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# EFFECT OF THE CONCRETE COMPRESSIVE STRENGTH ON THE SHEAR CONNECTOR BEHAVIOR FOR STEEL-CONCRETE SANDWICH BEAM

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## 1. INTODUCTION

To study further the effect of the concrete compressive strength on the shear connector behavior [1,2], a series of tests on simply supported beams with a symmetric two-point load was carried out. The object of this study is to investigate the effect of the concrete compressive strength, $f_c'$ on the relationship between transferred shear force and relative displacement of the shear connector. It was found in a previous study [2] that some of the measured strains of the lower flange plate were not reliable due to the local bending of the lower flange plate near the location of the shear connector. Hence in this study the proper location for measuring the strain of the lower flange plate which will be used to calculate the transferred shear force through the shear connector are also studied.

## 2. EXPERIMENT

### 2.1 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 plate. The shear connectors were welded perpendicularly to the steel plate. The spacing of the shear connector was 18.15 cm. Tests were carried out for three specimens. The concrete compressive strength for specimens S-1, S-4 and S-5 were 24.2 MPa, 33.4 MPa and 9.9 MPa respectively.

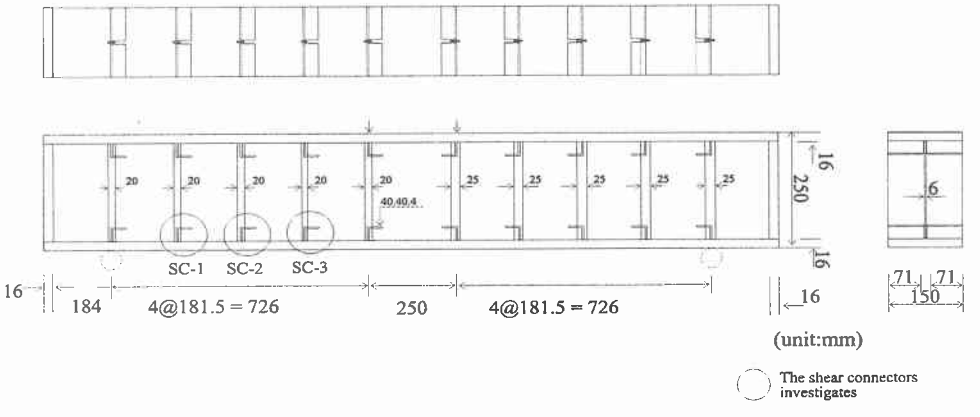



Fig. 1 Details of specimen

The details of the specimens are given in Fig. 1 and Table 1. Steel properties are given in Table 2. In order to estimate the vertical compression force in concrete surrounding the shear connector, a tie plate was put at the same location of the shear connector. The vertical compression force of the concrete is assumed to be the same as the tensile force of the tie plate.

Table 1 Details of specimens

| Speci-men | $t_w$ mm | $h$ mm | $b$ mm | $h_{sc}$ mm | $A_{tp\text{-}r}$ cm$^2$ | $A_{tp\text{-}l}$ cm$^2$ | $f_c'$ MPa |
|---|---|---|---|---|---|---|---|
| S-1 | 16 | 250 | 150 | 40 | 3.60 | 4.50 | 24.2 |
| S-4 | 16 | 250 | 150 | 40 | 3.60 | 4.50 | 33.4 |
| S-5 | 16 | 250 | 150 | 40 | 3.60 | 4.50 | 9.9 |

$t_w$ : thickness of flange plate  $h$ : height of beam
$f_c'$ : concrete compressive strength  $b$ : width of beam
$h_{sc}$: height of shear connector
$A_{tp\text{-}r}$ : area of tie plate (right side)
$A_{tp\text{-}l}$ : area of tie plate (left side)

Table 2 Steel properties

| Component | Steel type | $f_y$ (MPa) | $f_t$ (MPa) | $E_s$ (GPa) |
|---|---|---|---|---|
| Flange Plate | SM 450 A | 377.6 | 523.2 | 179 |
| Tie Plate | SM 450 A | 357.5 | 514.2 | 186 |
| Shear Connector | SS 400 | 367.7 | 526.1 | 213 |

