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EFFECT OF STRENGTH OF FILLED-CONCRETE ON STRUCTURAL PERFORMANCE OF CONTINUOUS BEAM-TYPE SQUARE CFST BEAM-TO-COLUMN CONNECTION

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Continuous beam-type concrete-filled steel tube (CFST) column connections are simple to fabricate and exhibit effective seismic performance. Fujinaga and Clifton have previously studied the performance of continuous beam-type square CFST beam-to-column connections using concrete of relatively high strength (85 MPa) and demonstrated their effective performance and high energy-absorbing capacity. However, in their study, it was found that the local deformation of the steel beam under bending-induced beam tension had a large effect on the steel tube flange near the connection. Further, it was observed that filled concrete may not contribute substantially to the transmission of compressive load at the connection panel if low-strength concrete is used. In this study, the square CFST beam-to-column connection was investigated, and the connection performance and load transfer mechanisms were examined when the strength of the concrete was relatively low (40 MPa). The specimens demonstrated effective seismic performance, exhibiting sufficient strength and stable hysteretic behavior with high energy absorption even when low-strength concrete was used. Irrespective of the strength of the concrete used, the strain developed in the steel tube flanges was low on the compression side, and the filled concrete contributed to the transmission of the compressive load at the connection panel. The compressive strain in the steel tube was slightly higher when the strength of the concrete was low.

Keywords: Concrete-filled steel tube, Cruciform shape, T-shape, Fillet welding, Energy absorption, Strain distribution.

1 INTRODUCTION

Concrete-filled steel tube (CFST) columns are widely used as components in building structures owing to their effective structural performance. Previously, a continuous beam-type connection through the column has been proposed for CFST beam-to-column connections (Azizinamini and Prakash 1993); the stress transmission mechanism and design formulas for circular CFST columns have also been studied (Azizinamini and Schneider 2004). Moreover, the elastoplastic behavior of the panel zone of beam-to-column CFT connections were investigated (Fukumoto and Morita 2005). Fujinaga and Clifton (2019) have experimented with continuous beam-type square CFST beam-to-column connections using relatively high-strength concrete (85 MPa) and reported their effective performance and high energy-absorbing capacity. However, in their study, it was found that the local deformation of the steel beam under bending-induced beam tension has a large effect on the steel tube flange near the connection. Further, filled concrete may not contribute substantially to the transmission of compressive load at a connection panel if low-strength concrete is used. In the present study, the results of the experimental testing of the cruciform and T-shaped frames of CFST beam-to-column connection are shown, and the structural performance of connection and load transfer mechanisms are discussed when the strength of the concrete is relatively low (40 MPa).

2 EXPERIMENT ON CFST BEAM-TO-COLUMN CONNECTION

2.1 Specimens

Figure 1 depicts the shapes and dimensions of the specimens, Table 1 lists the specimens, and Table 2 presents the material characteristics of the steel materials used for the specimens. The specimens are a continuous beam-type cruciform-shaped frame and a T-shaped frame that simulate the square CFST beam-to-column connection. The tube is BCR295 with a cross-sectional dimension of 250 × 250 × 9 mm, and the beam is SN400B with a cross-sectional dimension of H-300 × 150 × 6.5 × 9 mm. The specimens were designed so that the beams would yield before the columns. To fabricate the connection, I-section beam slot was cut in the column steel tube by plasma within 1 mm tolerance. After putting the beam through the I-shaped slot, the beam and the outer faces of the column were fillet-welded all around. The nominal strength of the filled concrete was 30 MPa, and the actual strength during the experiment was approximately 40 MPa, as listed in Table 1.

