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ROLE OF LATERAL REINFORCEMENT IN INTERIOR JOINTS

by

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INTRODUCTION

Lateral reinforcement in a joint resists joint shear, and confines the joint core concrete. Required amount of lateral reinforcement varies with the assigned role of the lateral reinforcement in a joint. NZS 3101:1982 (Ref.1) provides a large amount of lateral reinforcement in a joint assuming that a dominant part of the joint shear is resisted by the truss mechanism within a joint panel. On the other hand, recommendation suggested by ACI-ASCE 352 Committee (Ref.2) requires less amount of lateral reinforcement assuming that the diagonal compression concrete strut resists the joint shear.

This contrast in the joint lateral reinforcement between New Zealand and the United States results from the different assumptions in the shear resisting mechanisms of a joint.

SHEAR MECHANISMS IN JOINT

The effectiveness of joint lateral reinforcement in frames designed according to the weak-beam strong-column concept changes with the bond deterioration along the beam bars passing through a joint, associated with the shear resisting mechanisms in a joint as shown in Fig.1 (Ref.3). These mechanisms are called "diagonal strut mechanism" and "truss mechanism", suggested by Paulay et al. The diagonal compression strut is formed along the main diagonal of the joint panel as the resultant of the horizontal and vertical compression stresses acting at the beam and column critical sections. Note that the diagonal strut exists irrespective of the bond characteristics of beam bars within a joint. The truss mechanism requires good bond along the beam and column bars, formed with diagonal compression stresses distributed uniformly within the panel region. These diagonal strut stresses must balance with the tensile stress in the vertical and horizontal reinforcement and the bond stresses acting along the beam and column bars.

Note that the truss mechanism is developed only when a good bond stress transfer is maintained along the beam and column reinforcement. In this case, lateral reinforcement in a joint carries tensile stresses and contributes to resisting joint shear. However, the bond deterioration along the beam reinforcement is inevitable, especially after beam flexural yielding. With a bond deterioration along the beam reinforcement, the truss mechanism starts to diminish. Consequently, the diagonal strut mechanism carries the dominant part of joint shear. The principal role of the lateral reinforcement in this case is to confine the cracked joint core concrete. The confinement action by the lateral reinforcing bars in a joint is illustrated schematically in Fig.8 as mentioned after.

The bond characteristics along the beam reinforcement within a New Zealand joint is kept good generally under earthquake excitations since the longitudinal reinforcement with a small diameter and low strength is used. Therefore, the beam bars in the compression zone at a critical sections carry the compressive stresses and beam flexural cracks at opposite sides of the joint remain open during reversed cyclic loading, resulting in disappearance of the diagonal strut mechanism in a joint. Hence the truss mechanism has to resist the entire joint shear, requiring the tensile forces in lateral reinforcement equilibrated with the horizontal joint shear.

It is assumed in the recommendation proposed by ACI-ASCE 352 Committee that joint shear is carried by the diagonal compression strut. The lateral reinforcement is placed in a joint as is done in a column to confine the core concrete at a potentially hinzing region, regarding a joint as the part of a column.

Provisions for reinforced concrete beam-column joints was introduced for the first time in Japan in Design Guideline for Earthquake Resistant Buildings based on Ultimate Strength Concept published by Architectural Institute of Japan (Ref.4). It is not possible to prevent a bond deterioration along the beam reinforcement because a high strength steel is used. Therefore, the large part of the joint shear must be resisted by the diagonal compression strut concrete. Joint lateral reinforcement is placed to confine the core concrete and restrain the shear deformation of a joint. Required amount of lateral reinforcement in a joint region is as follows:

$$p_{jh} \geqq 0.003\ V_j \ / \ V_{ju} \tag{1}$$

and, $p_{jh} \geqq 0.002$ (2)

where p_{jh} : joint lateral reinforcement ratio, V_j : joint shear for design, and V_{ju} : shear strength of an interior joint specified by Eq.(3).

$$V_{ju} = 0.3\ f_c{}'\ b_j\ D_j \tag{3}$$

where $f_c{}'$: concrete compressive strength, D_j : column depth, and b_j : joint effective width defined below.

$$b_j = b_b + b_{a1} + b_{a2} \tag{4}$$

where b_b : beam width, and b_{ai} : $b_i/2$ or D/4 whichever is smaller in which D : column depth, and b_i : length defined in Fig. 2 (Ref.4).

