第V部門 *Cracking of RC Bridge Piers Due to Strong Ground Motion Effects*

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Objective
The present study intends to analize the cracking phenomena of RC bridge piers produced by the effects of earthquake loading. On this way, the characterization of cracking of concrete which may lead to nonlinearity in response is presented herein.

1. Analytical background

The great amount of collapsed RC single-column bents due to shear failure was clearly emphasized by the 1995 Great Hanshin Earthquake, it is a matter that really concern. It prompts to recognize the importance of the distribution of shear forces in plastic hinge zones, and also to consider an appropiated model for understanding the cracking phenomena in plastic hinge zones. On this basis, the present analysis considers among other features the softening of the the stiffness of the cracked element by reducing the concrete's elaticity modulus E_c according to a tensile-strain softening relationship. On the other hand, a yielding condition by meaning of the relation between normal stress " σ " and shear stress " τ " is also considered in order to take into account the coupling of stresses in the matrix that will govern the post-cracking stage of concrete. This matrix is expressed as follows:

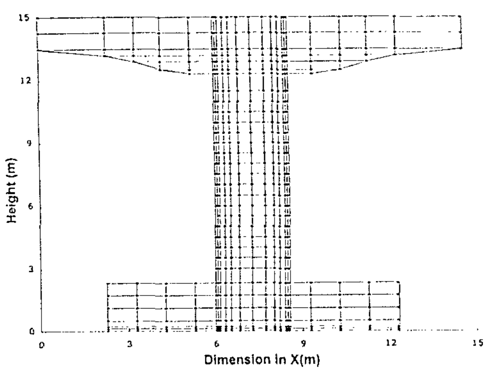
$$\begin{bmatrix} \sigma_n \\ \sigma_t \\ \tau_{nt} \end{bmatrix} = \begin{bmatrix} E_{11}(1 - 4E_{11} c\, \sigma_n^2) & 0 & -4c E_{11} G \sigma_n \tau_{nt} / \alpha^2 \\ 0 & E_{11} & 0 \\ \text{SYMM} & & G(1 - 4c\, G \tau_{nt}^2 / \alpha^4) \end{bmatrix} \begin{bmatrix} \varepsilon_n \\ \varepsilon_t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

where :

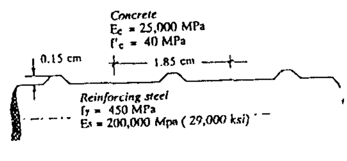
$$c = 1/(E_p + 4\sigma_n^2 E_n + 4\tau_{nt}^2 G/\alpha^4)$$
$$E_{11} = E/(1 - \nu^2)$$

2. Analitycal Model

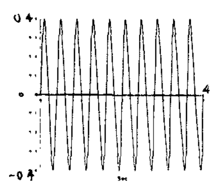
The finite element model of the RC single-column bent depicted in Fig. 1a is considered herein in order to carry out the analysis. The section is circular of 2.5 m diameter, reinforcing bars. The base is assumed to be fixed. The material properties are outlined in Fig.1b. The input motion considered is a piece-linear wave with peak acceleration of 0.4 G and 4 seconds of duration.



a) Finite element mesh



b) material properties



c) Input motion

Fig. 1 Analitycal model considered in the present analysis

4. Analitycal results

Fig. 2 shows the crack pattern at the plastic hinge zone formed near the base. The initial stage of cracking results in horizontal cracks which, with varying load, extend in a diagonal manner. These surfaces or stress trayectories at cracking are steep near the face of the pier and flatter in the upper part of the plastic hinge zone, it is because balance of the shear is transferred across the cracks. As consequence, cracks tends to migrate to zones at which the cracking stage has not still been reached. It emphasize that as important as consider the horizontal shear reinforcement is how it should be detailed in order to enhance force transfer more efficiency in ways that formed diagonal cracks not result in failure. In other words, it is necessary to limit maximum shear stresses in order to ensure that shear failure will not affect strongly ductile response.

