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SYNOPSIS By installing several sets of piezometors and a seismograph in a recently reclaimed sand deposit on Ohgishima island near Tokyo, Japan, an attempt was made to monitor pore water pressures as well as horizontal accelerations during earthquakes. The limited data obtained thus far have indicated that virtually no pore water could build up in the loose sand deposit with a small scale shaking having a maximum horizontal acceleration of 45 gal on the ground surface.

INTRODUCTION

In recent years there has been an increasing concern about the stability of underground structures such as lifelines and storage facilities during earthquakes. Recent major earthquakes in Niigata (1964), Alaska (1964), and San Fernando (1971) showed that the damage to embedded structures induced by liquefaction of soils was more critical than by any other types of soil failure. In an effort to investigate the resistance of sands to liquefaction, cyclic triaxial, simple shear, or torsion shear tests on laboratory-prepared samples of sands have been performed by many investigators. However, virtually no attempt has been made to investigate the liquefaction characteristics of sand deposits by directly observing the sand behavior that develops in the field during earthquake shaking. In view of this, an attempt was made to install sets of instruments in a recently reclaimed sand deposit and to monitor acceleractions and pore water pressures that would develop during an earthquake expected to occur in the near duture (JSSMFE, 1976). The following pages describe the overall observation program and some of the records obtained in recent earthquakes.

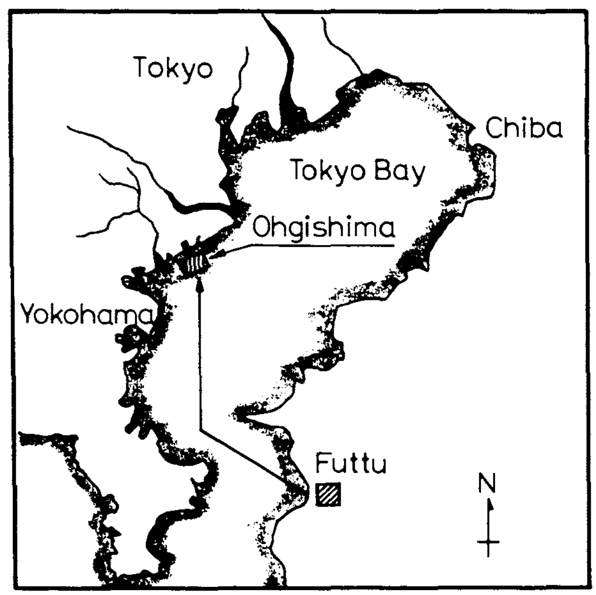

Fig.1 Location of Ohgishima Island

TEST SITE

As a test site for in-situ measurements of pore water pressures and accelerations during earthquakes, Ohgishima Island was selected. This site is located on the west side of the Tokyo Bay as shown in Fig.1. The island, 1.6km wide and 3.0km long, was reclaimed from 1971 to 1975 with sand transported by barges from borrow areas in Futtsu across Tokyo Bay (Fig.1). The soil was first towed in barges to the site and then dumped under water. When the sand surface reached a level about 3.0m below sea level, the barges were not able to approach the site due to the lack of freeboard. Therefore, a sand-water slurry was pumped from nearby sites through a pipe and discharged in the area being filled. Near the west end of the island, a lot 50m × 10m was offered by the Nippon Kokan Steel Company as a test site for the present investigation.

TEST PROGRAM

In view of the fact that pore water pressure is a most important factor by which liquefaction characteristics of a given sand deposit can be evaluated, several sets of piezometers were embedded at two depths in the ground. Also it was considered imperative to have some measure by which the intensity of the shaking could be evaluated. For this purpose, a two-component seismograph was installed on the ground surface permitting simultaneous recording of accelerations with pore water pressure changes induced by earthquakes.
It is well known that the characteristics of pore pressure build-up from earthquakes depends

on the density of the sand deposit concerned. It was considered meaningful, therefore, to provide two sand deposits each having different densities and to compare the pore pressure responses between these two deposits under the same intensity shaking of an earthquake.
In the light of the above consideration, the test lot was divided into two sections as shown in Fig.2 On the east section, a square portion