It appears difficult to place the lateral reinforcement more than 0.3 % in a joint region by only rectangular hoops, which are commonly used in Japanese construction.

Ichinose presented a design procedure to determine the amount of the lateral reinforcement required to resist a part of the joint shear on the basis of the equilibrium of stresses, assuming several shear resisting mechanisms in a joint as shown in Fig.3 (Ref.5). Required amount of the lateral reinforcement to resist joint shear is evaluated using notations in Fig. 3 as follows :

$$W_{sh} = W_{qa} + W_{ta} + W_{tc} \tag{5}$$

where W_{sh} is the required tensile force in the lateral reinforcement in a joint, W_{qa} in Fig.3(d(iii)) is equal to Q_{qa}, a part of the bond force along the beam reinforcement, and W_{ta} in Fig.3(e) and W_{tc} in Fig.3(f), clamping the joint core concrete, are determined by the Mohr's stress circle as shown in Fig.3(e(ii)).

The required tensile force in the joint lateral reinforcement, W_{sh}, is calculated by varying the bond strength (= $3\sqrt{fc'}$, unit in MPa) along beam bars and shown in Fig.4. W_{sh} increases with the bond strength, and reaches at the peak when the bond strength is sufficient to develop the tensile and compressive yielding of the beam reinforcement at opposite column faces. However, W_{sh} decreases after this particular point since Q_{sa} in Fig.3(a), a part of the bond force along the beam reinforcement, increases due to a good bond transfer.

The contribution of these shear resisting mechanisms to joint shear is calculated and shown in Fig.5. When a good bond along the beam reinforcement is maintained perfectly ($\tau_u/\tau_0 \geq 0.45$), all of a joint shear is transmitted into core concrete by the bond action. Therefore, diagonal compression struts formed by the compressive forces P_{sc} and P_{sd} at the column faces disappear.

TEST RESULTS

Strains in joint lateral reinforcement of a specimen with a good bond along beam bars were larger than those of a specimen with a bond deteriorated as shown in Fig.6 (Ref.6). This seems to show that the truss mechanism is formed within a joint panel.

Plane interior beam-column joint specimens (called Specimens B1, B2 and B3) were tested at the University of Tokyo to study the role of the lateral reinforcement in a joint, varying reinforcement details and the amount of lateral reinforcement (Ref.7). Legged ties were used in Specimens B1 and B3 as shown in Fig.7(a,c) to identify the strains associated with shear resistance and those associated with confinement of joint core concrete. Usual closed hoops as shown in Fig.7(b) were placed within the joint of Specimen B2. The joint lateral reinforcement ratio of Specimens B1 and B2 was 0.35 %. Whereas, that of Specimen B3 was increased to 0.88 %.

Ties parallel to the loading direction, indicated by circle 1 in Fig.7, can resist joint shear in the truss mechanism, whereas ties indicated by circle 2 restrain the expansion of the core concrete normal to the loading direction. The action of confinement by a closed joint hoop is illustrated in Fig.8. Radial pressure in the joint core concrete pushes out the corner column reinforcing bars. The diagonal force is balanced with tensile forces in the joint hoop supporting the corner bars. The tie (circle 1) supporting an intermediate column bar is not affected by this confining action because the tie of circle 2 perpendicular to that of circle 1 is hooked at a different column bar.

Bond deterioration along the beam reinforcement was developed for all specimens under cyclic load reversals. Joints of three specimens did not fail in shear up to a story drift angle of 1/50 rad although the joint shear stress reached as high as 0.31 f_c' in Specimens B1 and B2, and 0.28 f_c' in Specimen B3.