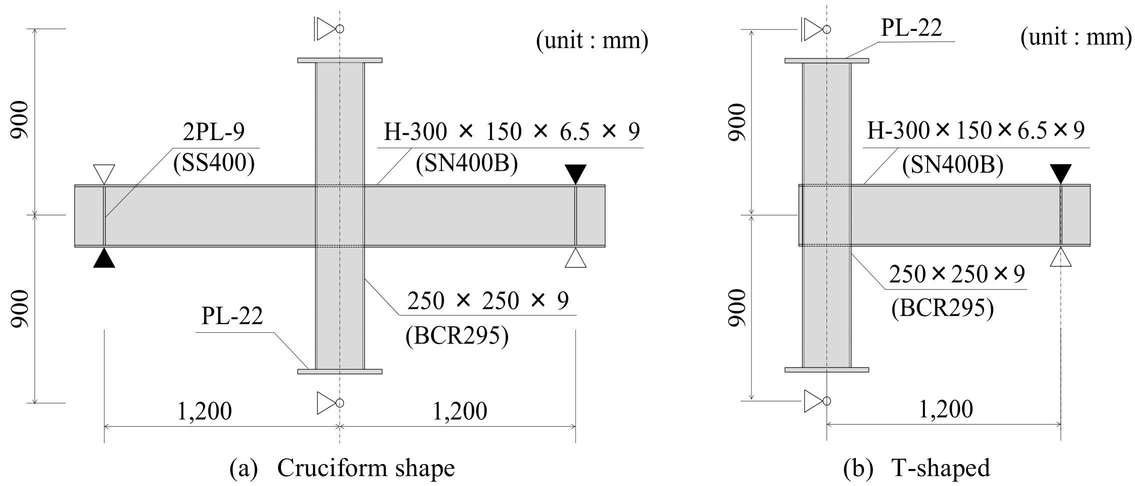


Figure 1. Shape and size of specimens.

Table 1. List of specimens used in experiment.

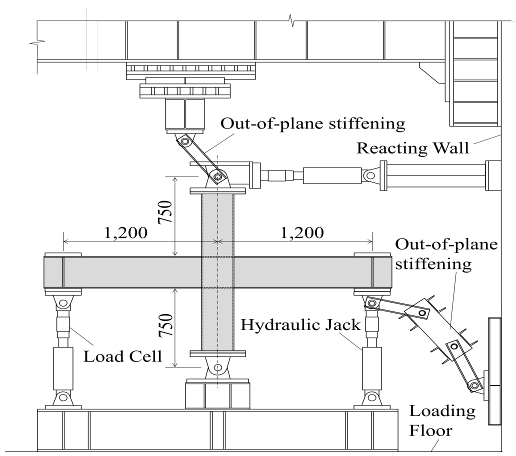
	Column	Beam	Strength of concrete (MPa)
Cruciform shape	250 × 250 × 9 (BCR295)	H-300 × 150 × 6.5 × 9 (SN400B)	40.1
T-shaped			41.6

Table 2. Material characteristics of steel.

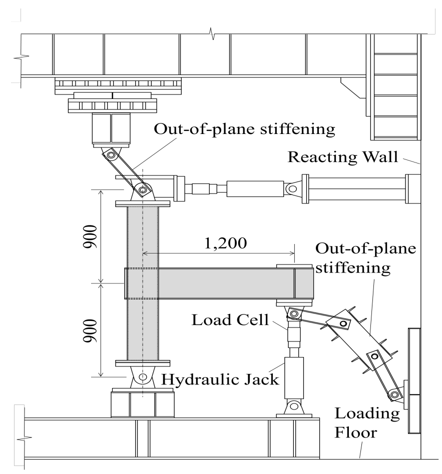
		Yield stress f_y (MPa)	Tensile strength f_u (MPa)	Young's modulus ${}_sE$ (MPa)
Beam	I-section flange	347	423	187
	I-section web	301	452	204
Column tube		361	473	203

2.2 Loading Method

Figure 2 illustrates the loading apparatus. The upper end of the column is supported by a pin and roller, the lower end of the column is supported by a pin, and a shear force is applied to the beam using a hydraulic jack attached to the beam end. Out-of-plane stiffening devices are attached at the upper ends of the column and beam. The displacement is controlled through the deformation angle R and reversed cyclic loading. The deformation angle is obtained by dividing the total vertical displacement of the loading points of both the beams by the distance (2400 mm) between them for the cruciform-shaped specimen. A distance of 1200 mm was used for the T-shaped specimen.



(a) Cruciform shape.



(b) T-shaped.

Figure 2. Loading apparatus.

