# SEISMIC PERFORMANCE OF URBAN, RECLAIMED AND PORT AREAS -FULL SCALE EXPERIMENT USING BLAST TECHNIQUE

by

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## ABSTRACT

A full scale lateral spreading experiment was carried out on November 13th, 2001 at Tokachi port in Hokkaido island, Japan. The primary objective of the experiment was to assess the performance of steel sheet pile quay walls subjected to liquefaction/lateral spreading. Two 5.5 m deep quay walls were designed and constructed, to investigate the damage mechanism of steel sheet pile quay walls. They were constructed with seismic design coefficients of k=0.15 and k=0 separately. The test site was reclaimed with dredged fine sand about 18 months before the test. The depth of the reclaimed sand layer was about 8 m and the test field area was around 4800 $m^2$ (50 m by 96 m).

Controlled blast technique was used to induce liquefaction/lateral spreading, and 127 blast holes each consisting 4 kg explosive material for lower part and 3 kg for upper part were charged. The total weight of explosive material was 840 kg.

Various structures such as group pipe piles, gas pipes and buried structures were installed with measuring instruments. Two liquefaction remediation methods and several new measurement techniques were adopted. Forteen organizations were participated in this project.

**KEYWORDS:** Full scale field experiment, Liquefaction, Lateral spreading, Reclaimed land

## 1. INTRODUCTION

The 1995 Hyogoken-Nambu earthquake caused severe soil liquefaction in extensive areas of reclaimed land in Kobe. The soil liquefaction induced large ground displacements in the horizontal direction, which resulted in damage to buried structure such as lifeline pipes and foundations. Also, many caisson type quay walls were damaged in Kobe Port during the earthquake.

Generally, three sets of data can be used to investigate the mechanism of damages;

1) Strong motion record nearby the damaged facility,
2) Geotechecnical data, design conditions and damage data ( i.e. deformation). and,
3) Numerical simulation or model test results

However, an important piece of information as ‘behavior of structures during earthquake’ is not available. In this project, we focused on the behavior of full scale structures during liquefaction state and 14 organizations were jointed in the project as shown in Table 1.

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## 2. OUTLINES OF THE EXPERIMENT

The test site was located in Pier No.4 at Tokachi Port in Hokkaido. The Pier No.4 filling construction was completed in June 2000 with use of dredged fine sands. The experimental yard area was around 4800 $m^2$ (50 m by 96 m) and it was separated into two parts. In one part, steel sheet pile quay wall which was designed with seismic coefficient of k=0.15 was installed the other part the one designed with k=0 was employed. In this paper, the k=0.15 part is refered as region (A), and k=0 part as region (B). In region (B), 4% slope (25 m width, 50 m long) were constructed to induce lateral spreading.

The typical soil profile is shown in Fig.1. The particle size distribution of the soils are shown in Fig.2, as can be sheen most of the soil samples are in 'possibility of liquefaction' zone.

2.1 Blast sequence

The blast hole is indicated in Fig.3 from A1 to A54 , from B1 to B48 and from C1 to C25. The first ignitions were A1 and B1 at the same time. Then, ignite next holes in order with 500 ms time interval which showed snake walking in plan view. Each hole consisting 4 kg explosive material for lower part and 3 kg for upper part were charged with 200 ms time interval, the ignite order was from lower part to top part.

2.2 Lift up mechanism (Fig.3)

In region (A), The Japanese Geotechinical Society installed eight buried structures such as sewage water pipes to investigate the lift up mechanism during liquefaction and the countermeasures. The dimensions of the installed cylindrical structures were 1 m in diameter and 3.8 m in length.

2.3 Performance of Cement deep mixing soil improvement/Permeable grouting improvement during liquefaction

UC Berkeley and Japan Cement Deep Mixing Association installed four cement deep mixed specimens in region (A) as a 3.4 m by 3.4 m foot print cement deep mixing improvement to depth of 8 m (full improvement of reclaimed layer), 5.5 m , 3.5 m and no treatment.

Permeable Grouting Method Association and Port and Airport Research Institute tried to injected 8 hrs gel time chemical grout in between sheet pile quay wall and the anchor pile to investigate the efficiency of permeable grouting method as shown left bottom zone of region (A) in Fig.3.

