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PILE DAMAGE DURING 1995 HYOUGOKEN–NANBU EARTHQUAKE IN JAPAN

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ABSTRACT

The objectives of the study are to survey and depict damage of pile foundations during Hyougoken–Nanbu Earthquake on January 17, 1995 in Japan, to classify pile damage cases to several categories of pile damage based on external causes, and to analyze the cases due to soil liquefaction lateral flow, one of the external causes. This study also includes comparison of the damage cases with previous pile damage since 1923 Kanto Earthquake.

KEYWORD

1995 Hyougoken–Nanbu Earthquake, Pile Damage, Inertial Force, Soil Movement, Liquefaction, Lateral Soil Flow, Previous Earthquakes

PREVIOUS PILE DAMAGE DURING EARTHQUAKES IN JAPAN

Several cases of pile damage in buildings were revealed in 1978 Miyagiken–Oki Earthquake. Sugimura, Y. and Oh'oka, H. (1981) summarized some cases of precast concrete pile damage during the earthquake, and related design documents. Mizuno, H. (1980), Mizuno, H. and Iiba, M. (1980) and Mizuno, H. (1985) surveyed previous damage of foundations since 1923 Kanto Earthquake. They considered classification of pile damage patterns and relationship between pile damage patterns and pile types, and classified external causes of pile damage based on the previous seismic pile damage cases.

An outlook of seismic foundation damage since 1923 Kanto Earthquake to 1994 is as follows ((Mizuno, H. (1985) and BRI (1994)); In Japan, several tens of seismic damage cases of wood piles, precast concrete piles (types: precast centrifugally compacted reinforced concrete pile (RC pile), precast centrifugally compacted prestressed concrete piles (PC pile), precast centrifugally compacted autoclave prestressed concrete pile (AC pile)), steel pipe piles, pile caps, raft foundations were reported. In 1923 Kanto Earthquake, damage of isolated raft foundations, strap beams, wood piles were presented with some figures and photo pictures. In 1948 Fukui Earthquake, shear failures of columns in isolated column footings were reported. In 1964 Niigata Earthquake, which is famous for liquefaction of sandy soils, seismic damage cases of steel piles and precast RC piles were surveyed on some reconnaissance reports, and has been reported on demolition of building structures. In 1969 Tokachi–Oki Earthquake, a few cases of precast RC piles in elevated railway bridges and a school building. In 1978 Miyagiken–Oki Earthquake, some damage cases of precast concrete piles, especially AC piles. were focused, and after the earthquake, check of lateral bearing capacity due to seismic inertial force of building, etc. was introduced in building regulation and its related technical documents. And after the earthquake, a Japanese Industrial standard on AC pile changed to one on pretentioned spun high strength pile (PHC pile). Manufacturing and curing method of the former is included in that of the latter. In 1982 Urakawa–Oki Earthquake, 1983 Nihonkai–Chubu Earthquake and 1993 Hokkaido–Nansei–Oki Earthquake, some damage cases of pile cap of steel pile, bent of steel pipe piles, RC piles, PC piles and PHC piles of some buildings and a cement silo structure.

From an epidemiological viewpoint, external causes and damage patterns of the typical pile damage were examined ((Mizuno, H. (1980) and Mizuno, H. (1985)). The external causes are classified into following five categories; 1. Lateral displacement of cohesive and/or organic soils. 2. Failure and movement of embankment. 3. Liquefaction and movement of sandy soil. 4. Vibration effects of the soil ground. 5. Vibration effects, especially inertial forces of a structure. And four damage patterns are as follows; 1. damage with subsidence of pile head (shear failure, compressive failure). 2. Ring-type crack due to bending moment (no subsidence of pile head). 3. Separation of pile from pile cap. 4. buckling failure of welding joint.

Almost all of previous pile damage survey had been carried out by excavation of soil near to surface and observation of pile head. Deeper parts damage of pile has not been known except for a few cases of steel pile and RC pile during 1964 Niigata Earthquake. These cases were carried out by excavation of soil along almost full length of piles or excavation of entire piles.

