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TRIAL CONSTRUCTION FOR SEISMIC RETROFIT BY CFT BRACE ON AN ISOLATED ISLAND

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The authors have been developing a seismic retrofitting method using concrete-filled steel tubular (CFT) members as a diagonal brace. The features of the method are easy set-up and low-cost because we made the enforcing devices lightweight and a simple connecting method to the existing structures. This method provides many advantages for the buildings located at the places where are difficult to transport heavy materials and equipment. An experimental construction for the seismic retrofit was conducted at the 2-story RC building on an isolated island in Japan. The construction was succeeded by only three persons in two days without heavy equipment. This paper is consisted of the reports of the constructing process and the loading test of the connecting part of the method. The trial construction includes a new detail of the connection. Two specimens were made and tested to estimate the lateral load carrying capacity of the connection.

Keywords: Easy set-up, Human-powered setting, Low-cost, Connecting block, Loading test.

1 INTRODUCTION

The big revision of the building codes of Japan was introduced in 1981. The revised codes require higher seismic performance of buildings than that of old ones. The buildings constructed before 1981 remains still weaker than new ones as the existing buildings out of law. In this situation, a lot of buildings which were vulnerable against earthquakes were retrofitted by many kinds of seismic retrofitting technologies. These are sometimes expensive because of using big and heavy members and equipment.

The authors have developed the retrofitting method by using concrete-filled steel tubular (CFT) members and put the method into practical applications in 2012 and 2013 under the support of the Japanese Government. The features of the method are quite, easy set-up and low-cost because we realized to make the enforcing devices lightweight members and to develop a simply connecting method between the members and the existing structures (Nakahara *et al.* 2013). These merits are derived from that the CFT braces are used only acting in compression. This method provides many advantages for the buildings located at the places where are difficult to transport the heavy materials and equipment, i.e.: an isolated island, a mountain-ringed region, a narrow space, and so on. In order to show the efficiency of our retrofitting method, we carried out a trial construction for the seismic reinforcing at the 2-story RC building on an isolated island in the Japanese archipelago. The process and cost of the constructing are described. The trial construction includes a new detail of the connection. Two specimens were made and tested to estimate the lateral load carrying capacity of the connection. The results of the loading test are also reported in the paper.

2 OUTLINE OF THE TRIAL CONSTRUCTION

Picture 1 shows the appearance of the target building for the seismic retrofit. It is called as "Promotion Center for Isolated Island" and located in Iriomote Island, where is south end of Japanese archipelago. Figure 1 shows the plan of the second story of the target building. This is a two-story RC building of which storied height and span are 3600 mm and 7,000 mm respectively. The retrofitted position is right end of the plan shown in Figure 1. The brace was installed on the interior sides of the frame. Figure 2 (a) shows the retrofitting way by one brace arrangement which was called as "D-type", hereafter. The D-type has been investigated at the authors' laboratory mainly and was chosen for the actual retrofits in two buildings. The D-type has some problems to be applied to structural frames with wide span because the diagonal member has to be long. As the length of a member increase, its weight increase. The merit of easy-set up, which is one of the features of our retrofitting method, will be spoiled. Also a long member is weak against compression owing to the decreases of its buckling capacity. A steel tube of 8 m length was required when the D-type was selected in the building. The weight of the steel tube, with cross section of 100 × 100 × 3.2 mm, is 76 kg even though concrete is not poured into it, so that the member may not be easy to carry and set by human power.

Picture 1. Appearance of the building.

In Figure 2(b), two braces were arranged in the V-shaped form which was called as "V-type". Because shorter members were available in the V-type, the advantage of our method was preserved. However, V-type brings the carefulness to the slip failure at a connection between diagonal members and a lower girder. The connection at the center of the girder in V-type must be weaker than that in D-type, since the column in D-type also resists lateral slip. The lateral load carrying capacity of the connection at the center of V-type is discussed in the section 4.

