INVESTIGATION ON THE LOAD TRANSFER MECHANISM FOR THE JOINT OF REINFORCED CONCRETE COLUMN AND STEEL BEAM

Seung Hun KIM[1], Sang Whan HAN[2] And Li Hyung LEE[3]

SUMMARY

The composite framed structures, which consist of reinforced concrete columns and steel beams, have become more popular in Korea because of their efficiency and quality. However, the load transfer mechanisms between the column and beam may be very complicated since the material properties of columns and beams are different. This study investigates the load transfer mechanisms for the composite joint and develops the type of joint which could improve its strength, deformation, and energy dissipation capacities compared to existing composite joints. The type of joint developed in this study is called "column penetration joint" where the web of steel beam does not penetrate into the column and which is confined by square tube and exterior diaphragm. So it can improve the compactness of concrete in the joint. The square tube and exterior diaphragm resist moment that is transferred from beam, and the cruciform stiffening plates confine the end of square tube. This paper describes an experimental investigation on the parameters such as the square tube, exterior diaphragm, and cruciform stiffening plates that can influence the load transfer mechanism for the joint. Two types of specimens are tested in this study. One is for the simple tension test of the joint to investigate the stress distribution and load transfer mechanism in the joint area. The other is for the cyclic test on the beam-column joint. This test is for investigating the hysteretic behavior of the joint. From this test its strength, stiffness, and ductility capacity are discussed.

INTRODUCTION

The demands on the development of structural system to economically satisfy different requirements on strength, ductility, and serviceability are increasing in Korea. One of the structural systems satisfying the demands is the composite framed structure in which both steel and concrete materials are effectively combined to maximize the advantages of each material. Figure 1 shows beam-column joints of various composite framed structures.

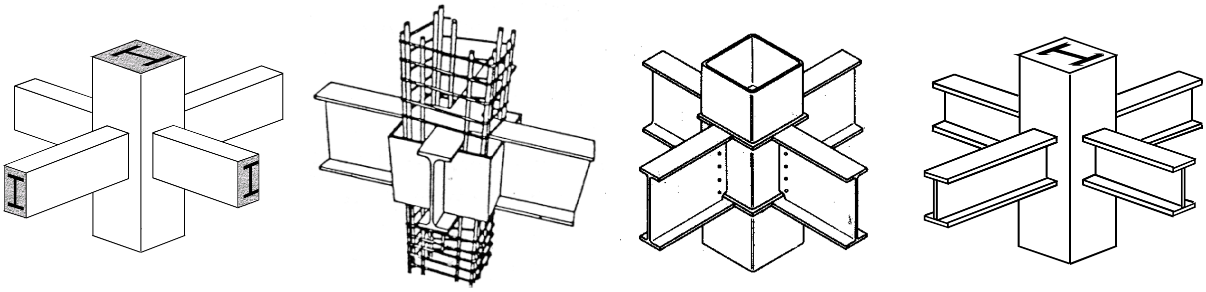


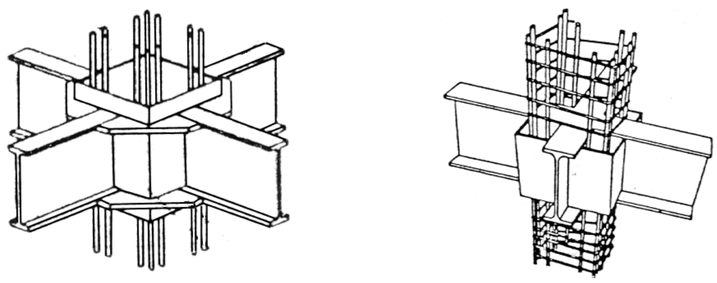
Figure 1 : Types of Composite Framed Structure.