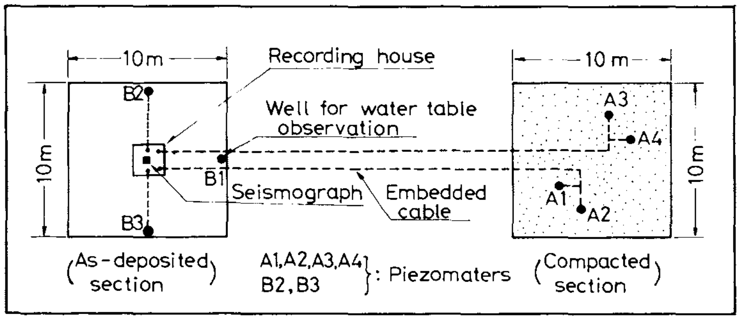

Fig.2 Details of test sites on Ohgishima Island

10m × 10m was compacted to a depth of 15m to provide a dense deposit. Compaction piles 40cm in diameter were installed at a spacing of 1.73 m as shown in Fig.3. Two sets of holes 116mm

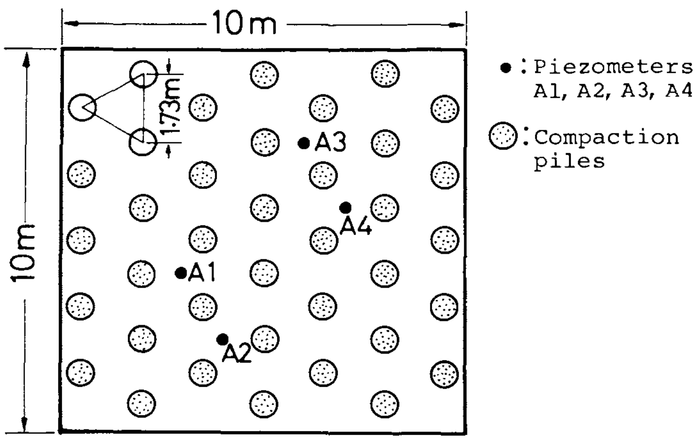

Fig.3 Plan view of measurement points in the compacted section

in diameter were drilled at the center between the piles each to depths of 8m and 12m (Fig.4) and four piezometers were embedded at the bottom. It was then possible to perform two independent measurements under the same shaking conditions. After backfilling the holes with sand, the cables were guided to the ground surface and then to a recording house through vinyl-chloride pipes laid down about 50cm beneath the ground surface.
The west section of the test lot was left intact, providing a loose sand deposit for pore water pressure measurements. In this section, two holes 116mm in diameter were drilled to a depth of 12m and two piezometers were embedded in each of these holes, one at the bottom and the other at a depth of 8.0m (Fig.4). Therefore, two sets of pore pressure measurements were made under identical conditions. The measurement cables

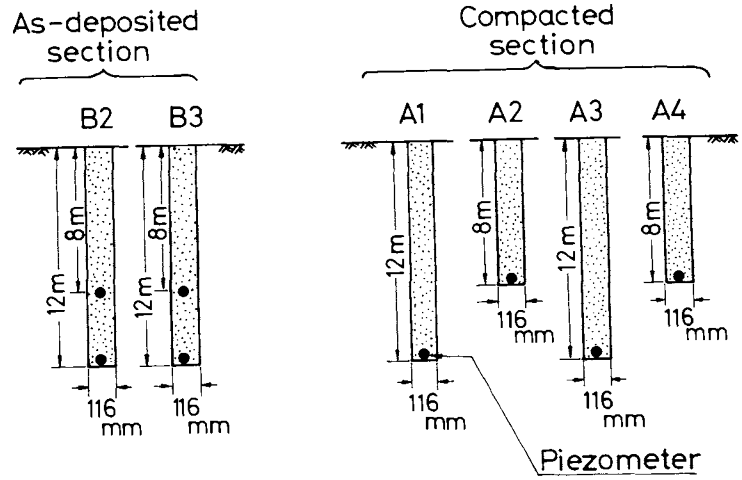

Fig.4 Profile showing the depths of piezometer embeddment

were also led to the nearby recording house. The transducers used for the piezometer were a piezoresistive type with a four arm bridge (Hokuto Riken Co. Tokyo) having a full range of 2.0 kg/cm^2 with diaphrams 1.8cm in diameter. The transducer was enclosed in the piezometer probe equipped with a porous ring near its tip. In the recording house, a set of two-component horizontal accelerometers was mounted on a square concrete block 50cm × 50cm in plan which was seperated from the floor of the house, as shown in Fig.5. The accelerometers were elec-