Strains in legged ties parallel to the loading direction within a joint of Specimens B1 and B3 are shown in Fig.9. Yield strain was defined as 0.2 % because the plain bar used as the lateral reinforcement in a joint did not have a distinct yield plateau. Strains in two specimens were almost constant after a story drift angle of 1/100 rad, not yielding up to a story drift angle of 1/50 rad. Hence, the truss mechanism contribution decreased with bond deterioration along the beam reinforcing bars. Strain distributions in two specimens were similar despite of different amounts of the lateral reinforcement within a joint. This shows that the shear carried by the joint lateral reinforcement is unreliable with a bond deterioration.

Strains orthogonal to the loading direction in Specimens B1 and B2 increased with the story drift as shown in Fig.10, but did not reach the yield strain up to a story drift angle of 1/50 rad. Therefore, the amount of the lateral reinforcement provided in Specimens B1 and B2, i.e., 0.35 % is sufficient to confine the joint core concrete.

EFFECT OF COLUMN AXIAL LOAD

Park and Paulay (Ref.8) suggest that it is possible to reduce the amount of the lateral reinforcement within a joint with an increase in the column axial load since the depth of a diagonal compression strut becomes large, increasing the part of the joint shear resisted by the diagonal concrete strut.

The method proposed by Ichinose (Ref.5), introduced previously in this paper, indicates that the amount of the lateral reinforcement contributing to carrying joint shear can be reduced if the column axial load increases as shown in Fig.11.

CONCLUDING REMARKS

Role of the lateral reinforcement within a joint changes with the variation of shear resisting mechanisms. The lateral reinforcement contributes to carrying joint shear due to the truss mechanism when a good bond is maintained along the beam reinforcement. However, a bond deterioration along beam bars is inevitable for moment resisting frames with the beam collapse mechanism, and the dominant part of the joint shear is resisted by the diagonal compression strut mechanism. The principal role of the joint lateral reinforcement in such case becomes to confine the cracked joint core concrete.

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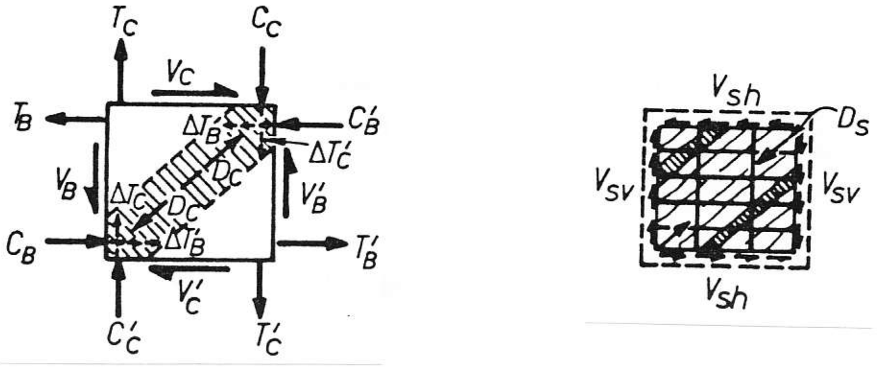