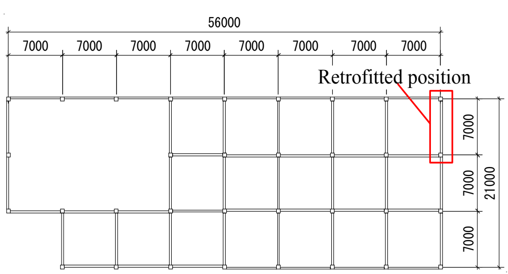
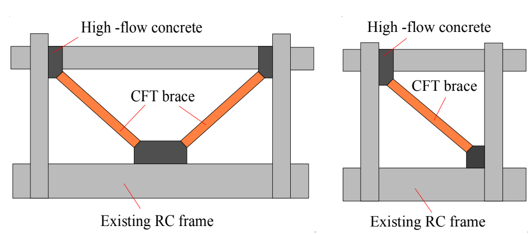


Figure 1. Framing plan of the building.

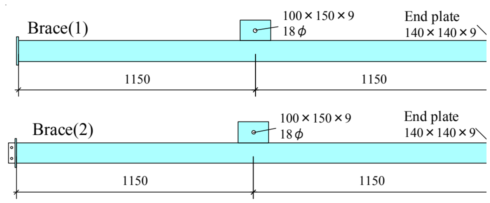


(a) V-type. (b) D-type.

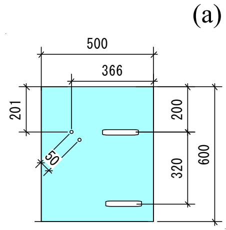
Figure 2. Elevations of the retrofitted frames.

3 CONSTRUCTION TEST

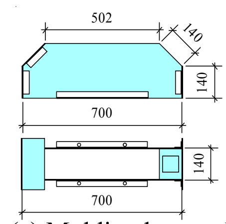
Figure 3 shows the members for the retrofit. The diagonal braces were made by square steel tubes (STKR400) of 100 × 100 × 3.2 mm. The end plates of 9 mm were welded on both ends of the brace as shown in Figure 3(a).



(a) Braces



(b) Molding box at bottom.



(c) Molding box at top.

Figure 3. Members for retrofit.

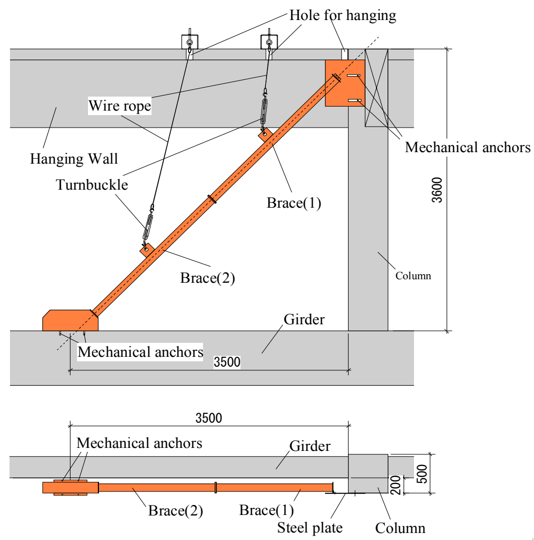


Figure 4. Schematic Drawing of retrofit.

(a) Core drilling.

(b) Installation of mechanical.

(c) Bottom of molding box.

(d) Hanging by the chain block.

(e) Replace with the wire rope.

(f) Completion.

Figure 5. Pictures of construction process.

A hanging jig of 9 mm thick plate was welded at the center of the each brace. Figure 3(b) showed the rectangular molding box for the connection between the brace and the corner part of the existing frame. Figure 3(c) showed the trapezoidal molding box for the connection between the brace and the existing girder. The brace was consisted of two steel tubes of 2.3 m length, which was 22 kg and was jointed with bolts longitudinally. Figure 4 shows the elevation and plan of the retrofit completed by our construction. The diagonal brace was set the one side of the V-type arrangement of which setting angle was 45 degree. All members were set between the column surface and the hanging wall in the plan, since the column was used as the role of the frame for the diagonal brace.

