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SEISMIC DAMAGE ANALYSIS OF BRIDGE PIER THROUGH NONLINEAR SSI

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1. INTRODUCTION

The 1995 Hyogo-ken Nanbu Earthquake caused severe damage to Hanshin Expressway, especially to RC Pilz type bridges. Most of the piers collapse were the consequence of flexural-shear failure at bottom of pier or cut-off main reinforcements. In this paper, the analysis considers the total interaction of the substructure and superstructure with special attention to linear or nonlinear characteristics of RC and soil. Damage factors are also evaluated to localize the dangerous weak zones.

2. ANALYSIS ASSUMPTIONS

The analysis is realized by the superposition of far and near field, it is based on that a large distance from pile foundations soils are less affected by the motion of piles. Therefore far field soil analysis is independently conducted to evaluate the input motion to the near field soil-pile system. The horizontally layered far soil is represented by the 1-D model with the modified Ramberg-Osgood relationship(1) for the nonlinear soil behavior. In the near field soil-pile interaction system the soil reaction to motion of piles is described by Wrinkler type spring(2), where the same modified Ramberg-Osgood relationship is utilized but considering a modified soil strain due to relative displacement of pile and far soil. The nonlinear RC elements are represented by the one component model(3). The nonlinear RC hysteresis model is represented by the Q-hyst model(4) with the inclusion of strength and shear degradation effects(5). The damage factors employed in this study are the proposed by Park and Ang(6) (DPA) and the proposed by Powell and Allahababi(7) based on maximum deformation ductility (DU) or energy dissipation (DE).

3. TYPICAL RESPONSE

Fig. 1 shows a typical Hanshin Expressway and its idealization. Table 1 and 2 show RC and soil properties, respectively. The cases of analysis are presented in table 3. The structure was excited by JMA-NS record (fig. 2). According fig. 3, the consideration of RC nonlinear behavior was point out at superstructure level. However, at substructure level, the RC nonlinear behavior was concentrated at pile-footing connection zone and the RC presents a linear behavior at deeper soil (fig. 3 and 4). It coincides with the small cracks or no damage observed in the piles during the 1995 Hyogo-ken Nanbu Earthquake. The maximum displacements are presented in figure 6.

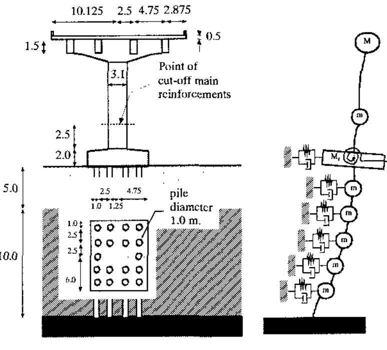

Figure 1. Hanshin Expressway pier bridge

ELEMENT	yield moment x 10^{7} N	yield curvature x 10^{3}
BOTTOM	6.87	0.795
TOP	5.59	0.729
PILE	0.146	2.406

Table 1. RC properties

LEVEL (m)	Vs (m/s)	density (kg/m^3)	poisson
-15 to -5	100	1800	0.4
-5 to 0	200	1800	0.4

Table 2. Soil properties

CASE	β	RC	soil
group-0.15	0.15	nonlinear	nonlinear
group-0.15-LN	null	linear	nonlinear

Table 3. Considerate cases

The DPA time histories present a big increment between 7 sec. and 10 sec. approximately, which coincide with the strong excitation zone of earthquake. In fig. 7, DPA presents similar values at pier bottom and cut-off main reinforcement zones (around 1.5), and lowest value at pile top (around 0.4). It confirms, in certain manner, the failure places observed during the earthquake. At pier bottom (fig. 8) and cut-off main reinforcement zones, DPA practically coincides with DU, which confirm that pier failed after absorption of relatively small amounts of energy. On the other hand, at pile top (fig. 9), the possible damage is governed by the dissipated energy. The hysteresis curves at pile top and pier bottom are showed in figure 10 and 11, respectively.

4. CONCLUSION

Conventionally the seismic design of bridges is conducted separately for the substructure and superstructure. However, in case of strong earthquakes, both are coupled together with possible RC and soil nonlinear behavior and consequent effects in pile-soil interaction. The present study clarified the effects of soil and RC nonlinear behavior and characteristics of failure of Hanshin Expressway.

