12th International Conference on Advances in Steel-Concrete Composite Structures (ASCCS 2018)
Universitat Politècnica de València, València, Spain, June 27-29, 2018
Doi: http://dx.doi.org/10.4995/ASCCS2018.2018.7007

Improvement of bearing failure behaviour of T-shaped steel beam-reinforced concrete columns joints using perfbond plate connectors

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Abstract

To improve the bearing failure behavior of T – shaped S beam – RC column joints, joint details using perfobond plate connectors were proposed. Perfobond plate connectors were attached on the bottom flanges at right angles to the steel flange. The objective of this study is to clarify the effectiveness of proposed joint details experimentally and theoretically.

Six specimens were tested. All specimens were T-shaped planar beam – column joints with 350mm square RC column and S beams with the width of 125mm and the depth of 300mm. The beams were all continuous through the column. Perfobond plate connectors were attached on the bottom flanges at right angles to the steel flange. Three holes were set up in the perfobond plate connectors. The diameter of the hole was 50mm. The experimental variable was the transverse reinforcement ratio of the joints. The transverse reinforcement ratio of the joints was 0.181% and 0.815%. For each transverse reinforcement ratio of the joints, specimen without the perfobond plate connectors, specimen with the perfobond plate connectors and specimen with the reinforcing bar inserted the hole of perfobond plate connectors were planned.

For all specimens, the hysteresis loop showed the reversed S-shape. However, energy dissipation for specimens with perfobond plate connectors was larger than that of specimen without perfobond plate connectors. Bearing strength of specimens with perfobond plate connectors was larger than that of specimen without perfobond plate connectors. From the test results, shear strength of concrete connector a hole was 0.7 times compression strength of concrete. On the other hand, shear strength of inserted reinforcing bar was 1.25 times shear strength of reinforcing bar.

Based on the stress transferring mechanism and resistance mechanism of 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 Column, T – Shaped Beam – Column joints, Perfobond plate connecters, Bearing Failure Behavior*

1. Introduction

The composite structure (RCS) in which the columns are composed of reinforced concrete (here in after referred to as RC) and the beams are composed of steel (here in after referred to as S) is a structure utilizing the property of the members. Reinforced concrete is strong against axial force, steel is structure against bending and shear force.

For the joint composed of steel beams and reinforced concrete columns, shear failure and bearing failure are the key failure modes. The shear failure indicates stable hysteresis loop 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 not be caused in RCS system.

To improve the bearing failure behavior of RCS joints, joints details using perfobond plate connectors were proposed.

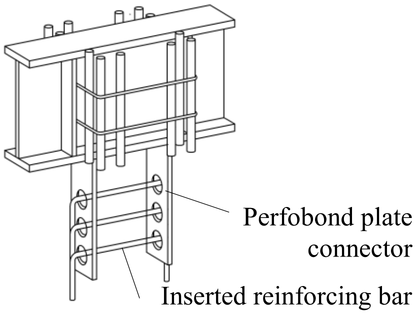


Fig.1. Proposed joint details

The objective of this study is to clarity the effectiveness of proposed joints details experimentally for the T-shaped RCS joints. 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 tranferring mechanism and resistance mechanism proposed by author [1].