The composite framed structure which consists of Reinforced Concrete Columns and Steel Beams(RCCSB) has become more popular in Korea because of their efficiency and quality. RCCSB is the system which increases strength and economy as using reinforced concrete, strong to compression, in column and using steel, strong to

[1] Department of Architecture, Hanyang University, Seoul, Korea 133-791
[2] Department of Architecture, Hanyang University, Seoul, Korea 133-791
[3] Department of Architecture, Hanyang University, Seoul, Korea 133-791

flexure and shear, in beam. In addition, it has many advantages such as easiness of the construction of a joint, economy from reinforced concrete construction, construction speed, and low self-weight of structural steel construction. However, since members of different materials are connected at the joints, the internal stress-transfer mechanisms are more complicated and not clearly understood than those in either reinforced concrete or steel structure. Thus many studies on the assessment of the internal stress-transfer mechanisms and the reinforcing details have been carried out.

RCCSB can be classified as two types as the beam-column joint details. One is a 'beam-penetration type' where the steel beam penetrates into the column, and the other is a 'column-penetration type' where the steel beam does not penetrate into the column as shown in Figure 2.



(a) Column-Penetration Type (b) Beam-Penetration Type

Figure 2 : Types of RCCSB

The objective of this research is to develop the joint details, which transfer the stress effectively, and evaluate the load transfer mechanism at the joint. In this study, RCCSB of the column-penetration type is developed. Then two types of experiment are conducted to evaluate the load transfer mechanism for the joint. One is the simple tension test of the joint to investigate the stress distribution and load transfer mechanism in the joint area. The other is the cyclic test on the beam-column joint. This test is for investigating the hysteretic behavior of the joint.

DEVELOP THE JOINT DETAILS OF RCCSB

A RCCSB of the column-penetration type has a problem on the load transfer mechanism at the joint, because beam is not continuous at the joint. To solve this problem, a rectangular steel tube was used at the joint to increase the strength of the joint and an exterior diaphragm is used to resist the tension at the beam flange. And a Cruciform Stiffening Plate(CSP) was welded at the upper and lower ends of a rectangular steel tube so as to resist the shear force, transferred from the beam, and to restrain the rectangular steel tube at the joint. The new joint of RCCSB developed is shown in Figure 3.

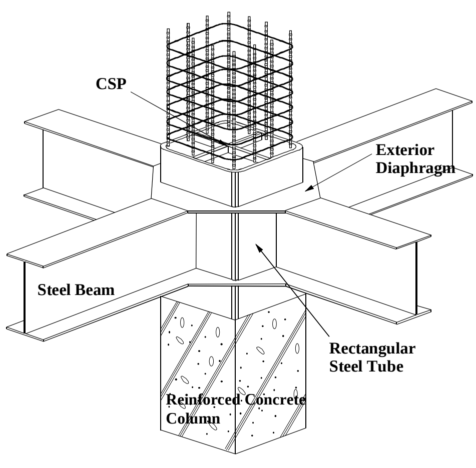


Figure 3 : The New Joint of RCCSB

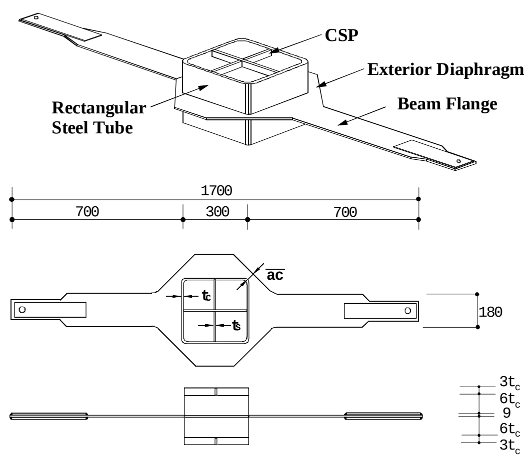


Figure 4 : Specimen for the Simple Tension Test

SIMPLE TENSION TEST

Test Specimens

To investigate the transfer mechanism of the tension force produced by bending moment acting on the steel beam, the specimens which have the joint connected only the upper flange of steel beam as shown in Figure 4 were designed for the simple tension test. Test parameters are (1)the existence of joint elements which are the square tube, exterior diaphragm, and CSP, (2)the failure modes which are joint failure mode and beam flange failure mode, (3)the strength by the size variation of joint elements, (4)the vertical stiffness for the exterior joint, and (5)the asymmetric steel tube. Table 1 presents the list of the specimens. Figure 5 shows details of specimens.