2.4 Performance of steel sheet pile quay walls

Port and Airport Research Institute, Japan Dredging and Reclamation Engineering Association and Japan Steel Pipe Pile Association constructed two steel sheet pile quay walls with different design seismic coefficients including strain gauges and load cells. In region (A), the quay wall with seismic coefficient of k=0.15 ,and in region (B), the quay wall with k=0 were constructed.

At the tie rod connectors just behind the sheet piles in region (B), special explosives were used so as to cut the tie rod to induce lateral spreading during liquefaction.

2.5 Performance of lifelines subjected to lateral spreading

UC San Diego and Waseda University carried out the pile experiment. The three sets of pile foundations were installed behind the k=0 quay walls to determine the effect of pile groups on the pile response.

300 mm diameter steel pipe piles in pile groups having 900 mm spacing and a concrete pile cap (three single piles, 4-pile group, and 9-pile group) were constructed.

Two pipes were installed to intersect the lateral spreading direction at 90 degree angle, and one pipe was installed in the lateral spreading direction as shown in the right bottom part of Fig.3.

Ten wireless transmition dynamic GPS devices (10 Hz time interval) were installed and attached to the structures to measure the deformation of structures during lateral spreading.

2.6 Investigation on the mechanism of lateral spreading

Waseda university installed 11 GPS devices on the surface of slope with 1 Hz measurement interval, and installed vertical optical fiber modules to measure the deformation inside the slope.

2.7 Evaluation of impervious sheet properties when large deformations occur during and after earthquake

National Institute for Land and Infrastructure Management Yokosuka, installed the impervious sheet used for garbage dumping ground. Many of Japanese garbage dumping grounds are located in coastal area. To keep the garbage material and polluting matter inside the designated area, the performance of impervious sheet is important.

2.8 Survey and Sounding techniques

Port and Airport Research Institute conducted several sounding tests as follows: SPT-blow count, seismic cone penetration test, portable cone penetration test, automatic Swedish weight sounding, and dilatometer test. These tests were conducted about a couple of months before, the day before and after the blast. It is also planed to perform them in June 2002.

National Institute of Advanced Industrial Science and Technology research team used the resistivity method to measure the density profile of the liquefied soil.

Earthquake Research Institute, Tokyo Univ. and Port and Airport Research Institute compared the data obtained from the dynamic GPS installed in region (A) and conventional laser survey data.

Chuo Univ. used the radio controlled helicopter to take photos of the experimental site before and after the blast and automatic computer processing technique to measure the deformation. Chuo Univ. also installed CCD camera into the vertical transparent cylinder to visualize the soil profile during the test.

Waseda Univ. team tried to detect the liquefied soil layer profile during liquefaction by using acoustic tomography with pseudo random binary sequence code technique.

UC Berkely and Port and Airport Research Institute installed both conventional strain gauge type accelerometers and wireless accelerometers which using the micro electro mechanical systems and bluetooth transmission. In this project around 800 sensors were installed and total length of signal cable between sensor and amplifier was about 40 km. The data obtained from wireless accelerometers showed good agreement with the data obtained from conventional accelerometers.

2.9 Re-liquefaction phenomena

Civil Engineering Research Institute of Hokkaido is interested in the re-liquefaction phenomena and curried out the post experiment on Dec. 14th , 2002 with UC San Diego and Port and Airport Research Institute. In region (B), the controlled blast were applied with the group pile foundations as its center.

## 3. SUMMARY OF RESULTS

The overall deformation of the test field is shown in Fig.4. The maximum horizontal displacement of quay wall in region (A) was about 30 cm, region (B) was about 130 cm respectively. Due to the horizontal movement of quay walls, lateral spreading was occurred in region (B). However, three sets of group piles played a role in control works against lateral spreading as shown in Fig.5.

In this experiment, acceleration caused by controlled blasting could not simulate actual earthquake acceleration as shown in Fig.5. Fig.5 shows an acceleration time history recorded at region (A) quay wall, the maximum acceleration was over 10 g. On the other hand, excess pore water pressure was built up overburden pressure as shown in Fig.6.

The bending moment distribution of initial condition, maximum displacement condition and residual condition are shown in Fig.7. The failure of sheet pile quay walls occurred due to the reduction of resistance of anchor pile during liquefaction, then sand water mixture fluid push the quay walls.

Many kinds of challenges to investigate seismic performance of urban, reclaimed and port were conducted in collaboration with 14 organizations. The reports in this paper include wide filed subjects related to liquefaction/lateral spreading phenomena. The analysis works is presently continuing by individual organization participated in this experiment. The results will be presented in the future.

