Effect of Horizontal Crack on Stirrup Stress of RC T-Beam

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1. Introduction

In the slab-beam-girder construction system, the beams are usually built monolithically with the slab. Hence, the portion of concrete slab, effectively connected together with beam, can be considered as the *flange* projecting from each side of beam. At the same time, the part of beam at the bottom of slab is working as the *web* or *stem* of T-shaped beam.

From the experiment, the horizontal shear cracks between the flange and the web of T-beam were observed. The effect of this crack on stirrup stresses is shown by the tested results. And, this phenomenon is simulated by the 3D finite element analysis as the verification.

2. Outline of the experimental program

Two reinforced concrete beams of rectangular and T-shape sections were tested. The rectangular beam had the size of 3800×150×350 mm (length×width×height) and effective depth of 300 mm. The full details of their dimensions, arrangement of reinforcing steel and loading condition are shown in **Fig. 1**. Both specimens had the same tension and compression reinforcement, four of D25 and two of D10 respectively. Shear reinforcement was D6 stirrup with closed-hoop shape. **Fig. 2** shows cross sections of the specimens. Concrete cylinder strength (f_c') for each specimen was 35 MPa. The main reinforcement ratio (ρ_l) and shear reinforcement ratio (r_w) were 4% and 0.4%, respectively. Yield point of the stirrup was 300 MPa. Strain gages were attached to measure strain in each stirrup at distances of 60, 130 and 220 mm above the centroid of the tension steel.

3. Outline of the finite element analysis

In the present study, the 3D nonlinear finite element program developing at the Hybrid Structure Engineering Laboratory of Hokkaido University is used. Three-dimensional 20 nodes iso-parametric solid element, which contains 8 Gauss points, can be used for representation of elements. The smeared crack concept and the fixed crack model were adopted. The constitutive laws used in the program are described as follows. The constitutive model for the reinforcing bar in concrete was modeled based both on the properties of bare bars and on the effect of the bond to concrete, at this point, tri-linear model presented by Maekawa et al [1)] expressing the strain hardening was adopted. The 3D Elasto-Plastic Fracture Model [2)-4)] was adopted for the concrete before cracking. The adopted failure criteria that acted in agreement with Niwa's model in tension-compression zone and Aoyanagi and Yamada's model in tension-tension region were extended to three-dimensional criteria by satisfying boundary conditions [5)].

When the first crack occurred, the stress of concrete element under uni-axial stress in the perpendicular direction to crack plane within the local coordinate system was calculated by Reinhardt's tension-softening model [1)]. Besides, in other two directions, which were parallel to crack plane, the model proposed by Vecchio&Collins [1)] was used for the local stress-strain relationship. Shear stress acted on the plane intersecting perpendicularly with a crack, was computed by using the average shear stiffness between shear stiffness of crack plane and shear stiffness from the concrete, which did not contain any cracks.

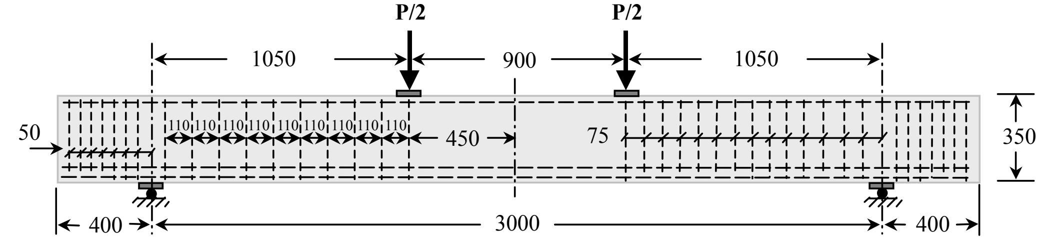

Fig. 1 Loading condition and stirrup arrangement (unit: mm)

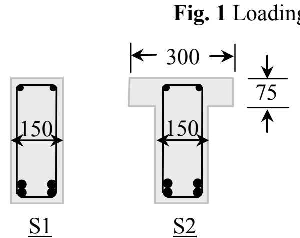

Fig. 2 Cross sections (unit: mm)

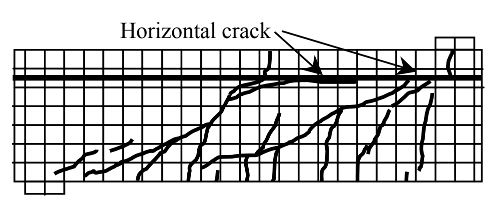

Fig. 3 Crack pattern of T-beam (S2)