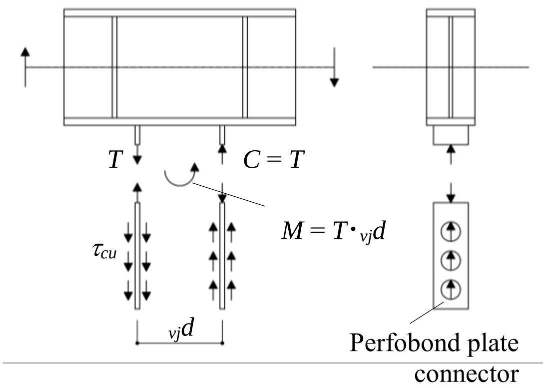
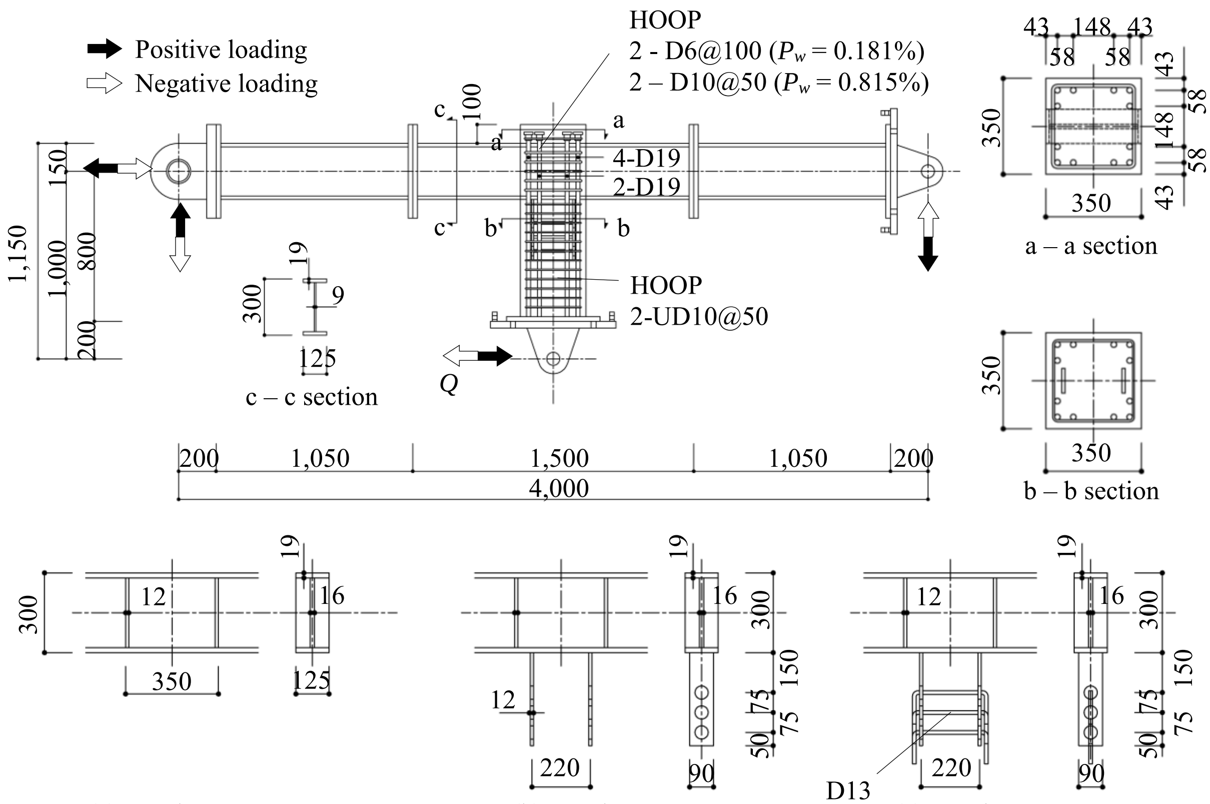


Fig.2. Bearing resistance mechanism of perfobond plate connector

2. Proposed joint detail using perfobond plate connector

Fig. 1 shows the proposed joint detail. In the joint detail, perfobond plate connectors were attached on the bottom flanges at right angle to the steel flange. As shown in Fig. 2, the proposed detail suppresses the rotation of the steel flange by applying compression force or tensile force as the S beam rotates.



(a) Specimen N, N2 (b) Specimen V, V2 (c) Specimen Vr, Vr2

Fig.3. 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 - UD10@50	H - 300× 125 × 9×25	2 - D6@100 (P_w = 0.181%)	-	-
V				vertical type	-
Vr					D13
N2			2 - D10@50 (P_w = 0.815%)	-	-
V2				vertical type	-
Vr2					D13

P_w : Transverse reinforcement ratio

Table.2. Mechanical properties of materials

Spcimen	Concrete σ_c N/mm^2	Concrete σ_t N/mm^2	Concrete E_c N/mm^2	Reinforcing bar	σ_y N/mm^2	σ_u N/mm^2	E_s N/mm^2	Steel	σ_y N/mm^2	σ_u N/mm^2	E_s N/mm^2
N	33.6	2.91	2.49× 10^4	D6	378	526	1.92× 10^5	PL 9	421	563	2.26× 10^5
V				D10	346	485	1.81× 10^5	PL 12	292	438	2.11× 10^5
Vr				UD10	966	1029	2.13× 10^5	PL 16	322	460	2.09× 10^5
N2	31.6	2.88	2.75× 10^4	D13	346	490	1.95× 10^5	PL 19	427	537	2.22× 10^5
V2				D19	373	554	1.82× 10^5				
Vr2											

