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EFFECT OF TRANSVERSE BEAMS AND FLOOR SLABS ON SHEAR STRENGTH IN INTERIOR JOINTS

by

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INTRODUCTION

Transverse beams and floor slabs are known to influence the shear strength of reinforced concrete beam-column joints, but has not been evaluated quantitatively. Transverse beams framing into a joint are likely to confine the joint core concrete, and enhance the joint shear strength. In ACI 318-83 (Ref.1), the allowable shear stress in the joints confined by framing beams increases by 4/3 times that of unconfined joints. However, the transverse beams may not confine the core concrete because transverse beams in actual frame structures are subjected to reversed cyclic loading under earthquake motions, developing flexural cracks at joint faces. Therefore, the contribution of the transverse beams with flexural cracks at a critical section is not considered in New Zealand (Ref.2) and in Japan (Ref.3).

The matter of concern for floor slabs is the cooperative width to the beam flexural resistance, the transfer mechanisms of tensile forces in slab reinforcement into a joint core concrete, and the confinement to the upper part of a joint.

In this paper, these effects of transverse beams and floor slabs primarily on the joint shear strength are reviewed through previous test results.

EFFECT OF TRANSVERSE BEAMS

Transverse beams without loading enhance the joint shear strength apparently because of the increase in effective volume of a joint to resist shear. The masking ratio of the cross sectional area of a transverse beam to that of a joint - the enhancement ratio of the joint shear strength with transverse beams relation is plotted in Fig.1 by Owada (Ref.4). Similar relation is shown in Fig.2 by Meinheit & Jirsa (Ref.5). Joint shear strength increased with the joint area with unloaded transverse beams, and in Fig.2 reached as high as 1.2 or 1.8 times that without transverse beams when unloaded transverse beams covered 70 % of the joint area.

However, the flexural cracks develop at the column faces of transverse beams in weak-beam strong-column frames under an earthquake loading, and open wide over the entire cross section. Consequently the beneficial effect of transverse beams on the joint shear strength seems to disappear.

Then the effect of cracked transverse beams on the joint shear strength was investigated at the University of Tokyo by the tests that transverse beams of three-dimensional interior beam-column joint specimens (called Specimen A2 without slabs and Specimen A3 with slabs) were initially loaded cyclically to develop flexural yielding in the transverse beam ends, and then the longitudinal beams were loaded to study the shear strength in a joint (Ref.6). Interior beam-column joints removed from a one-way frame without transverse beams (called Specimen A1 without slabs and Specimen A4 with slabs) were also tested for comparison.

Story drift - joint shear stress relations normalized by the concrete compressive strength are shown in Fig.3. The effective joint area to resist shear is defined by the column depth and the average of the beam and column widths. Three dimensional specimens A2 and A3 with loaded transverse beams developed flexural yielding at the beam ends and did not fail in joint shear even at a story drift angle of 1/15 rad. The maximum joint shear stress in Specimens A2 and A3 was as high as 0.36 f_c' and 0.40 f_c', respectively. Note that the joint shear strength was not obtained in Specimens A2 and A3 because the beams developed flexural yielding prior to joint shear failure. On the contrary, plane specimens A1 and A4 without transverse beams failed by diagonal compression in a joint core concrete, reaching the joint shear strength of 0.30 f_c' and 0.33 f_c', respectively. This shows that even if the flexural cracks remained open at the transverse beam-column interfaces, transverse beams enhanced the shear strength of a joint at least 1.2 times more than that without transverse beams.

Strains along a reinforcing bar in transverse beams of Specimen A2 under loading in a longitudinal direction, i.e., direction normal to the axis of transverse beams, are shown in Fig.4. Strains within and near the joint increased almost uniformly with the story drift, reaching the yield strain at a story drift angle greater than 1/25 rad although transverse beams were not loaded directly.

