IMPROVEMENT OF BEARING FAILURE BEHAVIOR OF S BEAM- RC COLUMN JOINTS USING FERFOBOND PLATE CONNECTORS

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SUMMARY:
To improve the bearing failure behavior of S beam – RC column joints, two joint details using perfobond plate connectors were proposed. In the horizontal type, perfobond plate connectors were attached on the upper and bottom flanges of the embedded steel beam on a parallel with the steel flange. In the vertical type, perfobond plate connectors were attached on the upper and bottom flanges at right angles to the steel flange. From the test results, seismic performance was shown to be improved by proposed joint details using perfobond plate connectors. Based on the stress transferring mechanism and resistance mechanism of the joints proposed by authors, the design formulae of joints with perfobond plate connectors were proposed. The predictions were shown to be in good agreement with the test results.

Keywords: S beam, RC Columns, Beam-Column Joints, Bearing Failure Behavior, Perfobond plate Connecters

1. INTRODUCTION

Recently, various innovative types of composite construction have been developed in Japan. One clear trend in composite construction has been the increased use of frames with reinforced concrete columns and steel beams. Seismic performance of the frame is considerably influenced by that of the joints. Accordingly, it is very important to clarify the behavior of the joints. So far many experimental and theoretical studies on the joints have been carried out. It was clarified that shear failure and bearing failure are the key failure modes for the joints composed of steel beam and reinforced concrete columns. The shear failure indicates stable hysteresis loops without the strength degradation. On the other hand, the bearing failure mode indicates large pinching and strength degradation after the attainment of the maximum load. Accordingly, bearing failure in the joints should be avoided in RCS

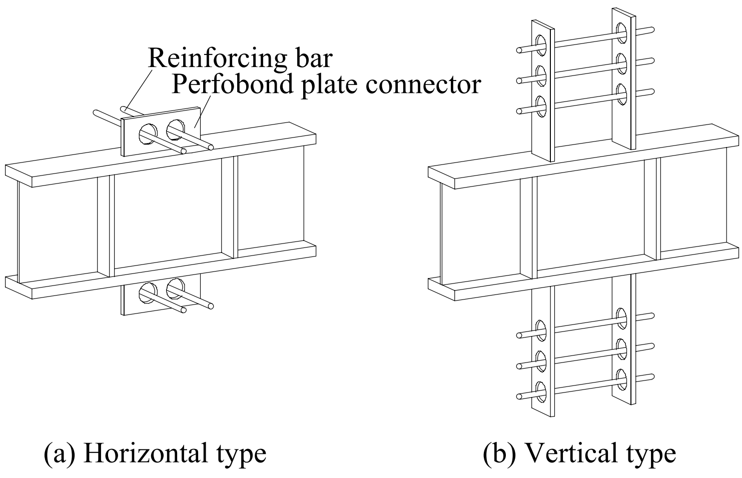

Figure 1. Proposed joint details

system. To improve the bearing failure behavior of S beam – RC column joints, joint details using perfobond plate connectors were proposed.
The objective of this study is to clarify the effectiveness of proposed joint details experimentally and theoretically. In addition, the objective of this study is to propose bearing design formulae taken account of the effect of perfobond plate connectors based on the stress transferring mechanism and resistance mechanism proposed by authors.

2. PROPOSED JOINTS DETAILS USING PERFOBOND PLATE CONNECTORS

To improve the bearing failure behavior of S beam – RC column joints, two joint details using perfobond plate connectors were proposed. Proposed joint details are shown in Fig.1. Fig.1 (a) shows the horizontal type. In the horizontal type, perfobond plate connectors were attached on the upper and bottom flanges of the embedded steel beam on a parallel with the steel flange. On the other hand, Fig. 1(b) shows the vertical type. In the vertical type, perfobond plate connectors were attached on the upper and bottom flanges at right angles to the steel flange. The embedded steel beam in the column is resisted by prying action. Accordingly, it is considered that perfobond plate connectors act for preventing rotation of the steel beam.

