

DAMAGE OF REINFORCED PRECAST CONCRETE PILES
DURING THE MIYAGIKEN-OKI EARTHQUAKE OF JUNE 12, 1978

Hideaki KISHIDA^I
Toshikazu HANAZATO^{II}
Shoichi NAKAI^{III}

SUMMARY

The piled foundation failure of the Maruyoshi building during the Miyagiken-oki earthquake was investigated and the observed damage of reinforced concrete piles was analyzed theoretically. The building is a three-storied reinforced concrete structure supported by reinforced precast concrete piles. Excavation was carried out to investigate the damage of piles, and many cracks due to bending moment were found at the pile shafts. The calculated distribution of cracks at the pile shaft showed a fairly good agreement with the observed ones.

INTRODUCTION

Field investigation of piles requires excavation and costs much money and, therefore, investigation of damage of piled foundations during earthquakes have been few as compared with those of superstructures. The senior author published the damage of reinforced precast concrete piles during the Niigata earthquake of 1964 (1965), which was caused by liquefaction of saturated loose sand during the earthquake. Tamura et al. reported the damage of reinforced precast concrete piles during the Tokachi-oki earthquake of 1968 (1973), which seemed to be caused by the slide of the embankment adjacent to the piled foundation. Zeevaert also shows the picture of bending cracks in a concrete pile due to earthquake (1972).

After the Miyagiken-oki earthquake of June 12, 1978, authors investigated the foundation failure of buildings, and observed the damage of reinforced precast concrete piles driven at the Maruyoshi building. The senior author also joined to the investigation team for the damage of piled foundation of the Sendai municipal apartment house. In addition to the above mentioned two buildings, some other buildings suffered damage of piled foundations during the earthquake (BRI: 1978).

The principal features of the damaged pile are the followings: (1) the materials of the pile shaft are reinforced precast and/or prestressed concrete piles, (2) the cracks due to bending moment are found at the pile shaft, and (3) the material of the heavily damaged pile is autoclaved high strength concrete having little ductility.

The detailed results of the investigation at the Maruyoshi building and the typical damaged pile at the Sendai municipal apartment house are presented. Theoretical analysis are made to the damage of piled foundation at the Maruyoshi building. The results of theoretical analysis showed a fairly good agreement with the observed ones.

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- I Associate Professor, Tokyo Institute of Technology
II Graduate student, Tokyo Institute of Technology
III Shimizu Construction Co., Ltd.

INVESTIGATION OF DAMAGE OF REINFORCED PRECAST CONCRETE PILES

The Maruyoshi building was a reinforced three-storied building located at Oroshi-machi of Sendai City. The superstructure of the building was collapsed as shown in Fig. 1. After the collapsed superstructure was removed, the foundation beams and pile caps were investigated. Some cracks were observed at the foundation beams and the typical one is shown in Fig. 2. The location of the observed cracks are shown in Fig. 3. Based on the results of the observation, the excavation of the piled foundation was carried out to investigate the damage of the pile shafts. Plan of the pile caps, foundation beams and location of piles are also shown in Fig. 3.

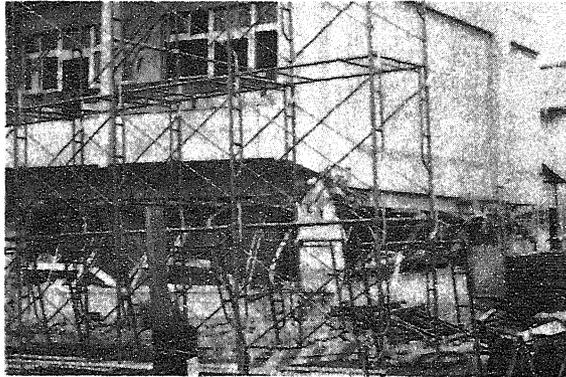


Fig. 1 The collapsed Maruyoshi building

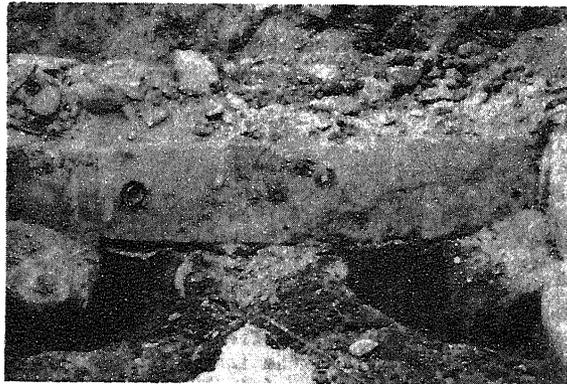


Fig. 2 Cracks at the foundation beam

The excavation was carried out at the hatched area in Fig. 3, and the five pile shafts were observed in detail. Dimensions of the observed pile cap and the spacing of the piles are shown in Fig. 4. These piles are reinforced precast concrete piles having 5 m in length and 250 mm in outside diameter. The piles are the hollow cylindrical ones, and the thickness of concrete is 50 mm. The general view of the excavation and the pile shafts of three piles (No. 2, No. 4 and No. 5 piles in Fig. 5) are given in Fig. 5.