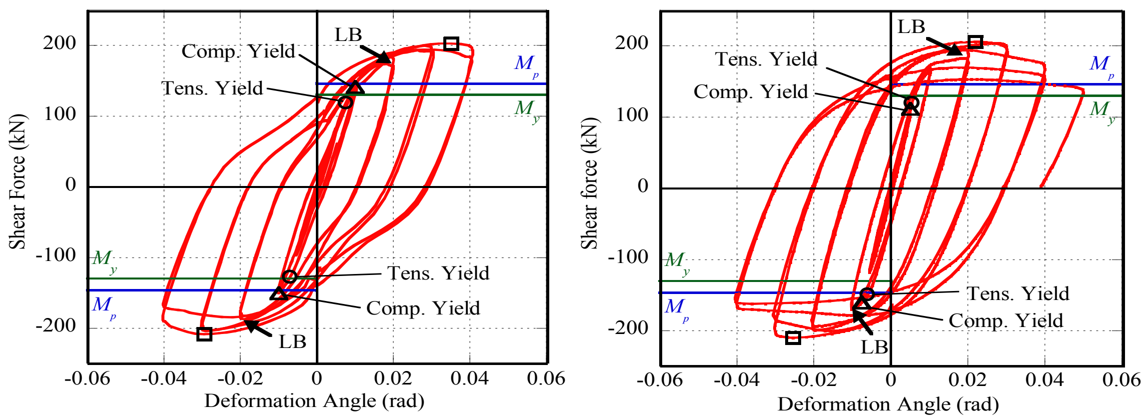
3 DISCUSSION OF TEST RESULTS

3.1 Shear Force - Deformation Angle Relationship

Figure 3 presents the relationship between the shear force and the deformation angle. In the figures, the points where the steel beam reaches the yield strain for the first time are marked with circles (tensile yield) and triangles (compression yield). The points where local buckling was first observed on the steel beam flange are indicated with arrows. Furthermore, the maximum strength points are represented with squares. The green and blue lines represent the strengths obtained using the yield flexural strength and full plastic strength of the beam section, respectively.

The cruciform specimen demonstrated effective seismic performance, exhibiting stable hysteretic behavior with high energy absorption, and its strength increased even after the steel beam flange yielded at R = 0.01 rad. Local buckling was observed in the steel beam flange at R = 0.02 rad. After reaching the maximum strength, local buckling in the flange increased, and its strength decreased. The T-shaped specimen also demonstrated stable hysteresis, and its strength increased even after the steel beam flange yielded at R = 0.005 rad. Local buckling was observed in the steel beam flange at R = 0.01 rad. After reaching the maximum strength in the cycle of R = 0.03 rad, local buckling in the flange increased, and the strength began to decline.

Table 3 presents a comparison between the experimental and calculated data of yield strength and maximum strength. Irrespective of the shape of the frame, the experimental value could be predicted with an error of approximately 5% on the average. The maximum strength of both the specimens exceeded the calculated maximum strength by approximately 40% on the average between the positive and negative sides.



(a) Cruciform shape. (b) T-shaped.

Figure 3. Shear force–deformation angle relationship.

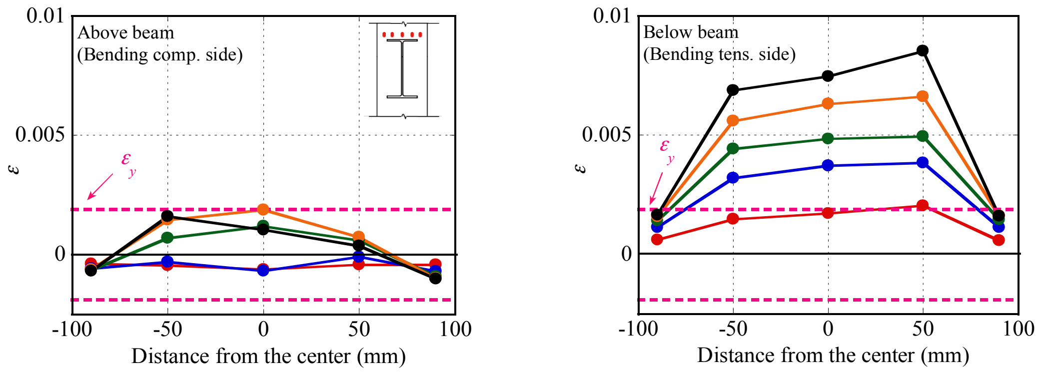
Table 3. Comparison between experimental and calculated values.

Specimen		Yeild strength (kN)			Maximum strength (kN)		
		Cal.	Exp.	Exp./Cal.	Cal.	Exp.	Exp./Cal.
Crruciform shape	+	130	119	0.92	146	203	1.38
	−		-127	-0.98		-208	-1.42
T-shaped	+		112	0.86		206	1.40
	−		-149	-1.15		-210	-1.43

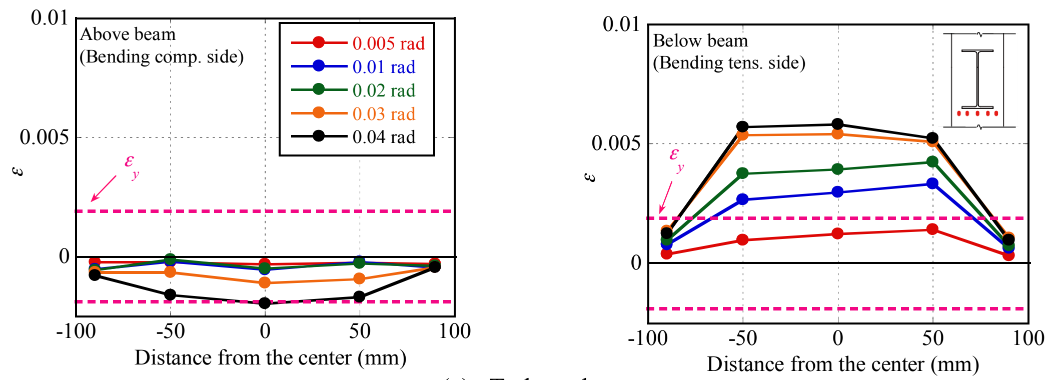
3.2 Strain Distribution in Column Steel Tube

Figure 4 presents an example of the strain distribution in a column steel tube flange just above and below the steel beam, measured using strain gauges attached at a point 25 mm from the surface of the flange.