The pictures in Figure 5 show six steps of the construction process of the retrofit. 1) Three holes, which were used to hang to set the brace, were opened by an electric core drill (Picture (a)). 2) Mechanical anchors were installed at the corner of beam-column connection and the floor (Picture (b)). 3) Molding boxes were set and fixed through the mechanical anchors on the floor (Picture (c)). The upper steel plate for the joint was set by a hanging jig and fixed with the mechanical anchors (Picture (d)). 4) The upper part of the brace was set diagonally by a hanging jig and a chain block through a turnbuckle (Picture (d)). 5) The chain block was replaced to the same length wire (Picture (e)). The lower part of the brace was set and fixed in the same way. 6) After hanging the braces, the end plates of the brace were connected to the molding boxes with bolts. Picture (d) showed the appearance after the completion of the retrofit. The setting of the brace was able to finish within five hours by three persons without any heavy equipment. All members and equipments were carried and set by only human power.

4 LOADING TEST

A Loading test was conducted for the connection between the lower girder and the brace in the V-type arrangement.

Figures 6 and 7 showed the elevation of the test specimens which were 1/1 scale models of the pilot retrofit at the Promotion Center for Isolated Island. There are two specimens which have different setting angles of braces. The setting angles of the braces were taken to be 30° (35-30DB) and 45° (35-40DB). After chipping the top surface of which area is 350 × 140 mm on the RC foundation beam, the molding box was set on there. The high-flow concrete was filled from the top of the steel tubes. The concrete was successfully filled in the steel tube and the molding box by its own weight. The chemical anchors were not used to the specimens because the aim of this test was to estimate the capacity of slip failure of concrete connection. Table 1 shows properties of concrete and steel tubes. The compressive strength of the concrete casted to the foundation beam was 35.7 N/mm2 and that filled into the molding box and steel tubes was 46.4 N/mm2. By a splitting tensile test of the concrete used or the foundation beam, tensile strength was obtained as 3.0 N/mm^2. A hydraulic jack of which capacity was 1 MN applied axial compression to the braces. The load was monitored by a load cell on the head of the hydraulic jack.

Figures 6 and 7 shows the measurement positions by transducers and strain gauges. The slips on the surface of the foundation beam were measured as the lateral displacements by the transducers set horizontally.

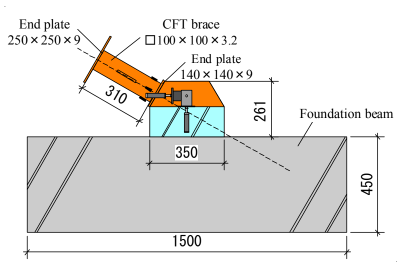


Figure 6. Elevation (35-30DB).

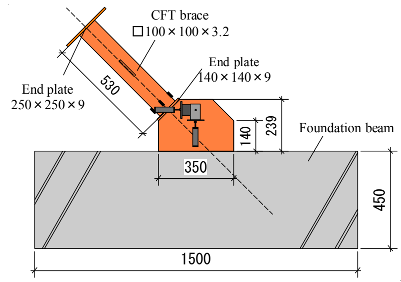


Figure 7. Elevation (35-45DB).

Table 1. Properties of concrete.

