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EXPERIMENTS ABOUT SEISMIC PERFORMANCE OF REINFORCED EARTH RETAINING WALL

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ABSTRACT

These experiments are carried out to inspect the internal seismic stability of the Reinforced Earth Retaining Wall. The numerous experiments are conducted on the magnitude of the seismic earth pressure acting on the Reinforced Earth Retaining Wall, the tensile forces of the reinforcements, and the behavior of the deformation of the wall. There are some problems for the behavior of the flexible high wall and for the magnitude of the action force in an earthquake. Major consideration items concernig the internal seismic stability design as follows; (a) Earth pressure to act on the walls. (b) Tensile force in the reinforcements. (c) Force on the foundations. (d) Deformation of the Reinforced Earth Retaining Wall.

KEYWORD

Large-scale experiment; reinforced earth; retaining walls; seismic stabilities; shaking table; earth pressure; foundations.

INTRODUCTION

In the last twenty-five years, the Reinforced Earth method by the high tensile strength materials has become a popular technique in the earth construstion. These reinforcements such as metal strips, plastic grids, and fabric have all been used to inclease the tensile strength, and the shear resistance of soils (Mitchell 1981). In Japan, a large portion of the land is comprised of steep mountainous and hilly regions. The Reinforced Earth is considered a very effective means of efficient utilization of land. In addition, as there are many earthquakes in Japan, this is also considered more effective because it does require heavy retaining walls. And, the Reinfprced Earth is known to have the resistance against seismic loadings by their the tensile forces in the backfill. However, the design of the Reinforced Earth has been only refered to the static conditions, as the mechanism of the material interaction under the dynamic conditions is complicated to know well. And, the soil-reinforcements interaction can be very difficult to design and may involve the compound behavior (Scott and Sousa 1991). To investigate the dynamic characteristic of the reinforcement earth, a common technique is the full-scale experiments on the shaking table. These experimental studies examine the magnitude of the earth pressure in the vibration tests to act on the full-scale specimen of the Reinforced Earth Retaining Wall, the tensile forces of the reinforcements and the dynamic behavior of the deformation of the walls.

OBJECTS OF THIS EXPERIMENTS

The objects of this experiments is to estimate the design for the internal seismic stability of the Reinforced Earth Retaining Wall. There have been numerous experiments conducted on the magnitude of the earth pressure in an earthquake acting on the Reinforced Earth Retaining Wall, the tensile forces of the reinforcements and the behavior of the deformation of the wall. The stability of the Reinforced Earth Retaining Wall in an earthquake is controlled by the magnitude of the seismic earth pressure, the stabilities on the structures such as the facing walls (concrete skin), the reinforcements (strip), and the foundations. The concrete skins and the stripts can evaluate the safety from the test of the strength. But, it is difficult to evaluate the magnitude of the tension to act on the strip in an earthquake and the soil-reinforcements friction precisely. There are some problems for the behavior of the flexible high wall and for the magnitude of the action force in an earthquake. With that purpose, the equilibrium conditions of the force acting on the concrete skins, the strips, the backfill materials, and the distribution of the contact pressure on the foundatins are investigated by the full-scale experiments on the shaking table.

Main features

Shaking Table	15.0m×14.5m, 160ton
Driving System	Electro-hydraulic system
Actuators	360tons (90tons×4)
Max. Model Weight	500tons
Max. Amplitude	±220mm
Max. Velosity	75cm/s
Max. Acceleration	0.5G (500ton model)
Frequency Range	DC~50Hz
Wave Type	Sinusoidal , Earthquake

