V－28 EXPERIMENTAL STUDY ON MECHANICAL BEHAVIOR OF SHEAR CONNECTOR FOR STEEL-CONCRETE SANDWICH BEAM

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1. INTRODUCTION

In steel-concrete composite structure, shear connector is required for transfer of shear force between concrete and steel element in order to develop the composite action. It is important to understand the behavior and capacity of shear as basic knowledge for design of composite structure. There are some studies relating to the behavior and capacity of shear connector. Ueda and Chin[1)] had carried out a series of test on single plate shape shear connector and further developed an equation to estimate the capacity of shear connector. Chuah et al[2)] derived an equation from a series of specimens with various numbers of plate shape shear connector to predict the capacity of plural shear connector. In both studies direct pull-out tests were carried out.

In actual structures, the shear connector not only subjected to the transfer of shear force but also compression force and the local bending deformation of the steel plate. The behavior and load carrying capacity of the shear connector may be different from those obtained by the direct pull-out test.

Considering this point the present study was conducted with a series of test on simply supported beam with a symmetric two-point loading. The transferred shear force - relative displacement relationship between shear connector and the lower flange plate as well as the strain of vertical part of shear connector were measured. The effects of angle to member axis of compression diagonal strut in core concrete was taken as a parameter in this study.

2. EXPERIMENT

(1) Description and preparation of specimens

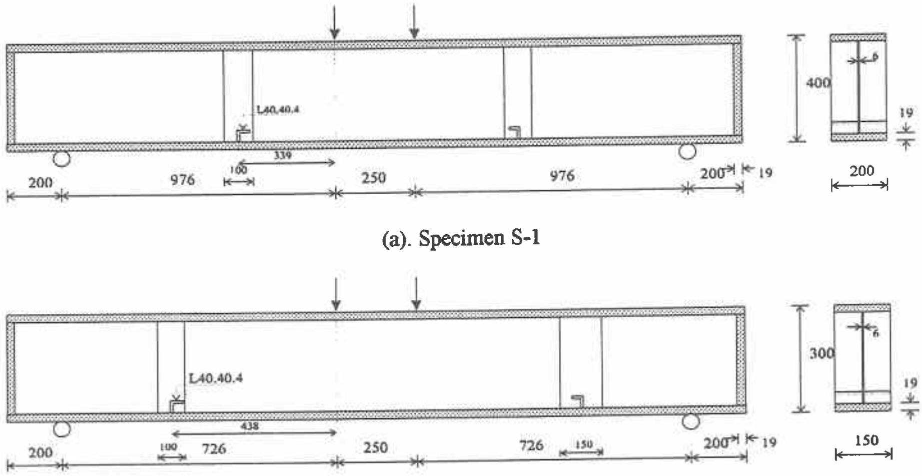
The experimental work was carried out for the steel-concrete sandwich beam shown in Fig. 1. L-shaped shear connectors (steel angle 40x40x4 mm) were provided at the interface between the concrete and the steel plates. Shear connectors were welded perpendicularly to the steel plates.

Two specimens were tested. The shear connector for specimen S-1 was put in such a way that the angle to the member axis of the line connecting the shear connector with the loading point, which indicates compression diagonal strut in core concrete, was 45 ° while in specimen S-2 it was 30°. The compressive strength of concrete for specimen S-1 was 22.2 MPa while for specimen S-2 it was 32.5 MPa. The details of the specimens and mechanical properties of the steel are given in Fig. 1 and Table 1 respectively.

In order to control vertical compression force of concrete surrounding the shear connector, a tie plate was put at position of the shear connector. The vertical compression force of concrete is assumed to be a same as the tensile force of the tie plate.