Table 1 : List of Specimens

Specimen		B_b	B_c	$\overline{ac}$	t_c	t_d	t_b	t_s	Comment
1	D0-C1-B1	180	300	-	9	-	9	9	No exterior diaphragm
2	D1-C0-B0	180	300	-	-	9	9	-	No steel tube
3	D1-C1-B0	180	300	25.5	9	9	9	-	No CPS
4	D1-C1-B1	180	300	25.5	9	9	9	9	Prototype specimen
5	D1-C1-B1a	180	300	25.5	9	9	9	9	Asymmetric specimen
6	D1-C1-B2	180	300	25.5	9	9	9	9	Variation of a CSP thickness
7	D2-C1-B3	180	300	43.5	9	9	9	9	Variation of a diaphragm weak section
8	D1-C2-B5	180	300	25.5	9	9	9	9	Variation of t_c, t_s
9	D1a-C1-B1	180	300	25.5	9	9	9	9	Exterior specimen

(unit: mm)

B_c : width of a rectangular steel tube
$\overline{ac}$: length of a diaphragm weak section
t_b : thickness of a beam flange

B_b : width of a beam flange
t_c : thickness of a rectangular steel tube
t_d : thickness of a diaphragm

t_s : thickness of a CSP

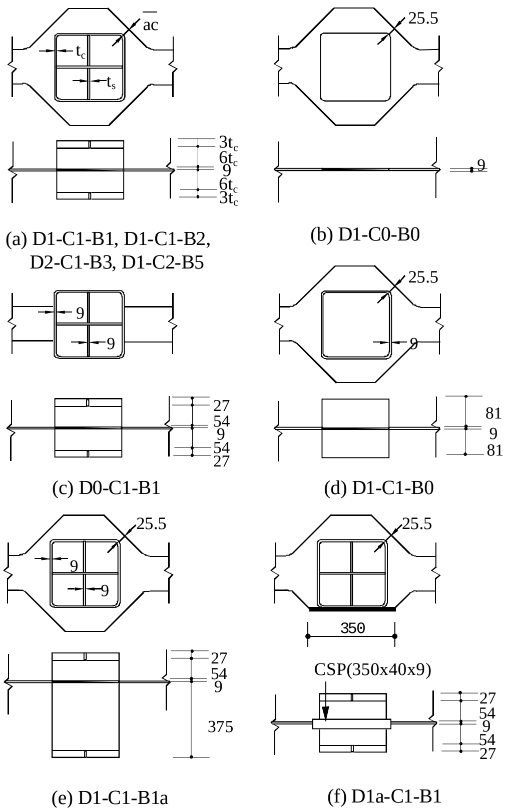


Figure 5 : Details of Specimen

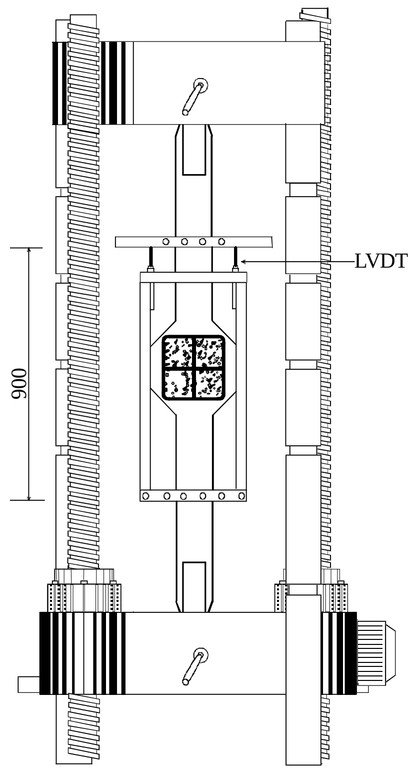


Figure 6 : Loading System

A prototype specimen is the D1-C1-B1 which have the rectangular steel tube, the exterior diaphragm and the CSP. The size of the rectangular steel tube is 300 mm × 300 mm square, while the width and the thickness of the steel beam flange is 180 mm and 9 mm, respectively. The thickness of the exterior diaphragm is also 9 mm. The variable of D0-C1-B1, D1-C0-B0 and D1-C1-B0 specimens is the existence of joint elements such as a rectangular steel tube, a exterior diaphragm and a CSP. D1-C1-B2, D2-C1-B3 and D1-C2-B5 specimens are designed for the assessment