KEY WORDS: RC nonlinear behavior, soil-pile interaction effect, damage factor

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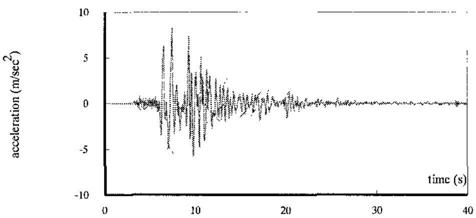

Fig. 2. Hyogo-ken Nanbu Earthquake, JMA-NS

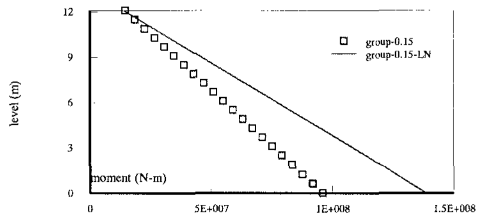

Fig. 3. Superstructure maximum moments

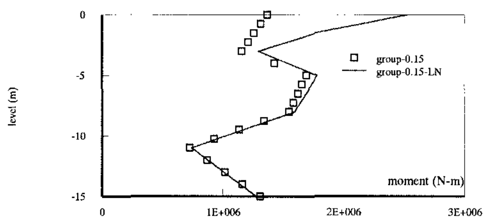

Fig. 4. Maximum moments at pile

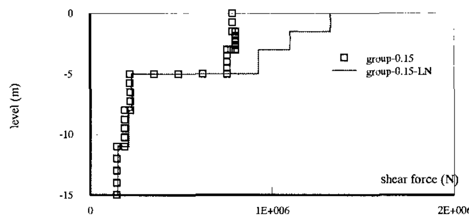

Fig. 5. Maximum shear forces at pile

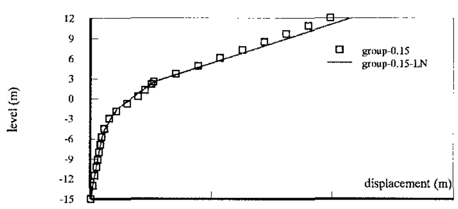

Fig. 6. Maximum displacements

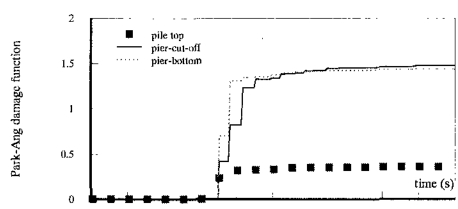

Fig. 7. DPA of group-0.15

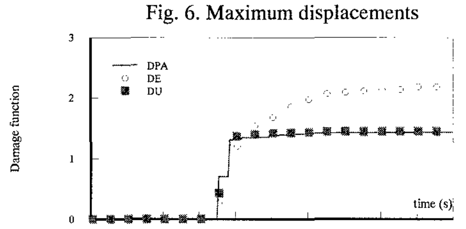

Fig. 8. DPA, DE and DU at bottom of pier

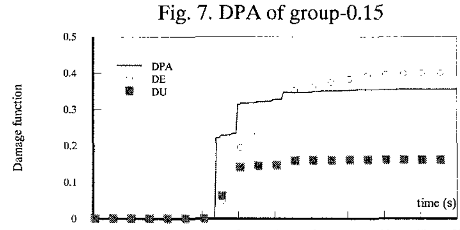

Fig. 9. DPA, DE, and DU at pile top

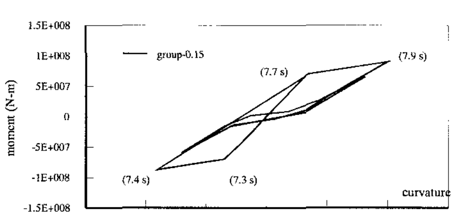

Fig. 10. Hysteresis at bottom of pier until 10 s.

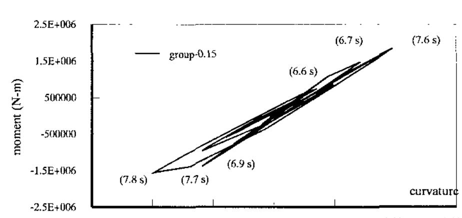

Fig. 11. Hysteresis at pile top until 10 s.