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STRUCTURAL BEHAVIOR OF CONNECTIONS BETWEEN CONCRETE COMPONENTS AND GUSSET PLATE WITH STUD BOLTS

YUSUKE MAIDA[1], SHUHEI HARADA[1], HIROYASU SAKATA[1], TAKUMI SATO[2], and MASAHARU KUBOTA[2]

[1]*Dept of Architecture and Build. Eng., Tokyo Institute of Technology, Meguro, Japan*
[2]*TOBISHIMA Corporation, Minato, Japan*

Dampers are effective in ensuring the earthquake resistance of reinforced concrete (RC) buildings. Reliable connections between dampers and concrete components are critical for dampers to effectively function in RC buildings. In this study, the structural behavior of connections between concrete components and a gusset plate with stud bolts to join the damper to the RC buildings was analyzed. Component tests of the connections between the concrete components and the gusset plate with stud bolts were conducted. The specimen parameters were the arrangement of stud bolts and the presence or absence of a closing plate. As a result of the tests, the stiffness of the connections was different depending on the arrangement of the stud bolts. In addition, the specimen with the closing plates exhibited high stiffness and strength. Finally, an evaluation method for the force–displacement curve of the connections between the concrete components and the gusset plate with stud bolts is provided.

Keywords: RC building, Earthquake resistant, Seismic response control, Damage control.

1 INTRODUCTION

Dampers are effective in ensuring the earthquake resistance of reinforced concrete (RC) buildings. In Japan, the applications of dampers to new constructions and existing buildings are increasing. However, in RC buildings, high stiffness is required at the connections between concrete components and dampers such that the dampers can effectively perform. In previous studies (Maida *et al.* 2021), the connections between concrete components and dampers sustained severe damage. Thus, it is significant that the connection details of concrete components and damper are established.

The purpose of this study is to analyze the structural behavior of a gusset plate with stud bolts embedded in concrete components for connecting RC buildings and dampers. In addition, the evaluation method for the force–displacement curve of the connections is examined.

2 TEST PROGRAM

2.1 Specimens

Figure 1 shows the details of the specimens. Figure 2 shows the outline of the gusset plate with stud bolts. Figure 3 shows the details of the specimen and gusset plate with stud bolts. Tables 1 and 2 list the material properties of concrete and steel.

The diameter of both, the longitudinal rebar and shear reinforcements of the concrete component of the specimen, was 10 mm (D10). The concrete strength f_c' was 39.5 N/mm^2. Eight stud bolts were welded to the part of the gusset plate embedded in the concrete, four on each side of the steel plate. The stud bolts had a diameter of ϕ 13 mm and length of 80 mm. The specimens were A type with a stud bolt arrangement of 150 × 100 mm, B type with an arrangement of 330 × 100 mm, and H type with an arrangement of 150 × 100 mm and closing plates attached. The gusset plate connection was designed assuming that the design force of the damper was 50 kN. The connection strength with only the upper four stud bolts was designed to exceed the design force of the damper (Architectural Institute of Japan 2010). The effects of the bearing plates and closing plates were not considered.