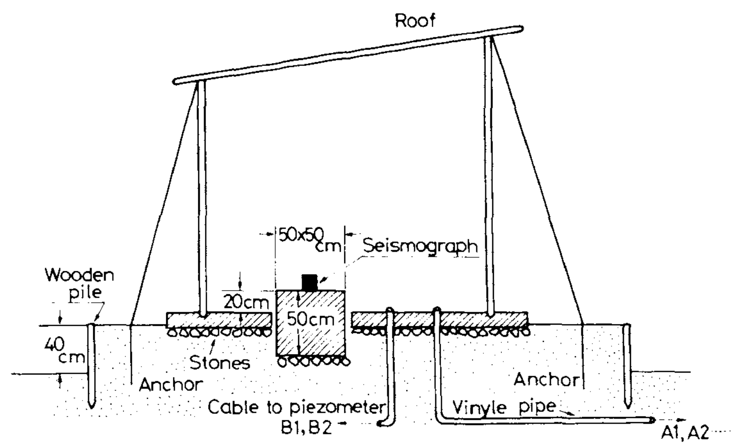

Fig.5 The house for recording instruments

tro-magnetic and self-starting(Model AJE-304, Akashi Seisakusho, Tokyo) with a full range of 1.000 gals within the frequency range between 0.1 and 30 Hz. An ancillary accelerometer monitoring vertical motion was also installed on the concrete block to provide a signal to a starter circuit which triggered the strip chart recorder. The starter circuit could be preset for triggering at any desired intensity of vertical accel-

eration between 1.0 and 10 gals. The oscillograph used (model 5M 11C, Sanei Sokki, Tokyo) has 12 channels and permits a continued recording from 2 to 180 sec.. A small watch was also incorporated to stamp the time and date at which an earthquake occurred.
The block diagram of the recording system is demonstrated in Fig.6. Eight signals from the

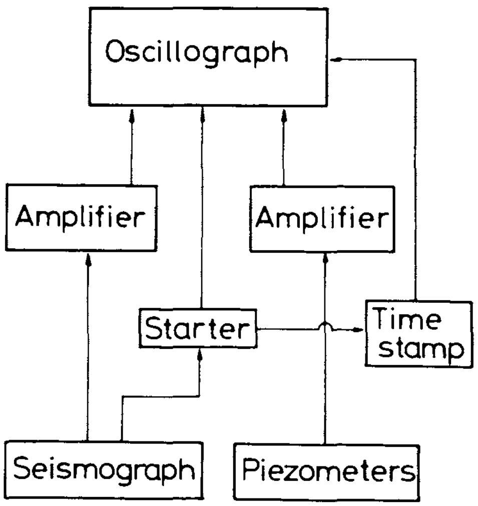

Fig.6 Block diagram of the measuring system

piezometers, four from loose and the other four from dense deposits, are sent to the smplifires and further transmitted to the oscillograph.
At the same time the two component accelerometers send out two signals first for amplification and then to the oscillograph. Once an earthquake hits this site, the starter circuit triggers the oscillograph. It is then possible to obtain ten simultaneous recordings on a running strip chart paper including accelerations and pore water pressures.

SUBSURFACE SOIL CONDITIONS

The soil conditions at the test site were investigated by the Standard Penetration Test (SPT) and by the measurements of in-situ density of intact sands. Two SPT's were carried out each for the intact and compacted deposits. The results of these tests are shown in Fig.7. It may be noted in the figure that the blow count number in the intact deposit is smallest at a depth between 5m and 7m. This corresponds to a depth where the deposit was sedimented under water by discharging a sand-water slurry through a pipe by a pump (pumping under water, Fig.8). It is generally known that this type of placement method produces a fairly loose deposit, as compared to a similar method which deposits sand in air above the sea water level (Pumping in air, Fig.8). In fact, blow counts in the deposit sedimented in air ranges between 7 and 18 as shown in Fig.7. When the sea bottom was still deep enough to permit barges to approach the site, a huge amount of sand was dumped by opening the bottom of the barges. This type of placement method (Dumping through water, Fig.8)