3. EXPERIMENT

To clarify the effectiveness of the proposed joint details, four specimens were tested. The overall dimensions of the specimen, the cross sections and reinforcement details are shown in Fig. 2. All specimens were interior planar beam-column joints with 350 mm square columns and steel beam with the width of 125 mm and the depth of 300 mm. The beams were all continuous through the column. All specimens were designed so that joint shear failure of the inner panel with steel flange width does not occur. The transverse reinforcement ratio of the joints was 0.81%. The joints details are shown in Fig.3. In the horizontal type, two holes were set up. On the other hand, three holes were set up in the vertical type. The diameter of the hole was 50 mm for all types. The inserted reinforcing bar was the deformed bar of the diameter of 13 mm.
The experimental variables were the type of perfobond plate connector and the existence of the reinforcing bars inserted in the holes. The overall test program was shown in Table 1.

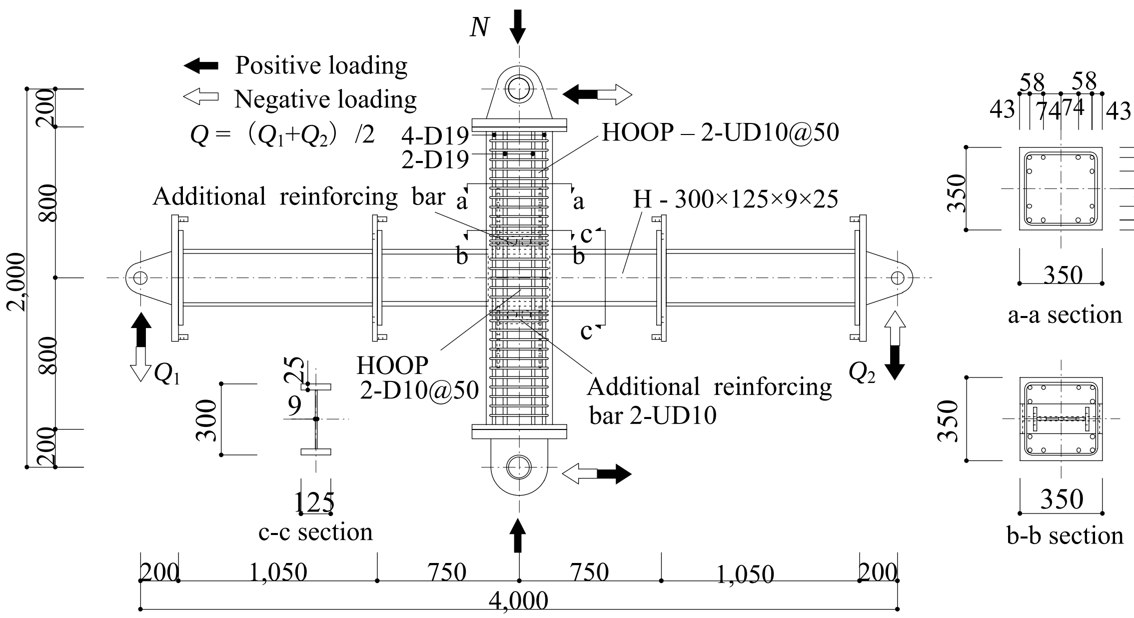

Figure 2. Test specimen

Table 1. Test program

Specimen	Column	Beam	Joint: Transverse Reinforcing bar	Joint: Perfobond plate connector	Joint: Reinforcing bar inserted in hole
N	350×350 (mm) Longitudinal reinforcing bar 12-D19 Hoop 2-D10@50	H-300×125 ×9×25	2-D10@50	-	-
H				Horizontal type	-
V				Vertical type	-
VR					D13

Table 2. Mechanical properties of materials

Steel	σ_y (N/mm²)	σ_u (N/mm²)	E_s (N/mm²)	Reinforcing bar	σ_y (N/mm²)	σ_u (N/mm²)	E_s (N/mm²)	Concrete σ_B (N/mm²)	σ_t (N/mm²)	E_c (N/mm²)
				D19	371	572	1.75×10^5			
PL 9	421	563	2.26×10^5		(383)	(549)	(1.83×10^5)			
PL12	282	434	2.04×10^5	UD10	981	1009	1.94×10^5	24.2	2.60	2.60×10^4
	(265)	(428)	(1.90×10^5)		(981)	(1009)	(2.05×10^5)	(26.1)	(2.23)	(2.42×10^4)
PL16	271	465	2.07×10^5	D10	342	468	1.62×10^5			
PL25	328	521	2.16×10^5		(398)	(463)	(1.64×10^5)			
				D13	(367)	(498)	(2.30×10^5)			