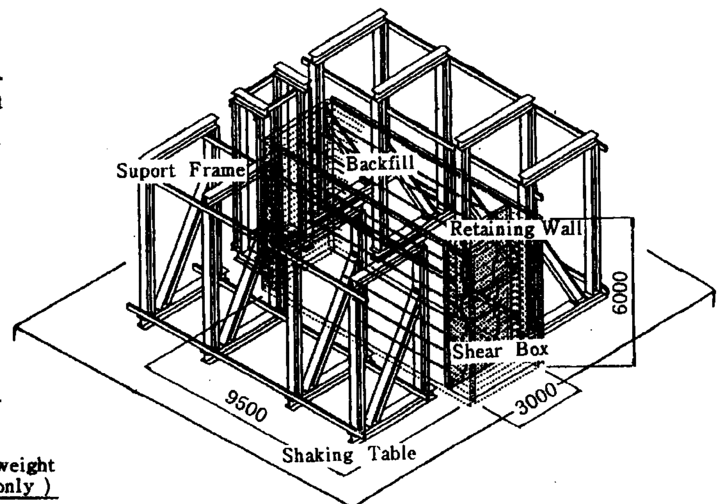


Figure 1. Scheme of the equipments

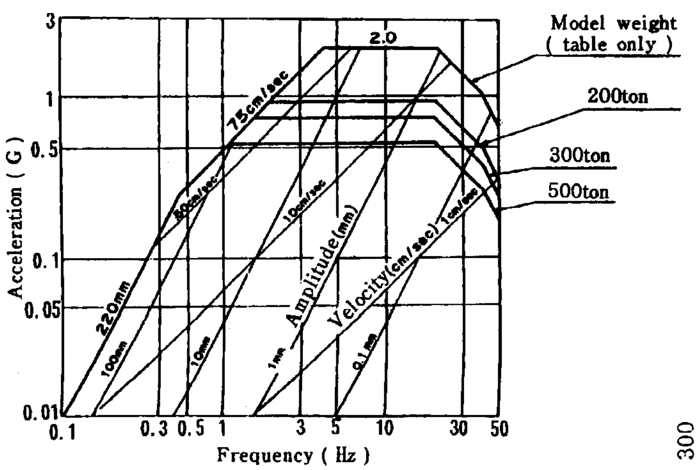


Figure 2. Main features and Limit performance diagram of the shaking table

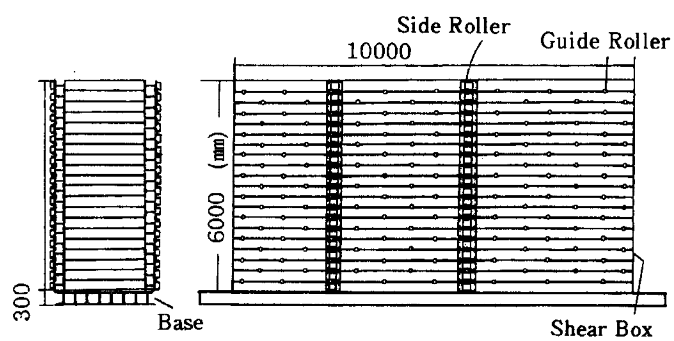


Figure 3. Scheme of the large-scale shear box of the simple shear type

EXPERIMENT METHODS AND CONDITIONS

THE EXPERIMENT EQUIPMENTS

Scheme of the experiment equipments is shown in figure 1. The equipments are constituted by the large-scale shear box (Futaki 1992) and the large-sized shaking table.

(1) The shaking table : We used the large-siged shaking table in the National Research Institute for Earth Science and Disaster Prevention. The main features and the limit performance diagram are shown in figure 2.

(2) The large-scale shear box of the simple shear type : The full-scale retaining wall can be built in the shear box and can reproduce the dynamic behavior. The large-scale shear box of the simple shear type is shown in figure 3. The shear box has 3.0m wide, 9.5m long, 6.0m high. The shear box has

Table 1. Physics properties and mechanical properties of the backfill

Specific gravity	2.721
Water contents	17 %
Gravel contents	0 %
Fine contents	19 %
Uniformity coeficient	5.1
Angle of internal friction	34.4 deg
Maximum dry density	1.51 g/cm³
Optimum moisture contents	21 %