CHARACTERISTICS OF PILE DAMAGE DURING 1995 HYOUGOKEN-NANNBU EARTHQUAKE

Survey method

Building Research Institute dispatched reconnaissance survey teams and study survey teams to Hanshin area, namely Kobe, Ashiya, Nishinomiya, Takarazuka and Akashi cities, and Awaji-Island to grasp an outlook of damage to buildings and related facilities and to make a research on buildings damage in 1995 Hyougoken-Nanbu Earthquake. This study is derived from above-mentioned BRI activities and continues as of June, 1995. So this is an intermediate report of pile damage.

On reconnaissance survey a week after the earthquake, two cases of damage to pile foundations were founded. Damaged pile types are prestressed concrete pile and cast-in situ concrete pile without bar reinforcements. In both cases, the buildings are located at distances of several meters and several tens of meters from quays. Pile heads of the two buildings were damaged due to lateral soil flow after liquefaction. Some other pile damage cases were informed us. In the previous earthquakes, cases of pile damage were usually revealed some or several months after the earthquakes. In 1995 Hyougoken-Nanbu Earthquake, however, several pile damage cases were soon known after the earthquake. Nevertheless, a lot of pile damage cases seem to exist, and have not been reported yet, especially in private buildings including apartment buildings (condominiums) and industrial facilities.

In order to survey pile damage during 1995 Hyougoken-Nanbu earthquake, we asked administrators of buildings and facilities in local governments, related affiliation etc. to cooperate with us for our pile damage survey. Through consulting repair and reconstruction with them, we surveyed pile damage by excavation of pile heads, nondestructive tests (wave propagation methods), etc. On the basis of the pile damage cases, we examined details of pile damage, damage patterns, external causes of damage with damage to surrounding soils and buildings.

Characteristics of pile damage during 1995 Hyougoken-Nanbu Earthquake

More than thirty cases of pile damage are plotted in Figure 1. Some cases are shown in other institutions reconnaissance reports. Pile types are precast concrete piles, cast-in-situ concrete piles and steel pipe piles. Those pile damage cases are found in reclaimed areas, hill areas and in severely shaken areas (JMA seismic intensity 7). Several buildings of pile damage are located near to quays and their piles were subjected to lateral soil flow with liquefaction.

Damage patterns of piles are 1) separation between pile caps and piles, 2) damage near to pile heads, 3) damage of deeper parts of piles. From an epidemiological viewpoint, external causes are classified into following categories; 1) Inertial forces due to building shaking, 2) lateral soil flow with liquefaction and 3) Movement of filled soils, 4) Movement of natural deposit soil.

SOME CASES OF PILE DAMAGE DURING 1995 HYOUGOKEN-NANBU EARTHQUAKE

CASE A : Due to lateral soil flow with liquefaction (Cast In-Situ Concrete Piles)

Cast-in-situ concrete piles and strap beams in a refuse incinerating plant near completion were damaged in Ashiyahama, Ashiya City during the earthquake. The site in Asiyahama Seaside Town, Ashiya City had been reclaimed by Awaji Island soils and dredged soils, and is surrounded by breakwater walls and the sea on the east and south sides. The plant is supported by 30 meters long cast in-situ concrete piles with 1 - 1.2 meters diameter and with enlarged diameter at the bottom. Many sand boils on the north of the plant, and many ground fissures around the plant occurred, as shown in Fig. 2. Ground settlements of the site were 20 - 100 cm, and the settlement amounts were largest on the east and south sides of the plant. A column bottom at south-east corner moved 10.2 cm to the south sea and 1.8 cm to the orthogonal direction from original positions by precise distance measurements in the plant. Horizontal displacements to the south at column bottoms on the south side of the plant were 2.4 - 19.8 cm to the south sea. The movement amounts were largest at the center of the south side, namely near to an assembled chimney. The chimney bottom moved 52.6 cm to the south sea and 21.3 cm to the orthogonal direction, and the chimney 1/240 radian to the south sea and 1/1500 radian to the west. Horizontal ground displacements in Fig.2 are derived from comparison of aerial pictures before the earthquake and after the earthquake (Hamada, M., Isoyama, R. and Wakamatsu, K., 1995). Due to comparison of measurements at very close two points on the south-east breakwater before the earthquake and after the earthquake, the south-east breakwater is evaluated to move 110 cm to the south, 60 cm to the east, and to settle 120 cm. On the other hand, by aerial pictures comparison, the south-east breakwater is evaluated to move 239 cm to the direction of an arrow at the south-east breakwater in Fig. 2. This numerical value is excluded and presented only by the length of the arrow in Fig. 2.

