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AXIAL STIFFNESS OF STEEL EMBEDDED IN CONCRETE UNDER SHEAR

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1. Introduction: The shear capacity across initially cracked reinforced concrete sections has been analytically predicted by combining models for steel axial pull-out [1] and model for stress transfer across plain concrete crack plane [2]. The compatibility relation between steel bar pull-out (s) and crack width (w) is simply taken as w = 2s. However, the mere combination of the above two models is not satisfactory to predict the stress transfer behaviour across an initially cracked RC plane, specially in the case of larger diameter steel reinforcing bar [3]. One possible explanation is the reduction in confinement given by the steel crossing the crack, owing to the local curvature induced in the reinforcement by the crack shear. The objective of this study is to determine possible reduction in the internal axial stiffness of the reinforcing bars, as compared to that derived from pure uniaxial pull-out tests, due to the localized bending moment induced by the crack shear. If such a reduction is substantial, then the constitutive equation for stress in steel, subjected to pull-out and crack shear, should not only be a function of steel pull-out (= w/2), but also that of shear displacement associated with the 3-dimensional aspect of generic steel model.

2. Experimental outline: For the above stated problem, two experiments were carried out with beam specimens, hereafter referred to as B1 and B2, having a vertical cold joint at mid-span, which was the expected crack location. Specimen B1 had five 12mm diameter bars and specimen B2 had a single 25mm diameter bar, crossing the crack plane. The experimental set-up is shown in Fig. 1.

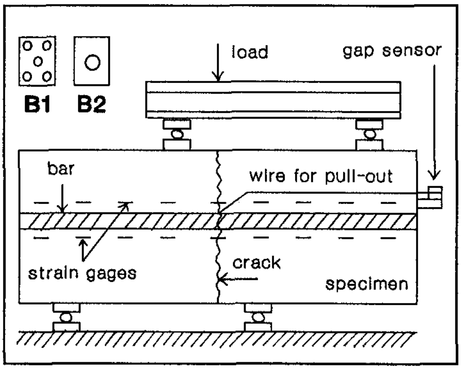

Figure 1: Experimental set-up

3. Reduced stiffness on pull-out of bars: From the experimental results it can be observed that the zone in which local curvature is induced for specimen B1, having 12mm diameter bar, is not so large and is limited to a region of '3D' (D: bar diameter) from the crack, with maximum curvature at '1.5D' (Fig. 2). Also it can be seen that the reduction in axial stiffness of this bar is not substantial (Fig. 3). This indicates that the local curvature has little effect on the mean stress and mean strain relation for a smaller diameter bar and the conventional 1-D model of reinforcement can give reasonable results. However, for specimen B2, having 25mm diameter bar, the zone of local curvature extends up to nearly '5D' from the crack, with maximum curvature at around '2D' (Fig. 2) and the reduction in axial stiffness is about 50% compared to the full tension capacity that can be developed, owing to the curvature effect (Fig. 3). Compatibility relation between the local curvature and the shear slip has been attempted by assuming a simplified second degree parabolic distribution as follows

$$\phi(x) = \frac{\phi_{max}}{6.25D}\left(5x - \frac{x^2}{D}\right) \quad (0 \leq x \leq 5D) \qquad (1)$$

$$\delta = \int \int_0^{5D} \phi(x)dx + \delta_o \qquad (2)$$

where $\phi(x)$ is the local curvature and ϕ_{max} is the maximum curvature within the influencing zone. δ is the shear slip at the crack. δ_0 is the shear slip originated from the local shear deformation of steel bars within the influencing zone which is not so significant before the yielding of the steel and is neglected for the present report. As can be observed from Fig. 4 the shear slip can be