σ_y : Yield strength, σ_u : Maximum strength, E_s : Young's modulus,
σ_B : Compressive strength, σ_t : Splitting tensile strength, E_c : Young's modulus,
( ) : Values used for specimen VR ,

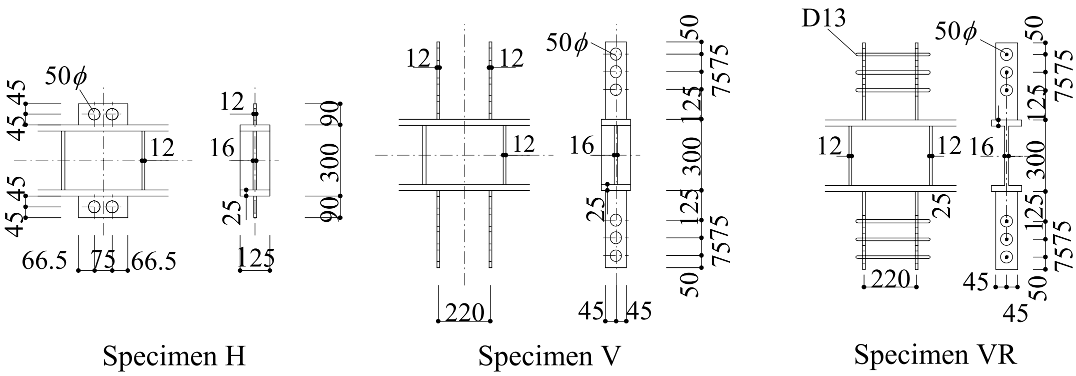

Figure 3. Joint details

The mechanical properties of the materials are listed in Table 2.
The reversed cyclic loading was applied at both ends of the beams anti-symmetrically under constant axial load: $N/bDF_c=0.167$, where N, bD and F_c represent the axial load, cross-sectional area of the columns and concrete compressive strength, respectively.

4. TEST RESULTS

Concrete crushing around the joints after test are shown in Fig. 4. In case of Specimen N, H and V, concrete crushing caused by bearing on the upper and bottom flanges of the embedded steel beam was remarkable. However, concrete crushing was not observed for Specimen VR with the reinforcing bars inserted in the holes.
Load-displacement relationships are shown in Fig.5. The vertical axis represents the applied load at the end of the beam. The horizontal axis gives the deflection of the beam relative to the column at the

