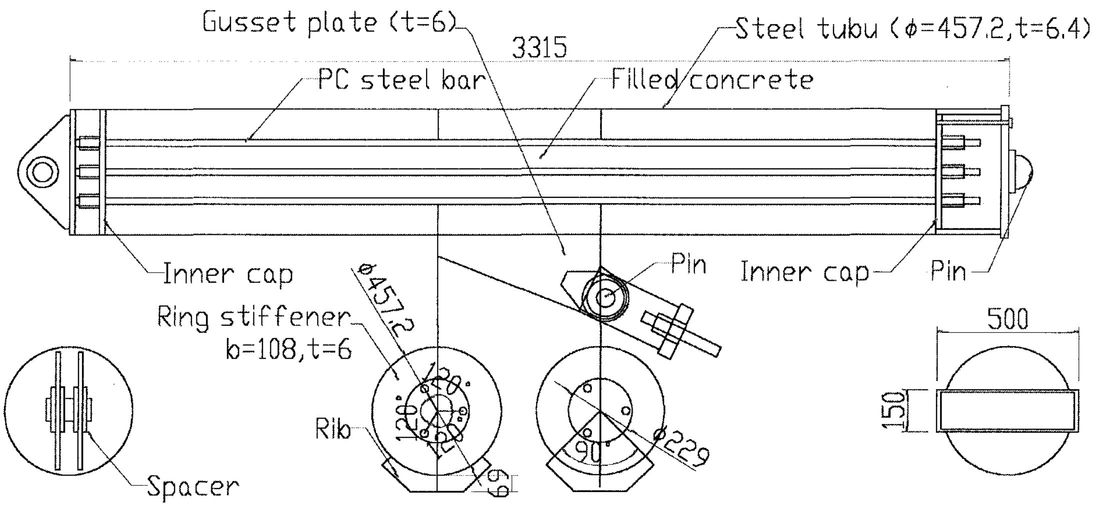

Fig. 3 Detail of Specimen for Type A (mm)

2.2 Test procedure

Fig.4 shows the set-up of the specimen. The specimen was set in the sideways condition, and the gusset-plate was arranged under the steel tube. The pin support was set at both ends of the main member, to satisfy the simple support condition. The axis force in the direction of the main member and bending moment and axis force in the diagonal direction acted on the joint in a real column at the same time. Bending moment and axis force of diagonal direction were gradually increased with the jack for a perpendicular and diagonal direction while keeping a design value the same ratio respectively until the specimen was fail.

The design load is the load for the perpendicular and diagonal which is necessary for introducing the design internal force. The introduction axis force by the design load and PC steel bar is shown in **Table 3**. That is, it was assumed that these loads reproduced the design force. Strain gauges were bonded to the steel pipe, gusset-plate and rib surfaces, as well as ring stiffener before concreting. Also, an automatic data acquisition system connected to a computer was used to monitor loading, as well as the deflection and deformation in the specimen.

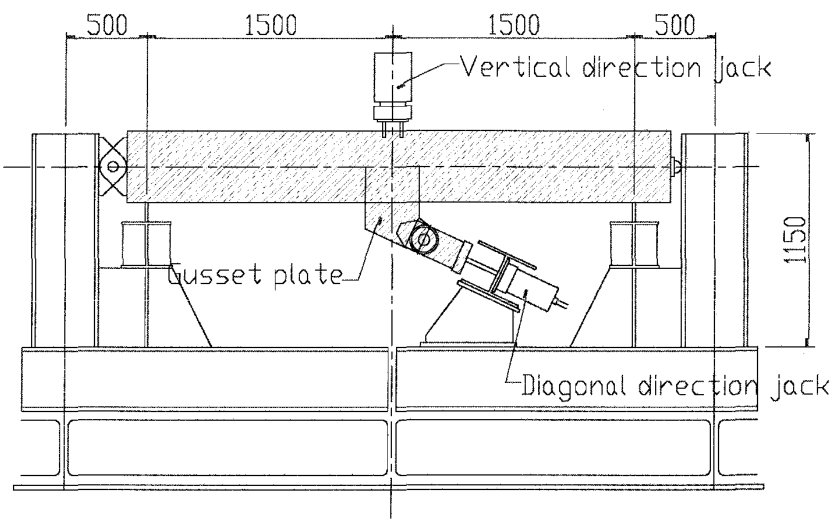

Fig. 4 Set-up of the Specimen (mm)

Table 3 Design Load and Prestress

Specimen Type	Vertical Load (kN)	Bending by Vertical Load (kN·m)	Diagonal Load (kN)	Bending by Diagonal Load (kN·m)	Prestress of PC Tendon (kN)
A-1	180	135	280	55	2110
A-2	73	55	280	55	780
B-1	87	65	140	35	1480
B-2	33	25	140	35	550