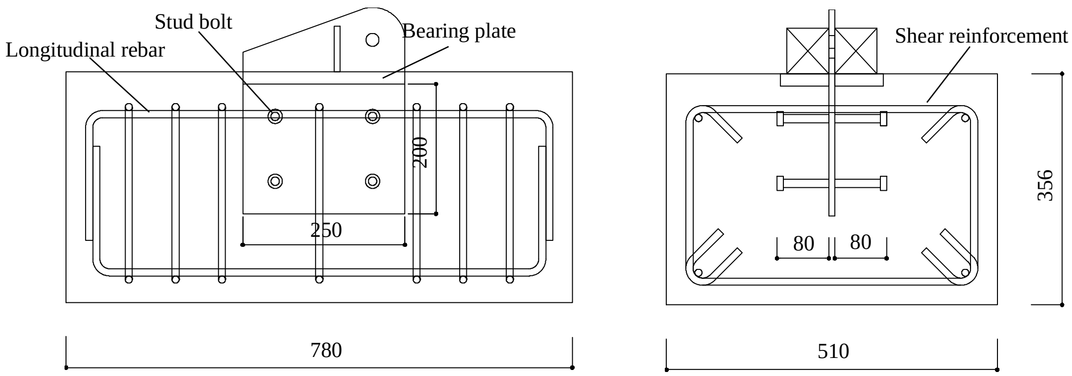
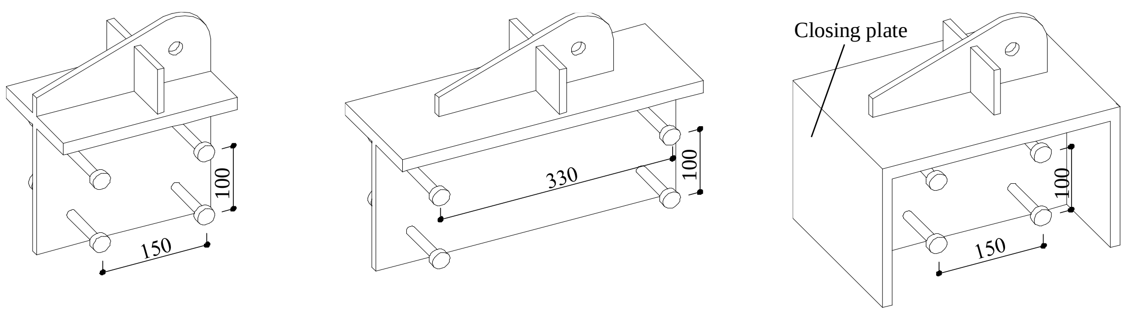
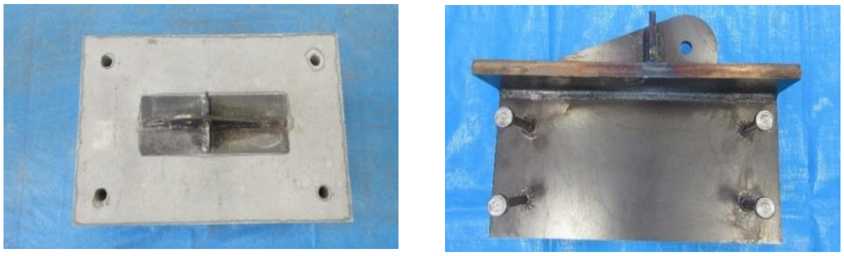


Figure 1. Details of the specimens in mm (A type).



(a) A type (b) B type (c) H type

Figure 2. Outline of the gusset plate with stud bolts.



(a) Specimen (b) Gusset plate with stud bolts

Figure 3. Details of the specimen and gusset plate with stud bolts.

Table 1. Material properties of the concrete.

Compressive strength f_c' (MPa)	39.5
Tensile strength f_t (MPa)	2.23
Young's modulus E_c (MPa)	28600

Table 2. Material properties of the rebar and steel.

Material type	Yield strength f_y (MPa)	Ultimate strength f_u (MPa)	Young's modulus E_S (MPa)
Rebar D10 (SD295A)	354	527	184000
Stud bolt ϕ13 (SS400)	383	506	-
Gusset plate steel (SS400)	307	466	-

2.2 Loading and Measurement

Figure 4 shows the test setup. The concrete component part in the specimen was tied to the strong floor. The jack was attached to the reaction wall at an angle of 45° and pin joined to the gusset plates.

The loading protocol was a one-sided repeated tensile loading *P*, in which the load was gradually increased by 10 kN up to 50 kN and then by 20 kN thereafter.

Figure 5 shows the measurements. The relative vertical δ_V and horizontal δ_H displacements between the concrete component and the gusset plate were measured. The strain at 20 mm from the joint surface of the stud bolt was measured.

