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STRUCTURAL BEHAVIOUR OF REINFORCED CONCRETE COLUMN TO ITECH COMPOSITE BEAM JOINT

Young K. JU[1], Chan-Hyong LEE[2], Sung-Chul CHUN[3], Sang-Dae KIM[4]

SUMMARY

Due to the limited city area, story height is a significant component for the tall residential structures. To occupy less story height, the wide reinforced concrete (RC) beam was adopted in some projects such as Trump World and Galleria Palace in Seoul. However, the space for the joints between the wide beam and the core wall was too narrow for the reinforcement. In this paper, an alternative composite beam is proposed. The proposed composite beam is named iTECH (Innovative, Technical, Economical, and Convenient Hybrid) beam. It has an asymmetric steel assembly with web openings, where the top plate is welded on top of an inverted structural tee cut "honeycomb" style. To satisfy the requirement for moment resisting connection, the joint of RC column-iTECH composite beam was experimentally explored in this study. The findings can be summarized as follows: (1) The factors contributing to shear strength within the panel zone were inner and outer concrete panel. From the test results, it could be concluded that inner concrete panel with effective width b_i was sufficient for the shear force required and used in design equation. (2) The ductility of the joint was over 4.0, indicating that the joint showed good moment resisting capacity. (3) The panel zone showed 10% or 20% greater shear force than that of analysis. This meant that the proposed joint provided enough shear for the moment resisting joint detail.

INTRODUCTION

The steel composite beam with deck is widely used in the world because of its simple construction. The advantages of this type of beam are good workability and absence of formwork [Park 1999; KIA 2001]. However, several disadvantages of this beam include: (1) the upper flange of its steel section does not produce its structural capacity at the positive moment region; (2) its shear stud has to be set up at the site on top of the upper flange; and (3) the fire proofing material has to cover the exposed steel surface [DICT 1999]. The fact that steel composite beams are deeper than reinforced concrete beams also puts the composite beams at a disadvantage when it comes to the construction of high-rise residential buildings.

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[1] Ph.D., Research Scholar, The University of Texas at Austin, United States
[2] Senior Engineer, Dongyang Structural Safety, South Korea
[3] P.E., Senior Researcher, Daewoo Institute of Construction Technology, South Korea
[4] Ph.D., Professor, Korea University, South Korea

To achieve less story height, a newly developed composite beam was proposed and experimentally explored [Chun 2002; Ju 2002]. This new system illustrated in Figure 1 was called iTECH (Innovative, Technical, Economical, and Convenient Hybrid) system. The iTECH system had an asymmetric steel assembly with web openings where the top plate was welded on top of an inverted structural tee cut "honeycomb" style. The steel assembly was fabricated in the factory. The flat deck which have a flat bottom surface was put on the c-channel. Both sides of the web and the slab were filled in situ with concrete. The iTECH beam showed good workability that was almost similar to steel construction. The c-channel was placed on top of the bottom flange at the shop and supported the deck in the field. The web with the opening integrated the concrete and the asymmetric steel.

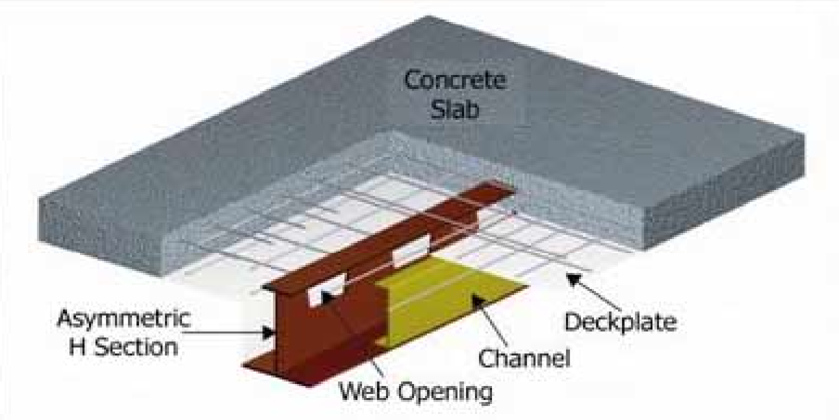


Figure 1. The iTECH composite beam.

