CRACKING ASSOCIATED WITH BOND-SLIP BEHAVIOUR IN RC BRIDGE PIERS SUBJECTED TO EARTHQUAKE EFFECTS

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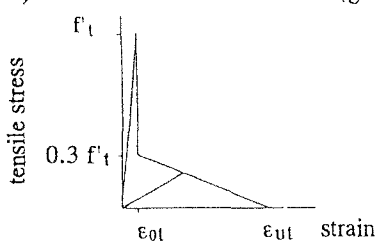
1. Objective

The present study aims to analize the cracking phenomena of concrete associated with bond-slip behaviour of steel reinforcing bars in reinforced concrete piers subjected to earthquake effects by considering a *fixed orthotropic plasticity-based smeared-cracking model*. The calculation of the crack width " h " is based on the *Mode I Failure* type of fracture mechanics theory applied to concrete structures. The degradation of strength due to tensile cracking and decohesion shear is controled directly through the anisotropic strain-softening σ_n - τ *yield condition*.

2. Tensile strain softening and fracture energy of concrete

The stiffness of the cracked element should be softened isotropically by reducing the initial modulus of elasticity E_c according to a stress-strain relationship including the tension-stiffening effect (cracking in tension) such as that used herein . See Fig. 1.



$f_t = 0.62\,(f'_c)1/2$: tensile strength of concrete (MPa)
$\varepsilon_{ot} = f'_t / E_c$: tensile strain of concrete
$\varepsilon_{ut} = 9.2\,\varepsilon_{ot}$: ultimate tensile strain of concrete

Fig. 1 Tensile-strain softening of concrete

3. The Modes I and Mode II Types crack model for concrete members

The maximum tensile criterion is considered herein to evaluate the orientation and crack development. The stress intensity factor for the combined crack mechanism is described by :

$$K = 1/4(1-\nu)\left\{ K_I\left[(3-5\nu)\cos\theta_0/2 + (1+\nu)\cos 3\theta_0/2\right] - (K_{II}/E)\left[(3-5\nu)\sin\theta_0/2 + 3(1+\nu)\sin 3\theta_0/2\right]\right\} \geq K_{Id} \quad (1)$$

Where K_I and K_{II} are the stress intensity factors for opening (type I) crack propagation and sliding (type II) crack propagation respectively.

4. Cracking of concrete in Finite Element Analysis

Initial cracking due to excessive tension in the n-direction is characterized by :

$$\begin{bmatrix}\sigma_n\\ \sigma_t\\ \tau_{nt}\end{bmatrix} = \begin{bmatrix}E_n & \nu & 0\\ \nu & E_t & 0\\ 0 & 0 & \beta_s G\end{bmatrix}\begin{bmatrix}\varepsilon_n\\ \varepsilon_t\\ \gamma_{nt}\end{bmatrix} \quad (2)$$

β_s is called " retention factor". It takes into account the asperities and aggregate interlock of concrete.
The stress-strain relationship in the post-cracking stage (softening behavior due to cracking) is obtained by differentiating Equation (2) and considering the following biaxial condition:

$$F(\sigma, \varepsilon_{np}) = \sigma_n^2 + \tau_{nt}^2/\alpha^2 - f_t^2 = 0 \quad (3)$$

Then, the stress-strain relationship in the post-cracking stage results as :

$$\begin{bmatrix}\sigma_n\\ \sigma_t\\ \tau_{nt}\end{bmatrix} = \begin{bmatrix}E_{11}(1-4E_{11}c\,\sigma_n^2) & 0 & -4cE_{11}G\,\sigma_n\tau_{nt}/\alpha^2\\ 0 & E_{11} & 0\\ \text{SYMM} & & G(1-4cG\tau_{nt}^2/\alpha^4)\end{bmatrix}\begin{bmatrix}\varepsilon_n\\ \varepsilon_t\\ \gamma_{nt}\end{bmatrix} \quad (4)$$

where : $c = 1/(E_p + 4\sigma_n^2 E_n + 4\tau_{nt}^2 G/\alpha^4)$
$E_{11} = E/(1-\nu^2)$ From isotropic linear elasticity

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6. Model problem

The model analized herein, consists of a reinforced concrete single-bent pier supporting a typical steel girder as shown in Fig. 2. The motion considered herein is a piece-linear wave with 4 seconds of duration and 0.4 g of maximum acceleration. The interval of time is 0.05 seconds.