σ_c : Compressive strength, σ_t : Tensile strength, E_c : Young's modulus of concrete

σ_y : Yield strength, σ_u : Maximum strength, E_s : Young's modulus of reinforcing bar and Steel

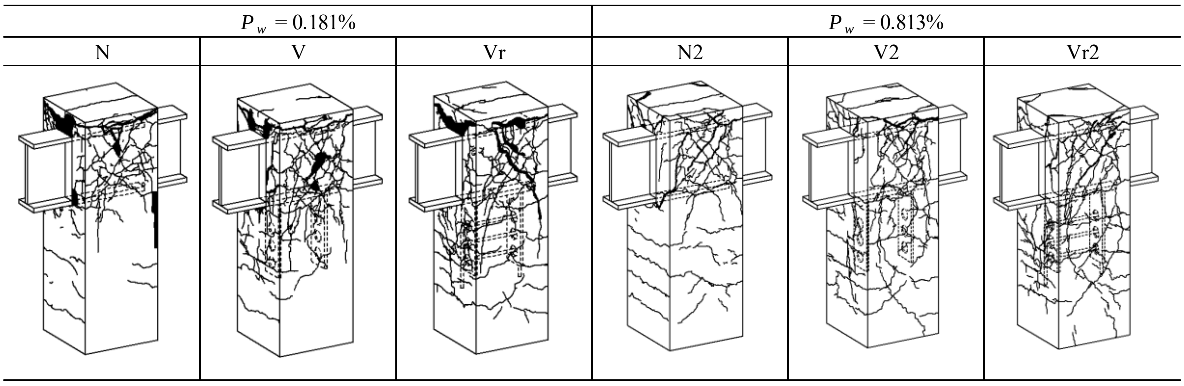


Fig.4. Crack patterns

3. Experiment

To clarify the effectiveness of the proposed joint d etails, six specimens were tested. [2, 3]

The overall dimensions of the specimen, the cross se ctions and reinforcement details are shown in Fig. 3. All specimens were T – shaped beam – column joints with 350mm square columns and steel beam with the width of 125mm and depth of 300mm. The transverse reinforcement ratio of joints was 0.181% and 0.815%. Perfobond plate connector had three holes. The diameter of the hole was 50 mm. The inserted reinforcing bar was the deformed bar of the diameter of 13 mm.

The experimental variables were the transverse reinforcement ratio of joints and reinforcing bars inserted in the holes. The overall test program was shown in the Table 1. The mechanical properties of the materials are listed in Table 2.

4. Test results

Crack pattens after test are shown in Fig. 4. For all specimens, punching shear failure was observed on the flange of the embedded steel