2.2 Instrumentation and test procedure

The experimental work of this study was performed by simply supported sandwich beam with a symmetric two-point loading system. The load was applied by a hydraulic jack and its magnitude was measured by an electrical load cell. Three electrical strain gauges were mounted on both sides of the vertical part of the shear connector to measure its deformation. In order to measure the transferred shear force between the concrete and the lower flange plate through the shear connector electrical strain gauges were mounted on the both sides of the lower flange plate. It was indicated in the previous study [2] that the local bending of the lower flange plate occurred at the location of the shear connector, which makes the measured strain not reliable to calculate the transferred shear force. Hence, the additional strain gauges were mounted on the both sides of the lower flange plate (specimen S-5) to find a proper location for the measured strains of the lower flange plate at which the local bending deformation does not exist. The gauges were also mounted on both sides of the tie plate to measure the vertical compression force of the concrete surrounding the shear connector. The detailed arrangement of the electrical strain gauges is shown in Figs. 2 and 3.

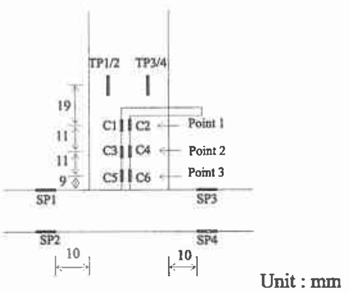



Fig. 2 Location of strain gauges

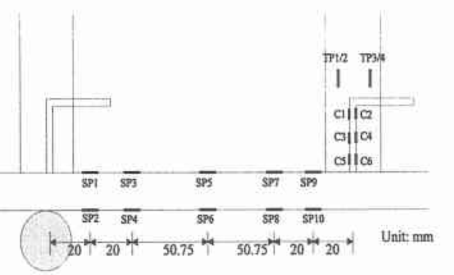



Fig. 3 Detailed arrangement of strain gauges at the lower flange plate for specimen S-5

The measuring system with contact gauges was used to measure relative displacements of the shear connector. The relative displacement was measured between the top of the shear connector and the lower flange plate. The details of the contact gauge arrangement is given in Fig.4. During the test, the deflection of the specimens, the relative displacement of the shear connector and the strains of the lower flange plate, the tie plate and the shear connector were measured at every load step. Crack propagation was observed in detail.

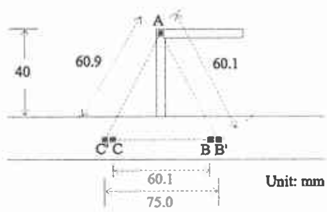
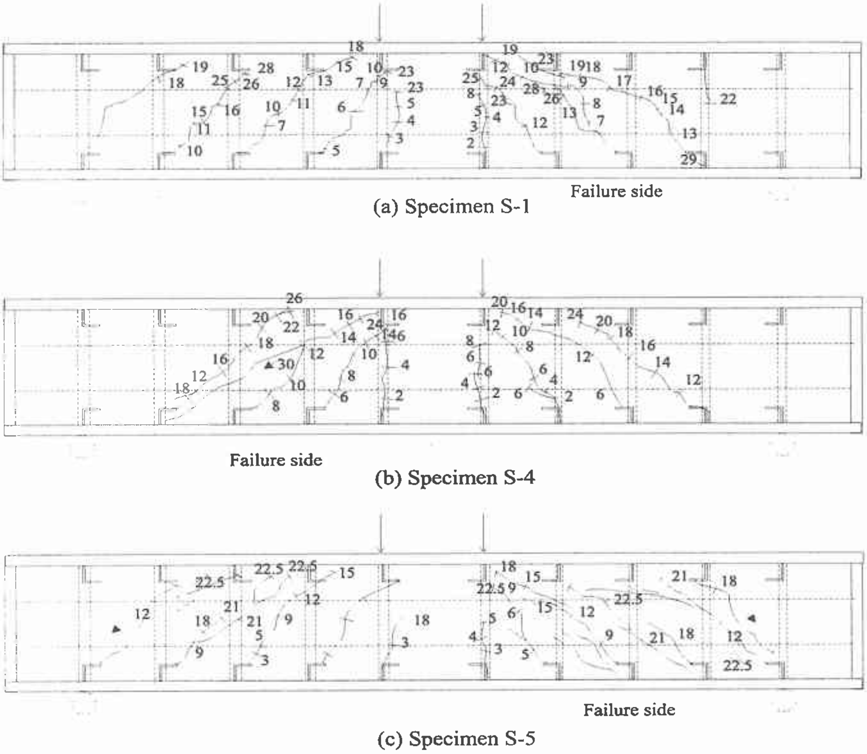