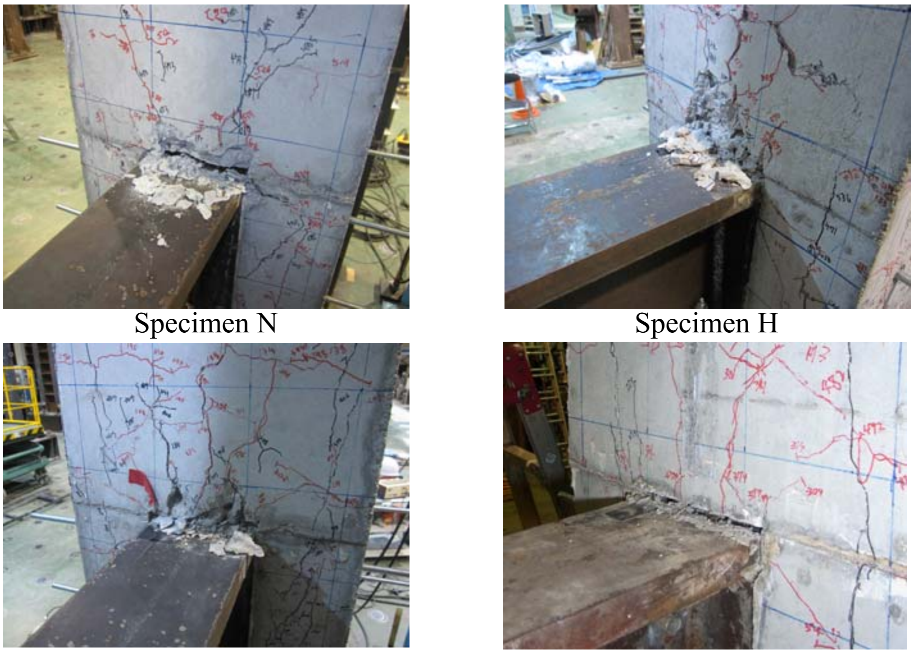

Figure 4. Concrete crushing around joint

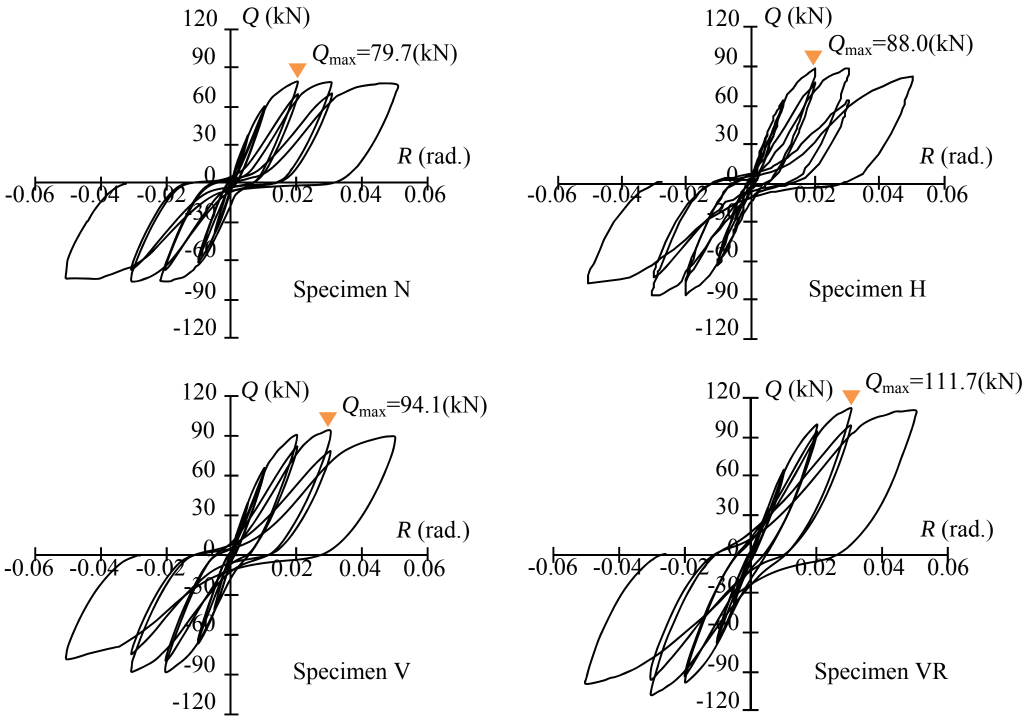

Figure 5. Load versus deflection angle relations

end of the beam. For all specimens, the hysteresis loop shows the reversed S-shape. However, energy dissipation for specimens with perfobond plate connectors was larger than that of specimen without perfobond plate connectors.

Fig. 6 shows the envelop curves for hysteresis loops. Deterioration of the strength after the maximum load was very small. Bearing strength of specimens with perfobond plate connectors was larger than that of specimen without perfobond plate connectors. Bearing strength of the specimen with reinforcing bars inserted in the hole was larger than that of the specimen without reinforcing bars.