This system achieved less story height than when steel composite beams were used. Shear connectors such as the stud bolts were not used; instead, longitudinal shear strength was obtained through the bond strength between steel and concrete and the bearing strength of the open web area. Therefore, iTECH could properly behave as a composite member [DICT 2002].

Many researchers studied and developed different types of joint, some of which were widely used in the world. However, each joint either had poor workability or cost limitations. The moment resisting joint was widely used in east asian countries while the pin joint was used in the western countries.[Nethercot, 1997] The details of moment resisting joint are more complicated than those of pin joint.

In this paper, a newly developed joint detail only for reinforced concrete column to iTECH beam joint was proposed and experimentally explored. Two full-scaled specimens were tested for the evaluation of panel zone detail. The test results were then compared with calculated values. The design equation for the proposed joint was also recommended.

RC COLUMN TO STEEL OR ITECH BEAM JOINTS

As illustrated in Figure 2, the bottom flange of iTECH beam was designed to resist the positive moment while the upper flange was for the negative moment at construction stage. The reinforcing bar in beam resisted the additional service load at negative moment zone. To obtain the continuity of tensile force through the panel zone, the bottom and upper flanges were connected with connection plate (CP).

The face bearing plate (FBP) was used to prevent concrete crushing within the panel zone. To transfer the force from beam to column, the hoop bar within the panel zone and band plate (BP) around the column were added.

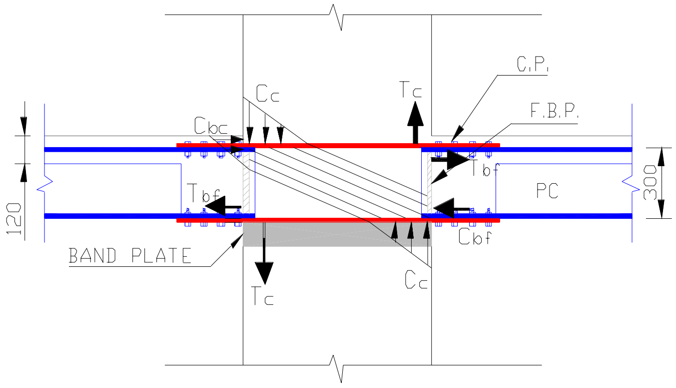


Figure 2. Schematic detail of joint force distribution within the panel zone.

For the reinforced concrete to steel beam(RCS) joint, steel web, inner and outer concrete panels resisted the force within the panel zone [ASCE 1997]. Figure 3 shows the details of the shear force-resisting components. The design equation was based on RCS recommendation [ASCE 1997].

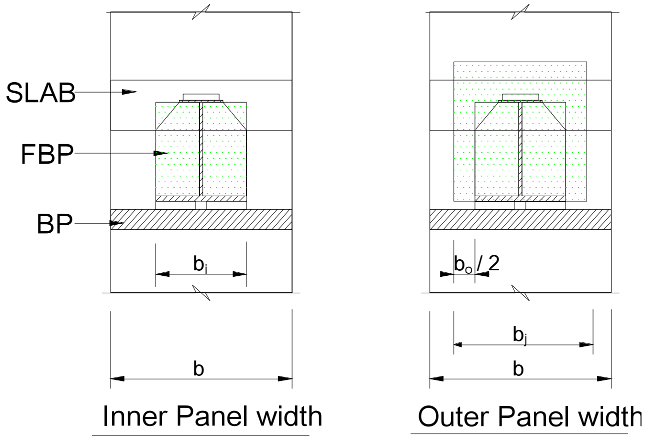


Figure 3. Effective width by RCS Recommendation.