Fig. 4 Distance points for contact gauge measurement

## 3. Test Result and Observation

### 3.1 Failure Pattern and Load-Displacement Relationship

Figure 5 shows the crack pattern of the tested specimens. The load–deflection relations for each specimen are presented in Fig. 6. The maximum load and the stiffness of the specimen increase with increasing the concrete compressive strength of the concrete. In the case of specimen S-5, the small diagonal cracks occurred between the shear connector prior to the maximum load. While for the specimen S-4 at about 297 kN a new diagonal crack suddenly originated from the second diagonal crack and propagated towards the shear connector SC-1.




(a) Specimen S-1

(b) Specimen S-4

(c) Specimen S-5

Fig. 5 Crack pattern (numbers indicating load in tf)

### 3.2 Strains in vertical part of the shear connector

For each specimen three shear connector were investigated (see Fig. 1). Figure 7 shows the relationship between the applied load and strain distributions the along vertical part of SC-1 for the tested specimens. As the concrete compressive strength increases the strains distributed along the vertical part of the shear connector decrease. For specimens S-1 and S-5 strains were rather bigger at point 1 (C1, C2) and point 3 (C5, C6), while for specimen S-4 at point 1 (C1, C2) and point 2 (C3, C4) (see Fig. 2).

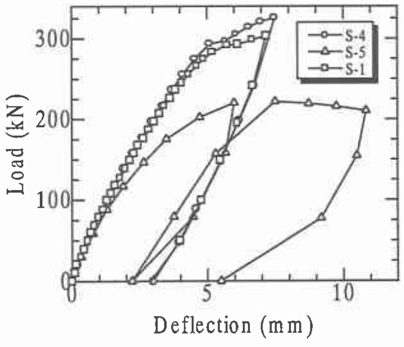
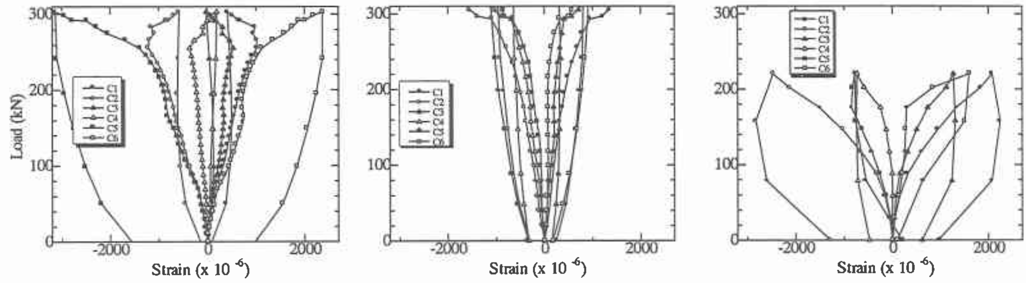