Figure 3 presented damage of the piles by televiewer observation in cored holes of the four piles after non-destructive tests as screening tests. The holes were cored down to a depth of 12 -16 meters. The locations of the four piles are shown in Fig. 2. Figures 4 and 5 present a video picture and damage to a strap beam near the south-east plant corner, respectively. The piles are considered to be ruptured due to lateral soil flow with liquefaction. From comparison of soil profile, soils from G.L. - 5 meters to -10 meters considered to liquefy and move.

The structure of the plant was slightly damaged, such as cracks of a reinforced concrete refuse pit and buckling of steel bracing. An old plant on the east of the pile-damaged plant had no damage except for slight cracks of a refuse pit.

CASE B : Due to lateral soil flow with liquefaction (Precast Concrete piles)

Figure 6 (a) presents ground fissures and horizontal soil displacements in a site of a junior high school at Ashiyahama. Horizontal ground displacements in Fig. 6 (a) are determined from an aerial photograph survey (Hamada, M., Isoyama, R. and Wakamatsu, K., 1995). South side of the site faces the sea. Buildings A, B and C are supported by precast concrete piles (PHC piles (type B and C), diameter ; 45cm, total length ; 32 meters). The buildings and passageways tilted to the south after the earthquake. The largest and the widest ground fissure ran through along the north side of the building B. Figure 7 shows relative displacements (change of distance) among the buildings and relative vertical displacements in the buildings. The largest horizontal relative displacement, 50 cm occurred between the building A and the building B. In summary, Figure 6 (b) depicts relative horizontal and vertical displacements among the buildings and the passageways in sectional view.

Excavation of pile heads and non-destructive tests were performed at No.s 1, 2 and 3 points in Fig. 7. Pile heads had no damage, although boiled sands were observed along piles and around strap beams. Figure 8 depicts soil profiles at the building A and B. Figure 9 presents the result of non-destructive test at No. 1 point, the building A with finite difference simulation result based on wave propagation analysis. In consequence, the pile is considered to be cracked at a depth of G.L. -8 meters, and to be broken at a depth of G.L. -16 meters.

Effects of lateral soil flow on the pile are examined on an analytical model shown in Fig.10. A beam theory on Winkler supports is used in piles and horizontal soil reaction coefficients are evaluated from SPT test results in the model. Forced displacements due to lateral soil flow are applied to the pile head vicinities. Figure 11 presents plan views of foundations and piles of the building B. The analytical results are presented in Fig. 12.

CASE C : Due to inertial forces of buildings (Precast Concrete Piles)

Tree twelve-story apartment houses buildings A, B and C were located near to Takatori station on JR line, Suma-ku, Kobe City, and supported by precast prestressed concrete piles, as shown in Fig. 13. The buildings A, B and C tilted 10/1000 radian to the east, 38/1000 radian to the north and 9/1000 radian to the east, respectively. The building B was judged dangerous by a team of quick safety judgement just after the earthquake, and demolished. The others were decided to be demolished a few weeks after the earthquake, because of foundation damage. After complete demolition of the three buildings, excavation survey of the piles were carried out.

Figures 14, 15, 16 and 17 are damage of piles. The main cause of pile damage, at least in the building B, is considered due to inertial forces of the buildings, although soil lateral displacements are observed in the damaged pile pictures of the building A and C.

Other cases

Case 1 ; Cast in-situ concrete piles were damaged before erection of a building. This case is considered due to soil movements without liquefaction in Kobe City. Case 2 ; Settlements of tips in cast in-situ concrete pile on cut and filled soil site in the mountainous area.

CONCLUDING REMARKS

External causes of pile damage during 1995 Hyougoken-Nanbu Earthquake are 1) movement of filled soils, 2) inertial forces due to building shaking, 3) lateral soil flow with liquefaction and 4) soil movement without liquefaction. A tendency of pile damage is as follows; Pile damage cases caused due to lateral soil flow with liquefaction is found in reclaimed areas, especially near to quays. In such situations, piles, even cast-in-situ concrete piles were damaged in deeper parts. Pile damage due to inertial forces is found in alluvial fan areas (in areas of JMA Intensity 7), and pile damage due to soil movement without liquefaction is found in mountainous areas. Case studies of pile damage should be done in detail to clarify effects of inertial forces and soil movements, and should be utilized to improve pile design method.