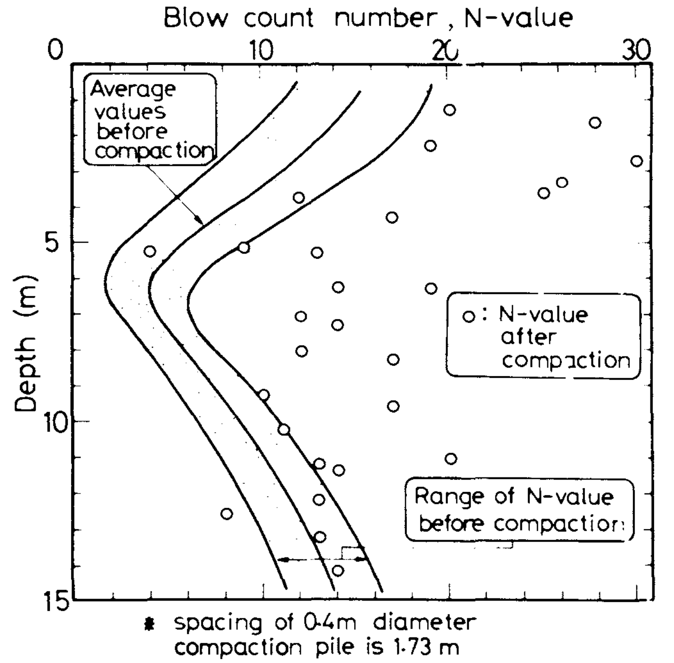

Fig.7 Change in standard penetration resistance before and after installation of compaction piles

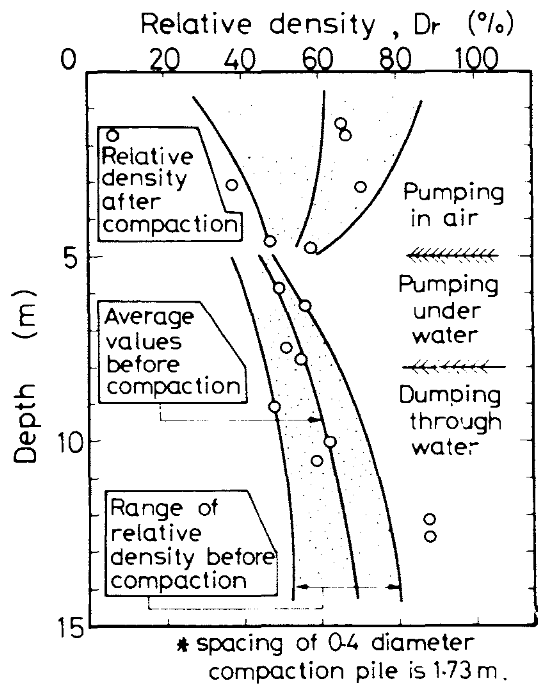

Fig.8 Change in relative density before and after installation of compaction piles

produced a relatively high resistance to penetration as exemplified by the data in Fig.7. Thus, the characteristic difference in blow count distribution in the as-deposited ground as seen in Fig.7 comes from the difference in the method of placement of sand as explained above. Standard Penetration Tests were also conducted on the deposit which had been compacted by means of compaction piles. The test result shown in Fig.7 indicates that N-values were increased almost equally throughout the deposit depth except at the bottom portion of the compaction piles.

For measurements of the in-situ density of the sand, a Bishop type sampler was used. This sampler employs an air space at the bottom of the drilled hole in order to prevent the washing out of the sample as it is withdrawn from the bore hole. In order to provide evidence as to how accurately relative densities measured by means of the Bishop type sampler reflect real densities in the field, a test pit 2.5m × 3m wide was excavated in the intact deposit to a depth of 3m (about 70cm below the water table) and block samples 30cm × 30cm × 20cm were dug out. The blocks were enclosed in steel boxes with praffin seals and transported carefully to the laboratory. A small tube 7cm long and 5cm in diameter was then pushed into the block sample in the laboratory to provide specimens for density measurements. The dry densities measured in this way are compared in Fig.9, with