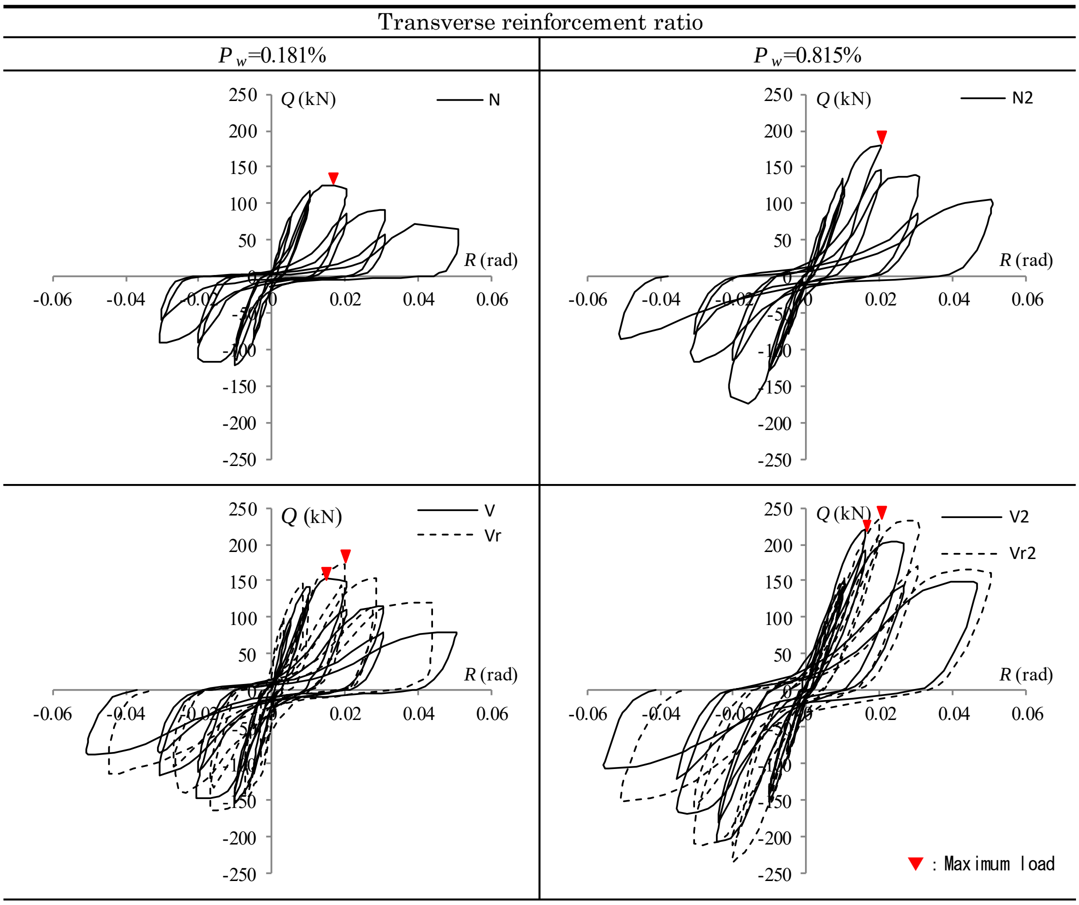


Fig.5. Load versus deflection angle relation

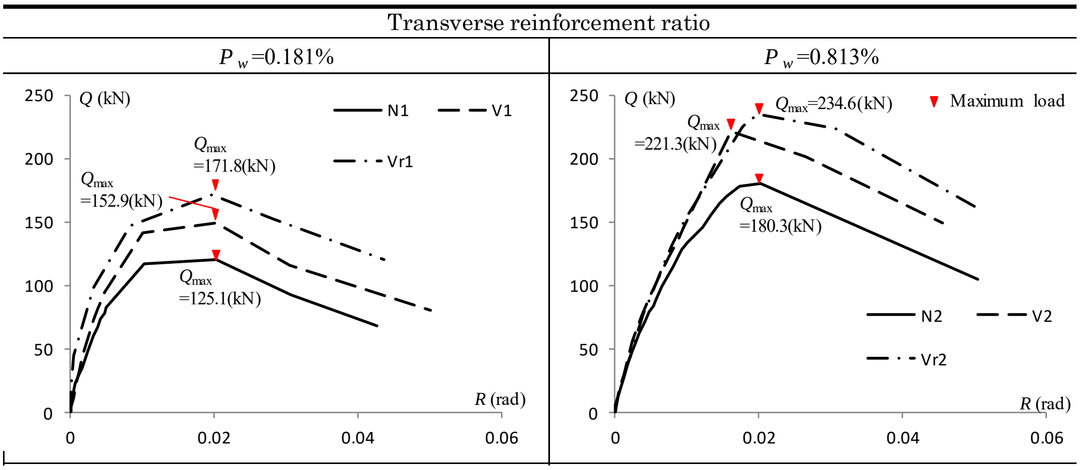


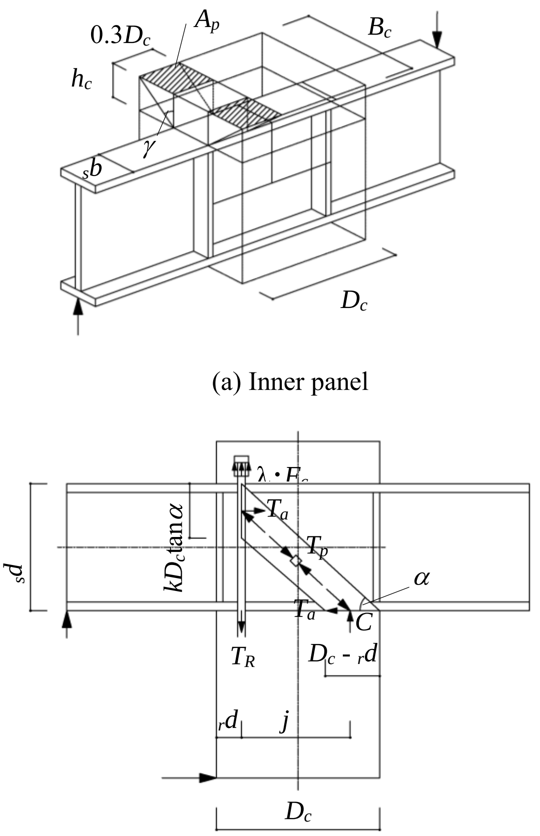
Fig.6. Envelope curves for hysteresis loops

beam. For specimens with $P_w = 0.181\%$, peeling of concrete was remarkable. On the other and, for the specimens with $P_w = 0.813\%$, no peeling of the concrete occurred.

The inner panel and outer panel were separated by torsion.

Load – displacement relationships are shown in Fig. 5. The vertical axis represents the applied load at the end of the column. The horizontal axis represents the sotry drift angle. For all specimens, the hysteresis loop shows the reversed S – shape.

Fig. 6 shows the envelop curves for hysteresis loops. Bearing strength of specimens with perfobond plate connectors was larger than that of specimen without perfobond plate connectors.



(a) Inner panel

(b) Outer panel

Fig.7. Resistance mechanism

Bearing strength of the specimens with reinforcing bars inserted in the hole was larger than that of the specimen without reinforcing bar.

From the test results, shear strength of concrete connector a hole was 0.7 times compression strength of concrete. On the other hand, shear strength of inserted reinforcing bar was 1.25 times shear strength of reinforcing bar.

5. Prediction of ultimate strength

The resistance mechanism of the T – shaped S beam – RC column joint was shown in Fig. 7.

The joint is assumed to be composed of the inner panel and the outer panel, and the ultimate strength of the joint is assumed to be estimated by superposing that of the inner panel and outer panel.

