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2-D NONLINEAR SEISMIC RESPONSE OF PILE FOUNDATION WITH ACCOUNT OF AXIAL FORCE

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1. INTRODUCTION

Seismic performance of pile foundations has been a subject of considerable attention in recent years, particularly after the severe damage experience of pile-supported bridges by the Hyogo-ken Nanbu Earthquake. This study investigates the effects of RC pile nonlinear behavior in view of the bending moment-axial force relationship on those responses.

2. MODELLING AND RESPONSE ANALYSIS

A 2-D seismic nonlinear soil-structure interaction analysis is conducted based on BEM-FEM hybrid technique(1). A typical bridge of the Hanshin Expressway and the idealization of soil-footing-pile system in the zone of interest are shown in **Fig. 1**. Since the plane strain condition is assumed, a width of 4.8 m is considered in third direction. The superstructural mass is concentrated at the footing, the piles are modeled by beam elements, the neighboring soil is discretized by FEM hose vertical side boundary is offset from the area of interest. Fictitious high damping coefficient is assumed along the boundary soil FEM elements to attenuate the reflected wave generation there. The inelastic behavior of pile is represented by one component model(2) with the consideration of sway motion at both ends of each element. The RC hysteresis model (**Fig. 2**) is treated by the Q-hyst model(3), which is modified so as to take into account of the relationship between bending moment and axial force. At each step, the yielding moment is defined from bending moment-axial force interaction diagram. The nonlinear soil behavior is characterized by the Hardin-Drnevich hyperbolic model(4) and the Mohr-Coulomb criterion. Two cases of analyses are performed; one considers RC pile linear behavior and the other is the RC pile nonlinear behavior, and both of which assume the soil nonlinear and footing linear behavior. The 1995 Hyogo-ken Nanbu Earthquake motion is used for the input to the structure (**Fig. 3**). According to the pile response in **Fig. 4**, the differences between the linear and nonlinear cases are concentrated near the footing and the transition zone of soil stiffness. The pile internal forces of nonlinear RC case become smaller than the linear RC case, while some increase of relative displacement due to the nonlinear RC behavior is observed. The nonlinear RC behavior is observed at the zone from the pile head to G.L. –4 m, and around G.L. –7 m (interface between upper and middle soil layers). The bending moment-rotation relationships for these zones are shown in **Fig. 5** and **Fig. 6**. The strong nonlinear behavior appears in piles as shown in **Fig. 7** such that the maximum moment coupled with axial force is practically twice of the yielding moment. Differences between linear or nonlinear RC cases are not clearly observed in the soil behavior, which implies that the effect of RC behavior on the soil is apparently small. Therefore, only the results of the nonlinear RC case are presented in the following figures. **Fig. 8** indicates that the maximum soil shear strains are concentrated at the zone where soil stiffness changes, but it is not so in the soil confined by piles due to the pile-soil-pile behavior during excitations. As consequence of this behavior, the outside piles present the bigger shear force than the inside piles at this zone (**Fig. 4**). Soil stress-strain curves at four locations are presented in **Fig. 9**, from which we can note that the maximum restoring force increases with depth.

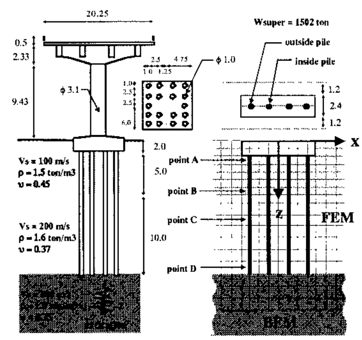

Fig. 1. Typical bridge pier and its model for analysis

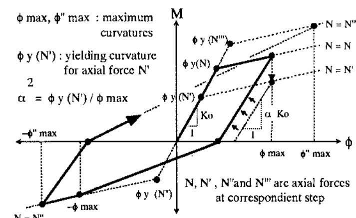

Fig. 2. RC hysteresis rule

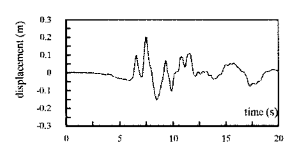

Fig. 3. Kobe-jma-ns

3. CONCLUSION

The nonlinear RC behavior gives rise to a clearly different internal pile forces at upper part and the transition zone of soil stiffness. However, the soil behavior is practically insensitive to this RC behavior. The presence of axial force in piles affects the pile nonlinear behavior and the heavy damage in the Hanshin Great disaster may possibly be due to tensional force and bending moment interaction.

