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I - B139

Effect of Axial Stress on Ductility and Confinement of RC Bridge Piers Subject to Earthquake.
--- A three dimensional finite element approach---

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1. OBJECTIVES OF THE STUDY

It is known that shear reinforcement has significant role on the inelastic behavior of RC bridge piers in such a way that it prevents shear failure, provides enough ductility, confines the concrete core and prevents buckling of the longitudinal reinforcement. However, this significant role is greatly affected by axial compressive stress level of the pier and consequently we carry out this study, focusing only on the ductility level and confinement of the piers. In this study, the role of axial compressive stress on ductility level and confinement of RC bridge piers subject to earthquake motion is focused using nonlinear 3D FEM. From the results of inelastic response analysis, we are able to study the interaction of percentage of shear reinforcement and axial stress level and their role on displacement ductility factor and confinement level of the piers and we obtain an equation for each. El Centro motion is scaled to have a peak acceleration of **0.8 g** and used in the analysis. Axial stress level is changed to be 0.1, 0.2, 0.3, 0.4, and 0.5. Percentage of shear reinforcement is changed to be 0.0, 0.05, 0.1, 0.15, 0.25, 0.35, 0.45, and 0.55 %. Percentage of shear reinforcement is expressed as $\frac{A_b}{h.e}$, in which; A_b is the area of bar, $\boldsymbol{h}$ is the width of the pier and $\boldsymbol{e}$ is the spacing between the transverse hoops. Axial compressive stress level is taken as $\frac{P}{A_c.F_c'}$, where $\boldsymbol{P}$ is the axial load, F_c is the compressive strength of concrete, and A_c is the cross sectional area. We consider the compressive strength of the pier corresponding to zero shear reinforcement as F_{co}. The ratio of concrete strength corresponding to any percentage of shear reinforcement relative to F_{co} is defined as confinement stress factor K_σ.

2. RESULTS AND DISCUSSIONS
2.1. Ductility

We calculate displacement ductility factor for different cases of shear reinforcement and axial stress level from the equation:$D.F = \frac{\Delta_u}{\Delta_y}$, where, $D.F$ is the displacement ductility factor, Δ_u is the ultimate displacement when the load reaches to **0.8** of the ultimate load carrying capacity, and $\Delta_y$is the displacement corresponding to the first yielding of main steel. Fig. 1 illustrates the relations of ductility factor and shear reinforcement ratio for different axial stress levels. The relations can be represented by the equation: $D.F = a_1 + b_1 * (A_{sh})$ [1] where: a_1 and b_1 are constants depending on axial stress level of the pier with the regression shown in Fig. 2 as follows:

$$a_1 = 8.32\text{-}7.45*\left(\frac{P}{A_c * F_c'}\right) \quad [2] \qquad b_1 = -1.87 + 28.34 * \left(\frac{P}{A_c * F_c'}\right) - 34.84 * \left(\frac{P}{A_c * F_c'}\right)^2 \quad [3]$$

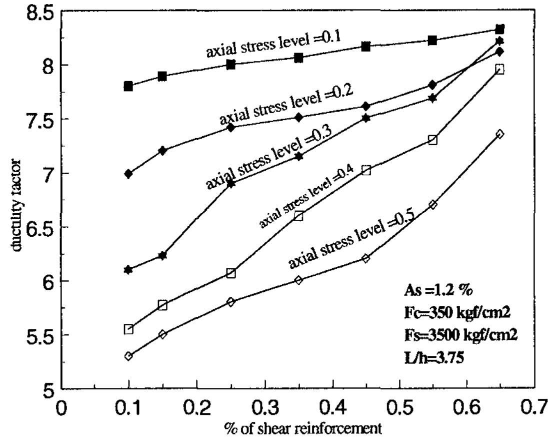

Fig. 1 Displacement ductility factor of RC piers

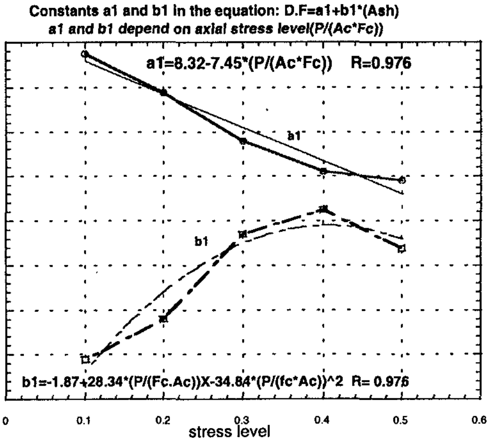

Fig. 2 Constants a_1 and b_1 of the equation [1]