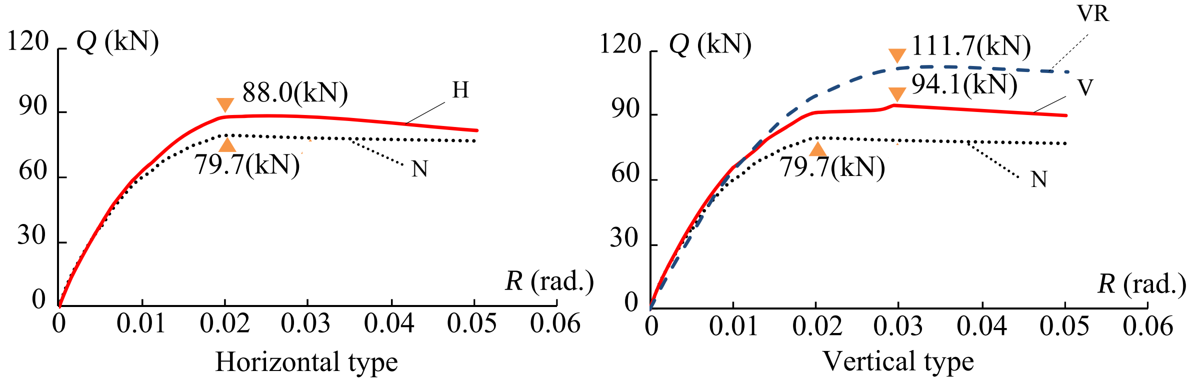

Figure 6. Envelope curves for load versus deflection angle relations

From the test results, shear strength of concrete connector a hole was 0.8 times compression strength of concrete. On the other hand, shear strength of inserted reinforcing bar was 0.8 times shear strength of reinforcing bar.

5. RESISTANCE MECHNISM AND PREDICTION OF ULTIMATE STRENGTH

RCS beam-column joint is assumed to be composed of the inner panel with the steel flange width and the outer panel outside the steel flange, and ultimate strength of the joint is assumed to be estimated by superposing that of the inner panel and the outer panel.

In this test, the ultimate strength of each specimen was determined by the bearing strength of the concrete on the upper and bottom flanges of the embedded steel beam. Accordingly, the bearing strength of the joint is described in this paper.

Resistance mechanism is shown in Fig. 7. As shown in Fig. 7(a) and (b), the inner panel is resisted by prying action. Accordingly, it is considered that perfobond plate connectors act for preventing rotation of the steel beam. The relationships between the resistance moment M and the axial compression N of the concrete section at the upper and bottom flanges of the embedded steel beam are given as ${}_{i}I_b$ as shown in Fig. 8 (a).

On the other hand, the outer panel is assumed to be resisted by a combination of the concrete compression strut (arch mechanism) and concrete compression field (truss mechanism) as shown in Fig. 7 (c) and (d). The ultimate strength of the arch mechanism is estimated as ${}_{o}I_a$ as shown in Fig. 8 (b). The ultimate strength of the truss mechanism is estimated as ${}_{o}I_b$ as shown in Fig. 8 (b). The ultimate strength of the outer panel ${}_{o}I_{ab}$ is obtained by superposing that of the arch mechanism ${}_{o}I_a$ and the truss mechanism ${}_{o}I_b$. It should be noted that if the stress developed at the inner panel is transferred to the outer panel perfectly, the ultimate strength of the outer panel can be estimated as the interaction