(a) Diagonal Strut Mechanism

(b) Truss Mechanism

Fig.1 : Shear Resisting Mechanisms in Joint by Paulay

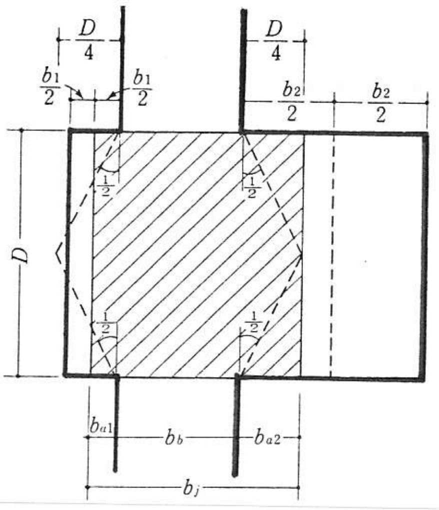
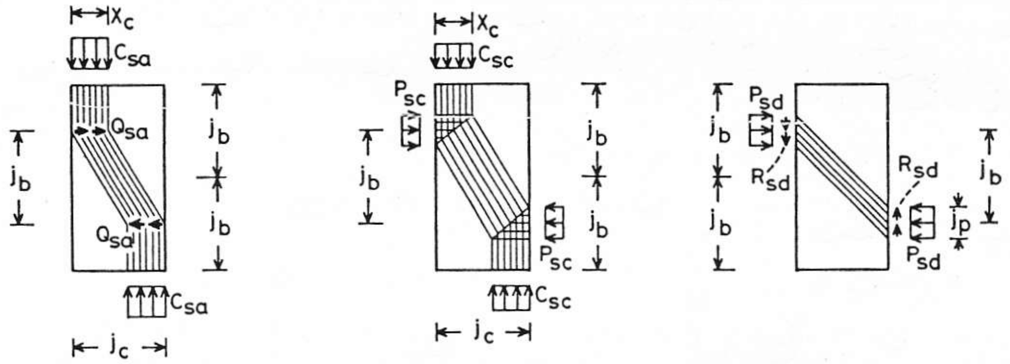
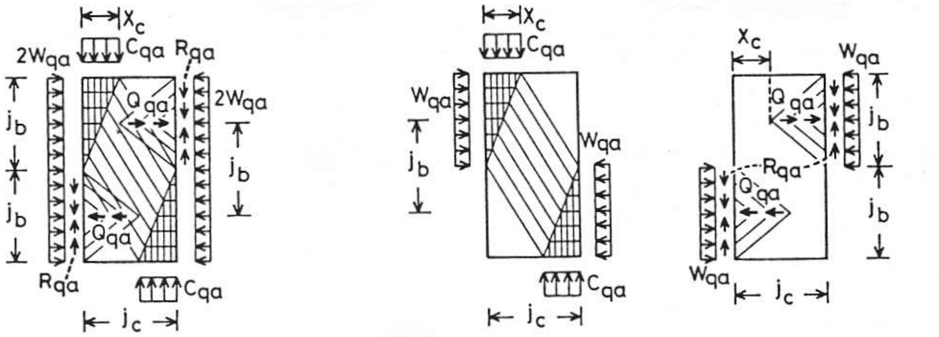


Fig.2 : Joint Effective Area by A.I.J.

