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DETERMINATION OF TENSION STIFFNESS OF CRACKED REINFORCED CONCRETE BASED ON MICRO-BOND CHARACTERISTICS

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1. INTRODUCTION

The aim of this study is to get the spatial average stress- average strain relationships of both reinforcing bars and cracked concrete in RC members based on the local bond characteristics between concrete and re-bars. The computational basis is the local bond-slip-strain model [1]. In the computation the local stress and strain profiles of both re-bars and concrete between two adjacent cracks are computed. Using these profiles, the spatial average stress and average strains can be computed. The computation is also capable of predicting the ultimate average strain of re-bars. The comparison with the experiments shows good agreement.

2. SPATIAL AVERAGED CONSTITUTIVE LAWS IN TENSION

2.1. BOND-SLIP-STRAIN MODEL:

Shima et al. [1] proposed a universal bond stress-axial slip-steel strain model for RC . The model offers unique relationship which expresses the bond characteristics derived from both pull out and axial tension tests. The constitutive law of bond is given by,

$$\tau(\varepsilon, s) = \tau_0(s)\ g(\varepsilon) \tag{1}$$

$\tau(\varepsilon, s)$: Bond stress, $\tau_0(s)$: Bond stress when strain is zero

$$\tau_o(s) = f'_c\, k[\ln(1+5s)]^c \tag{2}$$

$$g(\varepsilon) = \frac{1}{1+10^5\varepsilon} \tag{3}$$

f'_c: Compressive strength of concrete, k: Constant=0.73, c: Constant=3
s: Non dimensional slip =1000S/d , S: Slip , d: Diameter of bar, ε : Strain of bar

2.2. BOND DETERIORATION MODEL:

Shima's model can not be applied to the bond deterioration zone where the "near crack surface effect" is predominant. Qureshi et al.[3] assumed in the RC joint model that the bond stress is linearly decreasing to zero at a distance 5 d from the crack surface, and that the bond stresses drops suddenly to zero at a distance 2.5 d from the crack surface due to splitting and crushing of concrete around the bar beside the crack surface.

3. ANALYSIS

To get the steel stress profile, four equations should be solved simultaneously. By dividing the reinforcing bar between two adjacent cracks into small divisions or elements and studying the free body equilibrium of such elements, we get the following equilibrium equation,

$$\frac{d\sigma}{dx} = \frac{\pi d}{A_s}\bar{\tau} \tag{4}$$

where,

$\frac{d\sigma}{dx}$: Re-bar stress gradient along an axis, As: Re-bar cross sectional area, d : Diameter of reinforcing bar, $\bar{\tau}$: Average bond stress

The second equation is the bond-slip-strain model, together with the bond model in the bond-deterioration zone. The third equation is the slip compatibility equation. The slip is computed by integrating the strain over the length of the rebar starting from the midway between adjacent cracks, i.e. the slip at the midway between cracks is zero. Thus, we

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have,

$$S=\int \varepsilon dx \tag{5}$$

The fourth equation is the constitutive equation for the bare bar which represents the pointwise relationship between the re-bar stress and strain at each bar section,

$$\sigma=\sigma(\varepsilon) \tag{6}$$

Firstly, the crack spacing is equal to the total length of the specimen, and during analysis the local concrete tensile stresses are checked and a new crack is introduced whenever the stress reaches the cracking stress of concrete and a new average crack spacing is computed. Starting from the midway between two adjacent cracks, a finite segment with length Δx is studied. The boundary conditions are assumed by equating both the slip and the bond stress at the middle section to zero, and assuming a value to the strain at the middle. The four equations are simultaneously solved using an iterative procedure. Finishing the computation of this division, the boundary conditions of the next division are defined and a similar computation procedure is followed. Hence, the strain and stress profiles of the steel reinforcement can be drawn. It results in the average stress and average strain as,

$$\bar{\sigma}=\frac{2}{L_c}\int_0^{\frac{L_c}{2}}\sigma(x)dx \cong \frac{2}{L_c}\sum_0^{\frac{L_c}{2}}\sigma(x)\Delta x \tag{7}$$

$$\bar{\varepsilon}=\frac{2}{L_c}\int_0^{\frac{L_c}{2}}\varepsilon(x)dx \cong \frac{2}{L_c}\sum_0^{\frac{L_c}{2}}\varepsilon(x)\Delta x \tag{8}$$

By computing the stress profile of reinforcement, the stress profile of concrete is obtained by subtracting the reinforcement force profile from the total force which equal to the re-bar force at the cracked section. Then, the average stress of concrete is also mathematically defined. A comparison with the experiments by Shima [1]is shown in Fig.1 and Fig.2. The analysis agreed well with the reality .

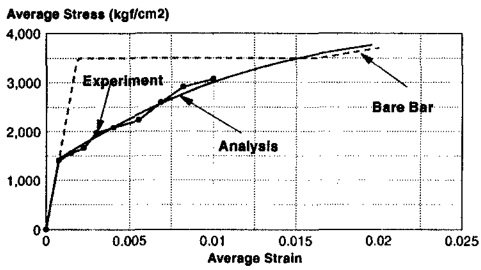

Fig.1: Average Stress Average Strain Relationship of Re-bars

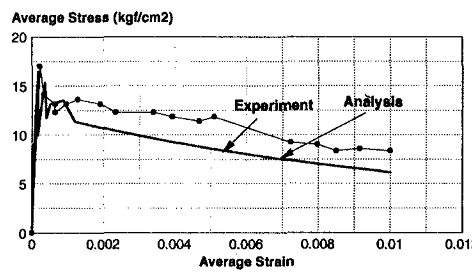

Fig.2 : Average Stress Average Strain Relationship of Concrete

5. CONCLUSIONS:

- Based on the microscopic bond-slip-strain model and bond deterioration, the stress profile as well as the strain profile of reinforcing bars embedded in concrete can be computed. Hence, the macro average stress- average strain relationship of reinforcing bars as well as the tension stiffening of concrete can be computed. From the microscopic behaviour of reinforced concrete, the macroscopic behaviour can be detected .

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