Fig. 6 Load-deflection relationship



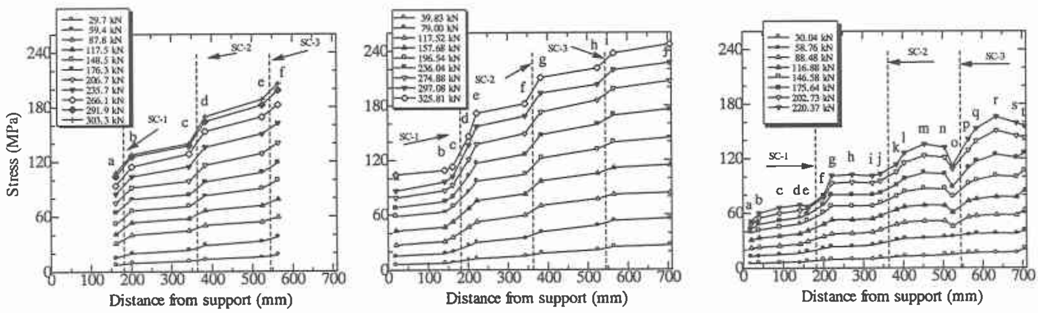
(a) Specimen S-1 (b) Specimen S-4 (c) Specimen S-5

Fig. 7 Strains along vertical part of shear connector

3.3 Stress distribution of lower flange plate

Figure 8 shows the measured stress distribution of the lower flange plate in the shear span of the tested specimens. As above mentioned, the local bending of the lower flange plate occurred near the shear connector. The slopes of the measured stress distribution between measured points of b-c and d-e in Figure 8 (b), and a-b, d-e, f-g, i-j, k-l, n-o, p-q and s-t in Figure 8 (c) were rather big although the distance between the measuring points was only 20 mm. This is believed the effect of the local bending of the lower flange plate. On the other hand, the measured stress between points b-c-d, g-h-i, l-m-n and q-r-s were rather constant (see Fig. 8 (c)).

Judging from the above mentioned, for specimen S-5 the difference of measured stress of points d-i, i-n and n-s were used to calculate the transferred shear force through the shear connector SC-1, SC-2 and SC-3 respectively. While for specimens S-4 and S-1 the average of the measured stresses between the shear connectors was taken and after that the difference of the average stress was used to calculate the transferred shear force.



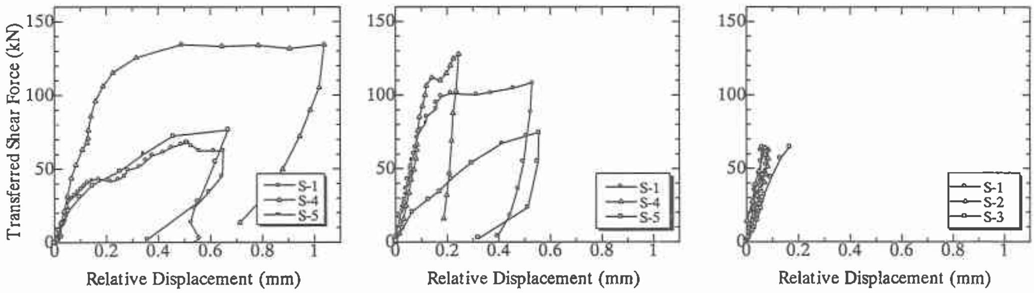
(a) Specimen S-1 (b) Specimen S-4 (c) Specimen S-5