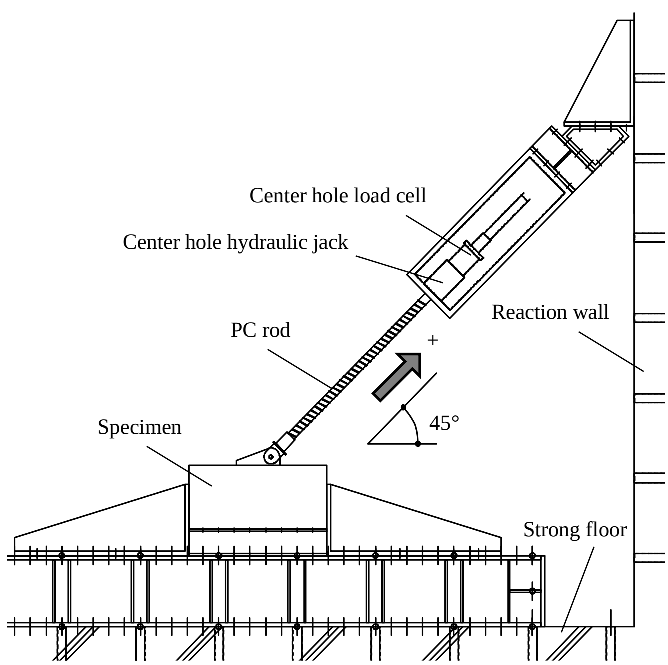
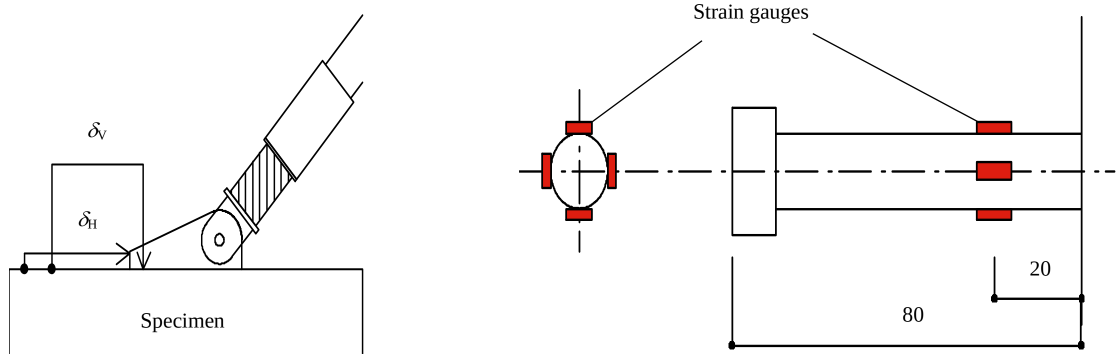


Figure 4. Test setup.



(a) Displacement (b) Strain gauges

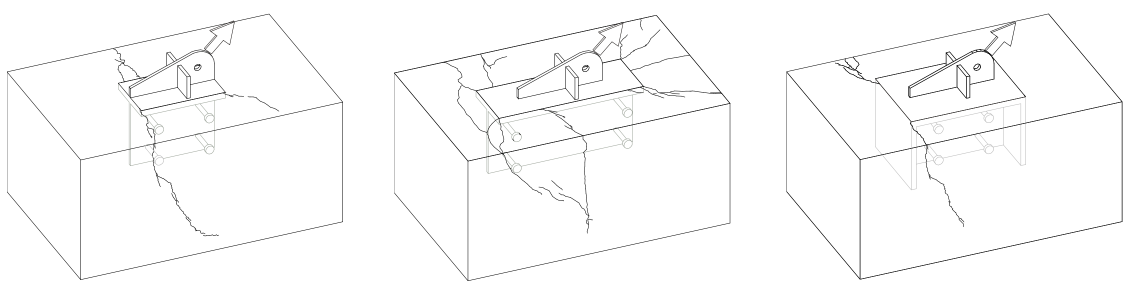
Figure 5. Measurements.

3 TEST RESULTS

3.1 Damage to the Concrete Components

Figure 6 shows the damage to the concrete components at fracture.

In the A and B types, cracks occurred in front of the bearing plate owing to the bearing pressure of approximately *P*=180 kN, and cracks occurred in the rear stud position at the maximum force. In the H type, the closing plates at both ends contributed to the bearing resistance, and cracks did not occur until the maximum force was reached. In the rear concrete of the gusset plate, cracks fractured and the force decreased.