KEY WORDS: soil-structure interaction, RC nonlinear behavior, bending moment-axial force interaction
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REFERENCES

(1)Takemiya, H., and Adam, M., "2D nonlinear seismic ground analysis by FEM-BEM: The Case of Kobe in Hyogo-ken Nanbu Earthquake", JSCE, No.584/I-42, 19-27. (2)Giberson, M. F. "Two Nonlinear Beams with definitions of ductility", ASCE, Vol. 95, ST2, 1969, 137-157. (3)Saiidi, M., and Sozen, M. A., "Simple and Complex Models for Nonlinear Seismic Response of Reinforced Concrete Structures", Structural Research Series No. 465,Civil Engineering Studies, University of Illinois, Urbana, Ill., Aug., 1979. (4)Hardin, B.O., and Drnevich, V. P., "Shear Modulus and Damping in Soils: Design Equations and Curves", ASCE, Vol. 98, SM7, 1972, 667-692

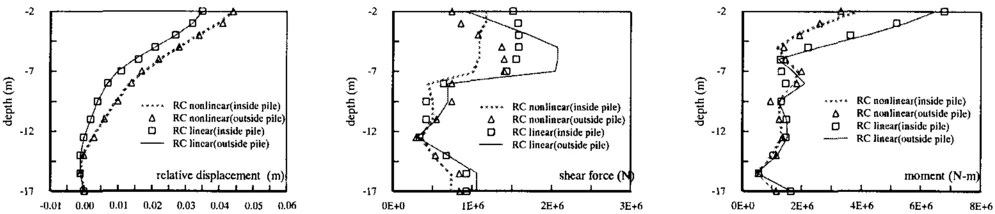


Fig. 4. Distributions of maximum relative displacements and internal forces of piles.

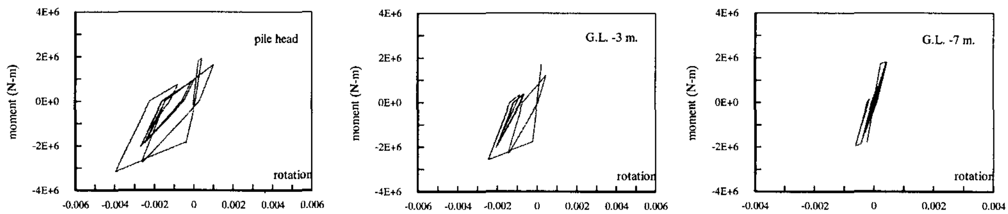


Fig. 5. Bending moment – rotation hysteresis of outside pile.

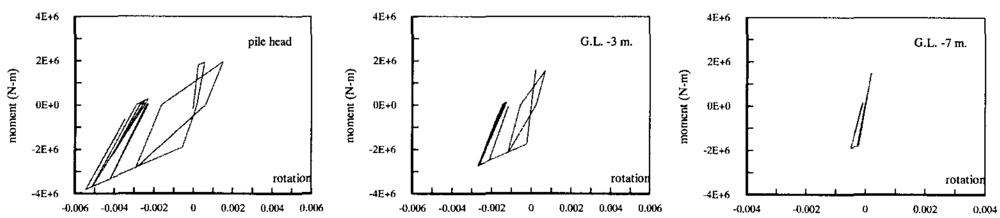
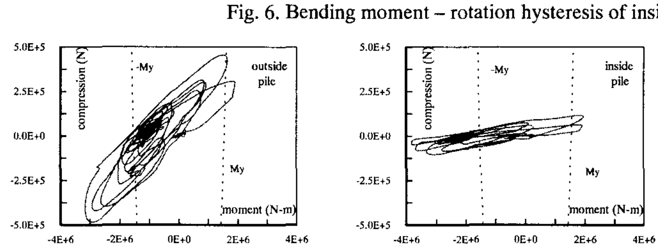


Fig. 6. Bending moment – rotation hysteresis of inside pile



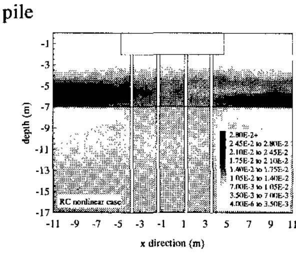


Fig. 7. Relationship between bending moment and axial force at pile head.

Fig. 8. Maximum shear strain.

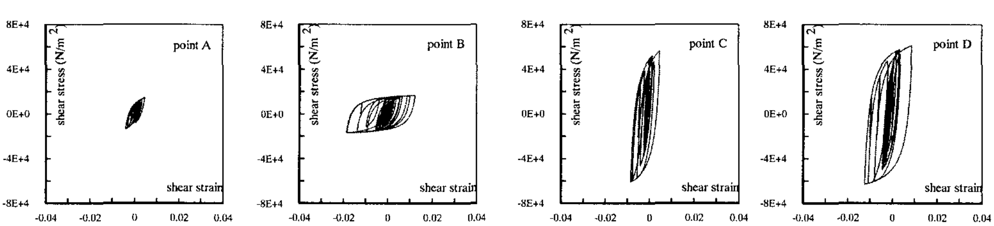


Fig. 9. Soil stress-strain hysteresis at different locations for nonlinear RC case.