The ultimate strength of the inner panel is governed by punching shear strength of concrete on the top flanges of the embedded steel beam. On the other hand, the outer panel is assumed to be resisted by concrete compression strut (arch mechanism). The ultimate strength of the outer panel was effected by the strength of concrete compression strut and torsional strength between the inner panel and outer panel.

Based on these mechanisms, the ultimate strength ${}_pM$ was given as follows :

$$ {}_pM = \left({}_iM + M_{PBL}\right) + {}_oM \qquad (1) $$

Where, ${}_iM$: strength of inner pannel

$$ = Q_p \cdot 0.7 D_c \qquad (2) $$

$$ Q_p = A_p \cdot \sqrt{F_c} \qquad (3) $$

$$ A_p = 2 \cdot h_c \cdot \tan\gamma \cdot 0.3 D_c \qquad (4) $$

M_{PBL} : strength of perfobond plate connectors

$$ = Q_{PBL} \cdot {}_{vj}d $$

$$ Q_{PBL} = Q_c + Q_r \qquad (5) $$

$$ Q_c = \tau_{cu} \cdot n \cdot \left(A_c - A_r\right) \qquad (6) $$

$$ Q_r = \tau_r \cdot n \cdot A_r \qquad (7) $$

$$ \tau_{cu} = \cdot 0.7 \cdot F_c \qquad (8) $$

$$ \tau_r = \cdot 1.25 \cdot \frac{{}_r\sigma_y}{\sqrt{3}} \qquad (9) $$

${}_oM$: strength of outer pannel

$$ = \min\left({}_oM_T, {}_oM_a\right) \qquad (10) $$

${}_oM_T$: torsional strength between inner panel and outer panel

$$ = \left(0.25 + 1.26 \cdot P_w \cdot {}_w\sigma_y \cdot \frac{B_c}{D_c} \cdot \frac{1}{F_c}\right) \cdot \frac{{}_sd^2 \cdot \left(3D_c - {}_sd\right) \cdot Fc}{6} \qquad (11) $$