of strength by the size variation of joint elements such as the thickness of the CPS, the length of weak cross-section of an exterior diaphragm and the thickness of a rectangular steel tube. D1-C1-B1a specimen, of which the upper and lower length of the steel tube from the beam flange are asymmetric like a real joint, is built for comparison with the strength of a symmetric specimen, D1-C1-B1. D1a-C1-B1 specimen that has a vertical stiffener instead of a diaphragm of the prototype specimen is designed for an exterior joint of a structure.

Beam flanges and exterior diaphragms were cut in V-shape and welded on the rectangular steel tube, while the corners of the rectangular steel tube which the exterior diaphragm meet are not welded. The face where the exterior diaphragm meets the beam flange is curved to prevent the concentration of stress.

Material Properties

The design strength of the concrete is 210 kg/cm^2. The mean ultimate compressive strength of concrete at 28 days by cylinder test was 229.5 kg/cm^2. The material properties of a steel tube and a steel plate used to specimens are presented in Table 2.

Table 2 : Material Properties of a Steel Tube and a Steel Plate

Type		σ_y (t/cm^2)	σ_u (t/cm^2)	σ_y / σ_u (t/cm^2)	Elo (%)
Steel tube	9 mm	3.81	4.74	0.80	22.23
	12 mm	3.5	4.93	0.71	22.73
Steel plate	6 mm	2.92	4.71	0.62	34.08
	9 mm	2.71	3.61	0.75	34.10
	12 mm	3.85	4.87	0.79	29.80
	16 mm	2.78	4.70	0.59	20.95

σ_y : The yield tensile strength, σ_u : The ultimate tensile strength, Elo : Elongation Ratio