(2) Instrumentation and test procedure

The specimens were tested by a symmetric two-point loading system. Relative displacement between top of the shear connector and the lower flange plate was measured by using a two directional displacement transducer. The load borne by the shear connector in two directions as well as the strain of the vertical part of the shear connector were measured. Therefore, the strain gages were mounted to the lower flange plate, the tie plate and the shear connector. The details of arrangement of the strain gages and displacement transducer are shown in Fig.2. Deflection of the specimens, the relative displacement of the shear connector and the strain of the lower flange plate, the tie plate and the shear connector were measured at every load step. Crack propagation was observed in detail.



(a). Specimen S-1

(b). Specimen S-2

Fig. 1 Test Specimens (in mm)

Table 1. Steel Properties

Component	Steel Type	fy (MPa)	ft (MPa)	Es (GPa)
Flange (19 mm)	SM 450 A	377.6	523.2	179
Tie Plate (6 mm)	SM 450 A	357.5	514.2	186
Shear Connector (4 mm)	SS 400	367.7	526.1	213

f_y: Yield strength
f_t: Tensile strength
Es: Young's modulus

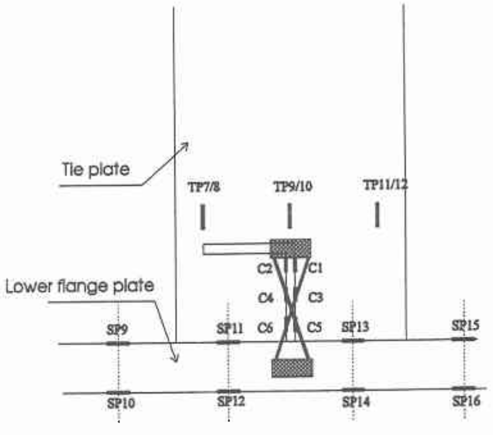


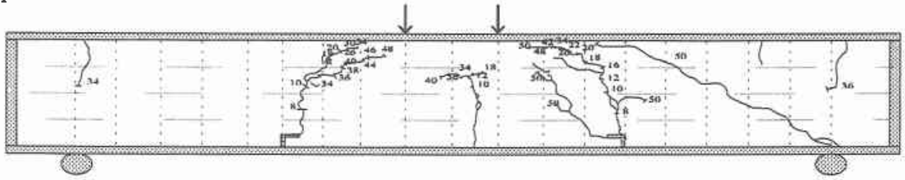
Fig. 2 Locations of Strain Gages and Displacement Transducer

3. TEST RESULTS AND OBSERVATION

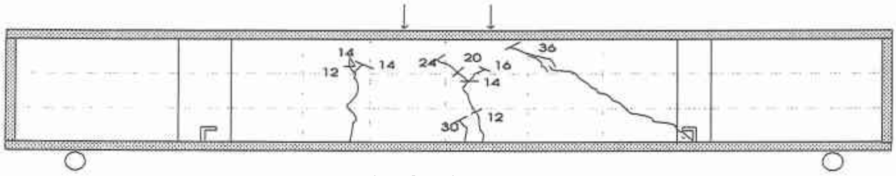
(1) Load - Carrying Capacity and Failure Characteristic

Load-carrying capacity and crack patterns of the tested specimens are summarized in Table 2 and schematically shown in Fig. 3 respectively. In both specimens, concrete crack were initiated from the welded point between the shear connector and the lower flange plate. In the case of specimen S-1, the crack initiated with a vertical crack at the

back side of the shear connector and after that propagated to be a diagonal crack. The tie plate on the left side started to yield at about 441.3 kN, diagonal crack appeared between support and this tie plate and propagated very rapidly.
On the contrary, in specimen S-2 a crack initiated with crashing of the concrete at the corner of the shear connector and after yielding of the shear connector a diagonal crack suddenly occurred (353 kN) from the welded point to the loading point.