In case of iTECH, there was no steel web within the panel zone. Therefore, the combination of inner and outer concrete panel resisted the shear strength required. As schematically illustrated in Figure 4, the strut was formed by the interaction between compression and tension. The shear force (kgf/cm^2) by inner concrete panel is the smallest of:

$$V_{cn1} = 5.49 b_i h_c \sqrt{f'_c} \tag{1}$$

$$V_{cn2} = 2 f'_c b_i (0.25) d_w \tag{2}$$

where d_w, b_i, f'_c, h_c are the web length of steel beam, effective width of inner concrete panel, compressive strength of concrete, and height of beam, respectively. The shear force(kgf/cm^2) by outer concrete panel is the smallest of:

$$V_{fn1} = 1.23 b_o h_c \sqrt{f'_c} + A_{ct} f_y \tag{3}$$

$$V_{fn2} = 5.49 b_o h_c \sqrt{f'_c} \tag{4}$$

where b_o, A_{ct}, f_y are effective width of outer concrete panel, hoop area, and yield strength of steel, respectively.

In the calculation of shear force within the panel zone, the effective widths of inner and outer concrete panels were the significant components. Therefore, the effective widths had to be verified by experimental test. Cyclic loading tests were performed to determine the appropriate effective widths.

CYCLIC LOADING TEST

Test Specimens

To obtain the shear capacity and seismic resistance of the joint, two specimens were tested. The stiffness of panel zone was the same for both cases. The shear failure and ultimate capacity of the panel zone were determined by increasing the stiffness of beam in the shear-failure specimen (RC-S). The failure of the flexure-failure specimen (RC-B) was determined by reducing the stiffness of the beam.

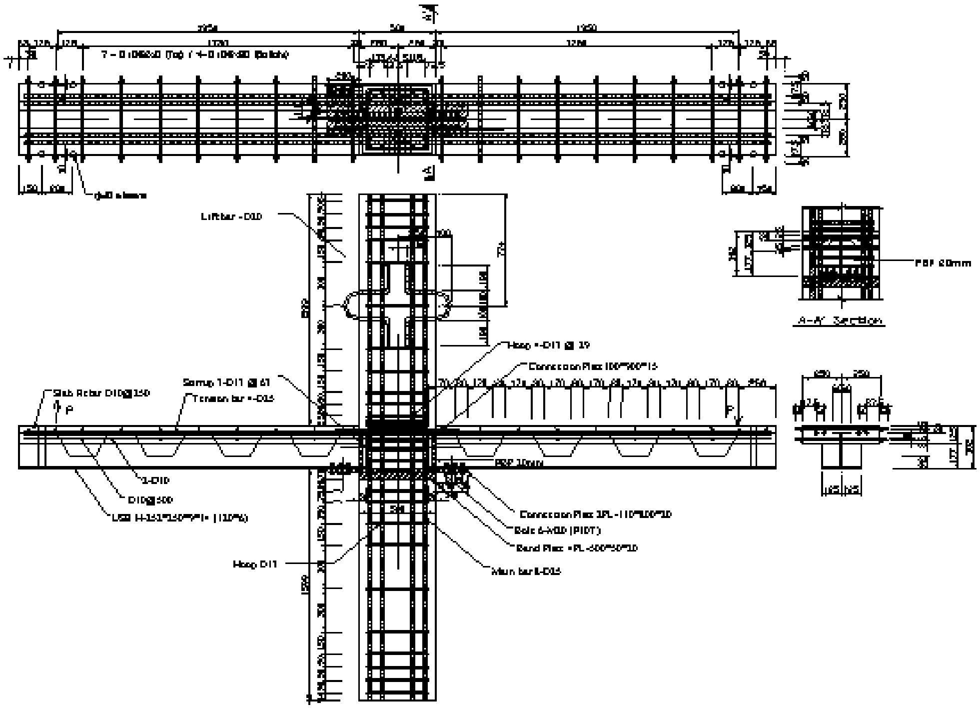


Figure 4. Details of specimen RC-S.

The plan and elevation of RC_S are illustrated in Figure 4. The significant difference between two specimens was the size of the reinforcing bar in beam. The details of the specimen are listed in Table 1. The beam was modeled as T section with column width 500 mm. The iTECH beam was placed on the reinforced concrete column by 50 mm offset. The connection plate joined the top and bottom flanges. The band plate was placed around the column and welded below the top connection plate.

Test Setup

As illustrated in Figure 5, the cyclic loading test was selected to obtain the seismic resistance of the joint. The load was applied 1.95m apart from the column. The cyclic load was applied under load control until yielding and displacement control after yielding. The load was increased to drift ratios 0.5%, 1.0%, 2.0%, 4.0%, and 8.0%. Each loading schedule was repeated to ensure the hysteretic behavior of the specimen. The criteria of failure consisted of concrete crushing, excessive deformation of tension bar and upper flange, occurrence of large crack, and reduction of strength of 85%.