It is clear that for higher axial compressive stress levels, the role of shear reinforcement becomes more significant than that in case of lower axial stresses. This is clear from the relatively high rate of increase of ductility factor for axial stress levels of 0.3 or more and smaller rate of increase when the stress level is 0.1 or 0.2. This is because when axial stress is high, the induced lateral strains are high and consequently the required quantity of shear reinforcement for the purpose of confinement becomes higher. For low axial stress, the stirrups are hardly stressed because of low lateral strains and hence the role of shear reinforcement is not so effective. From this, the authors conclude that for higher axial stresses, bigger quantity of shear reinforcement is needed to provide enough ductility for the piers. In a previous paper by the authors and based on comprehensive study of failure mechanism and the induced plastic strain, the optimum ratios of shear reinforcement are obtained and ranged from 0.25 to 0.55 % depending on axial compressive stress level, ratio of height to width of the pier and main reinforcement ratio.

2.2 Confinement

Fig. 3 shows the maximum induced compressive stresses for different ratios of shear reinforcement under different levels of axial stress. Fig. 4 illustrates the ratio of maximum stress at a certain shear reinforcement ratio relative to the maximum stress corresponding to zero shear steel for different ratios of shear steel under different levels of stress. The increase in K_σ depends on axial stress level as it is shown in the figure. As the axial compressive stress is high, the rate of increase is high. This is because when compressive stress on the pier is high, the induced lateral strains are high, consequently the role of shear reinforcement on confinement is significant. If the pier has zero axial stress, then the role of shear steel in confinement is negligible. The relations of Fig. 4 can be represented by linear regression as follows:

$$K_\sigma = a_2 + b_2 * (A_{sh}) \qquad [4]$$

in which a_2 and b_2 are constants depending on axial stress level with the regression shown in Fig. 5 as follows: $a_2 = 1.0 + 0.052 * (\frac{P}{A_c.F_c})$ [5]

$$b_2 = 0.265 + 0.872 * (\frac{P}{A_c.F_c}) \qquad [6]$$

In another work, a comprehensive study is carried out for stress confinement factor taking into account the effect of shear steel ratio, axial stress level and ratio of main reinforcement and a new approach is obtained.

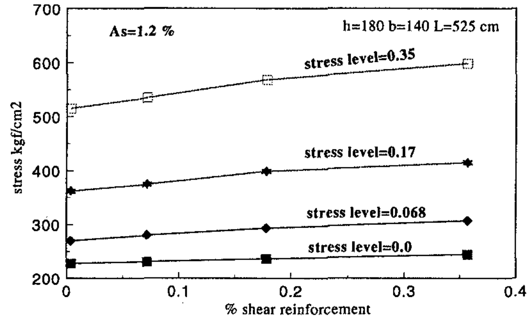

Fig. 3 Maximum induced axial stress for RC piers

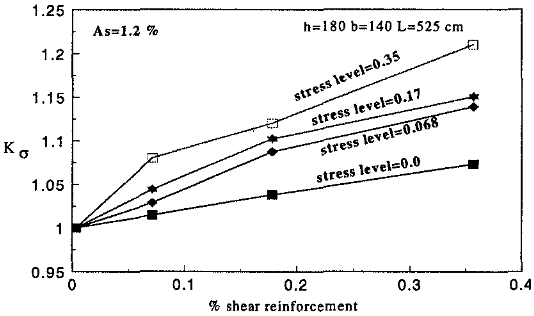

Fig. 4 Stress confinement factor for RC pier

3. CONCLUSIONS

It is proved that axial stress level has significant role on ductility level and confinement of RC bridge piers. At the same ratio of shear steel, as the stress level increases, ductility level of the pier decreases and confinement stress factor increases. The interaction of shear steel ratio and axial stress level is focused and new approaches for ductility level and stress confinement factor are obtained numerically.

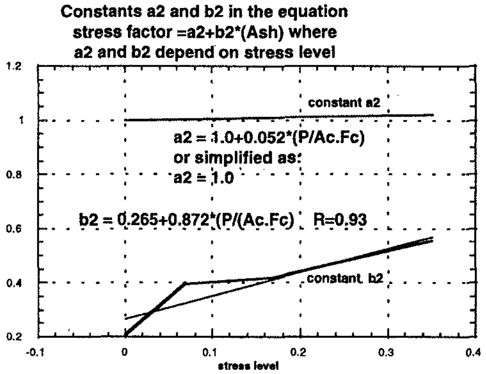

Fig. 5 Constants of the equation [4]

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