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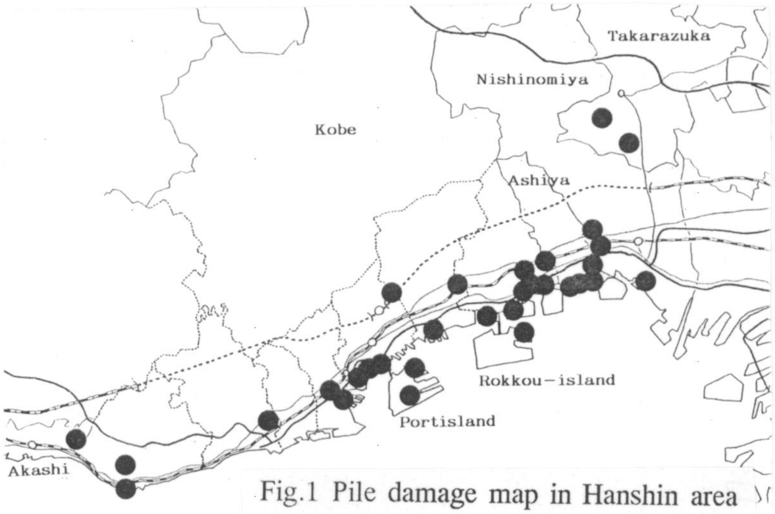