4. Stress development in stirrups

A typical pattern of the stress variation in stirrups for increasing loads was measured by the strain gages. The stresses plotted are the average for 3 locations of the stirrups in the tested part of the beams. The location and reference number of stirrups whose strains were measured in the experiment are shown in **Fig. 4**. From **Figs. 4** and **5**, the average stress of selected stirrups in the rectangular and T-beam are compared. It can be seen that the average stress of stirrup for both specimens are almost the same at the initial condition. After that, the average stress of stirrups in the T-beam becomes lower than that in the rectangular beam at around 300 and 250 kN of applied load at stirrup number 1 and number 5 respectively. Correspondingly, the load 300 and 250 kN were observed from the experiment that they were the load step that made cracks propagate into the connection zone of the top flange and the web at the same location of the considering stirrups (location near the loading point for 300 kN and around mid of shear span for 250 kN, see **Fig. 3**).

5. Numerical verification

Two numerical specimens, with and without bond-linkage elements, were conducted to simulate the existence of the horizontal crack. Both specimens had the same size as specimen S2, simply supported beam subjected to two-point monotonic loading. In the 3D FE analysis, the enforced displacements were given at the loading point, which were the nodes of steel element attached to specimen. Bond-linkage elements were installed in the position that the horizontal cracks were observed from the experiment (see **Fig. 3** and **6**). The horizontal crack was simulated by the suddenly reduction of the stiffness of bond-linkage elements at the certain load step after shear crack. From **Fig. 7**, after the stiffness of bond-linkage elements is reduced (horizontal crack is assumed to be occurred in the analysis), the stress of stirrups in the T-beam with the horizontal crack truly becomes lower than that in the beam without the crack at the same load step.

6. Discussion

From the shear resisting mechanism viewpoint, it can be considered that the horizontal crack between the flange and the web possibly reduces the effectiveness of the truss action and turns the shear governing mechanism of T-beam to the arch action. To indicate the precise shear resisting mechanism of T-beam, the further investigation is necessary. Moreover, this topic can confirm the importance of the top flange to the shear problem of T-beam.

7. Conclusions

The horizontal crack between the top flange and the web reduces the stress development in the stirrups of RC T-beam. And, this phenomenon can be simulated by the FE analysis as the verification.

References

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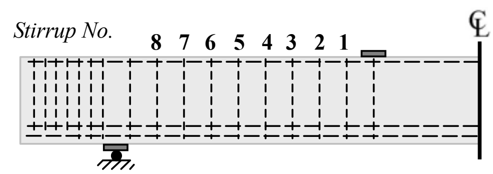

Fig. 4 Location and reference number of stirrups whose strains were measured in both specimens

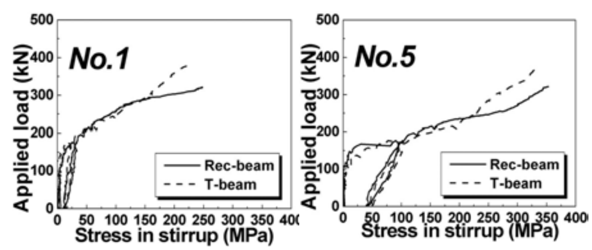

Fig. 5 Stress development in stirrups (tested results)

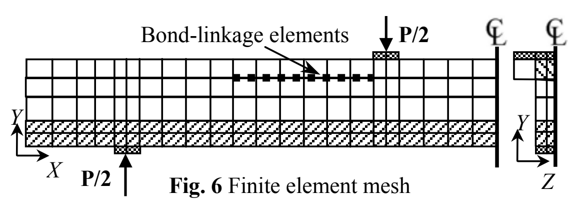

Fig. 6 Finite element mesh

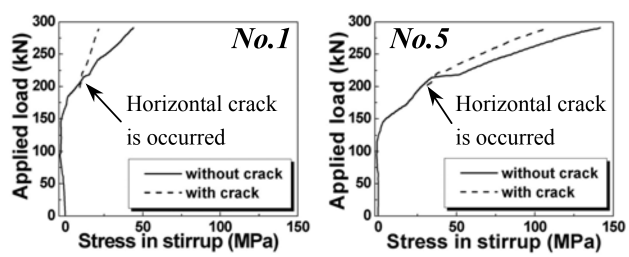

Fig. 7 Stress development in stirrups (numerical results)