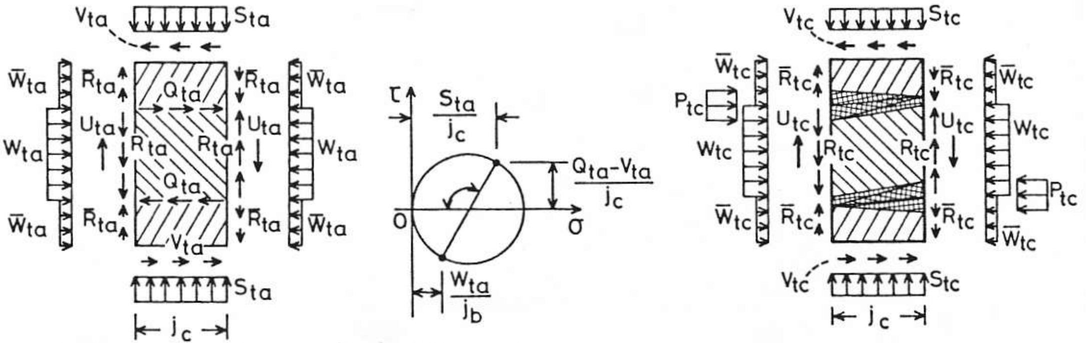


(a) Strut action A (b) Strut action C (c) Strut action D



(i) Total (ii) Strut action (iii) Bond action

(d) Quasi strut action A



(i) Truss action (ii) Mohr's circle

(e) Truss action A (f) Truss action C

Fig.3 : Shear Resisting Mechanisms in Joint by Ichinose

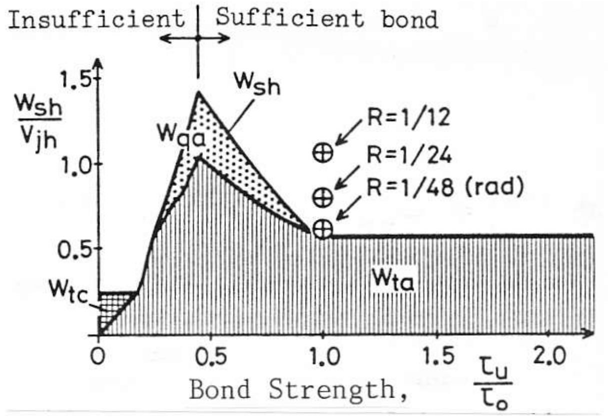


Fig.4 : Required Amount of Joint Lateral Reinforcement

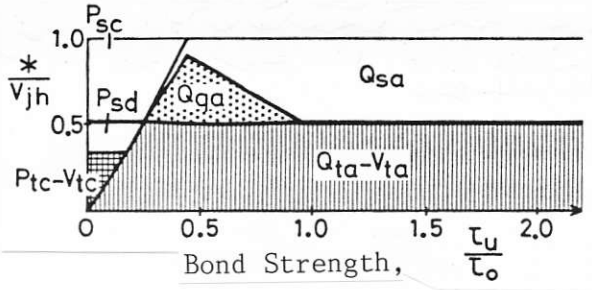
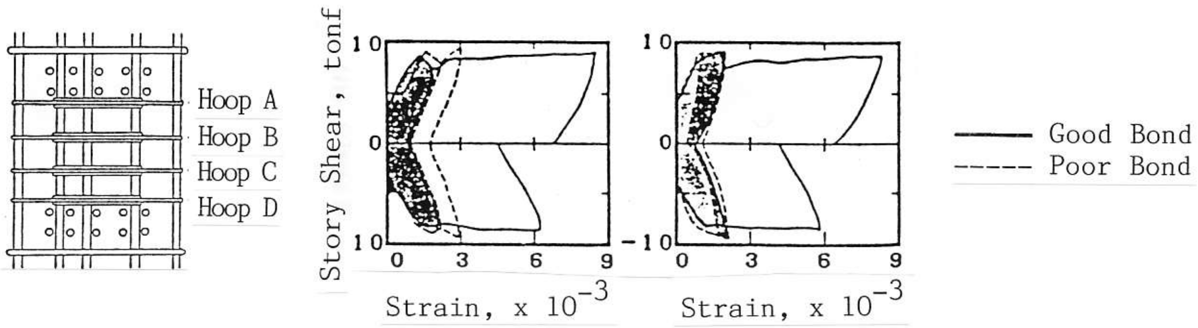
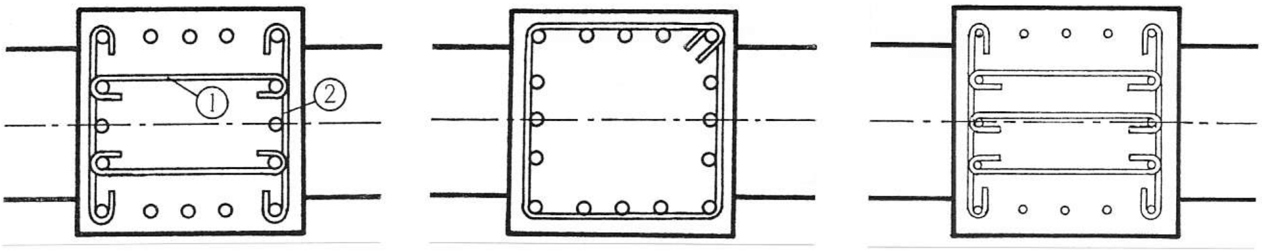