Loading System and Data Acquisition

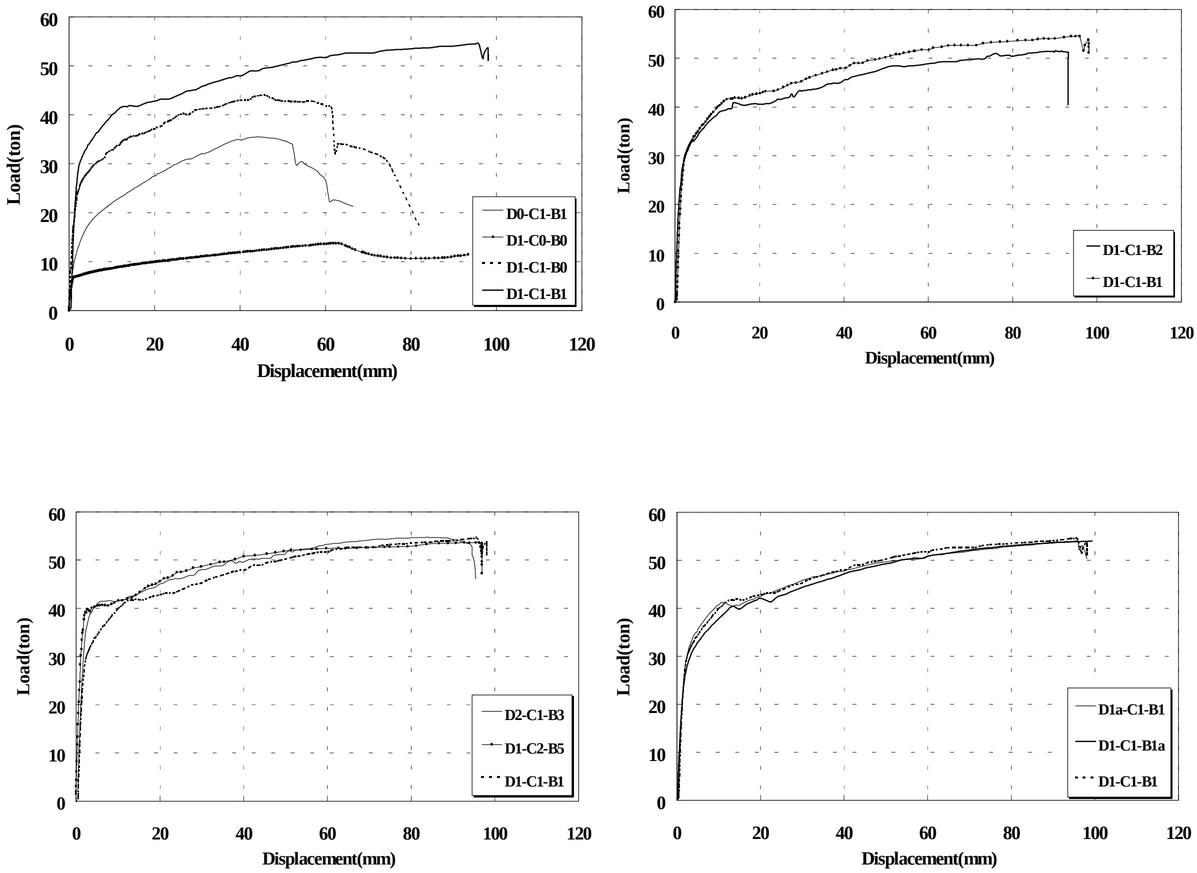
The loading system is shown in Figure 6. The tensile force, monotonically increased by using a Universal Testing Machine(UTM), was applied to the specimen until the beam flange or the weak section of a joint failed. The longitudinal displacement was measured by two Linear Variable Differential Transformers(LVDTs). Wire strain gauges were attached to the important region of the exterior diaphragm, the CSP, the rectangular steel tube and the beam flange to evaluate the stress distribution.

Experimental Results

The prototype specimen, D1-C1-B1, failed by the fracture of the weak cross-section of the exterior diaphragm and simultaneously the fracture of the upper and lower CPS, and then by the rip of the rectangular steel tube. The yielding and ultimate strength of the D1-C1-B0 specimen without a CPS was about 30% less than that of the prototype specimen. This shows that the CPS improves much the strength of the joint by constraining the deformation of upper and lower ends of the rectangular steel tube. D0-C1-B1 specimen failed by the fracture of the CSP. D2-C1-B3 and D1-C2-B5 specimens failed at the beam flange. The failure mode and the strength of the asymmetric D1-C1-B1a specimen were very similar to those of the prototype specimen. This shows that the strength of most specimens, which are symmetric in upper and lower, will be the same to the strength of a real joint. The strength of D1a-C1-B1 specimen with a vertical stiffener was similar to that of the prototype specimen. However, the ductility was less than 16 %. Table 3 presents experimental results on the strength and the displacement and Figure 7 shows the load and displacement relationship.

Table 3 : Experimental Results on the Strength and the Displacement

Specimen		Yield Strength (ton)	Yield Displacement (mm)	Ultimate Strength (ton)	Ultimate Displacement (mm)	Ductility Ratio (μ)
1	D0-C1-B1	22.02	9.65	35.51	44.27	4.59
2	D1-C0-B0	7.29	2.8	13.72	63.42	22.65
3	D1-C1-B0	31.13	13.99	44.05	45.72	3.27
4	D1-C1-B1	40.70	11.04	54.49	94.97	8.60
5	D1-C1-B1a	39.55	12.12	53.95	99.31	8.19
6	D1-C1-B2	39.06	10.65	51.14	85.62	8.04
7	D2-C1-B3	41.06	6.40	54.75	75.56	11.81
8	D1-C2-B5	41.17	9.17	53.63	95.42	10.41
9	D1a-C1-B1	40.46	13.34	53.98	95.95	7.19