Figure. 5. Test setup

To find the changes of strain within the member, steel strain gauges were attached on the anticipated plastic hinge and panel zone. To determine the displacement of the specimen at loading point, the displacement transducer was used; 200-mm displacement transducer for RC_S and 1,000-mm displacement transducer for RC_B due to large deflection. The rotational angle and shear deformation of panel zone were determined using 12.5-mm displacement transducer. The curvature of iTECH beam was obtained using 12.5-mm and 25-mm displacement transducers placed on both sides of iTECH beam.

TEST RESULTS

Material Properties

The properties of materials used in the test were verified using the standard testing method. The compressive strength of concrete, the tensile strength of steel and rebar, and the modulus of elasticity for each material were obtained. Three coupons for each case were tested. The 28-day concrete compressive strengths for RC-B and RC-S were 346 kgf/cm^2 and 380 kgf/cm^2, respectively. The measured yield strengths of rebar and steels were over 4,000 kgf/cm^2 and 2,700 kgf/cm^2, respectively.

Failure Patterns

In both cases, diagonal crack occurred from the upper edge of the specimen under negative moment. As shown in Figure 6, the failure pattern of RC-S was concrete crushing within the panel zone due to the break of the hoop-reinforcing bar. For RC-B, slab crushing occurred after the buckling of top flange and tension bar in beam.

Load Displacement Relationship

To find the real state of load-displacement relation, the load and displacement obtained in the test were transformed as the equivalent interstory shear force and drift, respectively.

$$V_{col} = \frac{P_1 l_1 + P_2 l_2}{l_c} \tag{5}$$

$$\delta_{col} = \frac{\delta_{B1} + \delta_{B2}}{l_1 + l_2} l_c \tag{6}$$

where V_{col} : equivalent interstory shear force

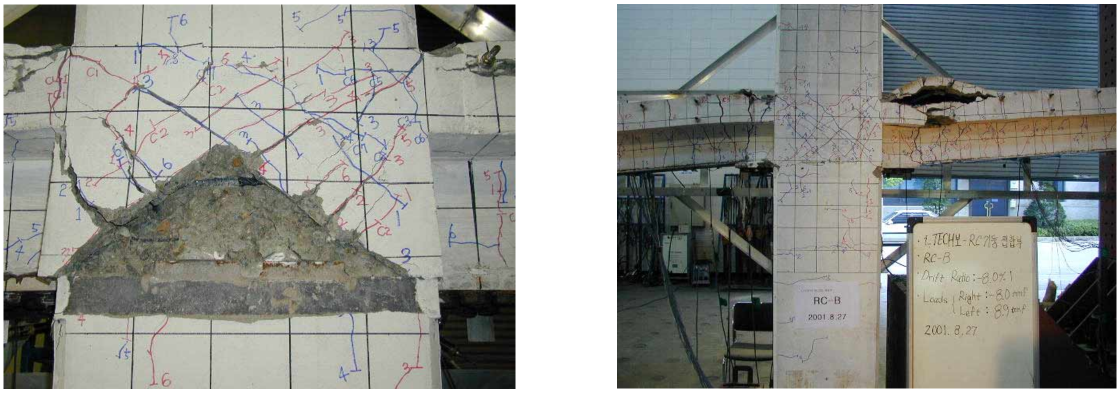
P_1 , P_2 : applied loads at both iTECH beams

l_1 , l_2 : length from center of column to both beam ends

δ_{B1} , δ_{B2} : beam deflection at loading points

δ_{col} : equivalent interstory drift

l_c : length from top to bottom of column



(a) RC-S (b) RC-B

Figure 6. Crack patterns.