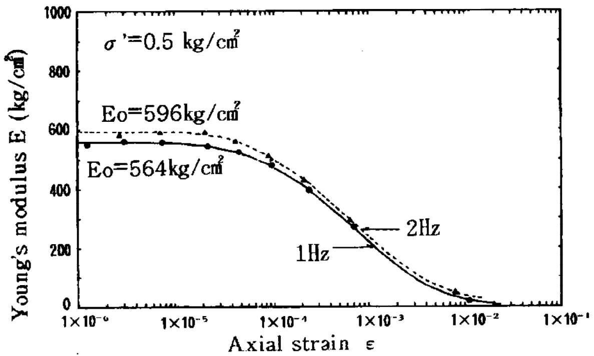


Figure 4. Dynamic deformation properties of the backfill materials

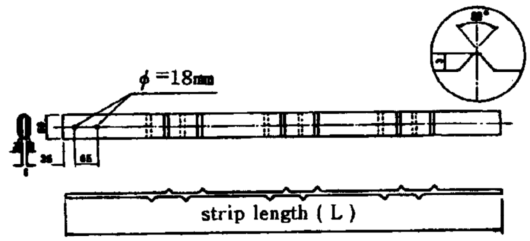


Figure 5. Reinforcements (ribbed strip)

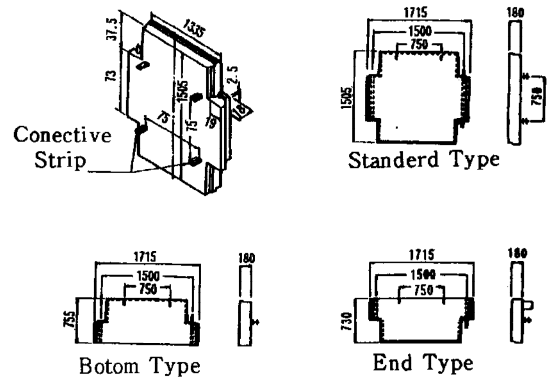


Figure 6. Facing walls (concrrete skins)

the layers structure that piled up the frames of H type steel of H250mm in multi-layers. The mutual displacement should occur between the each frame smoothly, and the many rollers enable it. There are some rollers on the long side of the shear box to restrict the side deformation and to make the plane strain condition. In addition, we established the seat of two stacks that applied grease to reduce the friction between the backfill and the frames of the shear box .

(3) The backfill : The physics properties and the mecanical properties of the backfill have been used for this experiments are shown in table 1. The soil classification of the backfill is silty sand (SM), the fine content is 19%, and the uniformity coefficient is 5.1. The results of the dynamic triaxal test for the backfill materials is shown in figure 4.

(4) The reinforcements and the facing walls : The reinforcements (the strip) is the ribbed strip in figure 5. The facing walls (the panel) called the concrete skin with the standard type, the bottom type and the end type is shown to figure 6.

(5) The construction of the specimen : The specimen was constructed by the recommendations for the construction of the Reinforced Earth. The soil compaction in the construction of the specimen is controlled as the degree of compaction Dc=85%, and 9 points density were measured by the core cutter method still more (25cm). The average density of the specimen is ρ t=1.37tf/m³. This density is equivalent to the degree of compaction Dc=87%, and almost equally in the standard value 85% of the management.

THE VIBRATION TEST CONDITION AND THE MEASURING METHOD

The vibration tests were carried out in the 4 cases (height: 2.5m, 3.5m, 4.5m, 6.0m) to confirm the dynamic behavior of the Reinforced Earth Retaining Wall. In the vibration tests, the sweep test and the step test were carried out for each the wall height. For the sweep test, the sin-wave was used in the uniform amplitude of the acceleration approximately 40 gal with the range of the 0.5Hz to 10Hz in frequency, and to know for the resonance vibration number of the specemen . In the step test, the amplitude of the input acceleration are changed step-by-step. The input waves are a sin-wave and the TAFT earthquake wave. As for the input frequency, 2.0Hz and 3.0Hz were selected from the results of the sweep test. The conditions of the shaking test are shown in table 2. The measuring position is shown in figure 7.

Table 2. Main conditions of the vibration tests

Height	Sweep test	Step test	Earthquake
2.5m	0.5～8Hz 49gal	2Hz 35～145gal	— —
3.5m	0.5～10Hz 38gal	2Hz 42～145gal	— —
4.5m	1.0～10Hz 46gal	2Hz 67～203gal	— —
6.0m	1.0～10Hz 46gal	2, 3Hz 35～178gal	TAFT-EW 112～220gal