(a). Specimen S-1



(b). Specimen S-2

Fig.3 Crack Pattern (number indicating load in tf)

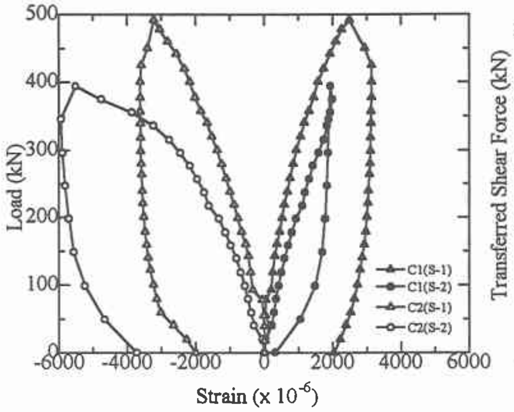
Table 2. Experimental and Calculation Result

Specimen	Experimental Results					Calculation Results		
	Pvc	Pdc	Ptpy	Pcr	Pmax	A	B	C
S-1	78.45	98.07	441.30	-	490.33	990.47	678.62	428.55
S-2	117.68	353.04	-	245.17	392.27	823.76	241.24	428.55

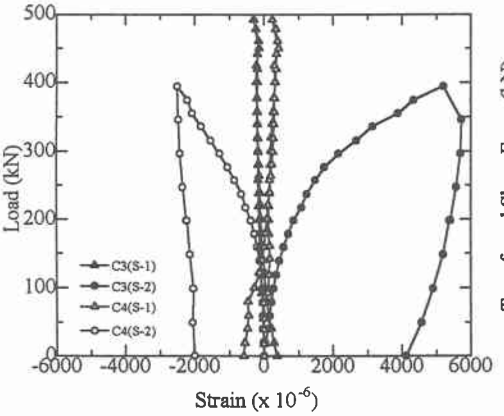
P_{vc}: Load at first vertical cracking, kN
P_{dc}: Load at first diagonal cracking, kN
P_{tpy}: Load at yielding of tie plate, kN
P_{cr}: Load at crashing of concrete in front of shear connector, kN
P_{max} : Ultimate load, kN
A: Load corresponding to flexural capacity using the assumption of an RC beam, kN
B: Shear strength when compression diagonal strut in core concrete fails (JSCE[4]), kN
C: Shear strength when yielding the tie plate (JSCE[4]), kN

(2) Reformation of Shear Connector

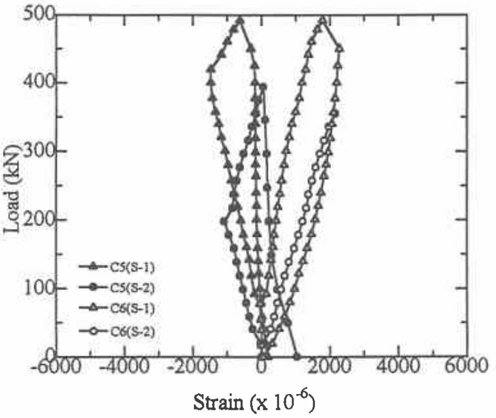
Strains distributions along the vertical part of the shear connector are shown in Fig. 4. In Both of the specimens, strain gages no. C_1 and C_6 indicate tensile strains while C_2 and C_5 compressive strains. It is seen also that the strain of shear connector for specimen S-2 was bigger than specimen S-1.
On the other hand, strains of strain gages no. C_3 in both specimens were in different sign which become rather large in tension for specimen S-2 and changed to small in compression for specimen S-1. Also for strain gages no. C_4, it strain were still in compression in specimen S-2 and changed to small in tension for specimen S-1. Regarding the effect of the angle to the member axis of the diagonal compression strut in the core concrete (θ), it was found that specimen S-1with θ of 45° the inflection point of the vertical part of the shear connector was around the middle of the height of the shear connector. While in specimen S-2 the inflection point was near the welding point.
Fig. 5 shows relationship between the transferred shear force and the curvature of shear connector for three location at the vertical part of the shear connector. The curvature of the shear connector was calculated by dividing the difference of the strains in front of and behind the vertical of the shear connector by the thickness of the shear connector. This figure shows that the maximum curvature for specimen S-1 was at point 1, while at point 2 for specimen S-2.



