(V－67) A VERSATILE COMPUTATIONAL MODEL FOR REINFORCED CONCRETE IN TENSION

The University of Tokyo Student Member M. SALEM, Hamed
The University of Tokyo Regular Member MAEKAWA , Koichi

1. INTRODUCTION

The aim of this study is to get a versatile 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 reinforcing bars. In the computation the local stress and strain profiles of both steel and concrete between two adjacent cracks are computed. Using these profiles, the spatial average stress and average strains can be computed [4]. Hence, a parametric study is carried out to develop an explicit model suitable for the use in FEM applications. The model can be used for wide ranges of reinforcement ratio, steel properties and concrete properties.

2. MODELNG OF REINFORCEMENT

2.1. AVERAGE YIELD STRESS:

A general model for average yield stress derives from a parametric study [4] taking into account yield stress, reinforcement ratio, concrete tensile and compressive strength, and bar diameter as shown in Fig.1 and,

$$\left(\bar{f}_y/f_y\right)=1.0-0.5\left(\rho_{cr}/\rho\right) \qquad (1)$$

where, $\bar{f}_y$: average yield stress ; f_y: yield stress ; ρ : reinforcement ratio and ρ_{cr} : critical reinforcement ratio $=f_t/f_y$.
Since in reinforced concrete, cracking should be controlled by reinforcement, yielding load should be higher than cracking load. In other words ρ/ρ_{cr} should be greater than one. Therefore, in Eq.1, the parameter ρ/ρ_{cr} is limited to be greater than one.

2.2. AVERAGE ULTIMATE STRESS:

A similar parametric study for average ultimate stress was carried out. Here, additional parameters are studied that are; tensile rupture strength and ratio of tensile rupture strength to yield strength. The post yield behavior is the point of discussion as shown in Fig.2 and formulated by,

$$\left(\frac{\bar{f}_u}{f_u}\right)=0.99-\left(0.22\left(\frac{f_u}{f_y}\right)^{-3}\Big/\left(\frac{\rho}{\rho_{cr}}\right)^{2}\right) \qquad (2)$$

where, $\bar{f}_u$: average tensile rupture strength ; f_u: tensile rupture strength.

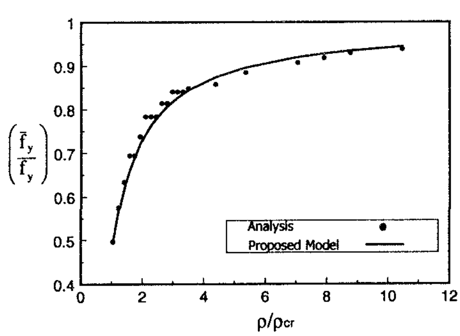

Figure 1 Normalized Average Yield Stress

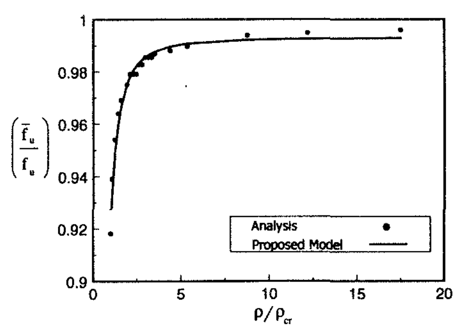

Figure 2 Normalized Average Ultimate Stress

2.3. TRI-CURVED MODEL:

In this model the average behavior of the reinforcement is composed of three curves. The first one is linear up to the yielding point, the second is linear reaching a point with coordinates (ε_{shl} , f_{yl}), while the third is in the form of exponential curve up to the failure point as follows.

Hamed M. SALEM, Koichi MAEKAWA.

$$\bar{\sigma}=E_s\bar{\varepsilon} \quad , \quad \{\bar{\varepsilon}\le\bar{\varepsilon}_y\} \tag{3}$$

$$\bar{\sigma}=\bar{f}_y+\left(\bar{\varepsilon}-\bar{\varepsilon}_y/\varepsilon_{sh1}-\bar{\varepsilon}_y\right)\left(\bar{f}_{y1}-\bar{f}_y\right),\ \{\bar{\varepsilon}_y<\bar{\varepsilon}\le\varepsilon_{sh1}\} \tag{4}$$

$$\bar{\sigma}=\bar{f}_{y1}+(1-e^{\left(\frac{\varepsilon_{sh1}-\bar{\varepsilon}}{k}\right)})(1.01f_u-\bar{f}_{y1}),\ \{\bar{\varepsilon}>\varepsilon_{sh1}\} \tag{5}$$