Fig.1 Pile damage map in Hanshin area

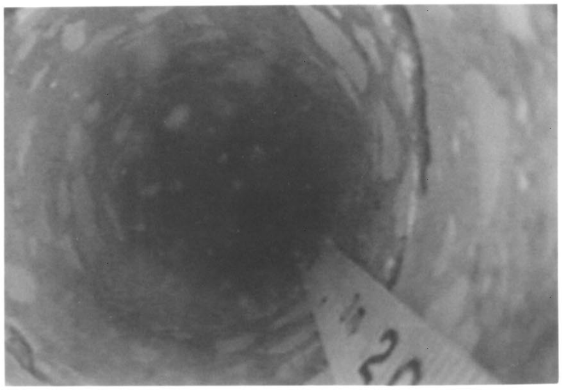


Fig.4 Video picture in cored hole of cast in-situ pile

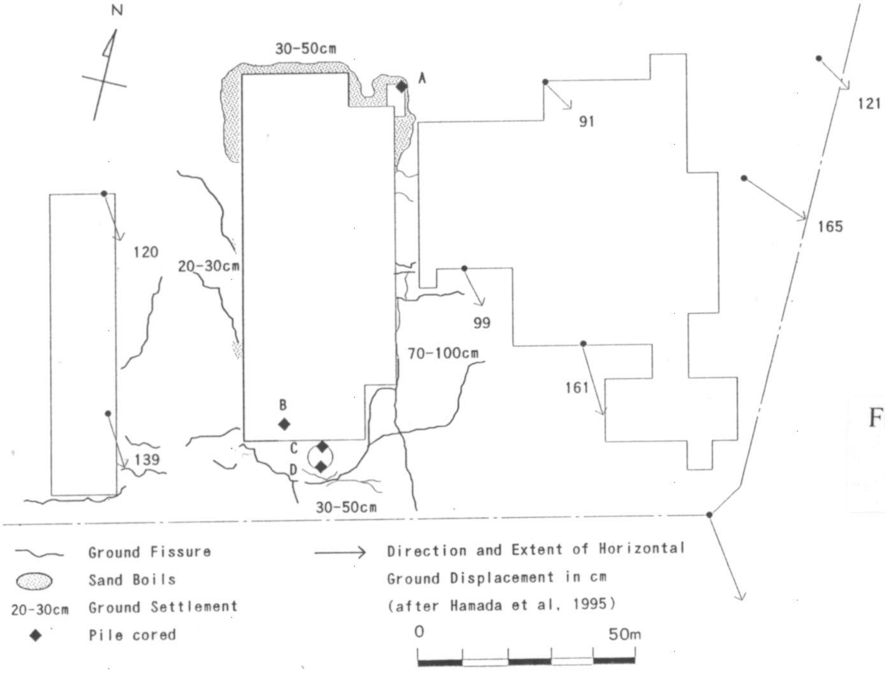