The mechanism of enhancement of the joint shear strength due to cracked transverse beams can be explained as follows: the joint core concrete expands in the direction perpendicular to a loading direction, resulting in that flexural cracks of transverse beams at both column sides are closed, and consequently transverse beams are to confine the joint core concrete laterally. In the case of flexural cracks opening very wide at the column faces, however, such a confinement action by cracked transverse beams may not develop. Average flexural crack width at the critical sections of transverse beams was 0.4 mm in Specimens A2 and A3.

EFFECT OF FLOOR SLABS

The influence of only floor slabs on the shear strength in interior joints has scarcely been investigated by tests. The contribution of floor slabs to the joint shear strength was observed in A-series tests as shown in Fig.3, comparing test results between specimens with and without floor slabs, i.e., one pair of Specimens A1 and A4, and another pair of Specimens A2 and A3. The joint shear strength of specimens adding the floor slabs was at least 1.1 times greater than that without floor slabs. This enhancement of the joint shear strength is attributed to shear stresses distributed uniformly in a joint panel concrete, not concentrated on a diagonal compression strut, by shear from the slab concrete adjacent to the upper part of a joint in Specimen A4 without transverse beams, and by torsion of transverse beams framing into a joint in Specimen A3.

Note that the joint shear strength of Specimen A3 with both transverse beams and floor slabs, modeling the subassemblage of the actual frame structures, was increased beyond 1.3 times more than that of Specimen A1 without transverse beams nor floor slabs.

Some researchers have pointed out that floor slabs can not contribute to increasing the joint shear strength by the confinement action to upper part of the joint panel (Refs.7 and 8).

Slab width participating in the beam flexural resistance increased with the torsional stiffness of transverse beams, but the difference of slab effective width due to various torsional stiffnesses was small at a large deformation (Ref.9).

The torsional moment acting on transverse beams in interior beam-column-slab subassemblages was considered to be small because the tensile stresses develop in slab reinforcing bars at opposite sides of transverse beams, cancelling tensile forces which induce torsion in a transverse beam as schematically shown in Fig.5 (Ref.10).

TRANSFER MECHANISMS OF TENSION IN SLAB REINFORCEMENT

The transfer mechanisms of tensile forces in the slab reinforcement introduced into a joint core concrete were discussed by Cheung et al (Ref.7). The diagonal compression concrete struts were assumed to be formed in the horizontal plane of a slab by equilibrating with the orthogonal bond forces along the longitudinal and transverse slab reinforcement as shown in Fig.6.

Transverse beams with a slab only on one side such as the exterior beam-column-slab subassemblages deflect in the plane of a slab, and twist. Behavior of slabs in such a condition was explained by Pantazopoulou & Moehle (Ref.11) using the diagonal tension struts connecting a longitudinal and transverse beam in the plane of a slab as illustrated in Fig.7.

CONCLUDING REMARKS

Transverse beams and floor slabs in interior beam-column-slab subassemblages contribute to increasing the joint shear strength even if the flexural cracks open wide at critical sections of transverse beams. Transverse beams with flexural cracking can confine the joint core concrete because the flexural cracks are closed by the lateral expansion of the joint concrete. A part of tensile forces in slab longitudinal reinforcing bars are transferred to the joint core concrete through the shear of the slab concrete covering the upper part of a joint face parallel to the loading direction, or through the torsion of transverse beams, moderating the concentration of joint shear stresses on the diagonal compression strut.

