A CASE STUDY ON THE PILE FOUNDATION DAMAGE DURING THE HYOGOKEN-NAMBU (KOBE) EARTHQUAKE

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INTRODUCTION

The details of the damage to pile foundations due to the January 17, 1995 Hyogoken-Nambu earthquake have continued to emerge as the affected structures are demolished, repaired and upgraded at different stages. From the statistics of the damage to buildings observed in the Hyogoken-Nambu earthquake (Karkee et al, 1997), it is observed that the instances of foundation damage in case of buildings with heavy damage to superstructures is significantly small in comparison to those with slight or no superstructure damage. This trend indicates that the existence of damage to foundation may mean lesser damage to the superstructure, leading to the difficulty in developing a clear picture of the foundation behavior during extreme earthquake events from visual inspection immediately after the earthquake. In understanding the relationship between the foundation damage and the superstructure damage, it would be logical to see whether the local ground response to the incident earthquake motion is dominated by the ground shaking or the ground failure. Situations where ground failure is likely, such as due to excessive liquefaction and lateral spreading, generally mean the use of relatively long piles taken down to deeper competent layers. In contrast, ground shaking effects tend to be dominant in relatively firmer ground conditions where shorter piles with adequate frictional and end-bearing resistance provide the bearing capacity required in general design practice. This paper presents a case study on a new seven storied condominium building supported by relatively short precast concrete piles at a fairly firm ground condition. The building seemed to have no structural damage, but detailed investigation revealed severe damage to the piles. The pile foundation damage is discussed in relation to the damage statistics (Karkee et al, 1997) and the interaction analysis of the soil-pile-building system (Karkee and Kishida, 1977).

INVESTIGATION OF THE DAMAGE

The building was located within the area of the highest JMA intensity of seven. Detailed measurement indicated that the building roof was out of plumb by 80mm as shown in Fig.1, a tilt of about 1 in 250. The maximum differential settlement at the plinth level was more than 90mm. As also indicated by the damage statistics (Karkee et al, 1977), existence of such significant tilting constitutes strong possibility of foundation damage. Excavation was carried out to expose for direct inspection the prestressed high strength concrete (PHC) piles supporting the building. It was found that most of the piles had completely failed. A typical damage to a PHC pile looking from four mutually perpendicular directions is shown in Fig.2.

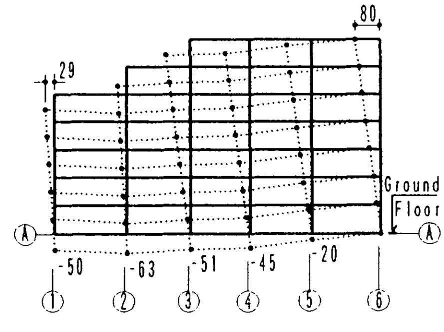

Fig.1 : Extent of Tilting in the Building

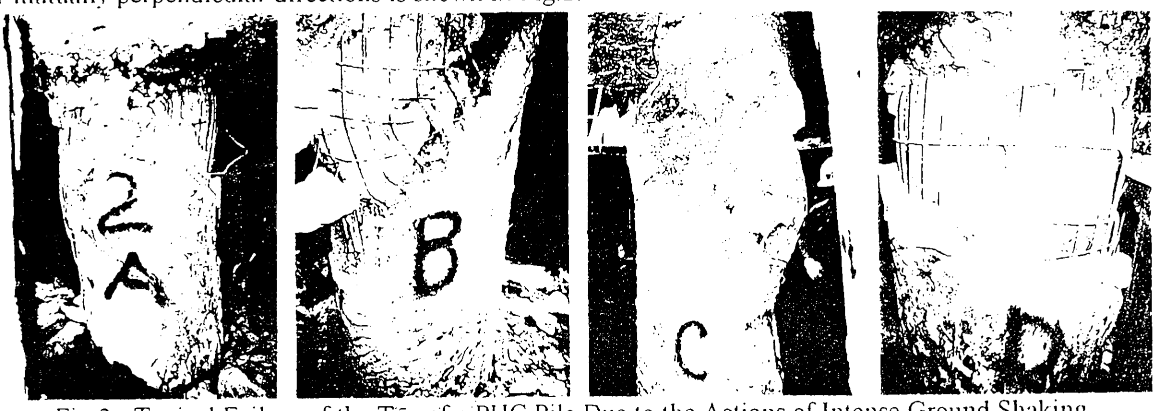

Fig.2 : Typical Failure of the Top of a PHC Pile Due to the Actions of Intense Ground Shaking

REHABILITATION OF THE BUILDING

Steel pipe piles (SPP) were installed under the footings by jacking against the building weight for temporary support of the building. Once the building load was transferred to SPP, and damaged portion of piles were cut-off from the footing, the jack-up operation was carried out. The jack-up process involved careful operation of selected jacks at a time with constant monitoring of the extent of settlement recovery. The result of monitoring at two of the footings is shown in Fig.3, where recovery of settlement at different loading step can be seen including the time taken for the operation. The building was jacked-up practically to its original plumb and level, and then finally repaired and strengthened.