${}_oM_a$: strength of arch mechanism

$$ = \min\left({}_oM_p, {}_oM_y, {}_oM_b\right) \qquad (12) $$

${}_oM_p$: compression strength of compression struts

$$ = \frac{\left(D_c - {}_rd\right)^2}{2} \cdot \sin^2\alpha \cdot \left(B_c - {}_sb\right) \cdot F_c \qquad (13) $$

${}_oM_y$: yieid strength of the longitudinal reinforcing bar

$$= \sigma_y \cdot a_t \cdot \left(D_c - {}_r d - \frac{\sigma_y \cdot a_t}{2 \sin^2 \alpha \cdot (B_c - {}_s b) \cdot F_c} \right) \quad (14)$$

${}_oM_b$: bearing strength of the end plate

$$= \lambda \cdot F_c \cdot a_p \cdot \left(D_c - {}_r d - \frac{\lambda \cdot F_c \cdot a_p}{2 \sin^2 \alpha \cdot (B_c - {}_s b) \cdot F_c} \right) \quad (15)$$

F_c : compressive strength of concrete

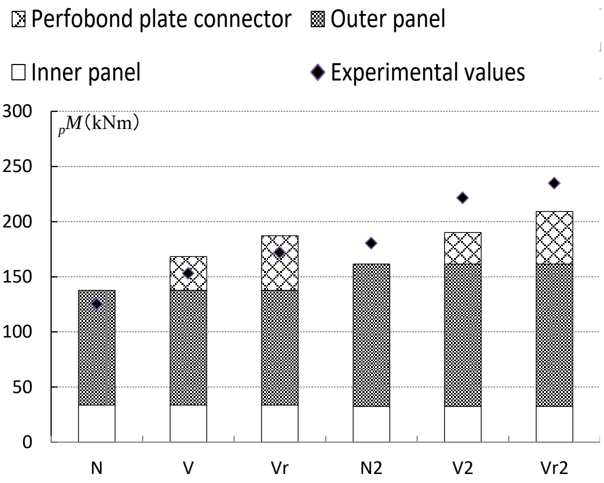


Fig.8. Application of proposed method

D_c : column depth

h_c : concrete height on the upper of the S flange

γ : $\gamma = \tan^{-1} \frac{(B_c - {}_s b)/2}{h_c}$

B_c : column width

${}_sb$: width of S flange

τ_{cu} : shear strength of concrete of perfobond plate connectors

τ_r : shear strength of inserted reinforcing bar of perfobond plate connectors

n : number of hole

A_c : section area of hole

A_r : section area of reinforcing bar inserted in hole

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

P_w : transverse reinforcement ratio of joint

${}_w\sigma_y$: yield stress of transverse reinforcing bar

${}_sd$: depth of steel beam

${}_rd$: distance from the column surface on the tensile side to the tensile longitudinal reinforcing bar center

α : $\alpha = \tan^{-1} \frac{{}_s d}{D_c - {}_r d}$

σ_y : yield stress of longitudinal reinforcing bar

a_t : section area of the tensile side longitudinal reinforcing bar

λ : bearing factor 1.5

a_p : section areas of end plate of the tensile side longitudinal reinforcing bar

The comparison of the calculated values obtained by proposed formulae with the test results is shown in Fig. 8. In the proposed formulae, the specimens N, V and Vr evaluated the test result to the unsafe side. On the other hand, the specimens N2, V2 and Vr2 evaluated on the safe side. This is presumed to be because the punching shear strength of the inner panel is assumed to be 0.3 · D_c, regardless of the transverse reinforcement ratio. However the calculated values were shown to be in good agreement with the test results.

6. Conclusions

1) For all specimens, the hysteresis loops show the reversed S – shape.

2) The maximum load increases with perfobond plate connectors. In addition, the maximum strength of the specimen with reinforcing bars inserted in the hole increases more than that of the specimen without reinforcing bar.

3） The shear strength of perfobond plate connectors can be evaluated by accumulating the shear strength of concrete and that of the inserted reinforcing bar. In this test, shear strength of consrete connector a hole was 0.7 times compression strength of concrete. On the other hand, shear strength of inserted reinforcing bar was 1.25 times shear strength of repinforcing bar.

4） The design formula considering the strength of perfobond plate connectors was proposed. The predictions were shown to be in good agreement with the test results.

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