Cracks were found at the pile shafts of the all observed piles, and the close up view of the pile shaft of No. 1 pile is given in Fig. 6 indicating visible cracks. The width and location of cracks in No. 1, No. 2 and No. 3 piles are shown in Fig. 7. All cracks occurred in a circumferential direction of the pile shafts, and no cracks were found in a diagonal direction of the pile shafts.

These piles were driven piles, and tensile stresses might caused the cracks at the pile shaft. The cracks due to tensile stresses usually occurs at an overall circumference of the pile shaft. The places of cracks at the circumference of one pile shaft were brought together at one plane.

The position of all cracks in the observed five piles were marked in black color as can be seen in Fig. 8.

The time of occurrence of the cracks were checked by investigating the neutralization of the concrete in the pile shaft using phenolphthalein. The result indicated that these cracks did not occur during pile driving. Considering the position of cracks in Fig. 8 and the phenolphthalein test results, these cracks seemed to occur during the earthquake.

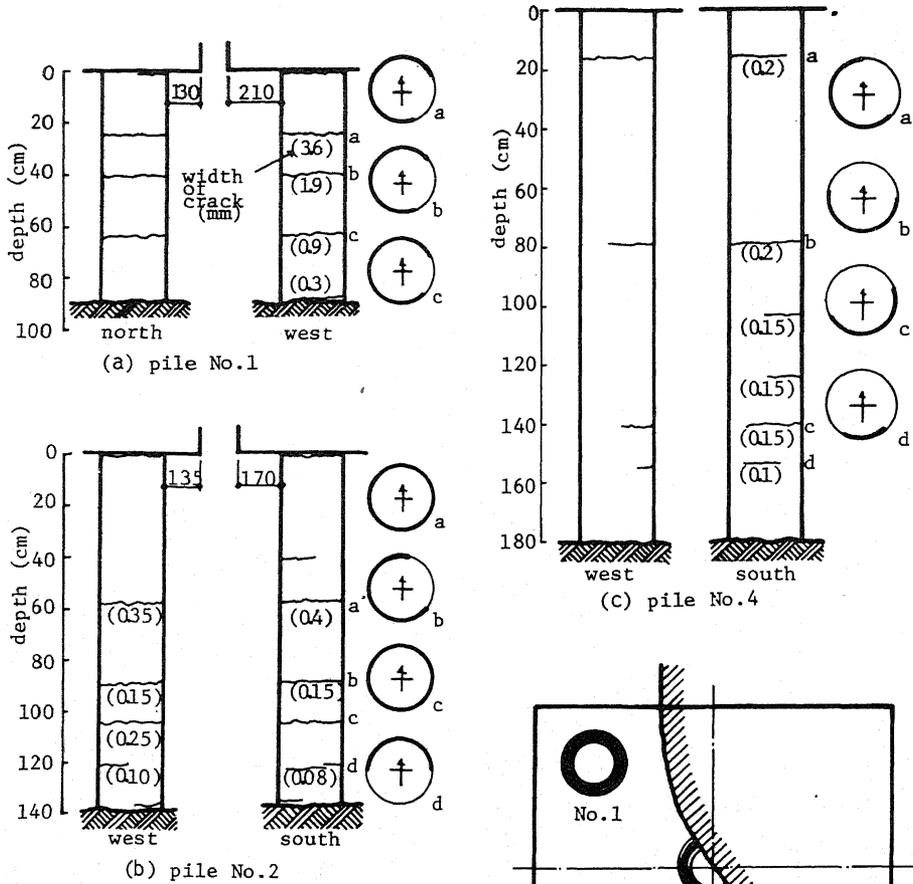


Fig. 7 Details of cracks in the pile shafts

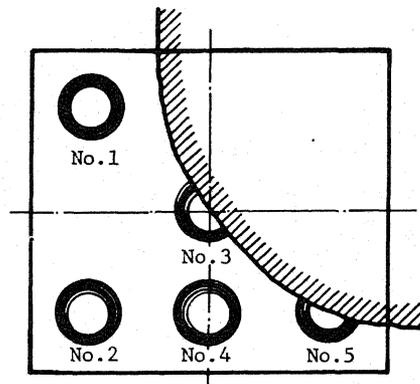


Fig. 8 Position of all cracks in the observed five piles

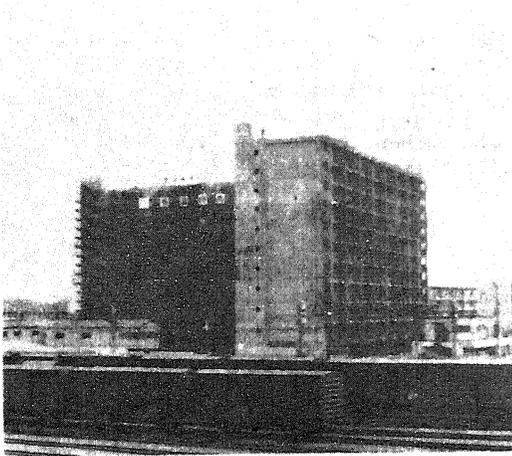


Fig. 9 The Sendai municipal apartment house

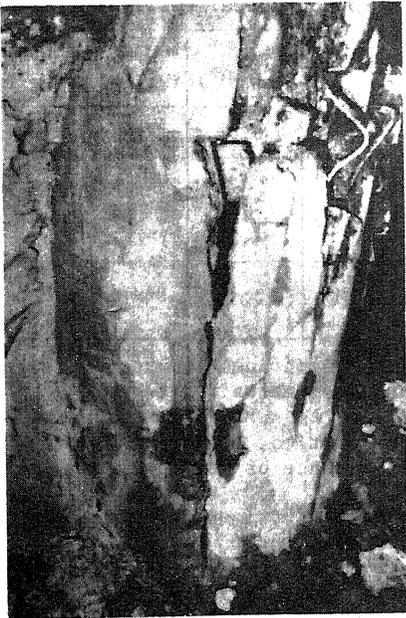


Fig. 10 Crush of the autoclaved high strength concrete piles

The autoclaved high strength concrete piles caused a severe damage at the Sendai municipal apartment house. The eleven-storied superstructure shown in Fig. 9 tilted and the piles were completely crushed as can be seen in Fig. 10. The detailed report of the damage of the piled foundation and the reconstruction of the apartment house is published in Nikkei architecture (1979).

ANALYSIS OF THE INVESTIGATED RESULTS AT THE MARUYOSHI BUILDING

The block samples of the undisturbed soil were taken at the site of the Maruyoshi building during the investigation, and the soil profiles are given in Fig. 11. The standard penetration test results obtained at other site apart about 200 m from the Maruyoshi site are also shown in Fig. 11. The data used for computation of horizontal resistance of piles at the Maruyoshi building is given in Table 1.