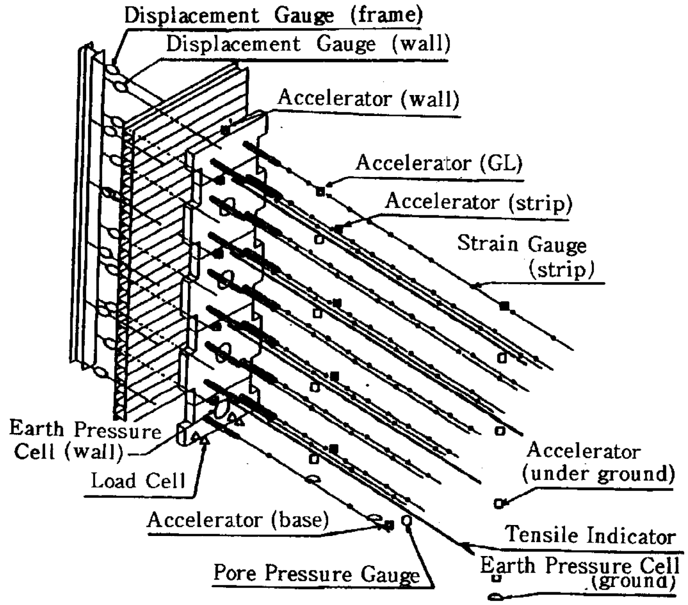
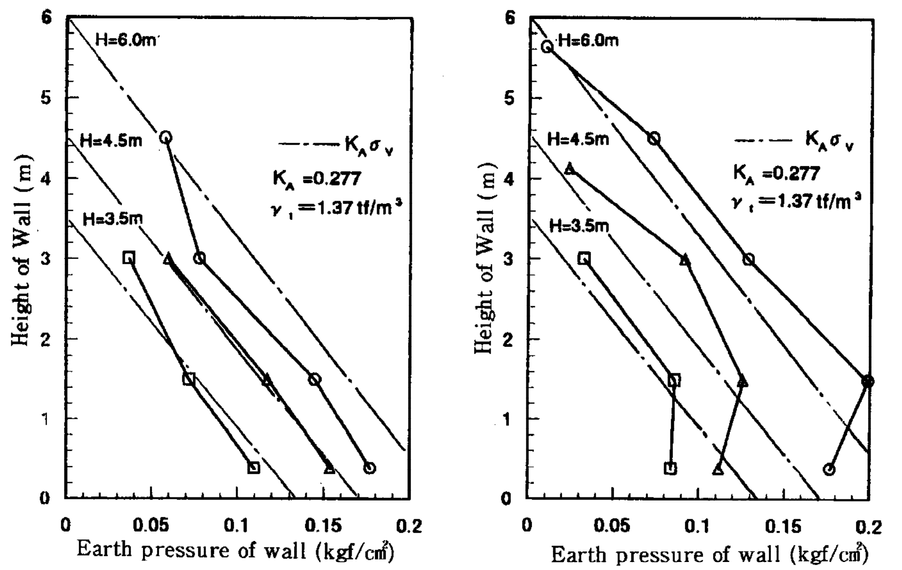


Figure 7. Measuring positions



(a) From the earth pressur gauge (b) From the tensile forces of the strip

Figure 8. Destributions of the earth pressure acting on the wall

SUMMARY OF EXPERIMENT REESULTS

THE EARTH PRESSURE DURING THE CONSTRUCTION

(1) The measured contact pressure of the foundations is almost equal to the overburden pressure.
(2) The measured earth pressure to act on the wall is larger slightly than the theoretical active earth pressure (figure 8).
(3) The maximum tensile forces of the strip increase for the correspondence to the overburden pressure (the wall height).
(4) The position of the maximum tension point in the strip is not removed for the correspondence to the wall height.
(5) The distribution of the tensile forces in the strip is not been uniform.