$$\bar{f}_{y1}=\bar{f}_y+\left(f_y-\bar{f}_y\right)f_1 \tag{6}$$

$$f_1=f_1\left(\varepsilon_{sh}/\varepsilon_y,\rho/\rho_{cr},f_u/f_y\right) \tag{7}$$

$$\varepsilon_{sh1}=\varepsilon_y\left(1.8+0.6\varepsilon_{sh}/\varepsilon_y\right)f_2 \tag{8}$$

$$f_2=f_2\left(\varepsilon_{sh}/\varepsilon_y,\rho/\rho_{cr},f_u/f_y\right) \tag{9}$$

$$k=0.035\left(4000/f_y\right)^{\frac{1}{3}} \tag{10}$$

where ε_{sh} is the strain at which the steel starts the strain hardening state and ε_y is the yielding strain. f_1 and f_2 are functions of the post yield behavior of steel that depend on the yielding plateau of steel, the ratio of the tensile rupture strength to yield strength ,concrete tensile strength and the percentage of steel reinforcement.

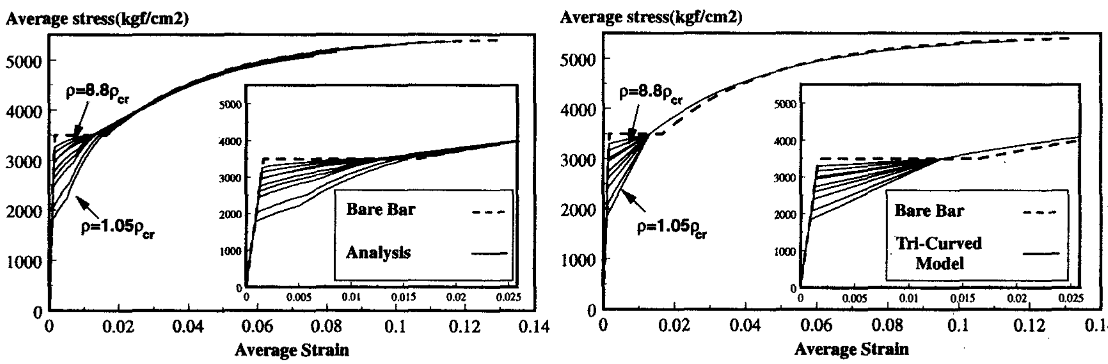

Figure 3 Microscopic Analysis and Proposed Model

3. MODELNG OF CONCRETE

It was found that the model of Okamure et al. [2] can be used for tension stiffening with acceptable accuracy in comparison to the analysis as shown in Fig. 4. However, for more accurate analysis, a model dependent on the reinforcement ratio should be used based on the microscopic approach.

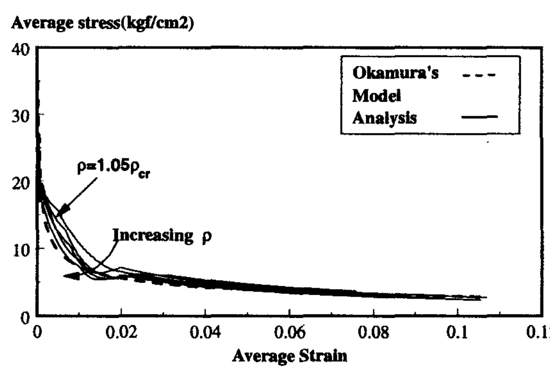

Figure 4 Modeling of concrete

4. CONCLUSIONS

- Based on the microscopic bond, the macroscopic response of concrete and reinforcement are computed. Afterwards, a systematic parametric study was conducted and an explicit model applicable to FEM analysis was proposed.

REFERENCES:

1. Shima H., Chou L., and Okamura, H " Micro and Macro Models for Bond in Reinforced Concrete" Journal of The Faculty of Engineering, The University of Tokyo(B), Vol.XXXIX, No 2, 1987.
2. Okamura, H. and Maekawa, K., "Nonlinear Analysis and Constitutive Models of Reinforced Concrete", Gihodo, Tokyo, 1990.
3. Qureshi, J. and Maekawa, K., "Computational Model for Steel Bar Embedded in Concrete under Combined Axial Pullout and Transverse Shear Displacement" , Proc. of JCI,Vol.15, No. 2, 1993, pp 1249-1254.
4. Hamed, M. S., and Maekawa, K., " Tension Stiffness for Cracked Reinforced Concrete Derived from Micro-bond Characterisics" Proc. of JCI, Vol.19, No.2 , 1997, pp 549-554