Table 1 Organizations of the research project

| Organization | Research content | Role |
|---|---|---|
| Port and Airport Research Institute (PARI) | 1. Investigation on the dynamic characteristics of ground before and after liquefaction<br>2. Investigation on seismic behavior of sheet piles, anchor piles and tie rods/wires | supervision of entire experiment, measurement of behavior of sheet piles and analysis |
| National Institute for Land and Infrastructure Management (NILIM) | 1. Evaluation of impervious sheet properties when large deformations occur during and after earthquake 2. Investigation on characteristic of microtremor before and after earthquake | analysis of experimental results |
| Japan Dredging and Reclamation Engineering Association (JDREA) | Investigation on seismic behavior of sheet piles, anchor piles, tie rods and surrounding ground | execution management and analysis |
| Japanese Association for Steel Pipe Piles (JASPP) | Investigation on seismic behavior of sheet piles, anchor piles, tie rods and surrounding ground | measurement of sheet piles displacement and analysis |
| University of California, San Diego (UCSD) | Investigation on behavior of pile groups and buried pipes | Measurement and analysis about interaction between structure and ground during lateral flow |
| Cement Deep Mixing Association (CDM Association) | Investigation on properties of ground improved by cement deep mixing method | cement mix design, execution management and analysis |
| University of California, Berkrey (UCB) | Investigation on properties of ground improved by cement deep mixing method | measurement of improved ground behavior and analysis |
| The Japanese Geotechnical Society (JGS) | Investigation on behavior of buried pipes imposed to up-lift pressure of liquefaction | measurement of underground pipe behavior and analysis |
| Waseda University (Waseda Univ.) | 1. Investigation on ground movement during and after lateral flow and behavior of buried single pile 2. Investigation on elastic wave velocity in liquefied ground 3. Measurement of vibration at adjacent buildings 4. Measurement of underground displacements | acoustic tomography, measurement of underground displacement by using optical fiber, GPS, etc. |
| Permeable Grouting Method Association (PGM Association) | Confirmation of efficiency of permeable grouting method | execution management and analysis |
| Tokyo University, Earthquake Research Institute (Tokyo Univ.) | Measurement of 3D dynamic displacements by GPS | measurement by dynamic GPS |
| Chuo University (Chuo Univ.) | 1. Investigation on water film phenomenon occurred by liquefaction<br>2. Measurement of ground displacements | measurement by borehole-camera and radio-control helicopter |
| National Institute of Advanced Industrial Science and Technology (NIAIST) | Investigation on underground density profile of liquefied soil | measurement by resistivity method |
| Civil Engineering Research Institute of Hokkaido (CERI) | Investigation on behavior of re-liquefied ground | analysis of experimental results |