(a) Load-Strain Relationships (strain gages C1&C2)

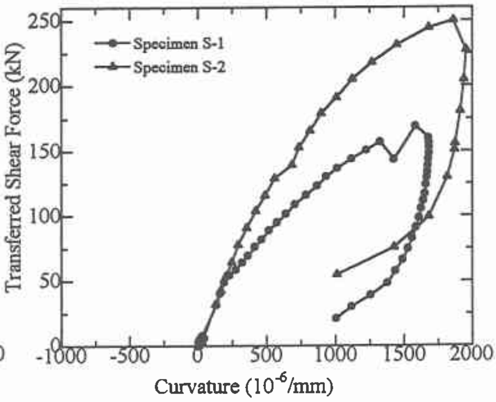


(b) Load-Strain Relationships (strain gages C3&C4)

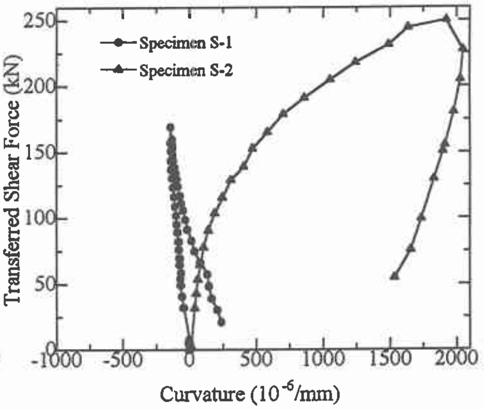


(c) Load-Strain Relationships (strain gages C5&C6)

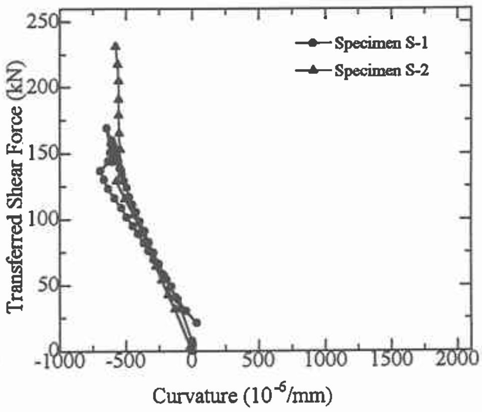
Fig. 4 Strains along Vertical Part of Shear Connector



(a) Point 1 (C1, C2)



(b) Point 2 (C3, C4)



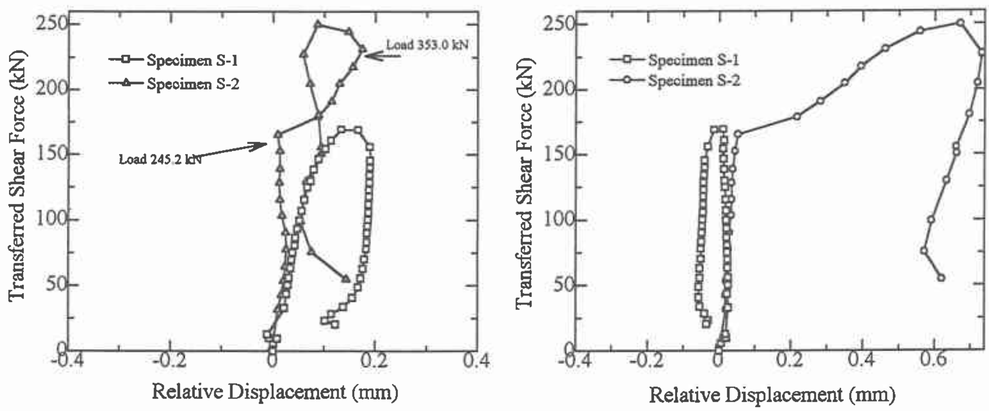
(c) Point 3 (C5, C6)

Fig. 5 Transferred Shear Force-Curvature Relationship of Shear Connector

(3) Transferred Shear Force - Relative Displacement Relationship of Shear Connector