(a) A type (b) B type (c) H type

Figure 6. Damage to the concrete components at fracture.

3.2 Curvature of the Stud Bolts

Figure 7 shows the vertical curvature of each of the four studs welded to one side of the steel plate.

In the A type, the difference in curvature between the stud bolts 1 and 2 was small, but in the B type, the curvature of stud bolt 2 was larger than that of stud bolt 1. This may be because the connection rotates around the bearing plate and the shear force generated in rear stud bolt 2 is large. In the H type, it is difficult for the connection to rotate because of the influence of the closing plates; hence, all stud bolts have a small curvature.

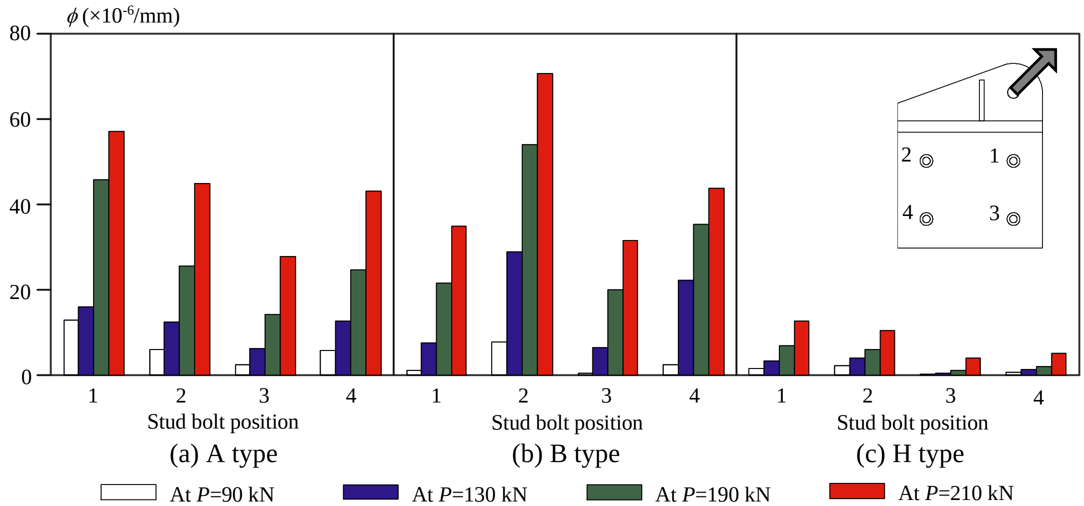


Figure 7. Vertical curvature of the stud bolts.

3.3 Relationship of the Displacement Versus Force

Figure 8(a) and 8(b) show the relationship of the relative vertical displacement δ_V versus force P and the relationship between the relative horizontal displacement δ_H and the force P, respectively.

At the design force of the damper (P=50 kN), almost no displacement occurred in any type. The H type showed considerable stiffness and strength owing to the bearing resistance of the closing plate.

Finally, the evaluation method for the force–displacement curve of the A and B types is examined. Assuming that the stiffness is reduced owing to the cone-shaped fracture of the concrete around the stud bolts, shear transmission with all eight stud bolts is considered until a cone-shaped fracture occurs. After this fracture occurs, shear transmission with the lower four stud bolts is considered. The relationship between the vertical force P_V and the vertical displacement δ_V of the connection was calculated by applying the equation that expresses the relationship of the shear force generated versus the displacement in one stud bolt (Architectural Institute of Japan 2011). Based on the above assumptions, the vertical force P_V was converted to the jack axial force P, and the calculated value was obtained as shown in Eq. (1), Eq. (2), Eq (3). The calculated values are also shown in Figure 8(a). The force–displacement curve could be evaluated using the calculated value from the above assumptions.