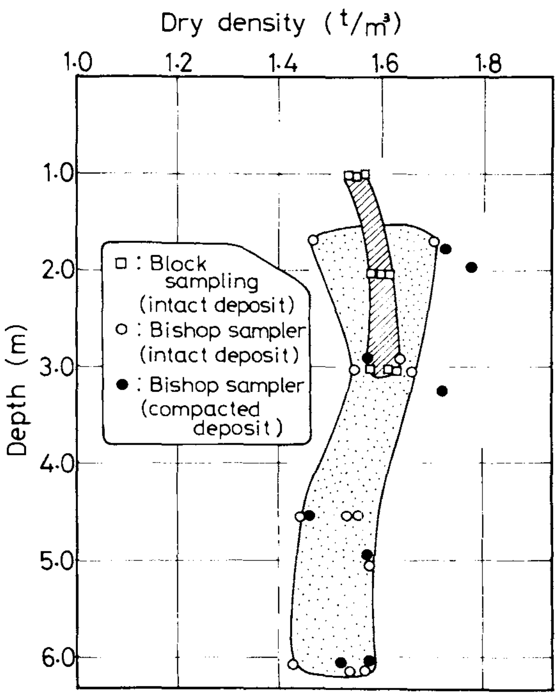

Fig.9 Comparison of measured densities between blocksampling and sampling by a Bishop sampler

those measured by the Bishop type sampler. Fig. 8 presents the results of density measurements made by Bishop sampling where it is noted that the same characteristic distribution as with blow count values is also observed in the intact deposit throughout the depth of the deposit. It is surprising to note, however, that there was virtually no change in density measured between before and after installation of the compaction piles. The obervation that N-values could be increased with little increase in density suggests that there must have been some other factors which acted to increase the penetration resistance as a result of vibrations inparted to the soil. The other factors that could possibly account for the observed increase in penetration resistance are an increase in the in-situ K_0-value and a change in the structure of the sand due to vibration. Although it is difficult at present to quantify the effects of these factors, it may well be assumed that the above two primary characteristics influencing the penetration resistance will all vary in the same way as the liquefaction resistance of the sand. Therefore the two deposits, intact and compacted, having different penetration resistances as shown in Fig.7 probably will also exhibit different resistance to liquefaction at the time of an earthquake, expected to hit the test site in the near future, although the density is almost the same. The results of sieve analysis made for the sands secured by the core catcher of the SPT sampler is presented in Fig.10 where it is noted that the sand is uniform and of medium size.

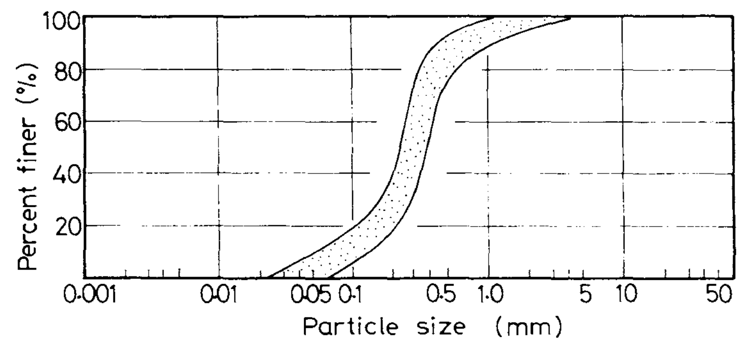

Fig.10 Grain size distribution of reclaimed sand (Ohgishima Island)

RESORDED RESULTS AND DISCUSSION

Since the start of observations in May, 1975, no significant earthquake great enough to build up pore pressures has hit the test site, although on several occassions small scale tremors have triggered the recording unit. The first quake ever experienced was the earthquake that occurred on June 16, 1976 with its epicenter located at the west part of Tokyo, Japan. The maximum accelerations recorded at this station were 36 gal in EW-component and 26 gal in NS-component. The second tremor felt in this area was at the time of the Izu-Ohshima Off-shore earthquake of January 14, 1978 (Magunitude = 7.0). The epicenter of this earthquake was approximately 90km southwest of the Ohgishima Island. The maximum accelerations recorded at this station were 45 gal and 26 gal in EW- and NS-direction, respectively. The third tremor great enough to trigger the instrumentation occurred on June 12, 1978, at the time of the Miyagiken-oki earthquake. The amgnitude was M = 7.4 and its epicenter was located approximately 350km northeast of the Ohgishima Island. The maximum accelerations monitored at this recording station were 28 gal and 23 gal in EW- and NS-direction, respectively. Of these three tremors the records obtained during the first earthquake appear to disclose some interesting fearure of the pore water pressure response. Shown in Fig.11 are the acceleration and pore water pressure records then obtained. Unfortunately four of the piezometer signals ran out of the recording paper and the remaining four piezometer records are shown in Fig.11.

