SHOULD PILES BE RIGID OR FLEXIBLE? LESSONS FROM THE DAMAGE CAUSED BY PAST EARTHQUAKES

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LESSONS FROM THE DAMAGE CAUSED BY PAST EARTHQUAKES

-Should piles be rigid or flexible?-

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INTRODUCTION

We could see every kind of damage pattern of pile foundations caused by the 1995 Kobe earthquake. This earthquake was the first one which gave us so much information about damage to piles. Of cause there were some reports of damage to piles and pile foundations before the event. For example, pile foundations were severely damaged by liquefaction-induced lateral ground displacements caused by the 1964 Niigata earthquake. Pile foundations were damaged by inertia force during the 1978 Off-Miyagi Pref. earthquake, and their failure mechanisms were investigated.

When we design a pile foundation, we neglect the displacement of piles even though the piles are subjected to ground motion. Besides, the variation of axial force with time is also neglected. In order to reduce stresses induced in a pile and the displacement of it, the stiffness of the pile is increased and the diameter of it is also increased. This is correct unless the surrounding ground is at rest. The piles, however, are subjected not only to forces from the superstructure but also to displacement of the surrounding ground. I would discuss this attitude to design the pile foundation is correct or not in this report.

DAMAGE TO PILES BY PAST EARTHQUAKES

a) The 1964 Niigata earthquake

The 1964 Niigata earthquake is noted for the occurrence of liquefaction in wide area. This caused severe damage to pipeline systems and pile foundations. The typical damage pattern of pile foundation caused by liquefaction is shown in Photo. 1 (Kawamura et al. 1985). Figure 1 shows the schematic drawing of the damaged pile with the ground condition at the site. We can see two positions where the pile was severely damaged. The upper position coincided with the underground water level and the lower position coincided with the ground level where the N-value suddenly increased from about 10 to about 20. The dislocation of the pile accorded with the magnitude of lateral ground displacement. Therefore, this damage pattern was attributed to the lateral ground displacement caused by liquefaction (Hamada et al. 1992).

b) The 1978 Off-Miyagi Pref. Earthquake

An eleven story reinforced concrete apartment building tilted during the 1978 Off-Miyagi Pref. earthquake. The building was almost completed. After the earthquake, the foundation of the building was dug and the damage of all the piles was investigated in detail. Almost all the piles were damaged except only four piles. There was a point in common between the four piles. That is, they had a joint as shown in Fig.2. At first, it was understood that the higher strength of the joint than that of the pile itself prevented the damage. Fukuzawa et al.(1994), however, tested the bending characteristics of the jointed pile and found that the bending rigidity of the joint was lower than that of the pile itself. This implies that the flexibility of a pile will be effective to prevent the damage caused by the inertia force.

c) The 1995 Kobe earthquake

We could see all kinds of failure modes of piles. Pile foundations were completely damaged by the strong motion and liquefied ground. Some piles without superstructure were also severely damaged. It is clear that they were not damaged by the inertia force because the superstructure was not built on them. This suggests that they were damaged by the ground motion itself.

DYNAMIC BEHAVIOR OF PILES DURING STRONG GROUND MOTION

Miura(1983) and Izumi et al.(1997) showed that the piles would displace almost same as the magnitude of ground displacement. Figure 3 shows one of the examples analyzed by Izumi et al. for 45cm diameter prestressed high strength concrete piles (PHC pile). As can be seen from this figure the distribution of pile displacement is almost same as that of the surrounding ground. Miura also showed the same tendency even for two-meters diameter cast-in place piles.

Piles are subjected to time varying axial forces during an earthquake. It is well known that the pile characteristics are strongly depend on the axial force. The ultimate bending moment is not the exception. Figure 4 illustrates the typical relationships between the ultimate bending moments and axial forces. As this figure shows, the higher the axial force, the higher the ultimate bending moment. However, the ultimate displacement which corresponds to the ultimate bending moment decreases as the axial force increases. This means that a pile subjected to larger axial force is more apt to failure than a pile subjected to smaller axial force for the same magnitude of displacement. This tendency is the same for the rigidity. That is, the higher the rigidity of a pile, the higher the ultimate bending moment, but smaller the ultimate displacement.

As mentioned above, the displacements of piles are almost same as that of the surrounding ground during an earthquake. This means that a pile with higher rigidity will be damaged faster than a pile with lower rigidity when they are subjected to the same ground motion, because the former has the smaller ultimate displacement than the latter does. This can be also said for the piles subjected to liquefaction-induced lateral ground displacements. From this point of view, we may be able to say that the pile with low rigidity, in other words, flexibility, is better than a pile with higher rigidity which we have tried to develop against the seismic force.

CONCLUSION

I showed typical three examples of damage pattern of piles. The damage was caused by liquefaction-induced lateral ground displacement, by inertia force and by ground displacement during strong earthquake motion. In all cases, if the piles had been more flexible, they might have survived. We have been tried to develop a pile to be harder and harder, but it might be the time to change this attitude toward the pile development.

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Photo. 1 Damaged piles. The piles were deformed in the same direction.