For the cruciform-shaped specimen, the strain reaches the yield strain at R = 0.005 rad at a point 50 mm from the center, just below the I-section beam, which is the bending tension side, and increases thereafter. However, it does not increase on the bending compression side. The slight increase observed after R = 0.02 rad is considered to be the effect of residual strain owing to plastic deformation after yielding under bending tensile loading. The same tendency is observed in the T-shaped specimen. The strain in the column flange above or below the beam increases on the bending tension side but remains low on the bending compression side, which indicates that the filled concrete contributes significantly to the compressive load resistance.



(b) Cruciform shape.



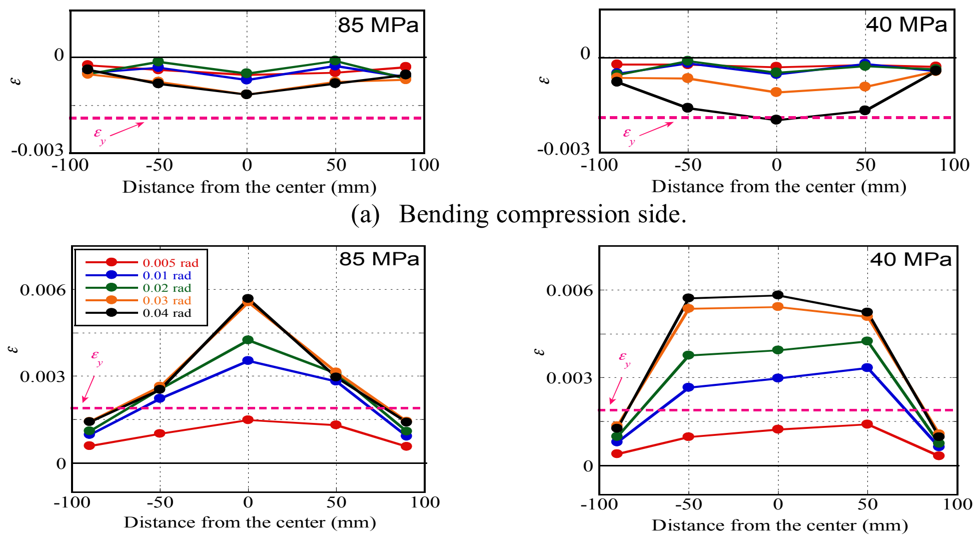
(a) T-shaped.

Figure 4. Strain distribution of column steel tube.

Figure 5 depicts the impact of the strength of the concrete on the strain distribution in the column steel tube in the case of the T-shaped specimens.

On the bending compression side, the strain increases slightly with an increase in the deformation angle in the case of both concrete strengths. Only a slight difference was observed in the strain distribution up to R = 0.03 rad. At R = 0.04 rad, the strain in the low-strength concrete specimen is slightly larger than that in the high-strength one, and it reaches the yield value only at the center (0 mm).

On the bending tension side, the strain increases with the deformation angle in the case of both concrete strengths. The strains at 0 and ±90 mm are approximately the same, until a large deformation occurs in both specimens. However, at ±50 mm, the strain in the low-strength concrete specimen was larger than that in the high-strength concrete specimen, and it was approximately the same as that at the center.



(a) Bending compression side.

(b) Bending tension side.

Figure 5. Impact of concrete strength on strain distribution in column steel tube.

4 CONCLUSIONS

From the experimental results obtained from the two specimens in this study, the followings conclusion can be made:

1) The cruciform and T-shaped specimens demonstrated effective seismic performance, exhibiting stable hysteresis curve with high energy dissipation ability, even when low-strength concrete was used. Furthermore, the maximum experimental strength was larger than the calculated value.
2) Irrespective of the strength of the concrete, the strain in the column flange above or below the beam increases on the bending tension side but remains low on the bending compression side, which indicates that the filled concrete contributes significantly to the compressive load resistance. However, when the concrete strength is relatively low, the strain in the column flange increases beyond that in a high-strength concrete specimen under a large deformation.

Acknowledgments

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