Based on the proposed method by the authors (1977), the bending moment occurred at the pile shaft were calculated applying the horizontal load at the top of the pile. The vertical design load is 20 tf per a pile, and three horizontal loads that are 2 tf, 4 tf and 6 tf were used for calculation. These loads are equal to 0.1 ($k = 0.1$), 0.2 ($k = 0.2$) and 0.3 ($k = 0.3$) times the vertical design load respectively. The maximum horizontal acceleration at the site seemed to be about 300 gals, and the bending moment calculated by the horizontal load of $k = 0.3$ seems to be approximately equal to the one occurred during the earthquake.

The calculated and the investigated results are shown in Fig. 12, in which the broken line means the bending crack moment (0.44 tf-m) of the pile shaft. In Fig. 12, the most of the observed cracks are placed at the part of the pile shaft where the calculated bending moments for horizontal load of $k = 0.3$ are more than the bending crack moment of the pile shaft. Fig. 12 also indicates that the calculated bending moment for horizontal load of $k = 0.1$ are less than the bending crack moment of the pile shaft.

During earthquakes, inertia force induced by vibration of a superstructure is applied at top of piled foundation, and, at the same time, a pile shaft is forced to deform following ground movement. The bending moment caused by the latter phenomenon was analyzed assuming the movement of ground as a fundamental mode.

The fundamental period of the ground was assumed to be 0.2 sec. The bending moment at the pile shaft caused by the forced deformation of the pile shaft was calculated assuming the linear spring connection between the pile shaft and the ground. The calculated results indicates that the moment caused by the ground movement are much smaller than the moment caused by the inertia force of the superstructure as can be seen in Fig. 13.

The ultimate horizontal resistance of the reinforced precast concrete piles at the Maruyoshi building was calculated by Broms' method (1964). The calculated results for the case of no axial load are smaller than the assumed horizontal load as can be seen in Table 2.