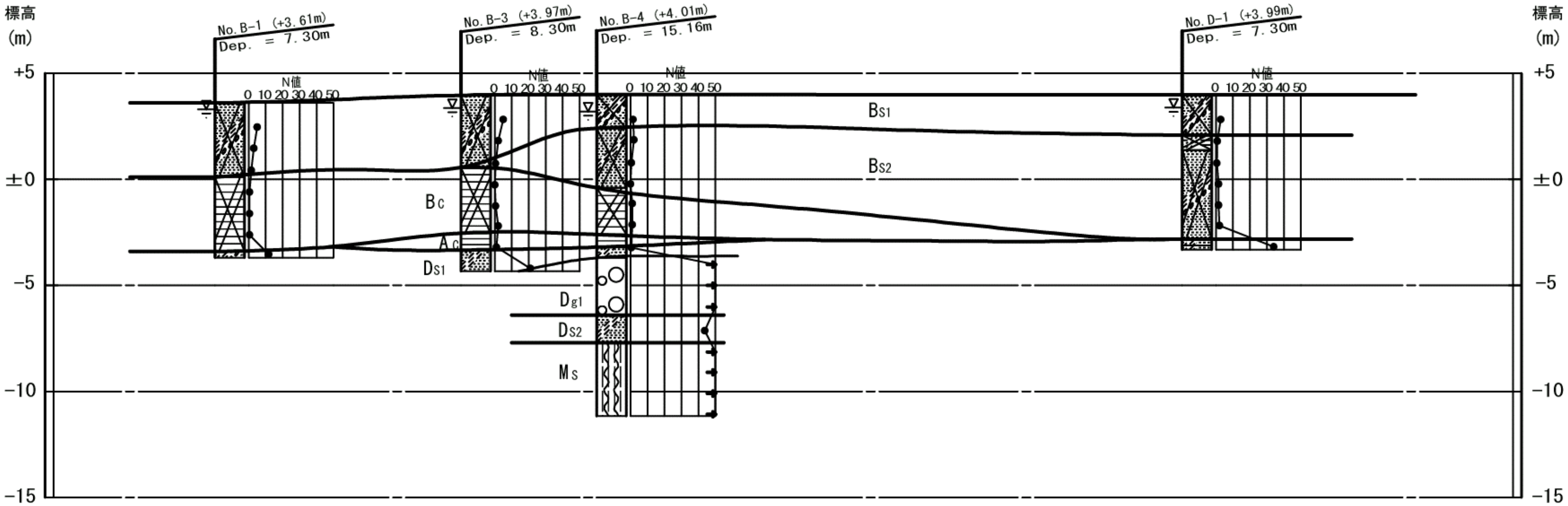



Fig.1 Typical soil profile

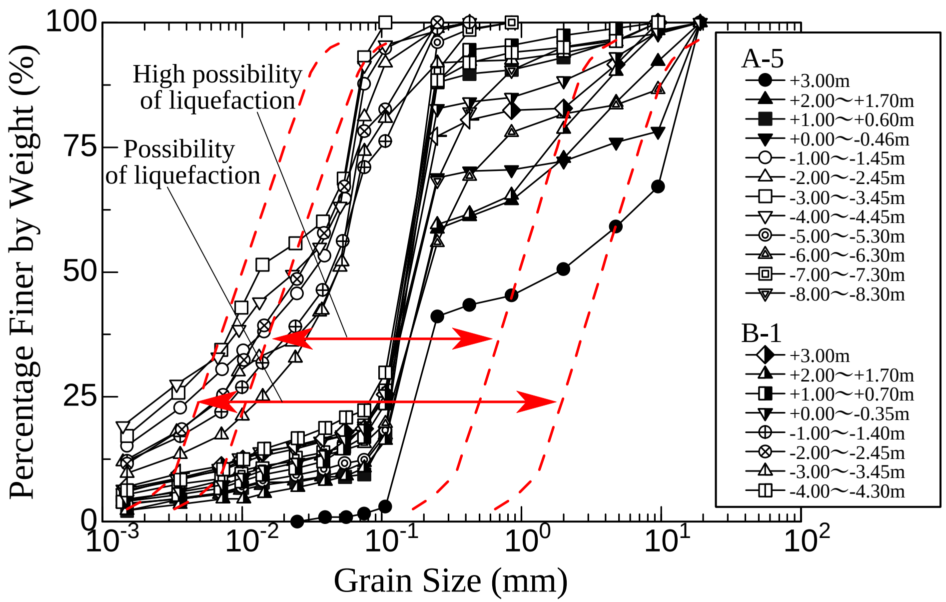



Fig.2 Particle size distribution

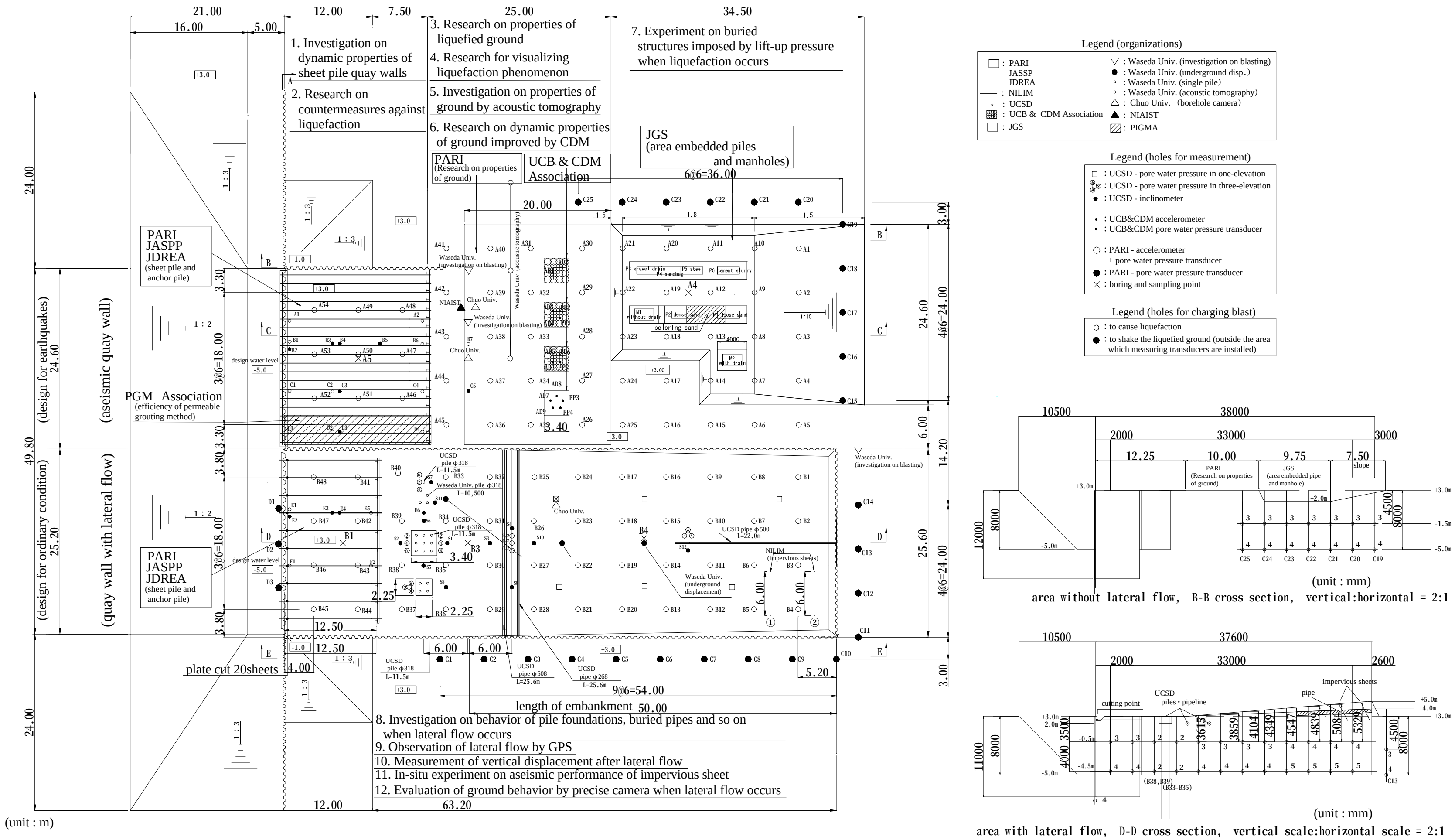