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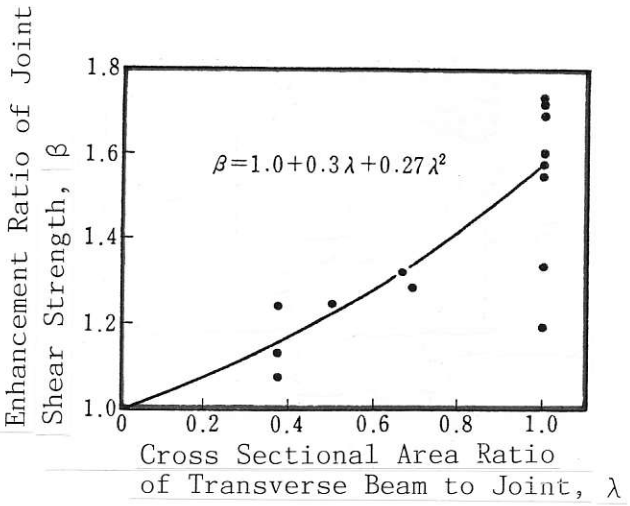


Fig.1 : Effect of Unloaded Transverse Beams by Owada

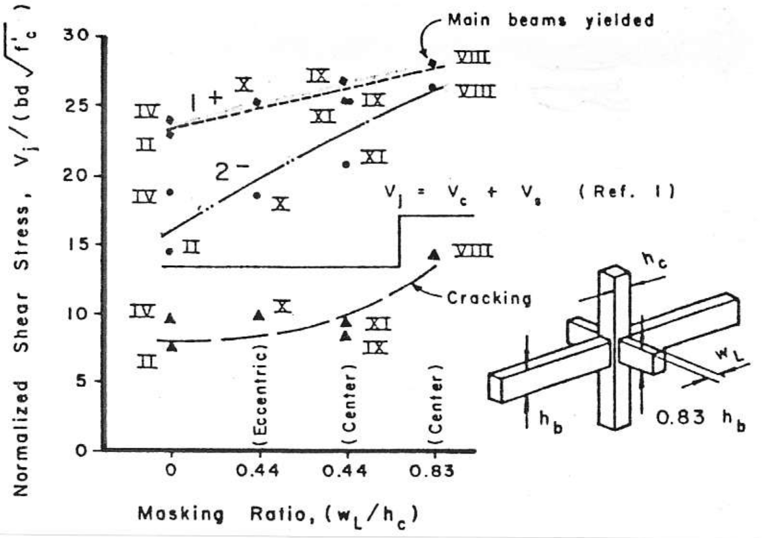