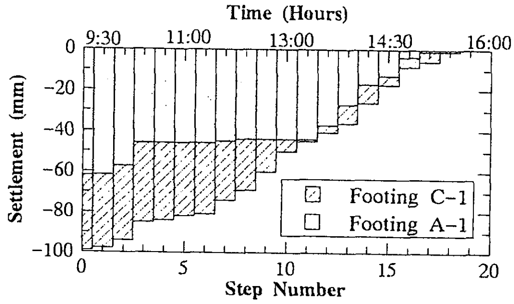

Fig.3 : Recovery of Differential Settlement

1-D SYSMIC RESPONSE ANALYSIS OF SOIL-PILE-BUILDING SYSTEM

Attempt was made to evaluate the extent of actions on piles during the earthquake shaking considering a simple 1-D dynamic soil-pile-structure interaction response analysis under the action of the earthquake motion recorded nearby (Karkee and Kishida, 1997). The nonlinearity in ground response was considered in the analysis, while the structure part was assumed to behave linearly. Three cases denoted as A, B and C soils correspond to the three exploration borings along the length of the building. The shear force and bending moment distribution on piles at selected times during the strong part of the shaking are shown in Fig.4.

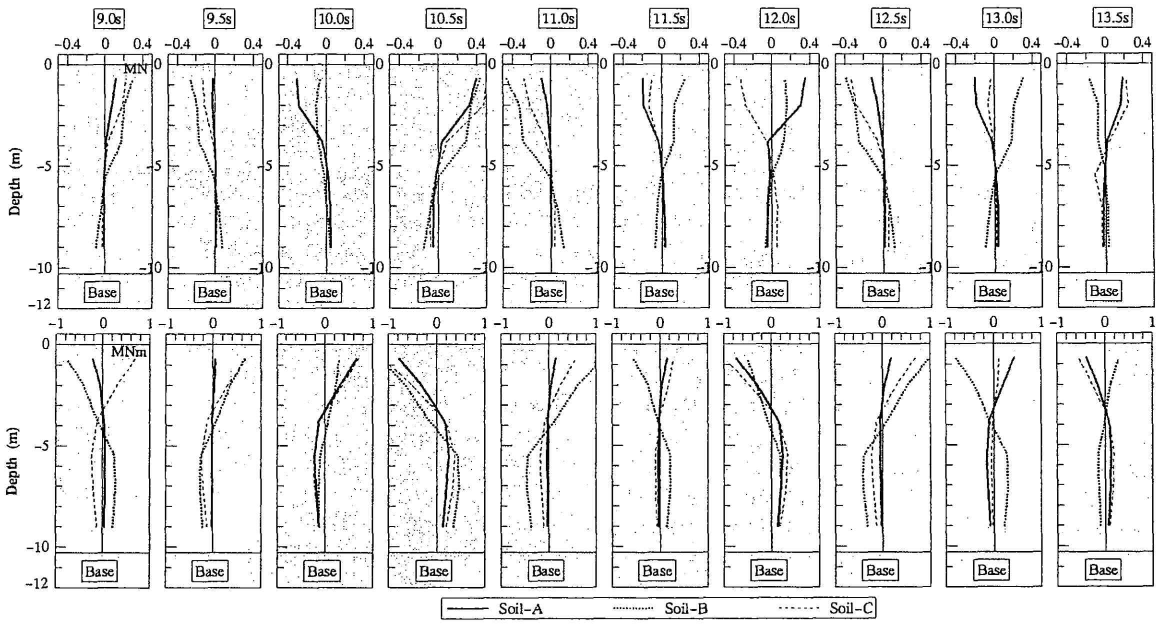

Fig.4 : Shear Force and Bending Moment Distribution in Piles from 1-D Seismic Response Analysis

Fig.4 shows that the shear force as well as the bending moment is largest at around 11s in case of B-soil, which corresponds to the side of the building that underwent largest differential settlement. Such combination of seismic actions may have resulted in the failure of pile shown in Fig.2. It is noted that simple 1-D free field and soil-pile-building interaction analysis can explain the essential behavior of piles during earthquake shaking.

REFERENCES

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