Fig. 3 Plan view of the test site

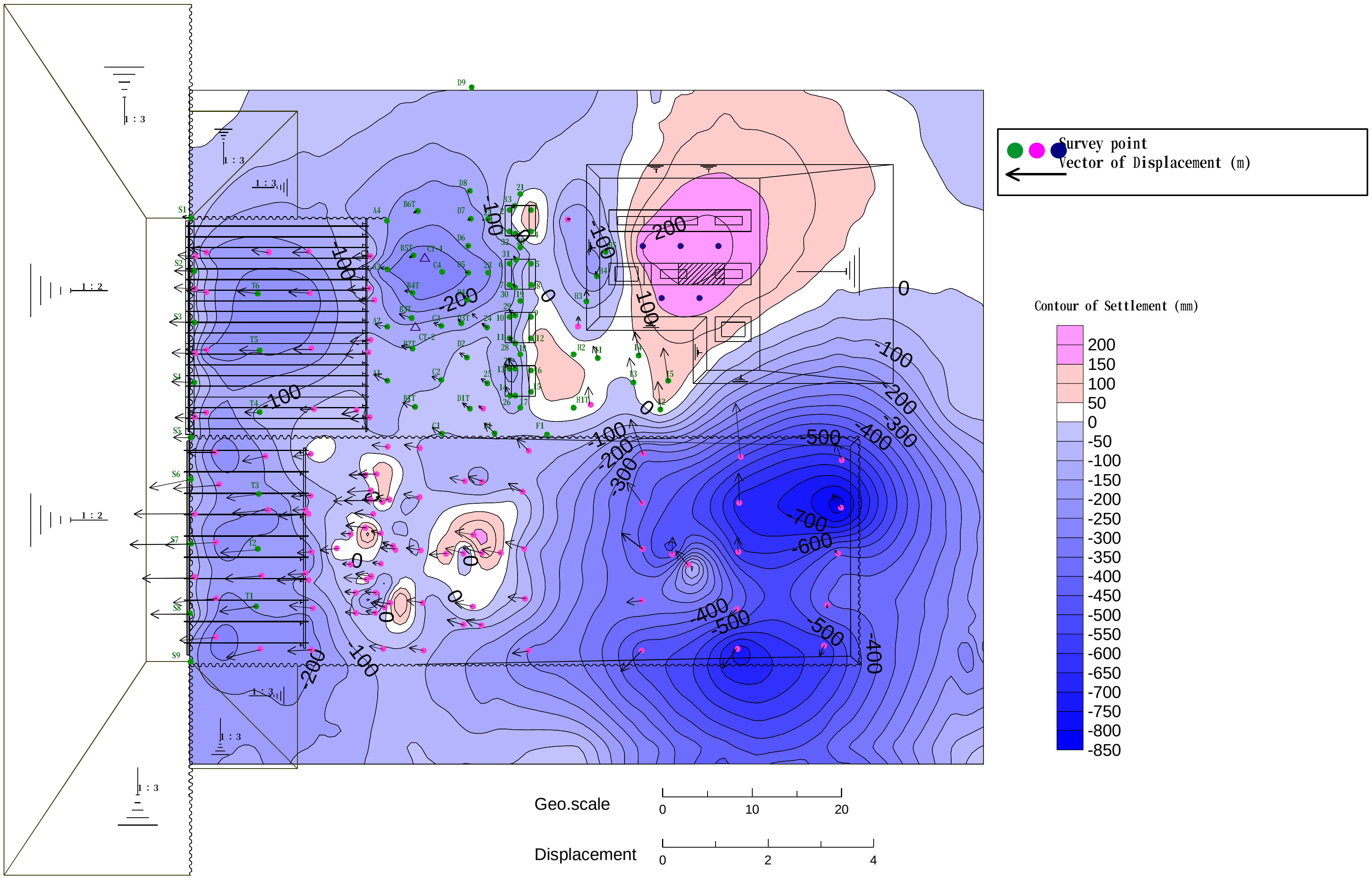



Fig.4　Deformation of test fields

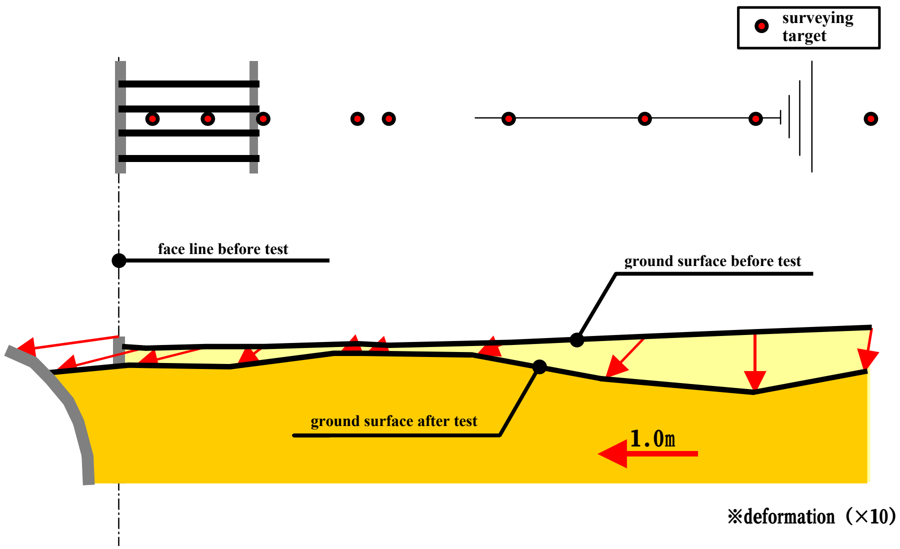



Fig.5 Lateral spreading deformation

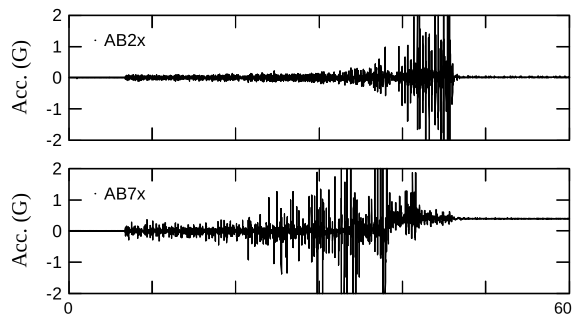