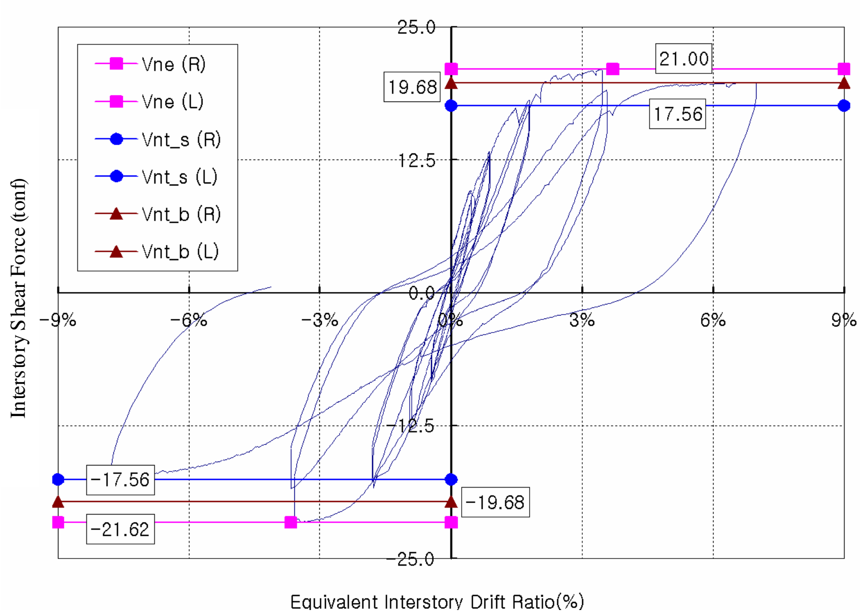


Figure 7. Load-displacement relationship for RC-S.

Figures 7 and 8 plot the equivalent interstory shear force-to-drift relation of the specimens. "R" and "L" stand for the right and left iTECH beam, respectively. V_{ne} is the experiment value while V_{nt} is the calculation value. For the shear failure model of RC-S, the yielding load was over the calculated loads, 17.56 tonf and 19.68 tonf from 10% to 20%. The analysis was based on AISC-LRFD [AISC 1994]. For RC-B, the analysis results were between beam failure load 16.55 tonf and joint failure load 17.93 tonf.

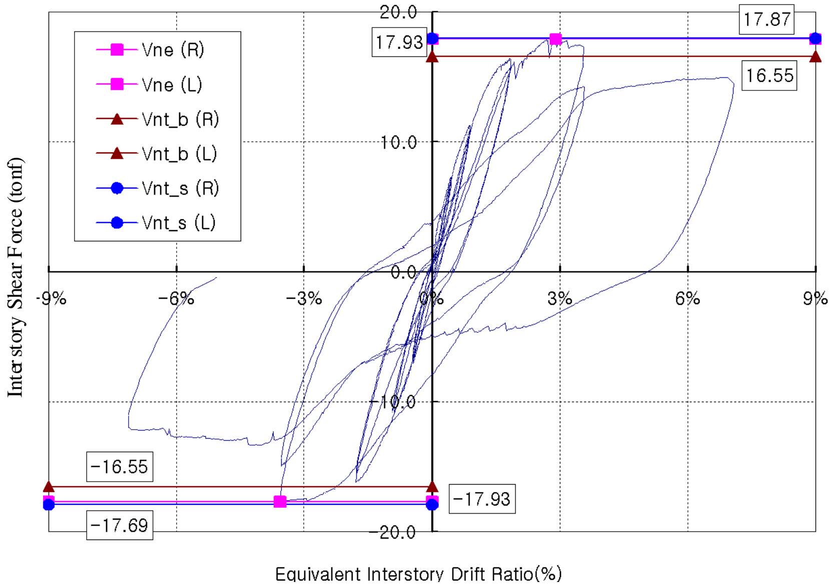
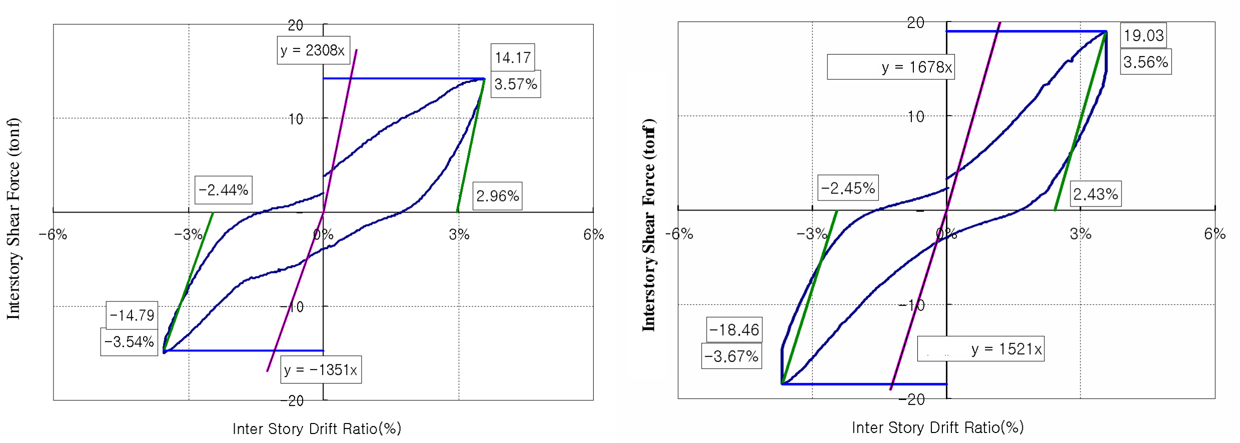