Fig.2 Ground fissures, sand boils and horizontal displacements, CASE A

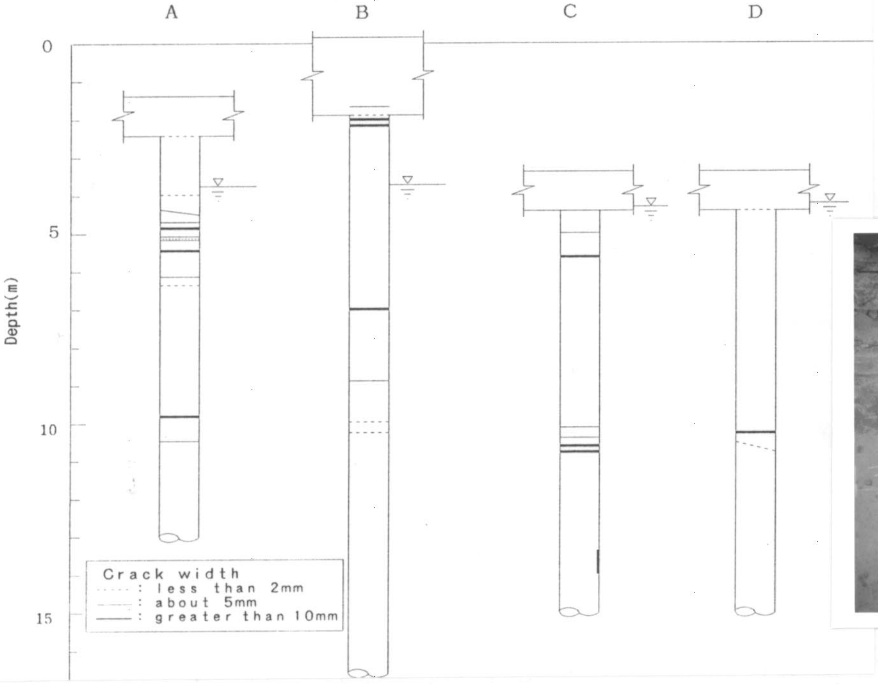
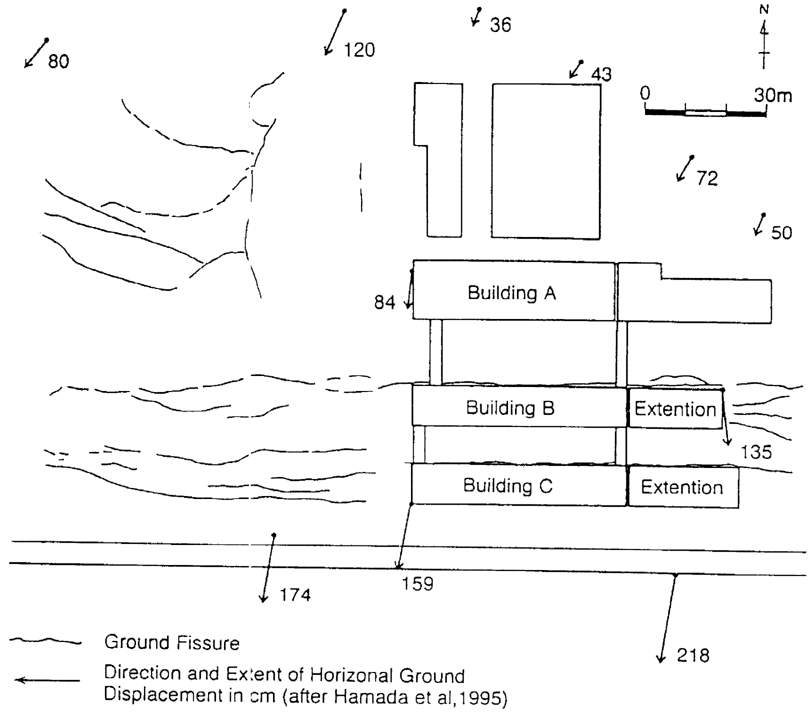
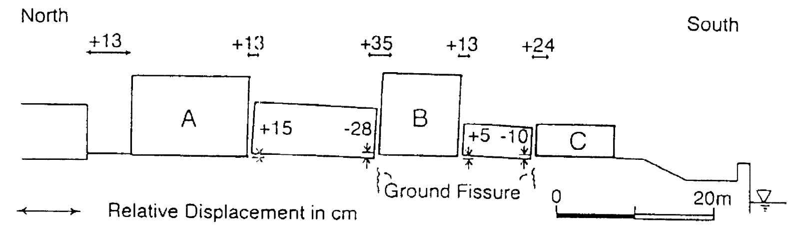