$$\delta_V = -\frac{{}_{st}D}{\alpha}\ln\left\{1-\left({P_V/8}\Big/{{}_{st}Q_U}\right)^{5/2}\right\} \text{ (Before the cone-shaped fracture occurs)} \quad (1)$$

$$\delta_V = -\frac{{}_{st}D}{\alpha}\ln\left\{1-\left({P_V/4}\Big/{{}_{st}Q_U}\right)^{5/2}\right\} \text{ (After the cone-shaped fracture occurs)} \quad (2)$$

$$\alpha = 11.5\{1.1({}_{st}\gamma - 1)^2 + 1\}\frac{f_{C'}}{f_{C0}} \quad (3)$$

where ${}_{st}D$ and ${}_{st}Q_U$ are the diameter and shear strength of the stud bolt, respectively, P_V is the vertical component of force, ${}_{st}\gamma$ is the ratio of ultimate force of stud bolt (The product of the cross-sectional area of the stud bolt and the ultimate strength f_u.) to the ultimate force obtained from regression analysis equation of past data (Hiragi *et al.* 1989), f_C' is the concrete strength, and f_{C0} = 30 N/mm^2.

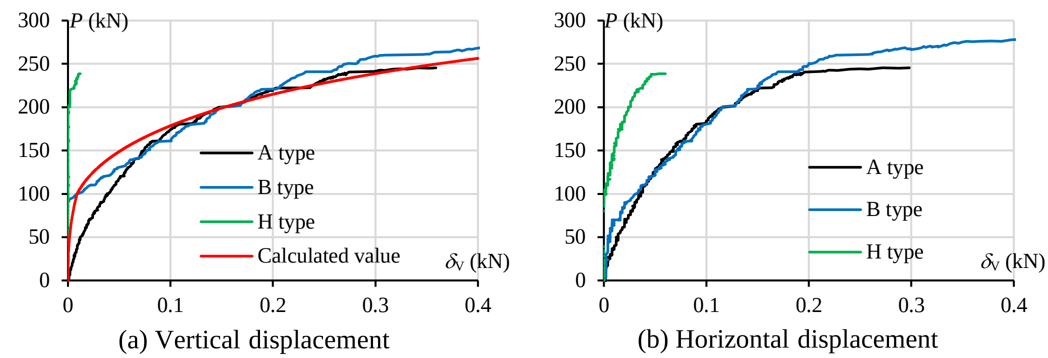


Figure 8. Relationship of the relative displacement versus force.

4 CONCLUSIONS

In this study, the structural behavior of connections between concrete components and a gusset plate with stud bolts was investigated using a component test. The results are summarized below.

(1) For the gusset plate with stud bolts embedded in concrete components, the stiffness of the connections was different depending on the arrangement of the stud bolts. In addition, the specimen with the closing plates had high stiffness and strength owing to the bearing resistance of the closing plates;

(2) The relationship between the vertical force P_V versus the vertical displacement δ_V of the connection was calculated by applying the equation that expresses the relationship of the shear force generated versus the displacement in one stud bolt. Assuming that the stiffness is reduced owing to the cone-shaped fracture of the concrete around the stud bolts, shear transmission with all eight stud bolts is considered until a cone-shaped fracture occurs. After this fracture occurs, shear transmission with the lower four stud bolts is considered. The force–displacement curve could be evaluated using the calculated value from the above assumptions.

Acknowledgments

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References

Architectural Institute of Japan, *Design Recommendations for Composite Structures* (in Japanese), November, 2010.

Architectural Institute of Japan, *Stress Transferring Mechanism and Resistance Mechanism of Steel-Reinforced Concrete Joints* (in Japanese), February, 2011.

Hiragi, H., Matsui, S., and Fukumoto, Y., *Derivation of Strength Equations of Headed Stud Shear Connectors - Static Strengths* (in Japanese), Journal of Structural Engineering, Japan Society of Civil Engineers, 35A, 1221-1232, March, 1989.

Maida, Y., Sakata, H., Qu, Z., Maegawa, T., and Suzuki, H., *Cyclic Loading Test of Lightly Reinforced Concrete Wall Piers with Slit Dampers in RC Frames*, Engineering Structures, 236, 112099, June, 2021.