Fig. 6(a) shows the relationship between transferred shear force and relative displacement of in horizontal direction between the top of the shear connector and the lower flange plate. Shear force carried by the shear connector was calculated by multiplying the difference in strains of the flange plate in front and behind the shear connector by the cross sectional area and Young's modulus of the lower flange plate. It is observed that the transferred shear force increases with rather high stiffness until the concrete surrounding the shear connector cracked. After that, the stiffness of shear connector was greatly influenced by the stiffness of the surrounding concrete. In the case of specimen S-1, in which the flexural deformation of the beam is dominant, the crack started early and caused a progressive loss of the stiffness of the surrounding concrete. Furthermore, since the shear connector was not rigid, the slipping at the shear connector caused a further reduction of the stiffness. In the case of specimen S-2, the relative displacement rapidly increased immediately after the concrete in front of the shear connector crashed at 245.2 kN. Then, the relative displacement started to decrease after diagonal crack occurred at about 353 kN.

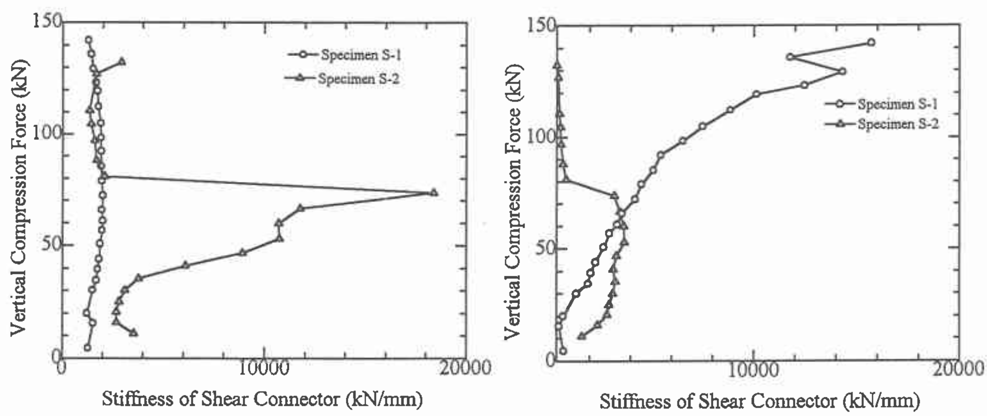
The relative displacements in vertical direction are shown in Fig. 6 (b). It was considered that the relative displacement of the shear connector in vertical direction was less than in horizontal direction for the same transferred shear force.



(a) Horizontal direction

(b) Vertical direction

Fig. 6 Transferred Shear Force -Relative Displacement Relationship



(a) Horizontal direction

(b) Vertical direction

Fig. 7 Vertical Compression Force - Stiffness of The Shear Connector Relationship

(4). Vertical Compression Force - Stiffness of Shear Connector Relationship

Fig. 7.a shows the relationship between the vertical compression force in the core concrete and the stiffness of the shear connector in horizontal direction. In both of the specimens, the vertical compression force increased with rather high stiffness of the shear connector until the concrete surrounding the shear connector cracked. Fig. 7.b shows the relationship between the vertical compression force and the stiffness of the shear connector in vertical direction. It also can be seen for specimen S-2 the vertical compression force increased with rather high stiffness of the shear connector until the concrete surrounding the shear connector cracked. While, for specimen S-1 the stiffness of shear connector was still increased after the concrete cracked.

4. CONCLUSIONS

(1) It is considered that the cracking pattern in the concrete surrounding the shear connector has a large influence on the stiffness of the shear connector.

(2) For the smaller angle to the member axis of the line between the loading point and the shear connector (in other word the smaller ratio of bending moment to shear force), only shear crack propagates around the shear connector. For the larger not only shear crack but also flexural crack propagates. Therefore, in the former case the stiffness of the shear connector is larger.

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