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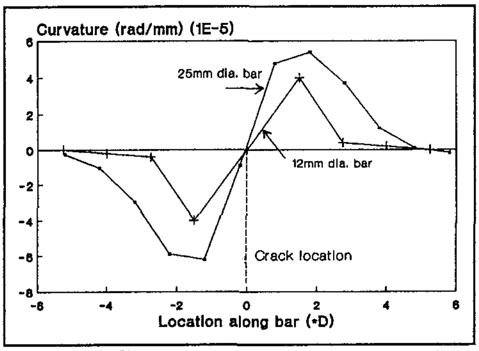

Figure 2: Curvature distribution along bar

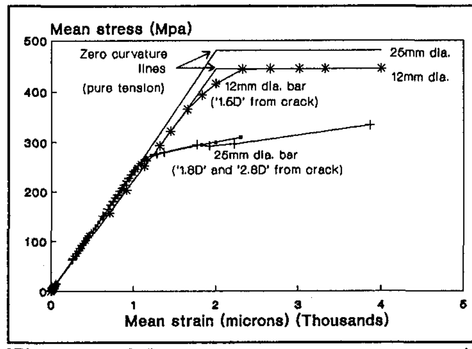

Figure 3: Mean stress vs. mean strain relation for 12mm and 25mm dia. bar

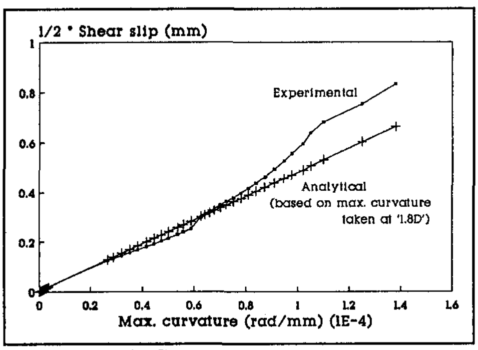

Figure 4: 1/2 Shear slip vs. max. curvature along bar (for 25mm dia. bar)

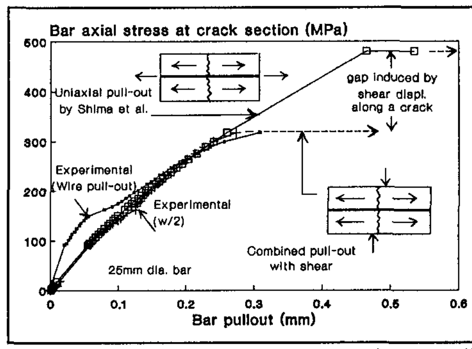

Figure 5: Bar axial stress at crack vs. pull-out (for 25mm dia. bar)

predicted with reasonable accuracy from the assumed curvature distribution profile. Fig. 5 shows that if the curvature influencing zone, taken as '5D' is considered, the axial stress in the bar at the crack can be predicted quite well from the bar pull-out upto the reduced yield mean stress level of the reinforcing bar. Beyond that, the mean steel axial stress is overestimated by the existing axial pull-out model [1] and there is a significant reduction in the sectionally averaged yield level obtained from the tests as compared to the model, due to the shear displacement along the crack.

5. Conclusions: From the above discussion it can be concluded that

i) Localized curvature is induced in steel bars due to shear across a crack plane, the magnitude and zone of influence of which varies with bar diameter.

ii) In the case of larger diameter steel bar axial stiffness is considerably reduced due to local curvature induced by shear slip along a crack.

ii) A simplified parabolic curvature distribution of the reinforcement can be used to predict the shear displacement of the specimen. In continuation an enhanced model for bar pull-out needs to be formulated as a function of shear slip and crack opening.

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References: 1) H. Shima, L. Chou and H. Okamura, "Micro and Macro Models for Bond Behaviour in Reinforced Concrete", J. of Faculty of Eng., Univ. of Tokyo (B), Vol. 39, No.2, 1987.
2) B. Li, K. Maekawa and H. Okamura, "Contact Density Model for Stress Transfer across Cracks in Concrete", Journal of Faculty of Eng., Univ. of Tokyo (B), March, 1989.
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