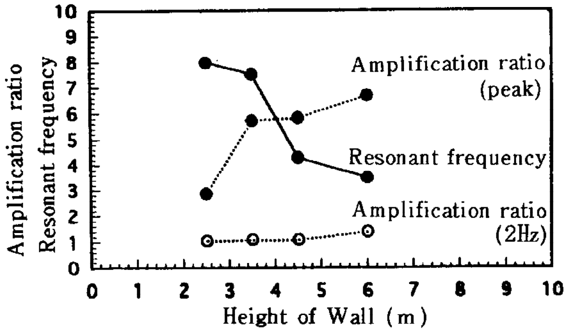


Figure 9. Amplification ratio and Resonant frequency for the wall height

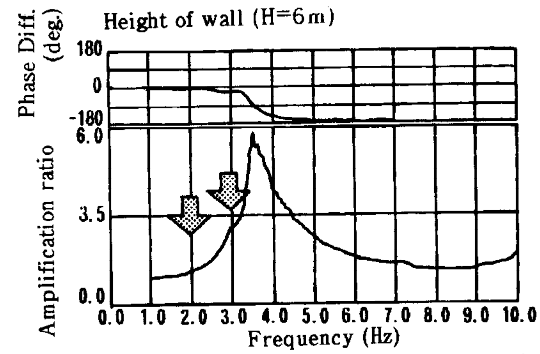


Figure 10. Resonance properties of the specimen (sweep test)

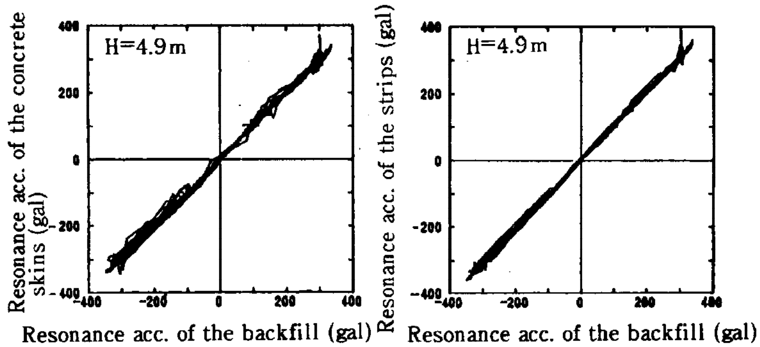


Figure 12. Resonance acceleration in the reinforced earth (185gal)