Fig.3 Damage of cast in-situ concrete piles, CASE A

Fig.5 Cracks of strap beam

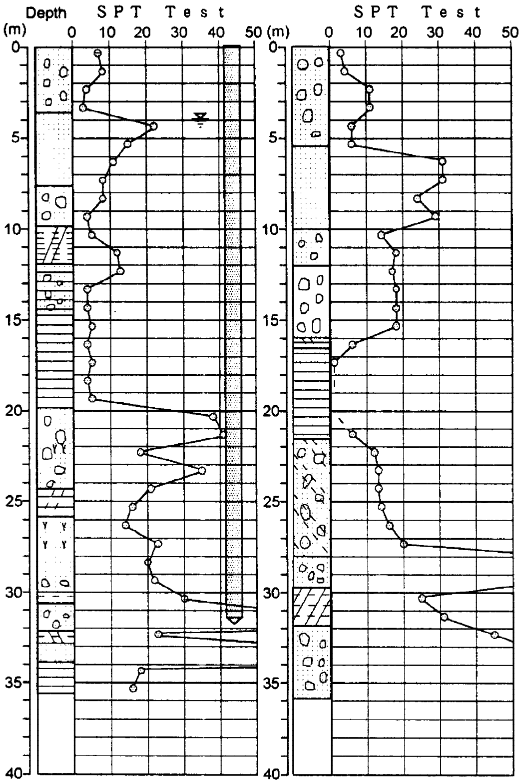


(a) Plan



(b) Section

Fig.6 Plan view and sectional view (ground fissures and displacements), CASE B



Soil Profile at B-building   Soil Profile at A-Building

Fig.8 Soil profile at buildings A and B

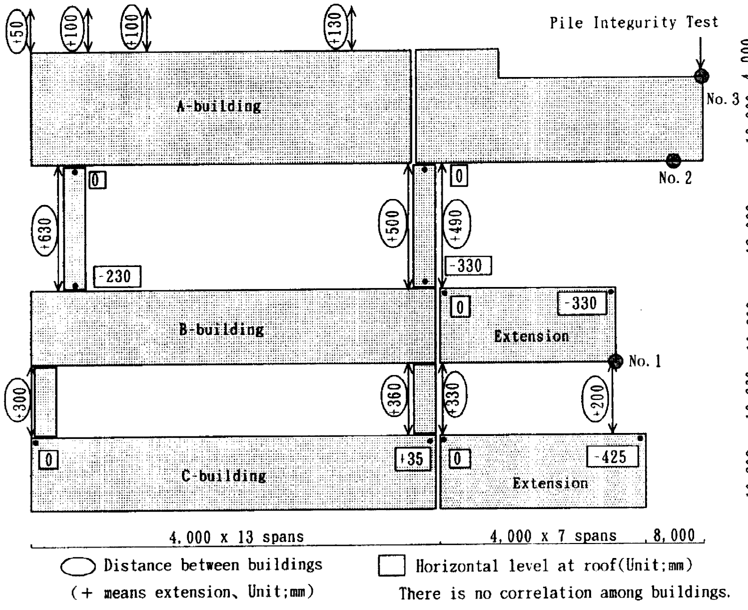


Fig.7 Change of distance among buildings and vertical displacements in buildings

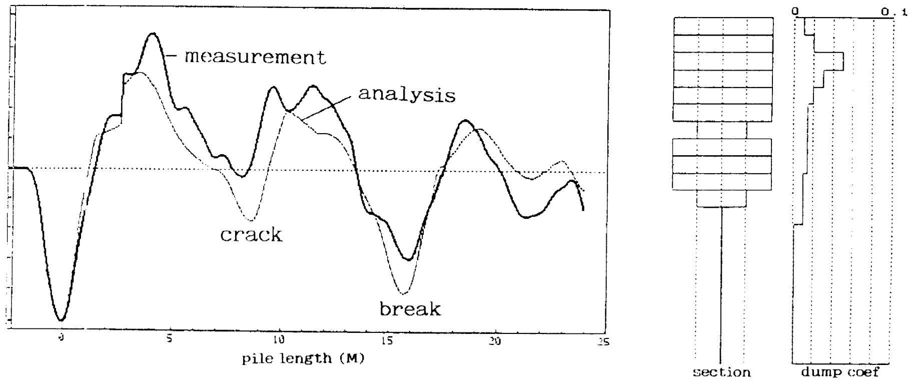


Fig.9 Result of non-destructive test

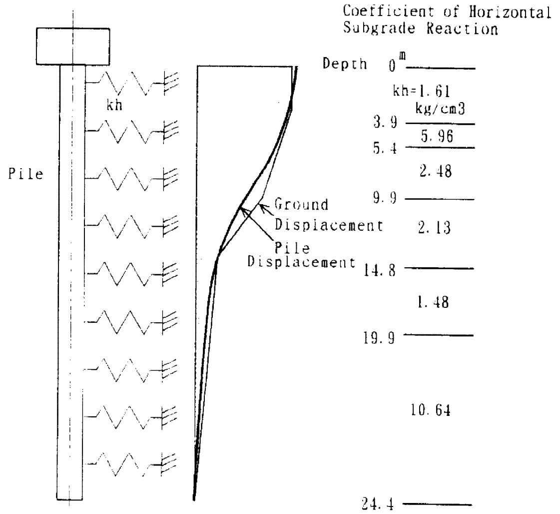
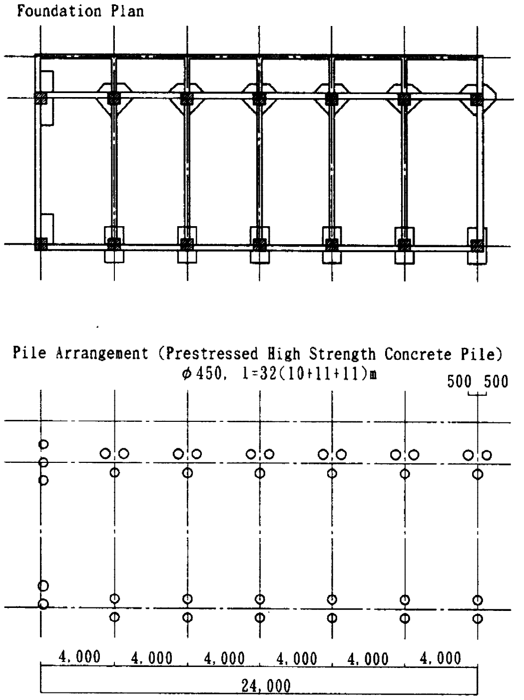