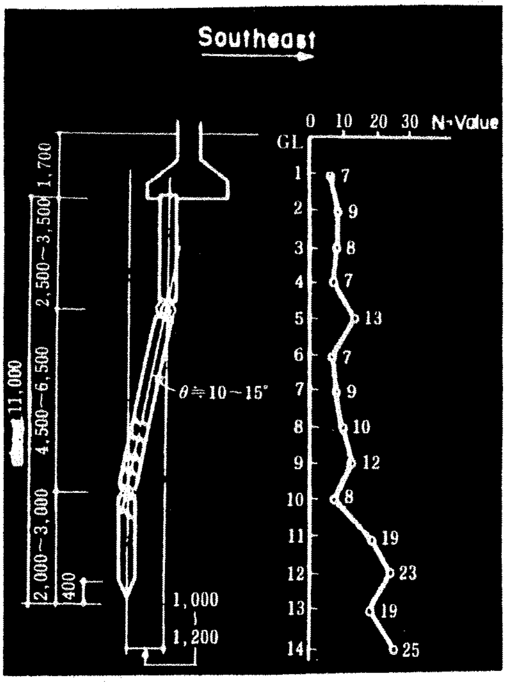


Fig. 1 Schematic drawing of the damaged pile and N-values of the surrounding soil.

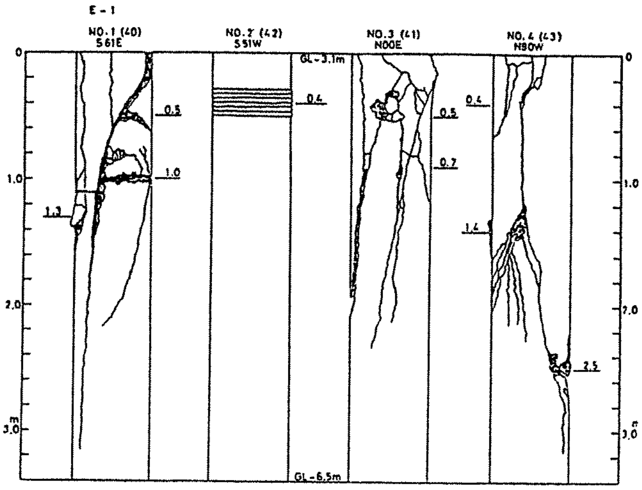


Fig. 2 Sketch of damage to piles and a jointed pile with no damage.

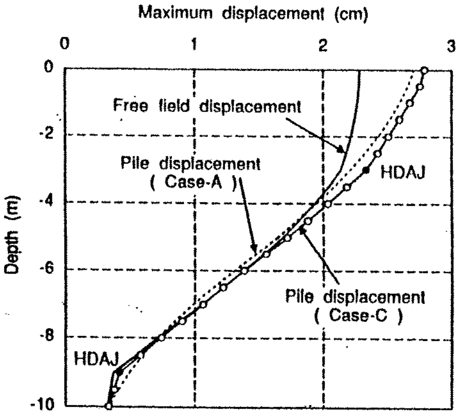
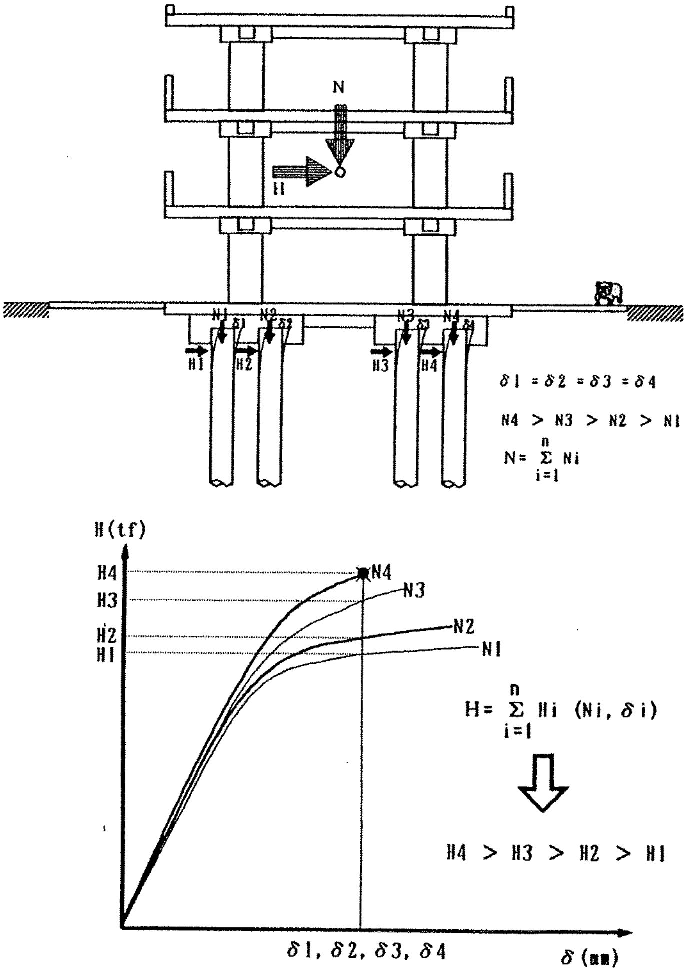


Fig. 3 Comparison of pile displacements and ground displacement. (Piles are linear and nonlinear materials)



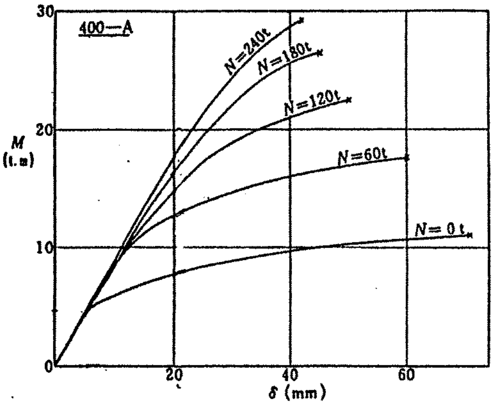


Fig. 4 Typical relationships between bending moments and axial forces.

Fig. 5 Schematic drawing of mechanism of pile failure subjected to seismic force.