Fig.5 : Contribution of Joint Shear Mechanisms



(a) Hoop A,D (b) Hoop B,C

Fig.6 : Strains in Joint Lateral Reinforcement



(a) Specimen B1 (b) Specimen B2 (c) Specimen B3

Fig.7 : Detail in Joint Lateral Reinforcement

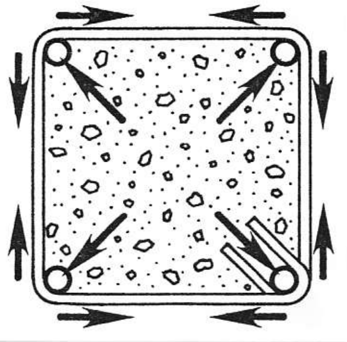


Fig.8 : Confinement Action by Closed Hoop

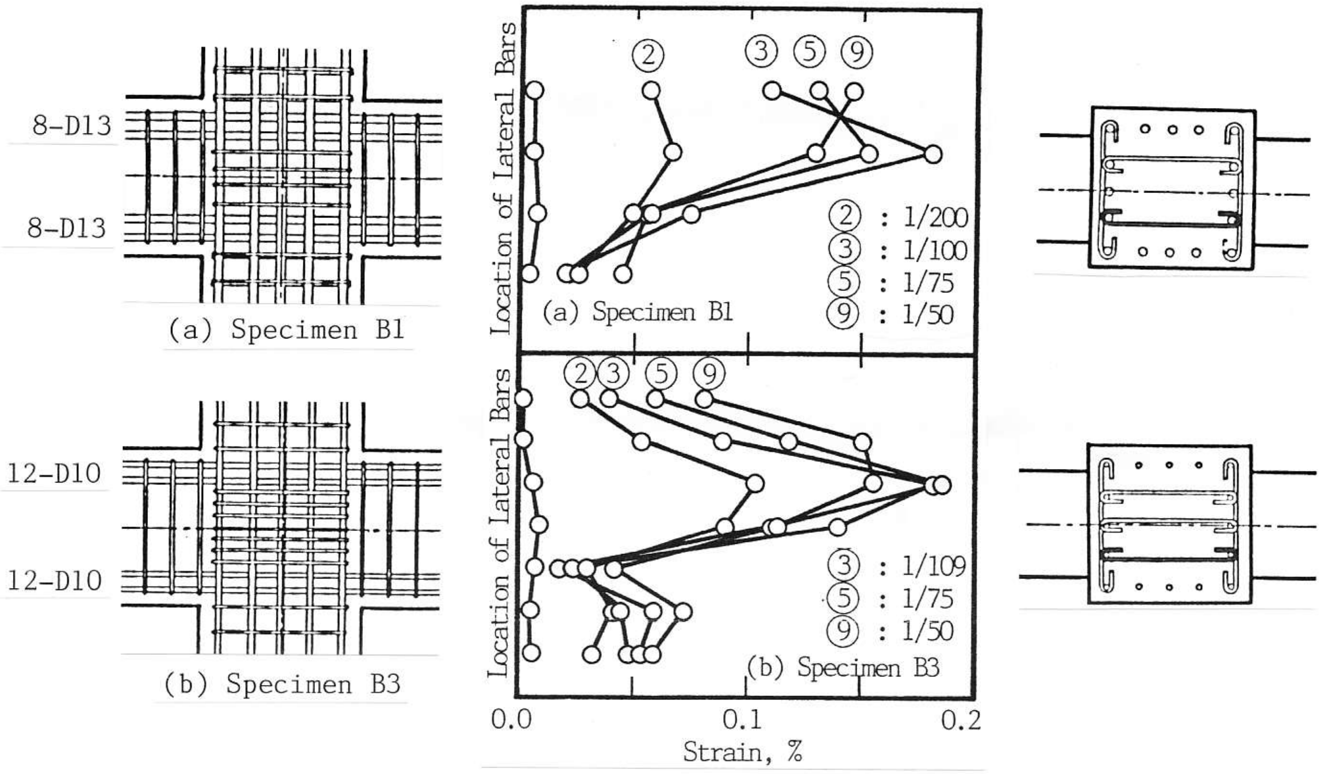


Fig.9 : Strains in Joint Ties Parallel to Loading Direction

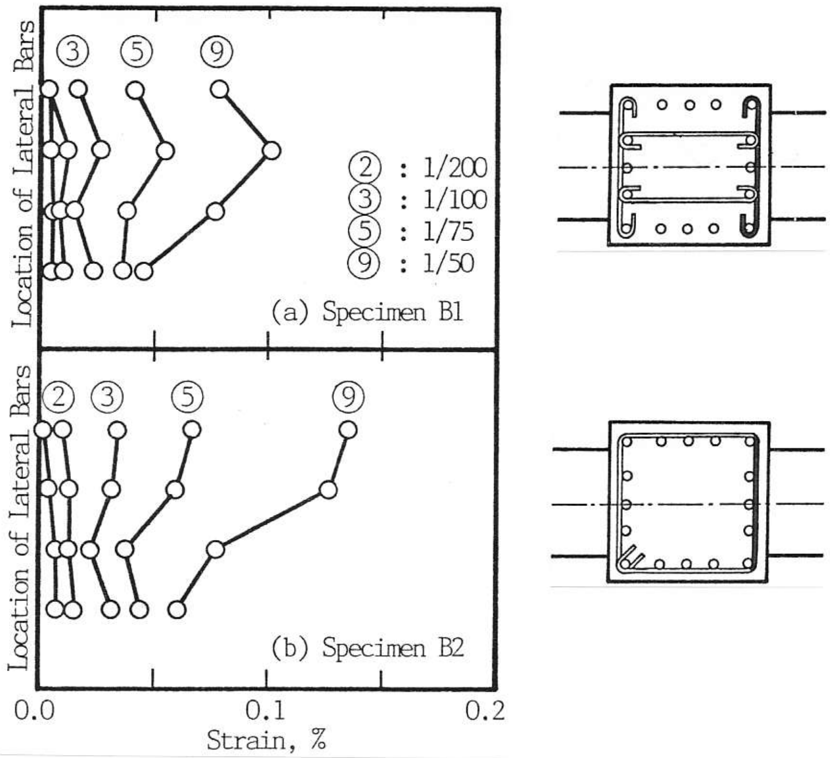


Fig.10 : Strains in Joint Reinforcement Orthogonal to Loading Direction

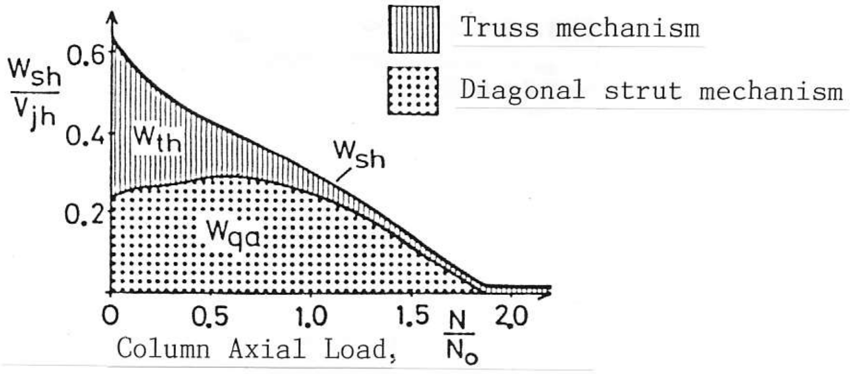


Fig.11 : Effect of Column Axial Load on Amount of Joint Lateral Reinforcement by Ichinose