	Nominal strength	Compressive strength (N/mm^2)	Tensile strength (N/mm^2)	Young's modulus (kN/mm^2)
Fundation beam	27	35.7	3.0	27.7
Specimen	36	46.4	—	31.6

Figure 8 shows the relations shearing stress τ and lateral displacement δ of the specimens. The values of τ were obtained by the lateral component of the axial force of the brace N_b divided by the area of the slip surface. In the case of 35-30DB, 0.5 mm displacement was observed under 4 N/mm^2 of lateral stress. The maximum stress was 1.7 N/mm^2. In the case of 35-45DB, the planed loading grogram was completed successfully before the load reached at the maximum stress of 6.54 N/mm^2. After the peak value, the strength decreased with the progress of the deformation and the shear slip failure occurred. Both of them were broken horizontally at the interface without debris. Figure 8 includes the calculated vales of punching shearing stress τ_p at the interfaces between the connection and the foundation beam. The τ_p was determined from the shearing capacity calculated by Mohr's stress circle as follows:

$$\tau_p = \min\left(\sqrt{\frac{N}{A}\sigma_t + \sigma_t^2}, \sqrt{-\frac{N}{A}\sigma_c + \sigma_c^2}\right) \tag{1}$$

where σ_t and σ_c were the tensile strength and compressive strength of the concrete of the foundation beam, respectively. Notations N and A were vertical force on slip surface and the sectional area of the connection of 140 mm × 350 mm.

From the comparisons between 35-30DB and 35-45DB, the former had lower performances of stiffness and strength. The reason was considered to be due to that the axis of the brace was out of the center of the connection in the case of 35-30DB as shown in Figure 6. The bending moment caused by eccentric compression affected to decrease the strength of 35-30DB. Zia (1961) compared the experimental results obtained by Humphreys (1957) with the calculation from Mohr's stress circle. Figure 9 showed the relation between the shear stress τ and axial stress σ. They were expressed by the ratios as τ/τ_0 and σ/σ_c where τ_0 was the shearing strength of the concrete under pure shear and σ_c was the compressive strength of the concrete. τ_0 equal to σ_t. In Figure

9, ●denotes the experimental results obtained by Humphreys. ▲ and ■ represent our results.

The calculation of Mohr's stress circle accurately evaluates the Humphreys' experimental results. The experimental results of 35-30DB is very smaller than the calculation of Mohr's stress circle, while the result of 35-45DB exists in a similar trend obtained by Humphreys.

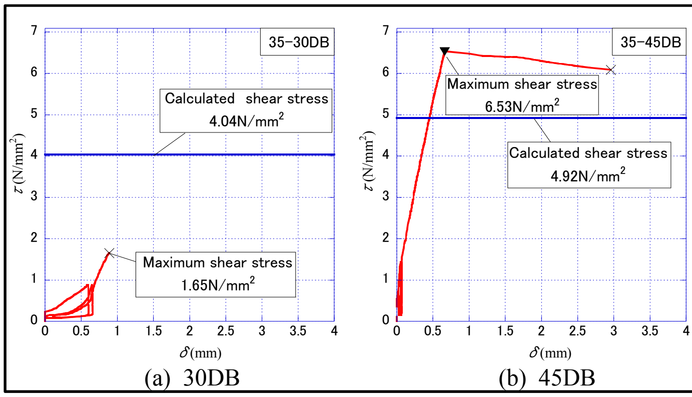


Figure 8. τ-δ relations.

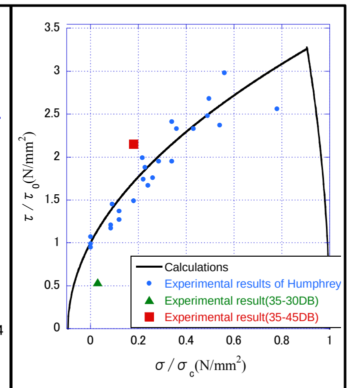


Figure 9. τ/τ_0-σ/σ_c relation.

7 CONCLUSIONS

A trial construction of our retrofitting method was conducted for the existing RC building which was located on an isolated island in Japan. The construction included a new connecting detail which was tested in our laboratory. The following conclusions can be reached by this study:

1) The construction was succeeded by the only three persons in five hours without heavy equipment owing to the features of our method which were light weight and simple connections.

2) The maximum strength of the specimen of which the brace set with 45 degree angle to foundation beam was estimated safely as the shear strength calculated by the theory of Mohr's stress circle.

Acknowledgments

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