The maximum acceleration of 36 gals was recorded in the EW-direction 11.5 seconds after the initiation of the shaking. It is of interest to note in Fig.11(a) that while high frequency accelerations are predominant in the early stage, the frequency becomes as low as 1.0 Hz after about 25 seconds of shaking, reflecting probably the characteristic frequency of the surface layer of the deposit.

It is noted that the records of pore water pressures fluctuate considerably almost independently of the change in acceleration. These fluctuations are considered to be caused by compression-extention stresses due to the propagation of longitudinal waves. It should also be noted that all records of the piezometers show time changes in phase with each other. Since the vertical acceleration was not monitored in this investigation, there is no way of exactly analyzing a correlation between the small fluctuations in pore water pressures and the compression-extention stresses which could have been inferred from the vertical motion on the ground surface.

Closely associated with the liquefaction of the deposit is a gradual build-up of pore water pressures during the shaking of the earthquake. This can be discerned by carefully reading a shift of neutral position on the recorded time histories of pore water pressures. Previous studies by Ishihara and Yasuda (1975) using a triaxial torsion shear device showed that the major portion of pore water pressure build-up generally occurs at the time a maximum shear stress is applied to a soil during earthquake shaking, and that the developed pore water pressure remained almost unchanged thereafter if the soil is kept undrained even when the shaking continues. In the light of this observation, attention is drawn to the instant of time (12 second point in Fig.11(a)) at which the maximum acceleration, 36 gals, occurs, and also to the period several seconds immediately following the maximum acceleration during which time the dissipation of pore water pressures might not yet have occurred. By drawing an approximate neutral line as illustrated in Fig.11(b) on the portion of the recorded data, a shift in the neutral position may be read off. Since the pore pressure immediately after the maximum spike is considered to be the pore pressure that would remain in the soil for the entire duration of shaking if the soil is kept undrained, it may be termed the "residual pore pressure". The residual pore pressures thus read off are listed in Table 1. It can be seen that the values of the residual pore pressure were so small that the sand deposit in question was far from liquefaction in this earthquake in which the maximum horizontal acceleration was 36 gals. It should be mentioned that the residual pore pressure observed in the intact deposit was a little higher than that recorded in the compacted deposit.

An attempt was also made to read off the residual pore water pressure from the piezometer records obtained during the two other earthquakes. As Table 1 indicates, there was virtually no residual pore water pressure build-up during these two earthquakes.

Table 1 Measured residual pore water pressures in the three earthquakes

	Piezometer	Depth (m)	June.16, 1976 a_{max}=36gal	Izu-Ohshima Jan.14, 1978 a_{max}=45gal	Miyagiken-oki June.12, 1978 a_{max}=28gal
Uncompacted deposit	B2-1	8.0	—	0	0
	B2-2	12.0	—	—	—
	B3-1	8.0	15cm	0	0
	B3-2	12.0	—	—	—
Compacted deposit	A1	12.0	0	0	0
	A2	8.0	—	0	0
	A3	12.0	0	0	0
	A4	8.0	8cm	0	0

CONCLUSIONS

An attempt was made to monitor pore water pressures as well as horizontal accelerations during earthquakes by installing several sets of piezometers and a seismograph in a recently reclaimed sand deposit on Ohgishima island near Tokyo, Japan. The limited data obtained in recent small earthquakes have shown that small scale shaking with a maximum horizontal acceleration on the order of 45 gal was not great enough to produce significant pore water pressures which could influence adversely the stability of the deposit and that a definite conclusion can not been drawn until a greater earthquake may shake the site in the future.

ACKNOWLEDGEMENTS

The studies described in the preceding pages were conducted under the sponsorship of the Science and Technology Agency of the Japanese Government during the fiscal years of 1974 and 1975. The Japanese National Society of Soil Mechanics and Foundation Engineering was commissioned to implement the test program under the Research program "Studies of Damage to Underground Facilities and Structures during Earthquakes". A Task Committee headed by Professor M. Fukuoka of University of Tokyo was organized in the Society to draft a research plan and to supervise the installation of test equipment. The Task Committee consisted of the following members: Professor K. Kubo, University of Tokyo; Professor Y. Yoshimi, Professor H. Kishida, Tokyo Institute of Technology; Professor K. Yamada, Nihon University; Dr. T. Iwasaki, Public Works Research Institute; and Dr. T. Tateishi, Nippon Kokan Steel Co.. Dr. Y. Sugimura, Building Research Institute and the present author acted as coordinators of this program. The field work was carried out with the contractor, Token Geotechnique Co. and Toa Kensetsu Co.. The electrical instrumentation was contracted to the Meiho Engineering Co.. The author would like to express his appreciation to the above individuals and companies who contributed to the execution of this test program.