Fig.2 : Effect of Unloaded Transverse Beams by Meinheit

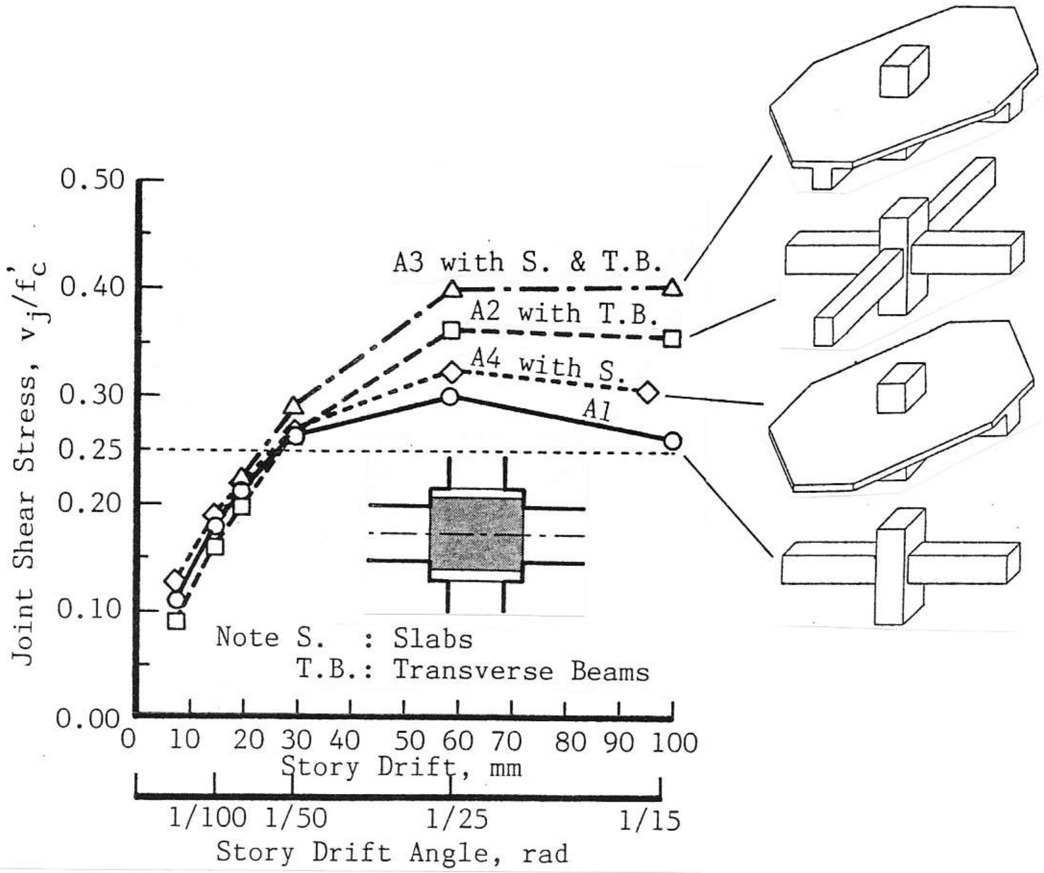


Fig.3 : Story Drift - Joint Shear Stress Relations

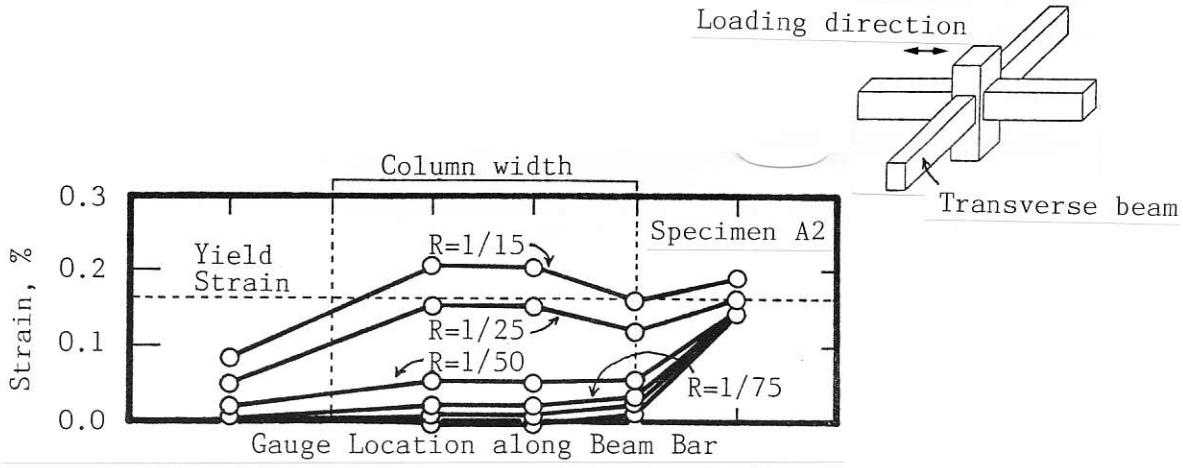


Fig.4 : Strains along Transverse Beam Bar