Figure 8. Load-displacement relationship of RC-B.

Energy Dissipation

Energy dissipation is the ratio of hysteretic area to the diamond shape area. To improve its safety, the structure subject to cyclic loadings had to sufficiently absorb the energy by the applied load. The energy dissipation capacity was assessed with the ACI ITG/T1 method. The maximum loads E_1, E_2 were calculated as the load at the last cyclic loading over 3.5% drift ratio. The story drift ratios θ_{1+}, θ_{1-} were obtained as the stiffness at maximum loading, in which the stiffness was the same as the initial stiffness K_{1+}, K_{1-}. As illustrated in Figure 9, the diamond shape area was obtained with the maximum loads and drift ratio. The criterion based on ACI ITG/T1 was 1/8 = 0.125. The calculated values were over the criteria with more than 100%. Therefore, it could be said that the proposed joint had sufficient energy dissipation capacity.



(a) RC-B (b) RC-S

Figure 9. Energy dissipation of RC-B.

Ductility

The ductility for both specimens is shown in Figures. 10 and 11. According to ACI ITG/T1, the required drift ratio without degradation of strength was 3.5%. In this test, the obtained drift ratio ranged from 6.98% to 7.78%, which were greater than the required 3.5%. Ductility factor is the ratio of displacement at ultimate strength to displacement at yielding strength. The ductility factors of both specimens satisfied the required value of ordinary reinforced concrete joint, 4.0. As the ductility factor became higher, the member or structure behaved more flexibly and could absorb more energy. Therefore, it could be said that the ductility of the joint tested was sufficient for moment resisting joint detail.

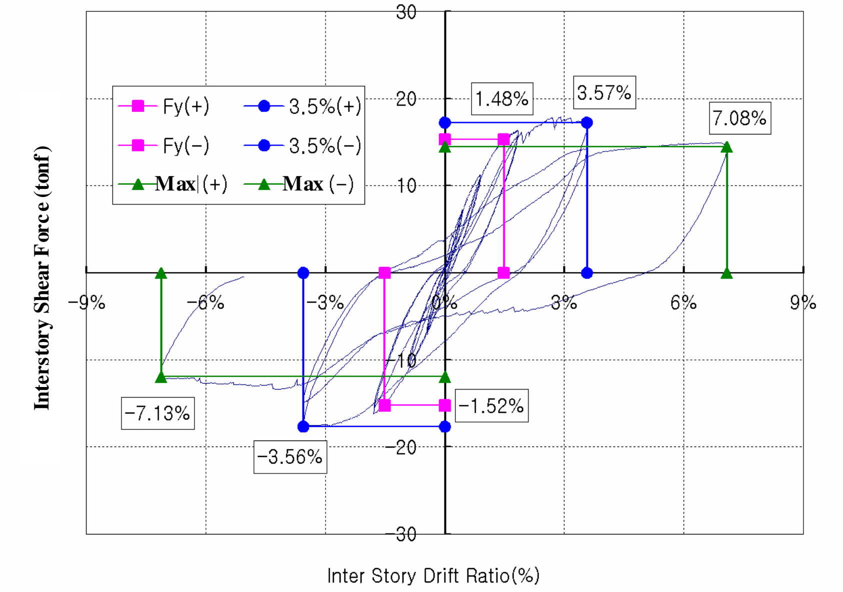


Figure 10. Ductility of RC-B.