Table 1 The data used for computation of horizontal resistance of piles

depth (cm)	Ground surface PILE	Soil condition	γ (t/m ³)	q_u (kg/cm ²)	N	ϕ (°)	E_s (kg/cm ²)	$k \cdot B$ (kg/cm ²)	P_u (kg/cm ²)
		0	Clay	1.50	0.515			87.6	118
59	Clay	1.50	0.515			87.6	118	2.317	
410	Sand	1.80		40	42	640.0	838	7.312 10.552	
500									

γ = Unit weight of soil, q_u = Unconfined compressive strength
 N = Number of blows of standard penetration test
 ϕ = Angle of internal friction, E_s = Elastic modulus of soil
 k = Coefficient of subgrade reaction, B = Diameter of pile
 P_u = Ultimate horizontal resistance of soil

Table 2 Comparison between the ultimate horizontal resistance of the pile and the horizontal load

	Pile head fix (tf)	Pile head hinge (tf)	Ultimate bending moment of the pile: 0.83 tf-m
Broms	2.72	1.61	
$k = 0.3$	6.0	6.0	

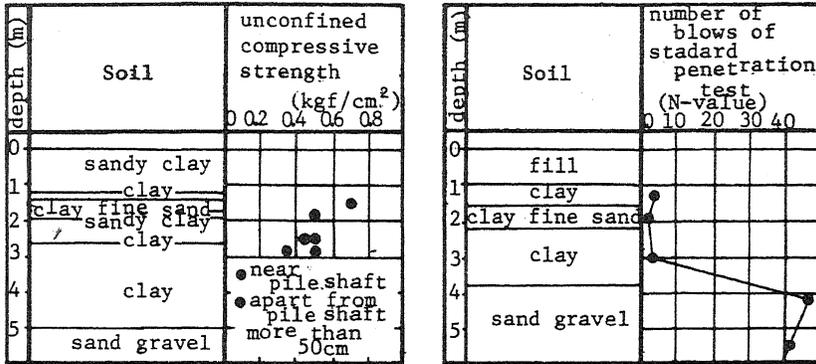


Fig. 11 Soil profiles of Oroshi-machi, Sendai City

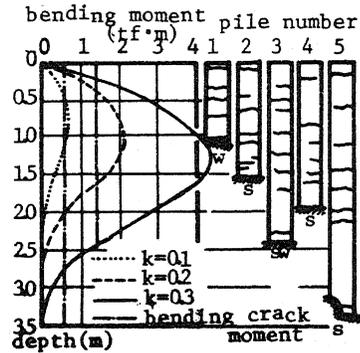
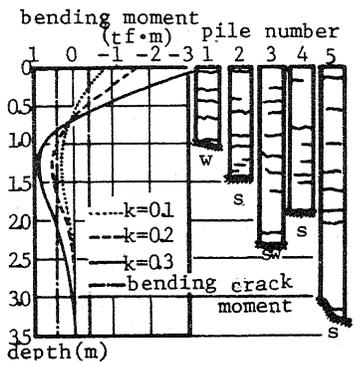


Fig. 12 Calculated bending moment and observed cracks at the pile shaft

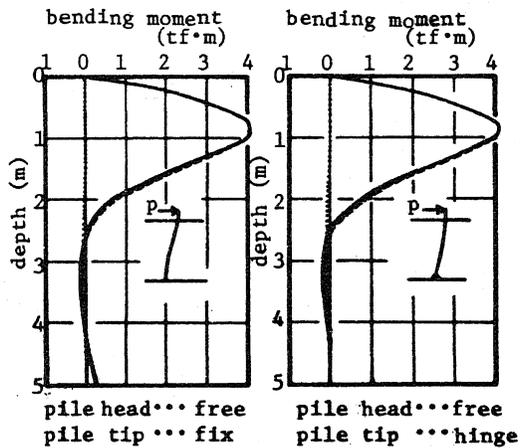
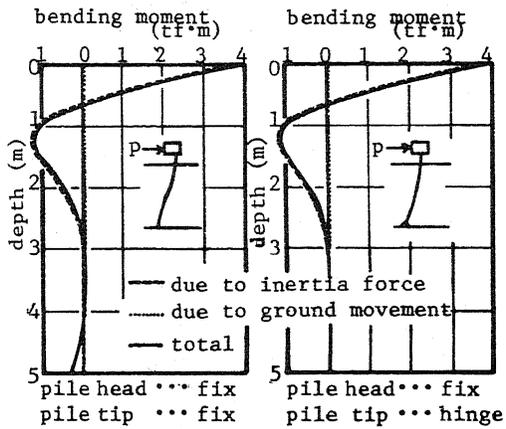


Fig. 13 Calculated moment referring to ground movement

acceleration of ground surface = 300gal
 displacement of ground surface = 0.39cm
 inertia force at pile head P = 6 tf

CONCLUSION

- (1) The observed cracks in the pile shafts at the Maruyoshi building occurred during the Miyagiken-oki earthquake of June 12, 1978.
- (2) The calculated results can explain well the place of the observed cracks in the pile shafts.

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