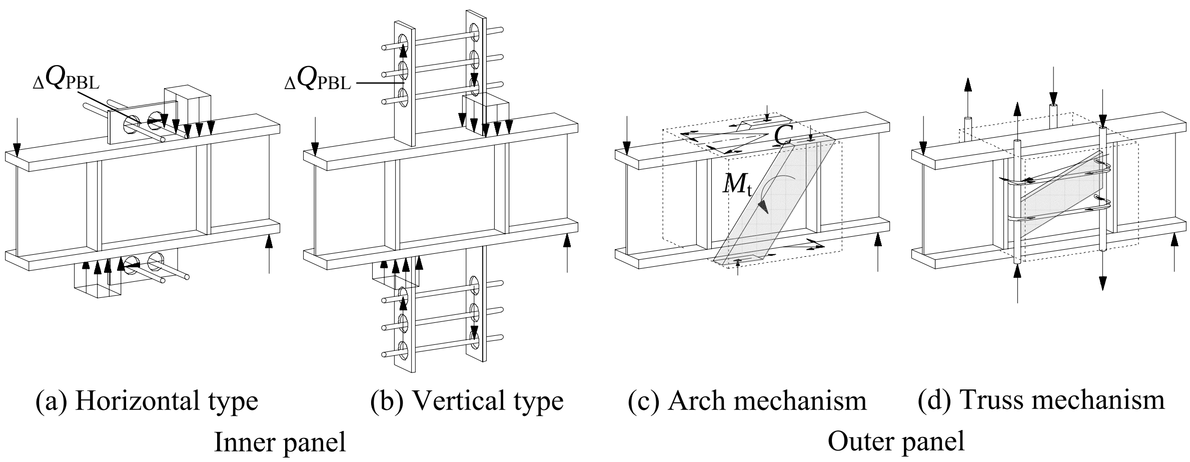

Figure 7. Resistance and stress transferring mechanism

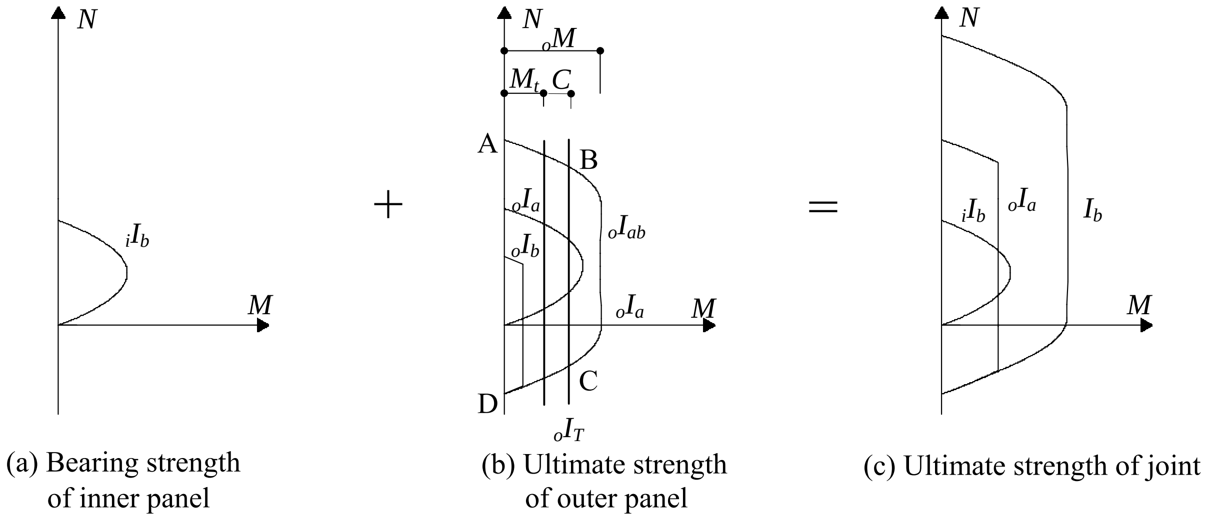

Figure 8. Predictions of ultimate strength

curve $_oI_{ab}$. However, the ultimate strength of the outer panel is controlled by the strength $_oI_T$ transferred from the inner panel to the outer panel. The strength $_oI_T$ transferred from the inner panel to the outer panel is developed by the strength C of the horizontal strut-and-tie mechanism and the strength M_t of the torsion between the inner panel and the outer panel as shown in Fig.7 (c) and (d), respectively.
The ultimate strength I_B of the joint can be estimated by superposing that of the inner panel $_iI_b$ and the outer panel $_oI_{ab}$ as shown in Fig. 7 (c).
Based on these mechanisms, bearing strength $_pM_b$ was given as follows:
In case of horizontal type
i) $M_t \geq {_oM}$

$$_pM_b = \left({_iM_b} + Q_{PBL} \cdot {_jd}\right) + {_oM} \tag{5.1}$$

ii) $M_t \leq {_oM}$ *and* $Q_{PBL} \cdot {_jd} \leq \left({_oM} - M_t\right)$

$$_pM_b = {_iM_b} + \left(M_t + Q_{PBL} \cdot {_jd}\right) \tag{5.2}$$

iii) $M_t \leq {_oM}$ *and* $Q_{PBL} \cdot {_jd} \geq \left({_oM} - M_t\right)$

$$_pM_b = \left\{{_iM_b} + Q_{PBL} \cdot {_jd} - \left({_oM} - M_t\right)\right\} + {_oM} \tag{5.3}$$

In case of vertical type

$$_pM_b = \left({_iM_b} + Q_{PBL} \cdot {_jd}\right) + \min\left({_oM}, M_t\right) \tag{5.4}$$

Where, $_iM_b$: Bearing strength of inner panel

$$= 0.21 \cdot {_cD^2} \cdot {_sb} \cdot \lambda F_c$$

$_oM$: strength of outer panel

$$= 0.6 \cdot D_c \cdot \left(B_c - {_sb}\right) \cdot F_c \cdot {_sj_b} \cdot \sin\alpha \cdot \cos\alpha$$