3. Analytical Study

Table 4 shows parameters list in the three-dimensional elastic-plastic FEM analysis using commercial software, LUSAS Ver 13.2[4)]. The solid element with twenty-node isoparametric was used to model the filling concrete. The shell element with eight-node and six-node isoparametric was used to model steel member, where as the bar element was used to model steel bar. The stress and strain of relationship of materials were obtained from the material test result. The model for analytical study is shown in **Fig.5.**

Table 4 Analytical Conditions

Element	Steel	Thin Shell
	PC Steel Bar	Bar
	Concrete	Solid Continuum
	Connect Surface	Spring
Yield Condition		von Mises
Geometric Nonlinear		Total Lagrangian
Control Method		Loading Control
Solution Procedures		Newton Raphson Method

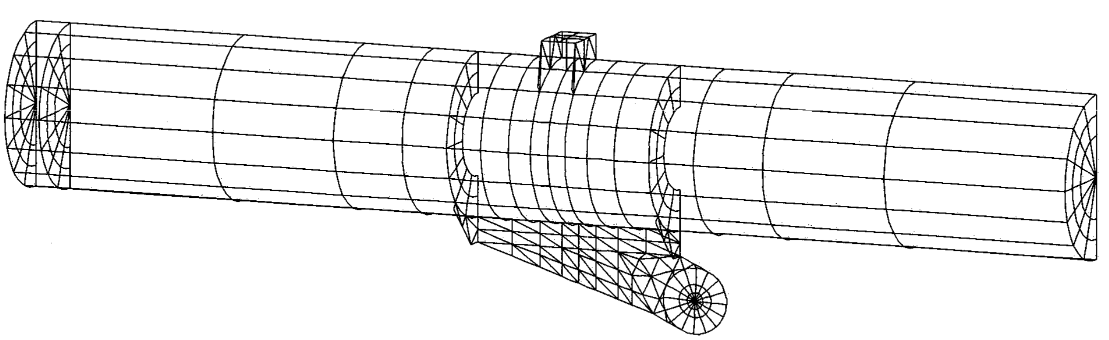

Fig. 5 Analytical Model

4. Test Results and Discussion

4.1 Maximum capacity

On the specimen A-1 and B-1, the crack occurred at the weld of gusset-plate and the rib. While on specimen A-2 and B-2, local buckling developed in the steel pipe in the vicinity of loading plate of a perpendicular direction.

The comparisons of the ultimate capacity and the design load as well as the failure mode obtained from the test are shown in **Table 5**. Compared to the design load, the ultimate capacity are approximately 3 times higher in specimen A-1 and A-2, and 5 times higher in specimen B-1 and B-2, respectively. The capacity ratio by filling concrete is very small though filling concrete is larger than hollow specimen. Local buckling in the vicinity of the loading plate on the hollow specimen is only caused by the loading procedure. This local buckling may not occur in the real structure.

4.2 Deformation property of steel pipe

Fig.6 and **Fig.7** show load-deflection curves at the center of span. Here, the deflection is perpendicular to the longitudinal direction of specimen and the load is in diagonal direction. Compared to the hollow specimen, filling concrete specimen had a high flexural stiffness at all the loading stage. Deflection of subject member is small. Also, the inclination change on the filling concrete is slower than hollow specimen. With further loading for diagonal direction, the separation between the steel pipe and the filled concrete, as well as concrete cracking occurred. This caused the reduction of flexural stiffness in the subject member.

Fig.8 shows load-strain curve of the steel pipe. The strain is the value of the direction of the subject member direction in the local buckling for hollow specimen. Calculated compression stress occurred on the steel pipe under design load for hollow specimen and filling concrete specimen is approximately 140 N/mm^2 and 100 N/mm^2, respectively. But the test results of both specimens are smaller than the calculation value. Therefore, the safety is confirmed from the test at the design load.

Table 5 Ultimate Capacity and Failure Mode

Specimen Type	Design Load (kN)		Ultimate Capacity (kN)		Ratio	Failure Mode
	Vertical	Diagonal	Vertical	Diagonal		
A-1	180	280	525	813	2.90	Cracking at the weld of Gusset-plate
A-2	73	280	200	779	2.78	Local buckling of steel pipe in the vicinity of loading plate
B-1	87	140	462	737	5.26	Cracking at the weld of Gusset-plate
B-2	33	140	179	706	5.04	Local buckling of steel pipe in the vicinity of loading plate