(a) D0-C1-B1, D1-C0-B0, D1-C1-B0, D1-C1-B1 **(b) D1-C1-B2, D1-C1-B1**

(c) D1-C2-B5, D2-C1-B3, D1-C1-B1 **(d) D1a-C1-B1, D1-C1-B1a, D1-C1-B1**

Figure 7 : Load-Displacement Diagrams

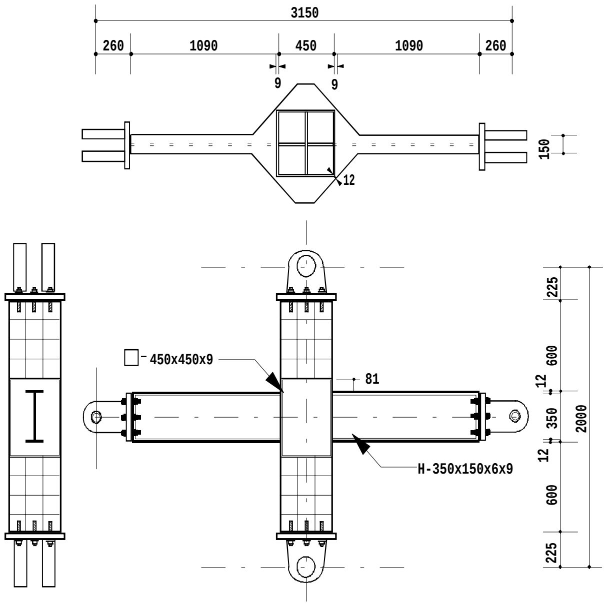
CYCLIC TEST ON THE BEAM-COLUMN JOINT

Test Specimens

Total three specimens are designed to evaluate the structural behavior of a column-penetrated RC column and steel beam joint where lateral loads such as seismic and wind loads are applied. Experimental variables are the length of weak cross section in diaphragm and the thickness of diaphragm in the beam-column joint. Table 4 presents the list of the specimens and the configuration of the prototype specimen is shown in Figure 8. The rectangular RC column section is 450×450 mm. The prototype specimen is C1-D1-A1 specimen. C1-D1-A2 specimen has twice weak section area than the prototype specimen through the weak cross section length of diaphragm is increased. In the C1-D2-A1 specimen, the weak section area is smaller than the prototype specimen through the weak cross section length of diaphragm and the thickness of diaphragm is decreased. These specimens are designed to fail in weak cross section of the diaphragm and the rectangular steel tube.

Table 4 : List of Specimens

Specimen	$\overline{ac}$	t_c	T_d	B_b	T_s	Comment
C1-D1-A1	12	9	12	150	16	Standard specimen
C1-D1-A2	24	9	12	150	16	Variation of □weak cross-section length
C1-D2-A1	9	9	9	150	16	Variation of the weak cross section length of diaphragm and the thickness of diaphragm



(unit: mm)

Figure 8 : Configuration of the Prototype Specimen

Material Properties

The design strength of the concrete is 350 kg/cm^2. The mean ultimate compressive strength of concrete at 28 days by cylinder test was 393 kg/cm^2. The material properties of a steel tube and a steel plate used to specimens for the cyclic test are presented in Table 5.

Table 5 : Material Properties of a Steel Tube and a Steel Plate

Type		σ_y (t/cm^2)	σ_u (t/cm^2)	σ_y / σ_u (t/cm^2)	Elo (%)
Steel tube	D10	4.21	6.83	0.62	13.43
	D22	4.48	6.59	0.68	17.99
Steel plate	6 mm	3.26	3.99	0.82	24.27
	9 mm	2.90	4.06	0.71	25.08
	12 mm	2.60	3.67	0.71	23.29
	16 mm	2.82	4.55	0.62	24.68
	20 mm	3.72	5.72	0.65	20.17
	26 mm	2.78	4.63	0.60	18.15

σ_y : The yield tensile strength, σ_u : The ultimate tensile strength, Elo : Elongation Ratio

Loading System and Data Acquisition

Reverse cyclic loads were applied at the end of both steel beams by 25 ton actuator, and simultaneously a constant axial load, 70.9 ton, was applied at the RC column ends by the 100 ton oil jack. The ends of column and beam were connected with actuators, oil jack, and strong frame in the pin. Test set-up is shown in Figure 9. The cyclic loading was controlled by drift angle calculated by dividing the vertical displacement of loading point of beam end by the distance from loading point to the column mid-point. Two cycles were applied to each drift angle increased as 1/400, 2/400, 4/400, 6/400, 8/400, 16/400, 24/400(Rad) as shown in Figure 10. Loads are applied quite slowly so that there is little effect of loading rate on the structural response.