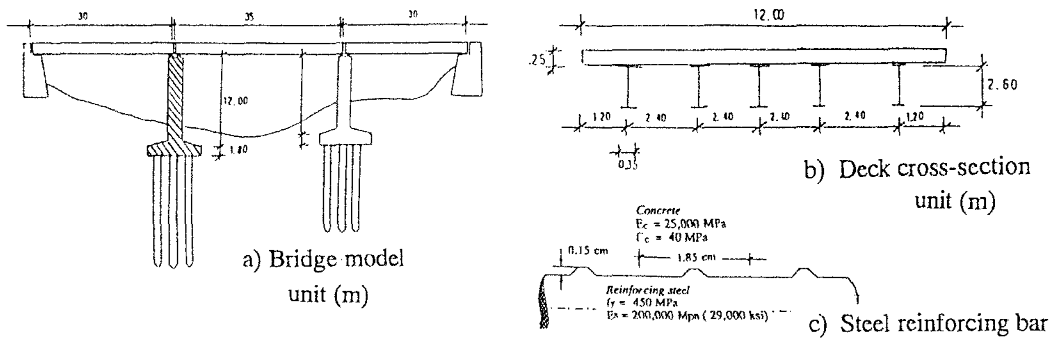

Fig. 2 Characteristics of the bridge pier

6. Numerical results

Fig.3 shows the variation of the critical moment (M_{cr}) along the height of the column. The critical moment (M_{cr}) is defined as the moment at which cracking initiates. By the other hand, Fig 4 shows the strain at cracking along the height of the pier. Fig. 5 shows the critical rotation versus the critical moment. It is clear from these figures that the formation of plastic hinge at approximately between the bottom and the midheight of the column. Finally Fig. 6 shows the rotation at cracking.

7. Conclusions

The purpose of this study was achieved by the analysis of a reinforced concrete pier considering the material nonlinearities, bond behaviour by the meaning of bearing of lugs against concrete and tension stiffening of concrete during cracking. The results related with the moments, stresses, strains and rotations, all of them at cracking stage, indicates that cracking phenomena of concrete can be modeled by combining the smeared crack approach with the concepts of cracking from fracture mechanics theory.

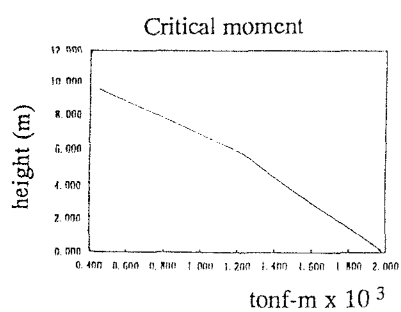

Fig. 3 Critical moment (at cracking) versus height of pier

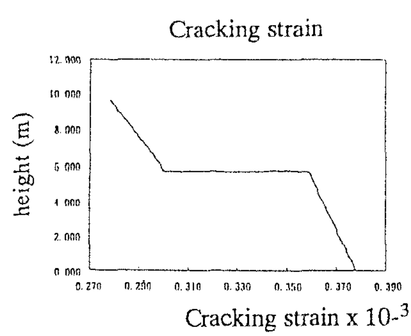

Fig. 4 Cracking strain along the height of the pier

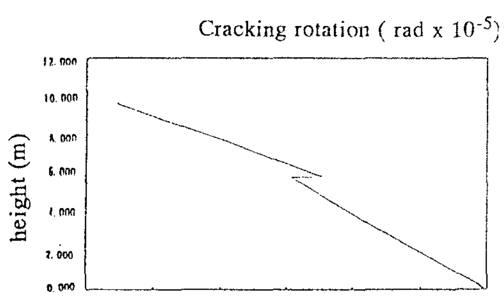

Fig. 5 Rotations at cracking along the the height of the pier

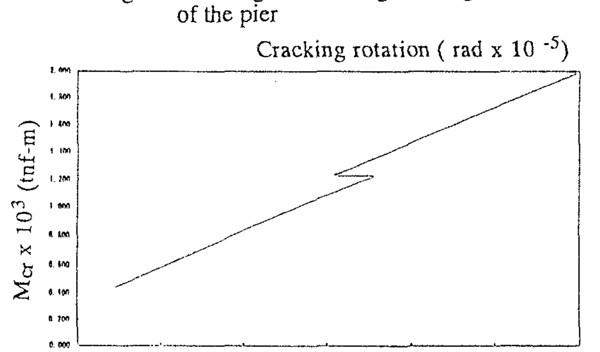

Fig. 6 M_{cr}-ϕ_{cr} curve. ϕ_{cr}