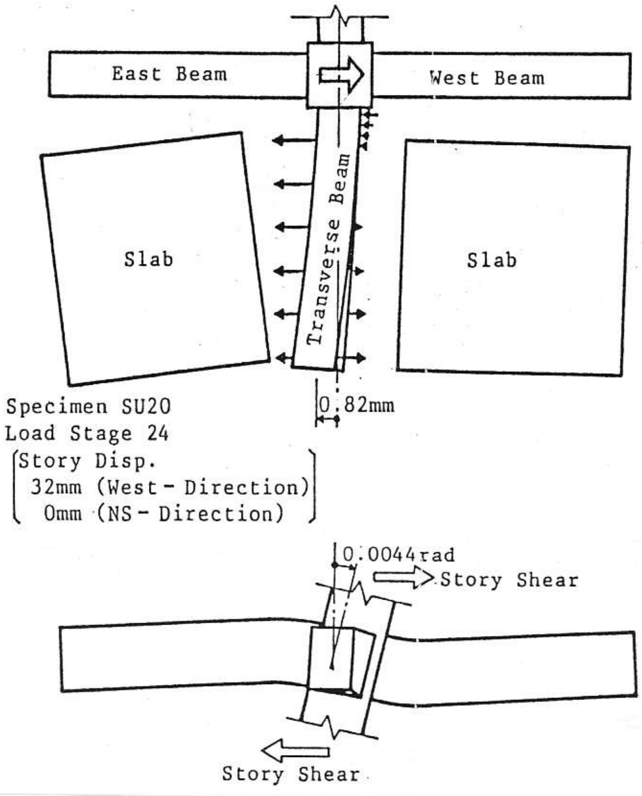


Fig.5 : Stresses Acting on Transverse Beam by Suzuki

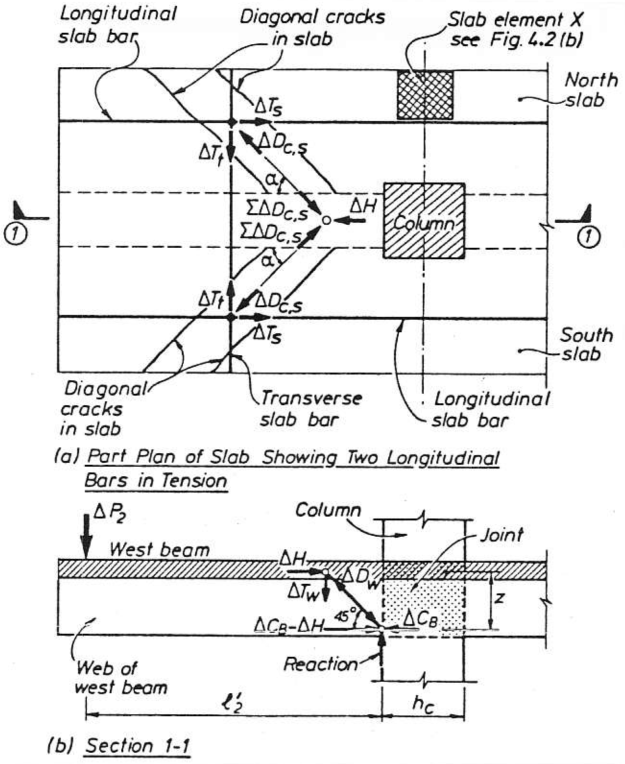
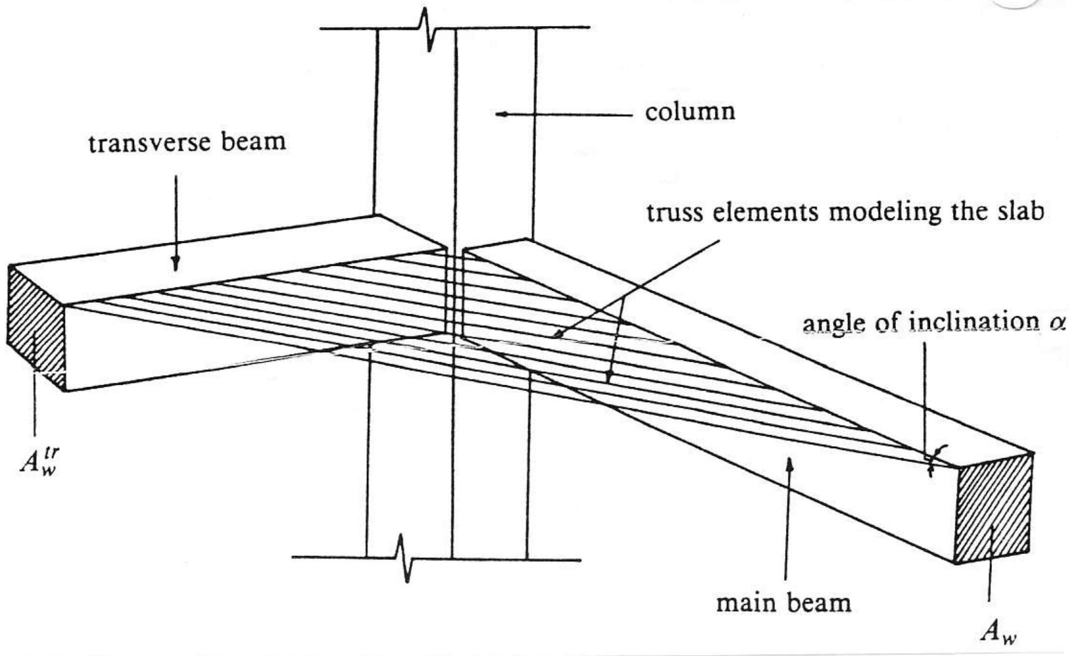
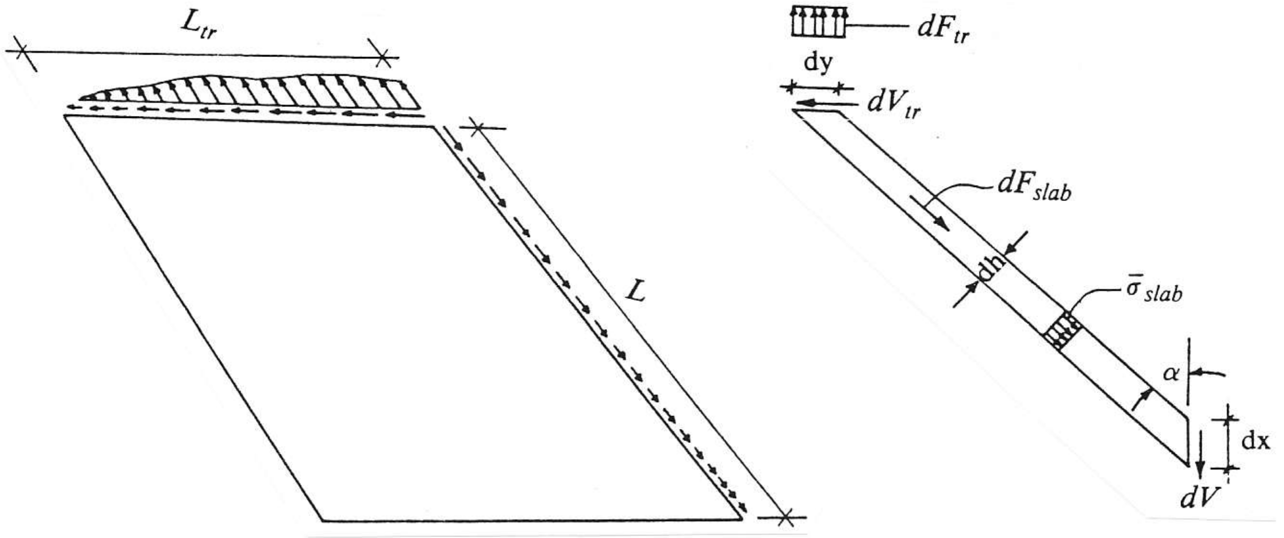


Fig.6 : Truss Model in Slab by Cheung



(a) Three-Dimensional Equivalent Structure



(b) Action on Slab

(c) Free Body Diagram
of Isolated Slab Strip

Fig.7 : Truss Model in Slab by Pantazopoulou