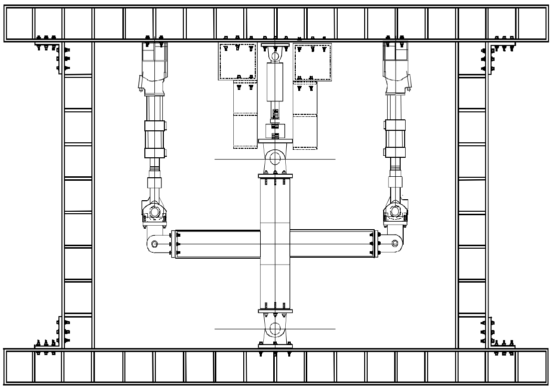


Figure 9 : Test Set-up

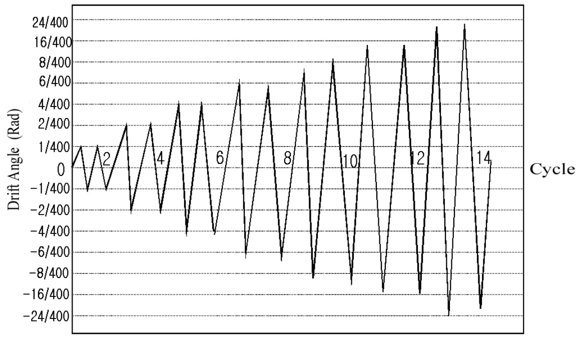


Figure 10 : Loading History

Instrumentation for displacement and rotation measurements of the joint was planned considering the characteristics of the joint deformation. 50mm and 100mm LVDTs were attached to the panel zone of joint, the top and bottom concrete column, and the ends of the steel beam. Wire strain gauges were attached to the rectangular steel tube, diaphragm and CSP to analyze the stress flow.

Experimental Results

In all specimens, the horizontal cracks initiating from the corners of the concrete column at the top and bottom of the joint were observed at the 7 cycle. They seemed to be caused by bearing stresses of the rectangular steel tube in the connected zone of the rectangular steel tube and concrete. In the prototype specimen, at 12 cycle, the cracks occurred in the weak cross section of diaphragm. At 13cycle, the weak cross section of diaphragm and the top and bottom of CSP were cut when the maximum load is 13.72 ton, and then failed finally. C1-D1-A2 specimen was similar to the prototype specimen. It’s maximum strength is 14.26 ton, up to 4% than the prototype specimen. In the C1-D2-A1 specimen, at 12 cycle, the CSP was cut, and then the weak cross section of the diaphragm and the rectangular steel tube were torn. It’s maximum load is 10.62 ton, which was decreased to 23% than the prototype specimen. Initial stiffness is 0.86 ton/mm. These experimental results on the yield and ultimate strength are shown in Table 6. Figure 11 shows the load and drift angle relationship. Accumulated absorption energy of specimens was compared in Figure 12. Figure 12 shows that accumulated absorption energy increases in proportion to the area of the weak cross section in diaphragm

Table 6 : List of test result

Specimen	Yield strength, P_y (ton)	Maximum strength, P_u (ton)	P_u / P_y
C1-D1-A1	9.28	13.72	1.4 8
C1-D1-A2	9.94	14.26	1.43
C1-D2-A1	8.23	10.62	1.29

CONCLUSIONS

RCCSB system of the column-penetration type, which has the steel tube, the exterior diaphragm, and the CSP, was developed. Two types of experiment, the simple tension test and the cyclic test, are conducted to evaluate the load transfer mechanism for the joint. Conclusions from these tests are as follows.