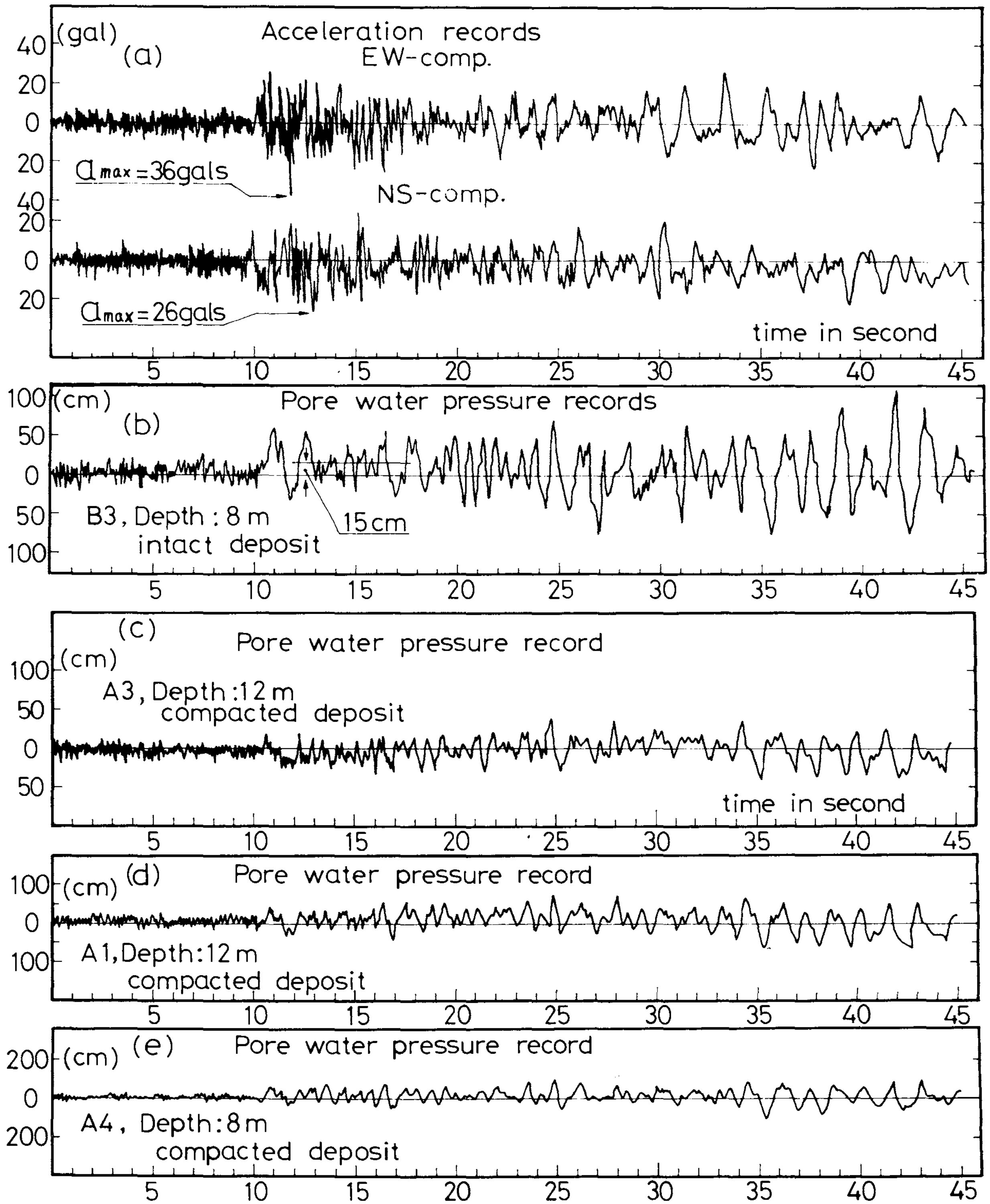

Fig.11 Accelerations and pore water pressure records made during the earthquake of June 16, 1976

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