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Modelling of Reinforced Concrete Beam with Shear Reinforcement

Etude par modèle d'une poutre en béton armé

Modell eines Stahlbetonbalkens mit Schubbewehrung

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1. INTRODUCTION

There have been many models on shear resistance mechanism of reinforced concrete beam with shear reinforcement. The model commonly accepted is a sort of truss model which is a combination of "truss with 45° strut" and so-called "shear force carried by concrete." However, the previous experimental observation disclosed that inclination of compressive force in concrete between shear cracks was less than 45° and not constant[1], and that stress in shear reinforcement dose not follow the truss model above under repeated loading[2]. Many analytical approaches have been done on shear resistance mechanism, but no satisfactory results have been obtained except on ultimate strength. The reason for this is believed that prediction of shear crack propagation, modelling of forces transferred at shear crack, nor modelling of bond characteristics is not accurate enough in the analyses.

In this study two reinforced concrete beam with vertical stirrup were tested under repeated loading. The main parameter was bond characteristics of stirrup. Detailed measurements were done on shear crack displacements, strain in concrete between cracks, and strains in stirrup and tensile reinforcement. To estimate stresses transferred at crack, the recent study[3] was applied.

2. TEST RESULTS

Test results are summerized as follows. (1)Tensile stresses induced by shear cracking in reinforcement crossed by shear crack increase more or less linearly as external shear force increases. (2)Shear and compressive normal stresses transferred at shear crack increase approximately in a linear manner with external shear force until reinforcement crossed by the same shear crack starts yielding (see Fig.1). (3)Vertical components of forces transferred at shear crack and forces in stirrup increase also linearly as external shear force increases, but the remaining vertical component decreases. (4)Direction of compressive force in concrete between shear cracks more or less coincides with that of force transferred at the shear cracks. (5)Bond characteristics of shear reinforcement indicate negligible effects on shear resistance mechanism.

3. NEW TRUSS MODEL

It can be said that the test results are expressed by a new truss model as follows. (1)Inclination of compressive diagonal strut is less than 45° and can be assumed to be constant. (2)Shear force carried by other than truss (or concrete) decreases as external shear force increases. This truss model is given by Eq.(1) and illustrated in Fig.2.

$$V = V_c + V_s = \nu V_{co} + A_w \sigma_w (z/s) \cot\theta \qquad (1)$$

where V_{co} : shear force carried by other than truss, ν : reduction factor, A_w : area of shear reinforcement within s, σ_w : stress of shear reinforcement, s : spacing of shear reinforcement, z : distance between tension and compression chord (=d/1.15), d : effective depth, θ : inclination of diagonal strut. As shown in Fig.2, contribution of truss, V_s is greater than that with θ of 45° , but decrease in V_c compensates the increase in V_s. Since the inclination of diagonal strut is not equal to that of shear crack, force transferred by aggregate interlocking should match with compressive force in diagonal strut.

Model description so far concerns shear resistance behavior at monotonic loading. At unloading and reloading the followings were found. (1)Crack displacements (opening and shearing displacements) vary linearly with external shear force, but rate of change is smaller. (2)Inclination of compressive force in concrete between shear cracks is the smaller with the lower external shear force. These experimental facts indicate that diagonal strut in the truss model should be with variable angle at unloading and reloading. Because of plastic characteristics of shear transfer constitutive laws at shear crack, the truss mechanism indicates plastic behavior. The change in inclination of diagonal strut implies that compressive normal stress at shear crack becomes relatively the larger with the lower external shear force, compared with shear stress.

4. CONCLUDING REMARKS

The new truss model can explain satisfactorily the experimental facts. Features of the truss model, such as inclination of strut indicate strong dependency on stress transfer constitutive laws at shear crack.

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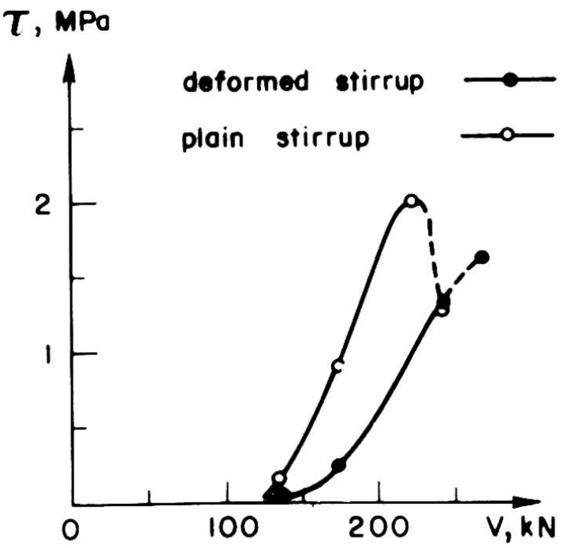

Fig.1 Shear stress at shear crack

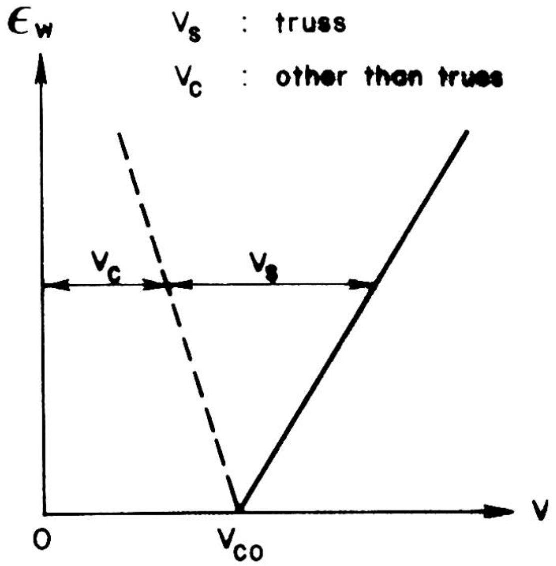

Fig.2 New truss model