Fig.6 Acc. caused by blast

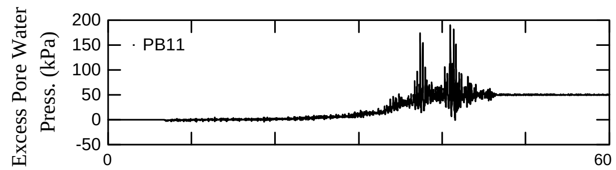
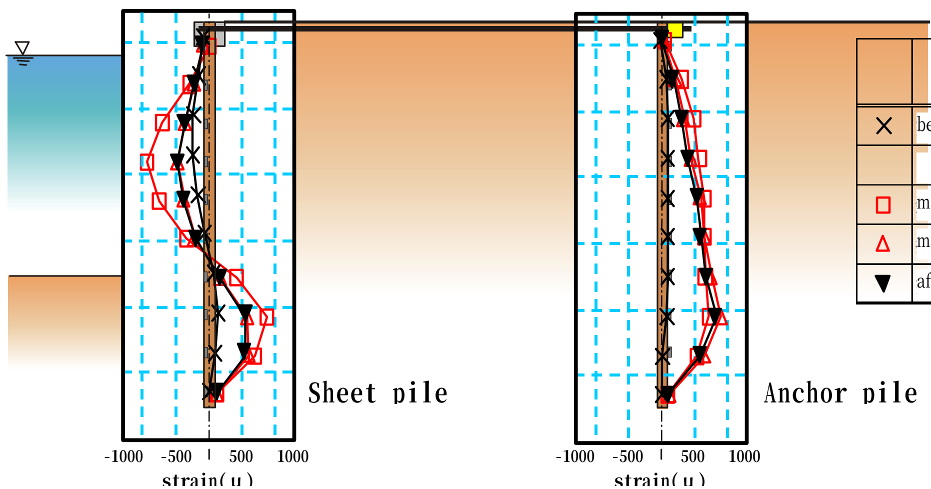



Fig.7 Excess pore water pressure




| | イベント | Time (sec) | Tension in tie rod (kN/m) |
|---|---|---|---|
| × | before test | 0.000 | 52.2 |
| | | 45.725 | 184.4 |
| □ | max strain in sheet pile | 45.760 | 150.2 |
| △ | max strain in anchor pile | 46.575 | 99.4 |
| ▼ | after test | 90.000 | 90.2 |