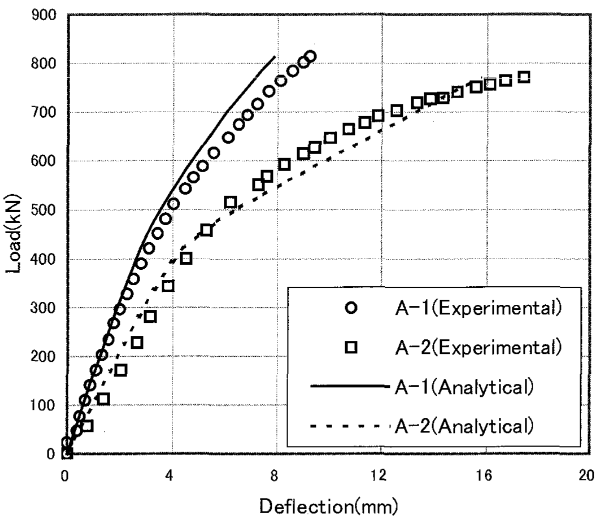

Fig. 6 Load-Deflection Curves for Type A

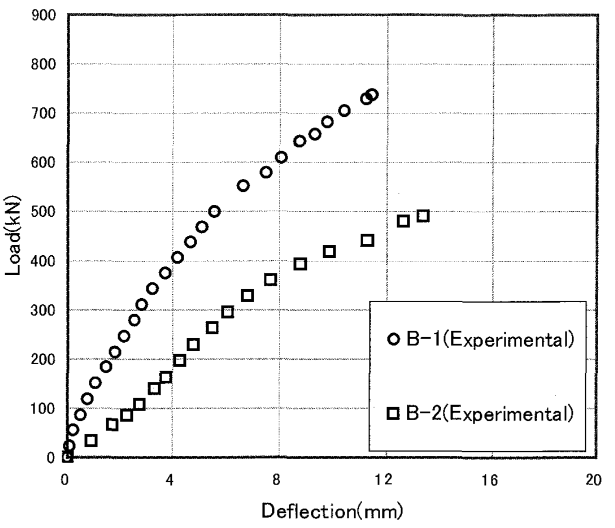

Fig. 7 Load-Deflection Curves for Type B

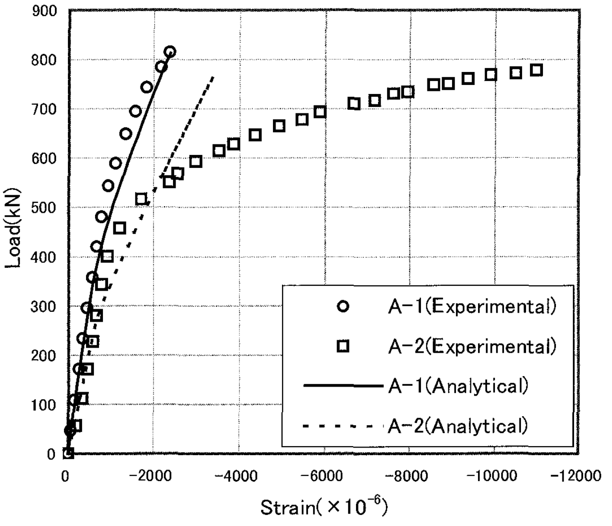

Fig. 8 Load-Strain Curves for Type A

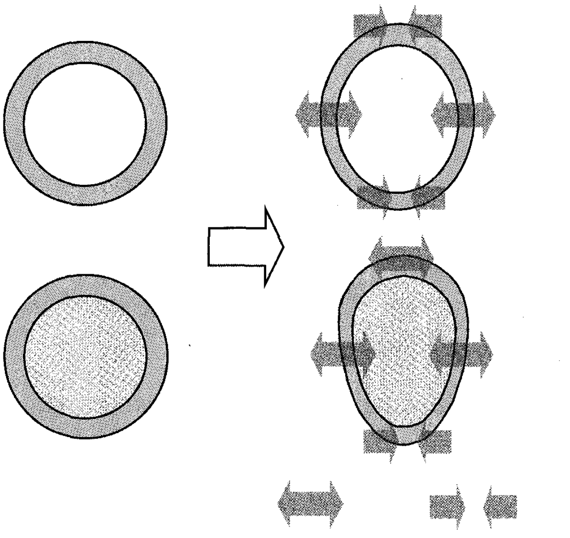

Fig. 9 Deformation of Ring Stiffener

4.3 Deformation property of ring stiffener

Fig.9 shows the concept of strain in the vicinity direction of the ring stiffener for both the filled concrete and hollow specimen. The strain of upper and lower part at the ring stiffener are shown in **Fig.10** and **Fig.11**, respectively.