Fig.10 Analytical model



Foundation and Pile Plans of Extention Part of B-building

Fig.11 Plan view of foundations and piles, building B

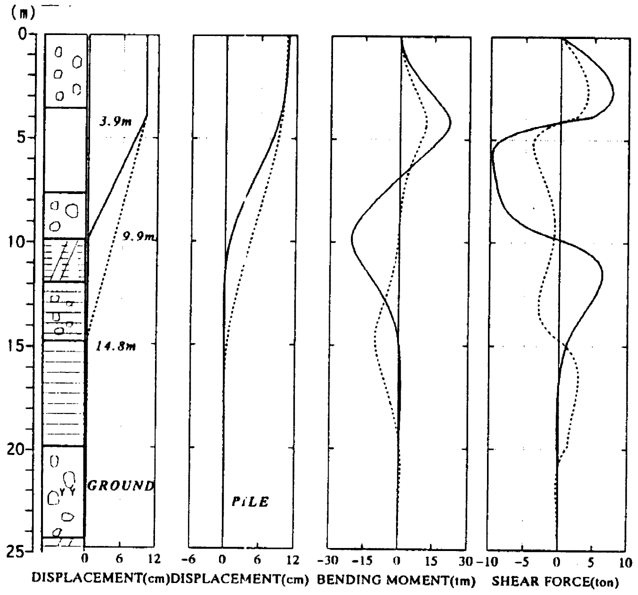


Fig.12 Analytical results of lateral soil flow on piles, CASE B

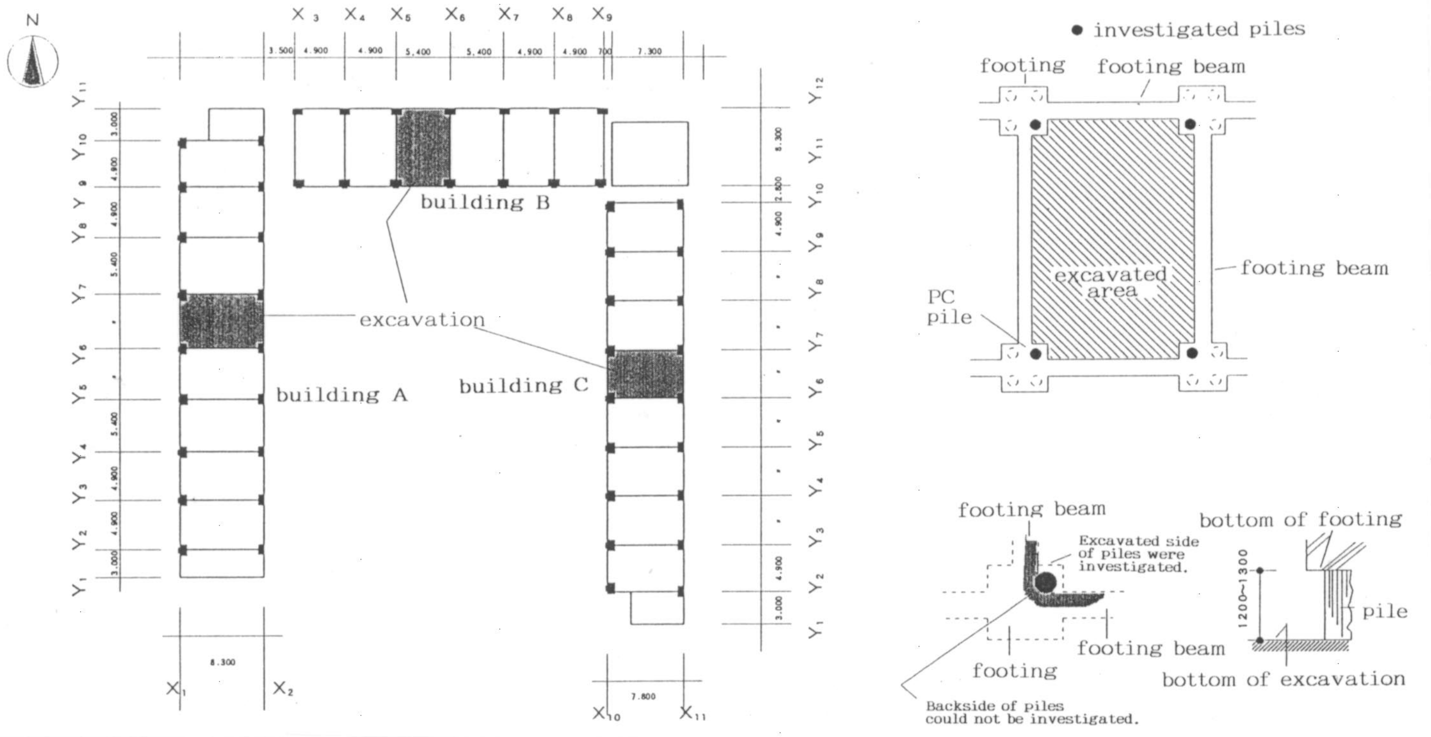


Fig.13 Site and excavation location, CASE C

Fig.14 Damage of precast prestressed concrete piles, CASE C (Compressive failure, building A)

Fig.15 Damage of precast prestressed concrete piles, CASE C (shear failure, building B)

Fig.16 Damage of precast prestressed concrete piles, CASE C (shear failure + compressive failure, building C)

Fig.17 Damage of precast prestressed concrete piles, CASE C (Soil moved and pile head remained)