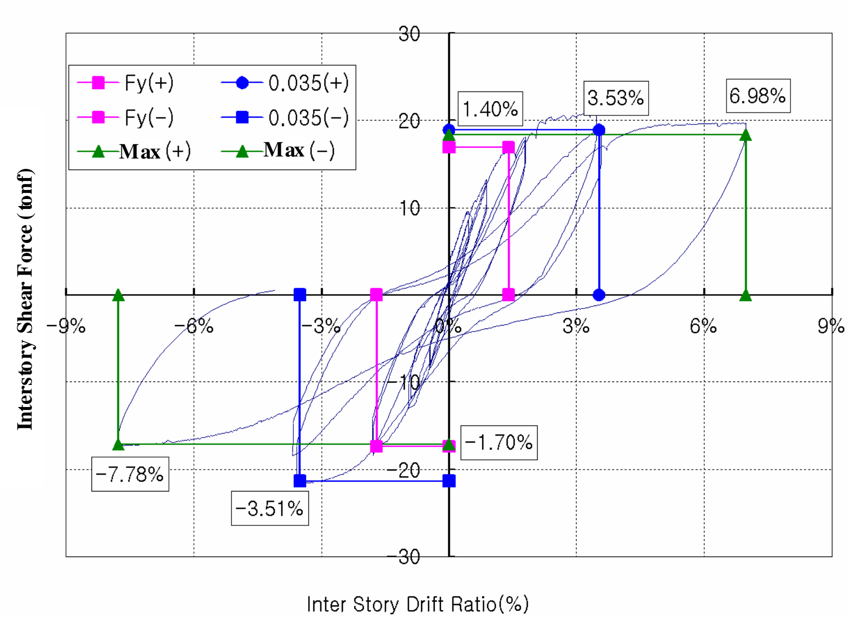


Figure 11. Ductility of RC-S.

Effective Width of Panel Zone

In calculating the inner concrete panel, the effective width of the panel zone was the significant factor, which had to be verified by the test. The area contributing to the shear force is shown in the left part of Figure 12. The effective width was determined from right part of the same figure for the design purpose. The shear force by inner concrete panel was determined as the smallest of Equations (1) and (2). The effective width of the inner concrete panel is shown in Figure 16. The outer concrete panel was not considered in the design equation.

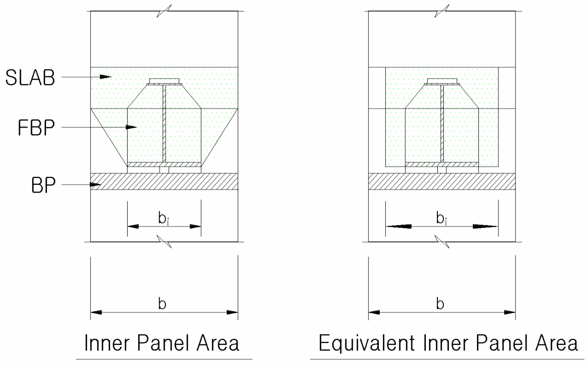


Figure 12. Effective width.

CONCLUSION

To save the story height, a new shallow beam named iTECH composite beam was introduced. To satisfy the requirement for moment resisting connection, the joint of RC column-iTECH composite beam was experimentally explored. The findings could be summarized as follows:

1. The factors contributing to shear strength within the panel zone were inner and outer concrete panel. From the test results, it could be said that inner concrete panel with effective width was sufficient for the shear force required.
2. The ductility of the joint was over 4.0, indicating that the joint showed good moment resisting capacity.
3. The panel zone showed 10% or 20% greater shear force than that of analysis. This meant that the proposed joint provided enough shear for the moment resisting joint detail.

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