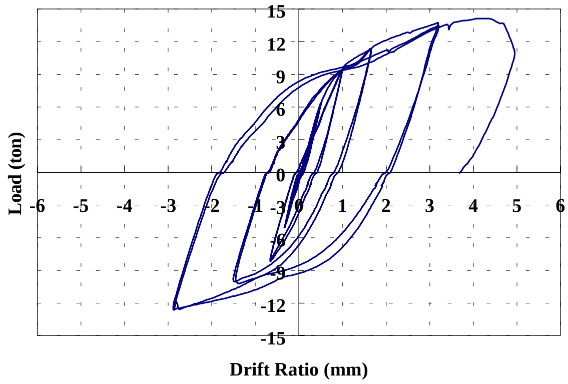
(1) In the simple tension test, most of specimens failed by the fracture of the weak cross-section of the exterior diaphragm and simultaneously the fracture of the upper and lower CPS, and then by the rip of the rectangular steel tube.

(2) The CPS improves much the strength of the joint by constraining the deformation of upper and lower ends of the rectangular steel tube.

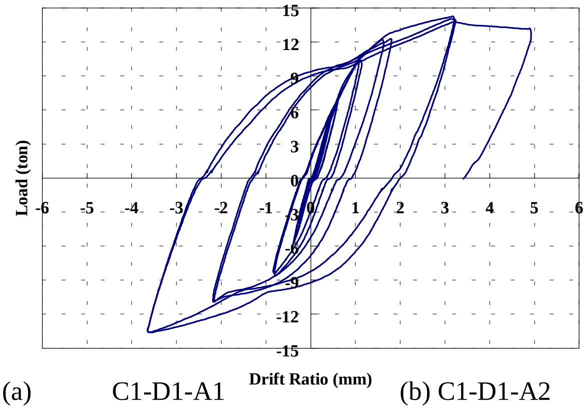
(3) The specimen that has a vertical stiffener instead of a diaphragm can be designed for an exterior joint of a structure because the strength of the specimen with a vertical stiffener is similar to that of the specimen with diaphragm.

(4) In the cyclic test, a load - drift ratio relationship curve has a spindle shape.

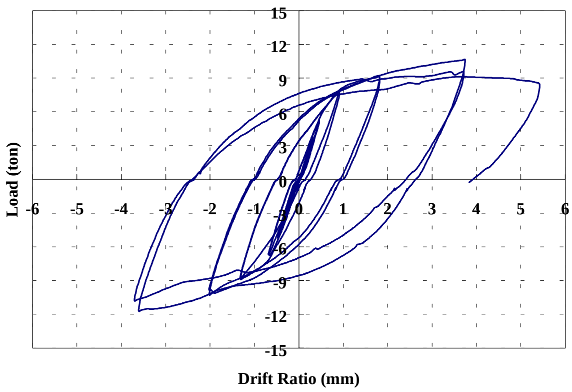
(5) As the area of the weak cross section in diaphragm is lager, the strength and the accumulated absorption energy is increased more.



(a) C1-D1-A1



(b) C1-D1-A2



(c) C1-D2-A1

Figure 11 : Load-Drift Angle Diagrams

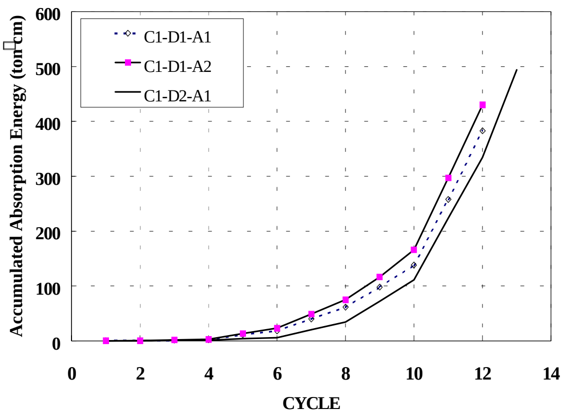


Figure 12 : Accumulated Absorption Energy

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