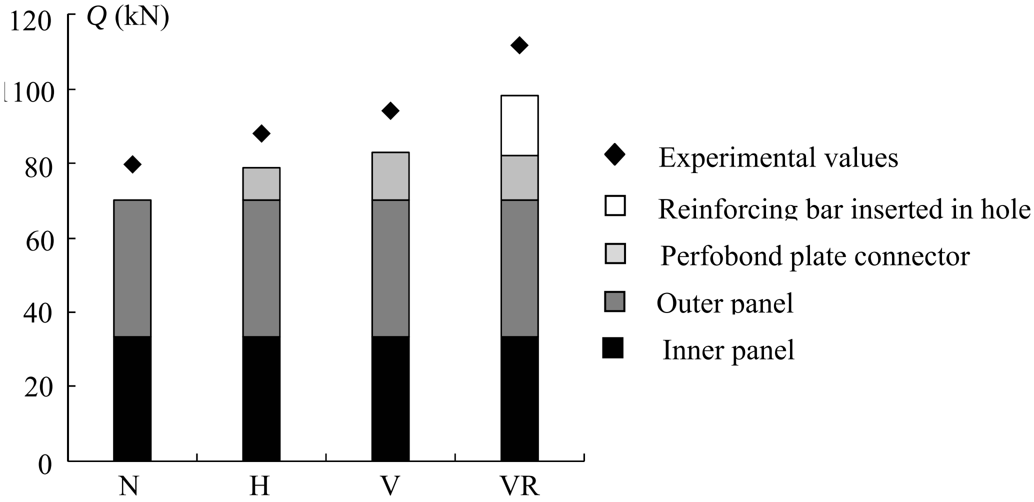

Figure 9. Application of proposed method

M_t : torsional strength between inner panel and outer panel

$$= \left(0.26 + 3.22 \cdot p_w \cdot \sigma_{wy} \cdot \frac{B_c}{D_c} \cdot \frac{1}{F_c}\right) \cdot \left\{\frac{{}_s d^2 \cdot (3 \cdot D_c - {}_s d) \cdot F_c}{6}\right\}$$

Q_{PBL} : strength of perfobond plate connectors

$$= {}_\Delta Q_c + {}_\Delta Q_r$$

$$\Delta Q_c = 0.8n(A_c - A_r) \cdot F_c$$

$$_\Delta Q_r = 0.8n \frac{{}_r\sigma_y}{\sqrt{3}} \cdot A_r$$

A_c : section area of hole
A_r : section area of reinforcing bar inserted in hole
B_c : column width
D_c : column depth
${}_j d$: in case of horizontal type , distance between hole and hole of perfobond plate connector attached on the upper and bottom flanges.
in case of vertical type, distance between perfobond plate connector and perfobond plate connector attached on the upper and bottom flanges.
${}_s d$: depth of steel beam
F_c : compressive strength of concrete
${}_s j_b$: $= {}_s d - t_f$
n : number of hole
p_w : transverse reinforcement ratio of joint
t_f : thickness of flange
α : angle between concrete strut of joint and axis of beam $\alpha = \cos^{-1} \frac{0.4 D_c}{\sqrt{0.16 {D_c}^2 + {}_s {j_b}^2}}$

λ : bearing factor 1.5

σ_{wy} : yield stress of transverse reinforcing bar

${}_r\sigma_y$ = yield stress of reinforcing bar inserted in hole

The comparison of the calculated vales obtained by the proposed formulae with the test results is shown in Fig. 9. The calculated vales were shown to be in good agreement with the test results.

6. CONCLUSIONS

1) For all specimens, the hysteresis loop shows the reversed S-shape. However, energy dissipation for specimens with perfobond plate connectors was larger than that of specimen without perfobond plate connectors. From test results, Seismic performance was shown to be improved by proposed joint details using perfobond plate connectors.
2) Shear strength of perfobond plate connectors was estimated by superposing concrete shear strength and that of the inserted reinforcing bar. In this test, shear strength of concrete connector a hole was 0.8 times compression strength of concrete. On the other hand, shear strength of inserted reinforcing bar was 0.8 times shear strength of reinforcing bar.
3) Based on the stress transferring mechanism and resistance mechanism of the joints proposed by authors, the design formulae of joints with perfobond plate connectors were proposed. The predictions were shown to be in good agreement with the test results.

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