The strain on the upper part of ring stiffener for the hollow specimen and filling concrete specimen is in compression and tension, respectively. Strain distribution in filling concrete specimen is smaller than hollow specimen. The strain distribution pattern at the lower side for the both types is compression. Thus, it is possible to guess that concrete influence the deformation property of the ring stiffener. As for hollow specimen, the lower side of the steel pipe was downward pulled by the diagonal direction load, and the section deformed like an oval as shown in **Fig.9**. Therefore, the stress distribution of the steel pipe on the upper and lower side and beside is compression and tension, respectively. As for the filling concrete specimen, steel pipe and concrete in the lower side are about to flake off by the diagonal load, but the deformation in the upper side is restrained with concrete.

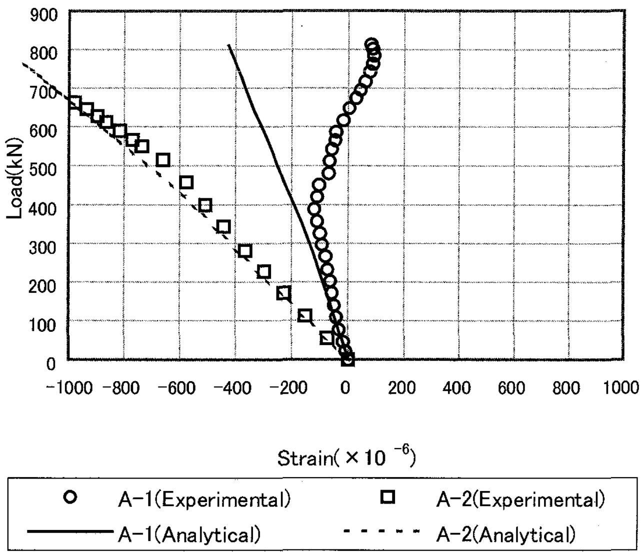

Fig.10 Load-Strain Curves of Ring Stiffener (Upper)

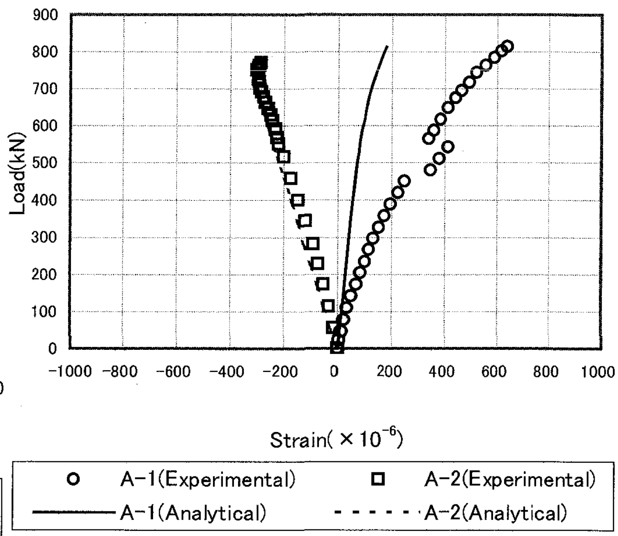

Fig.11 Load-Strain Curves of Ring Stiffener (Lower)

As a result, the stress distributions of steel pipe on the lower side, upper side and beside parts are compression and tension, respectively. Thus, the deformation property of ring stiffener is different according to a filling concrete, but both have enough safety because the strain of ring stiffener is less than the yield strain at the ultimate load. This indicates that filled concrete is effective in resisting deformation of ring stiffener.

4.4 Deformation property of gusset-plate and rib

The strain in gusset-plate and rib was almost same both for hollow and filled concrete specimen. The strain did not occurred until 500 kN. Afterwards, the strain rapidly progressed. The cracking at the welded parts between gusset-plate and rib caused the failure in the filling concrete specimen. From the result, it confirmed that filling concrete is also effective in resisting deformation of gusset-plate and the rib.

5. Conclusion

This study was carried out to obtain the grasp of the deformation condition and knowledge of design for the joint in the multi-column composite bridge pier with concrete filled tube.

The result of test is summarized as follows.

(1) Compared with design load, the maximum capacity of filled concrete specimen and hollow specimen are 3 times and 5 times higher, respectively. Therefore, it resulted in an enough safety side.

(2) The ultimate deformation in concrete filled specimen is small enough because of the stiffened effect by filled concrete.

(3) The failure pattern in hollow specimen is local buckling at the steel pipe. In the filling concrete specimen, local buckling did not occur, but cracking in the welded joint occurred.

(4) It is confirmed that the tubular joint in multi-column composite bridge pier can be designed enough safely by the present design specification. But it is neces-

sary to evaluate the stiffened effect of the filling concrete for a more reasonable design.

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