Fig.8 Strain distribution of sheet and anchor pile

Photograph Test site : before experiment

Photograph Tokachi port from window of airplane

Photograph Under construction

Photograph Installing blast

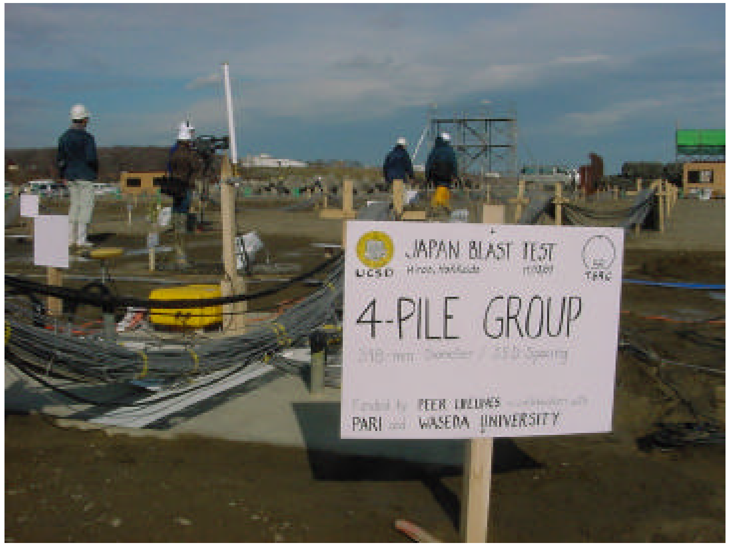
Photograph During blast

Photograph Visitors during blast

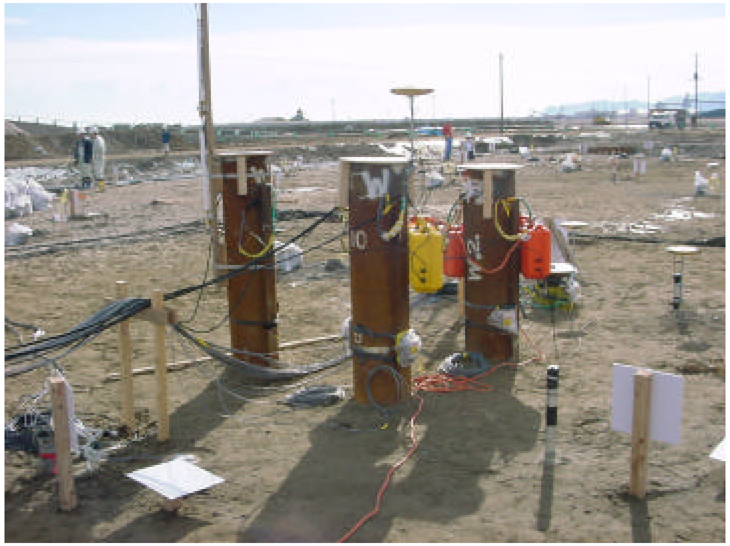
Photograph Boiling sand caused by liquefaction

Photograph After sand boil

Photograph Sheet pile quay wall after blast (PARI, JDREA & JASPP)




Photograph Pile groups (UCSD)



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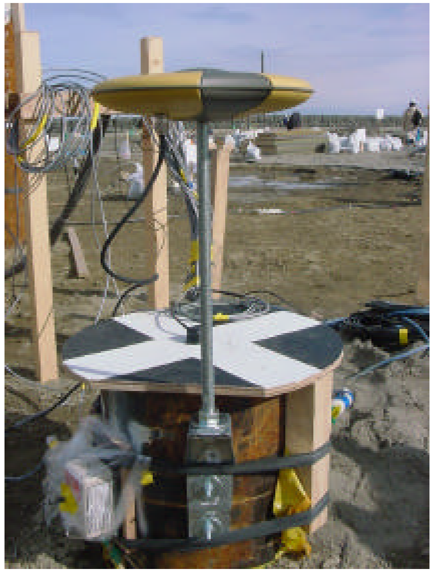


Photograph Single Pile (Waseda Univ.)

Photograph Impervious sheet (NILIM)

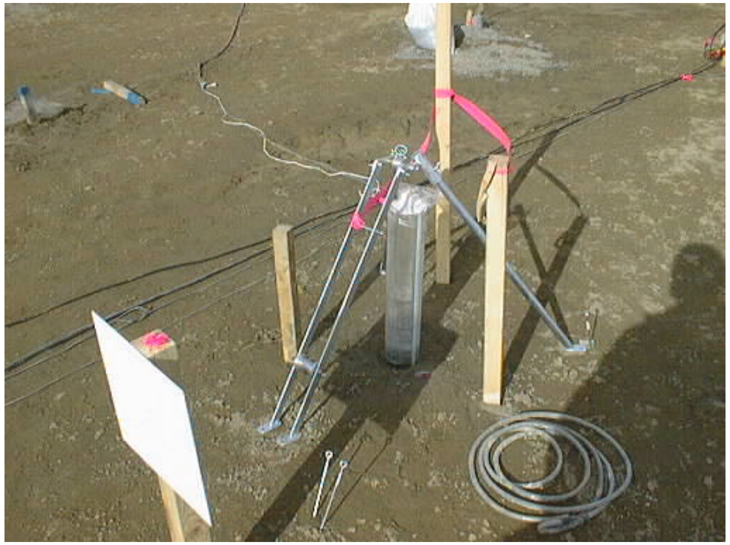
Photograph Lift-up of buried pipe (JGS)


Photograph Improved ground by CDM (UCB & CDM Association)

Photograph Execution of PGM (PGM Association)

Photograph Radio control helicopter (Chuo Univ.)

Photograph Test site from helicopter's camera (Chuo Univ.)



Photograph Borehole camera (Chuo Univ.)

Photograph　Re-liquefaction test during heavy storm on Dec 14th, 2002