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Fig. 3 shows the maximum stresses that correspond to the crack pattern depicted in Fig. 2. The maximum stresses represented in Fig. 4 reveals that concrete sustain severe cracking at the corners and the zone very close to the base of the pier. From this, it is expected that spalling of concrete will start to propagate upward just from this zones of maximum concentration of stresses. Fig. 3 also seems to indicate that the major part of the shear force at the pier base is transmitted across the flexural compression zone. At this stage, the stresses in the outermost steel layer exceeded narrowly the yield stress, steel bars of this layer were the only that reached the yield stress. If these outermost steel bars are subjected to compresive stresses a crack will form, then, during the cyclic motion this crack will open and close producing that shear force will be transmitted by dowell action, consequently, it will lead to a reduction of both the strength and stiffness of the shear friction mechanism.

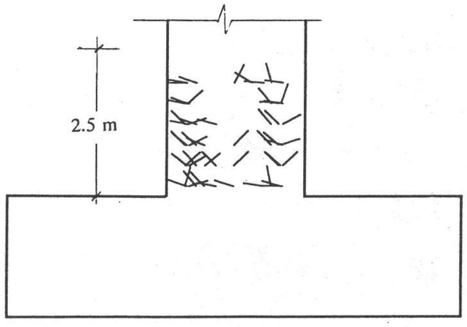

Fig. 2 Crack pattern formed at the plastic hinge

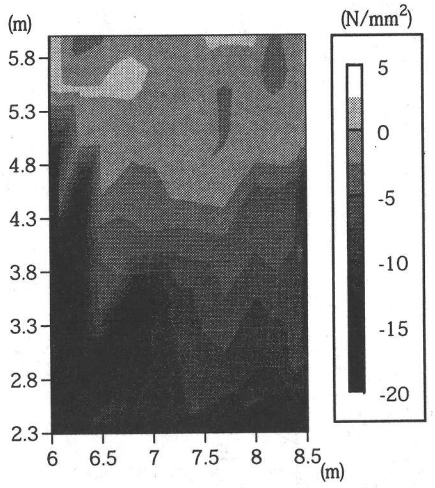

Fig. 3 Maximum concrete stresses that correspond to the crack pattern of Fig.2

Fig. 4 shows the deformation stage of the pier at t=3.6 secs. At this stage, maximum deformations at the base and its vicinity exceeded the elastic values. As a result, the overall stiffness of the bridge pier decreased significantly.
By the other way, hence, plastic deformations are obtained as hinge rotations, an important problem is to relate the plastic hinge rotations to curvature to obtain meaningful measure of ductility demand. It is because the *inelatic* rotation should not exceed the rotational capacity of the region in order to prevent shear failure or minimize the risk of structural collapse caused by shear failure mechanisms. On this way, Fig. 5 shows the variation of base shear due to variations of rotational stiffness at pier base. From this, it appears that shear is very sensitive to the variation of rotations (rotational stiffness). From the design point of view, it means that conditions for shear friction and dowell action should be improved. The maximum ductility (defined as the maximum rotation divided by yield rotation) for this pier is less than one, it is 0.7.

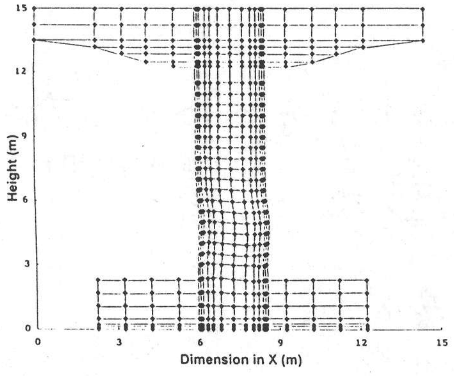

Fig. 4 Deformation of the pier at t=3.6 sec

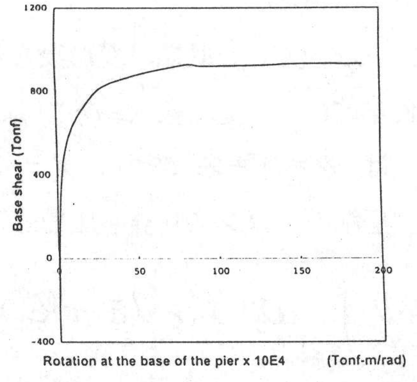

Fig. 5 Variation of base shear due to variations of rotational stiffnesses at the base of the pier

Conclusions

This study showed that cracking in plastic hinge zones is very sensitive to the variation of stresses due to the reduction of strength and stiffness, thus, a control in the mechanism of transfer of stresses appear to be a key point to consider in the structural design of new RC bridge piers in order to ensure enough ductility as well as moderate cracking during an strong earthquake.