Fig. 8 Stress distribution of the lower flange plate

3.4 Transferred shear force - relative displacement relationship of the shear connector

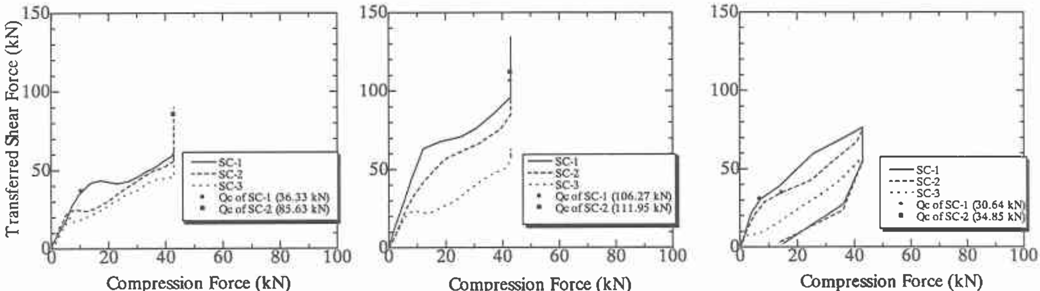
The transferred shear force-relative displacement relationships of the shear connector are shown in Fig. 9. It can be seen that as the concrete compressive strength increases the initial equivalent stiffness of the shear connector as well as the value of the transferred shear force when a sudden decrease of the equivalent stiffness of the shear connector occurs, $Q_c$ increase. In the case of SC-3, the $Q_c$ did not appear although a rather large relative displacement was seen for specimen S-5 with $f_c'$ of 9.9 MPa (see Fig. 9 (c)). This was probably due to the low rigidity of the concrete surrounding the shear connector as indicated by the diagonal cracking between the shear connectors (see Fig 5 (c)).

The value of $Q_c$ increases when the compression force increases as shown in Fig. 10. In the case of SC-1 of the specimen S-4, an unexpectedly large value of $Q_c$ is seen compared with the cases of specimens S-1 and S-5 (see Figs. 9 and 10). The reason of this phenomenon should be studied.




(a) SC-1 (b) SC-2 (c) SC-3

Fig. 9 Transferred shear force-relative displacement relationship




(a) Specimen S-1 (b) Specimen S-4 (c) Specimen S-5

Fig. 10 The relationship between transferred shear force and compression force

3.5 Initial equivalent stiffness of the shear connector

Table 3 shows the initial equivalent stiffness properties of the shear connector of the tested specimens. The equivalent stiffness of the shear connector is the stiffness provided by the stiffness of the shear connector it self and the concrete surrounding the shear connector [2]. For each tested specimen, the average value of the initial equivalent stiffness among the initial equivalent stiffness of shear connector SC-1, SC-2 and SC-3 was taken as its initial equivalent stiffness. It was observed that the initial equivalent stiffness increases when the concrete compressive strength increases, while the effective thickness of the surrounding concrete, $t_c$ was rather constant (see Table 3). It can be said that the concrete compressive strength did not affect the effective thickness of the surrounding concrete, $t_c$.

Table 3 Initial equivalent stiffness properties

| Specimen | $(EI)_{eq.I}$ kN.mm$^2$ | $(EI)_{sc}$ kN.mm$^2$ | $(EI)_{con}$ kN.mm$^2$ | $f'_c$ MPa | $E_c$ MPa | $I_c$ mm$^4$ | $t_c$ mm |
|---|---|---|---|---|---|---|---|
| S-1 | 1.72x10$^6$ | 3.33x10$^5$ | 1.39x10$^6$ | 24.16 | 23251.01 | 59696.23 | 16.84 |
| S-4 | 1.84x10$^6$ | 3.33x10$^5$ | 1.51x10$^6$ | 33.39 | 27332.54 | 55253.47 | 16.41 |
| S-5 | 9.47x10$^5$ | 3.33x10$^5$ | 6.15x10$^5$ | 9.91 | 14893.51 | 41259.86 | 14.89 |

$E_c = 4730\sqrt{f'_c}\ N/mm^2$ 6)

$I_{con} = (EI)_{con}/E_c$ , $t_c = \sqrt[3]{\frac{12 I_{con}}{b}}$

4. Conclusions

From the test results the following conclusions can be drawn:

1. The initial stiffness of the shear connector as well as the $Q_c$ value increased when the concrete compressive strength increased.
2. It is considered that the transferred shear force only occurred through the shear connector, in the other word the transferred shear force between the shear connectors is negligibly small.
3. The proper location to measure the stress of lower flange plate that will be used to calculate the transferred shear force should be at some distance from a shear connector, so that the effect of the local bending of the lower flange plate near the shear connector can be avoided.

## ACKNOWLEDGEMENT

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