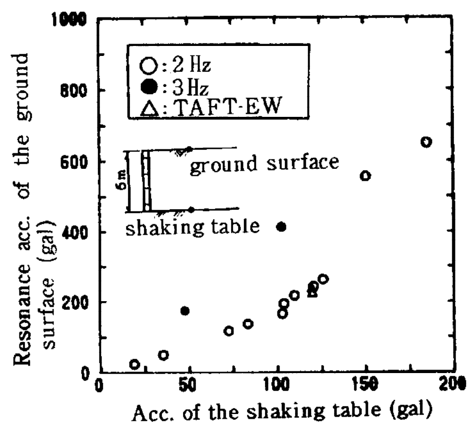


Figure 11. Resonance acceleration of the ground surface

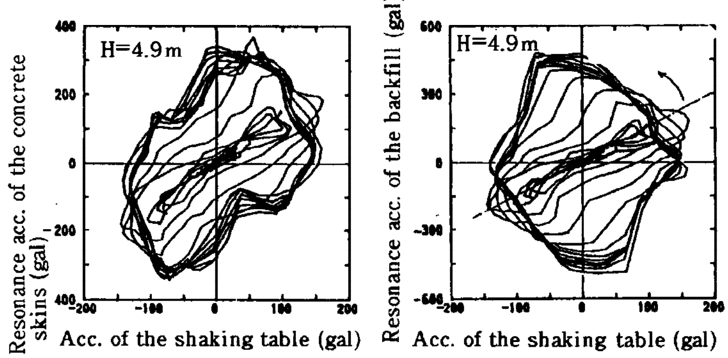


Figure 13. Phase of the resonance acceleration in the reinforced earth

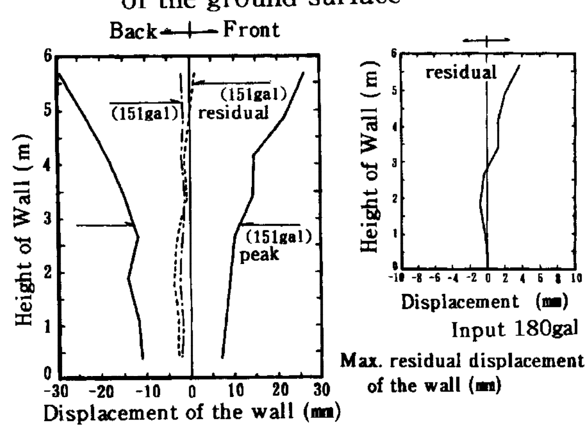
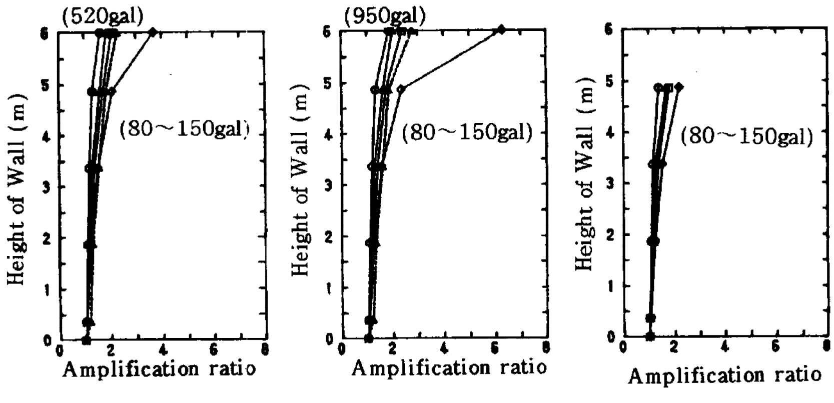


Figure 14. Deformation of the concrete skins in the vibration

THE VIBRATION PERFORMACE

(1) The resonance frequency becomes low with the height of the wall. In the case of 6m high, the resonance frequency is 3.5Hz, and the amplification ratio is approximately 7 (figure 9, figure 10).
(2) The response acceleration of the specimen is amplified toward the surface, and the amplification ratio of the surface was shown approximately 3 for the input acceleration of the shaking table of 150gal (figure 11).
(3) The response acceleration of the strip is almost equal to the response acceleration in the ground.
(4) The strip and the ground have the almost same movement (figure 12).
(5) The response accelerations of the Reinforced Earth shows the delay of the phase. In particular, the delay of the phase is remarkable when the input acceleration exceeds 150gal (figure 13).
(6) The deformation of the concrete skin is almost symmetrical for the back side and the front side, and the residual displacement to the front side was few (figure 14).
(7) The damping factor of the specimen was not depended on the height being approximately 6.7%.



(a) Backfill (b) Concrete skin (c) Strip

Figure 15. Amplification ratio in the reinforced earth

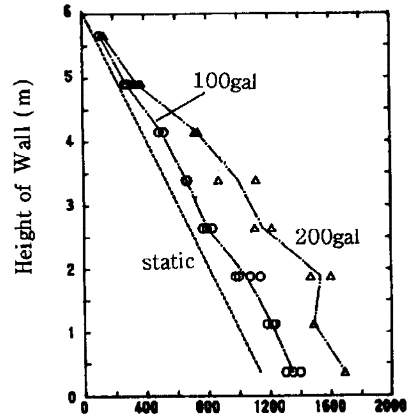


Figure 16. Seismic earth pressure coeficient on the acceleration level

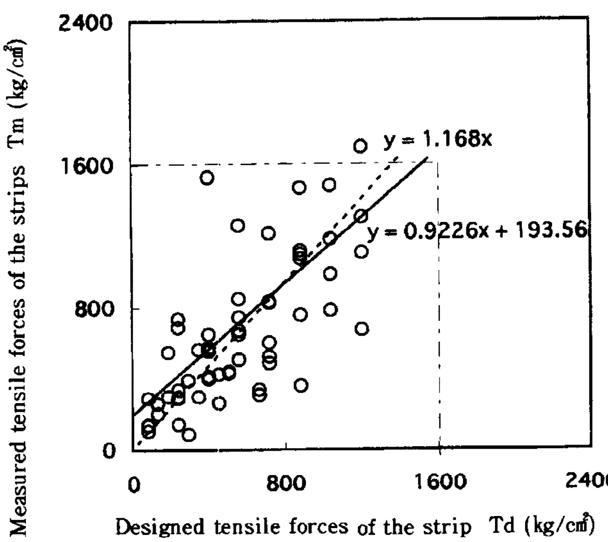


Figure 17. Measured tensile forces of the strips in the ordinary conditions

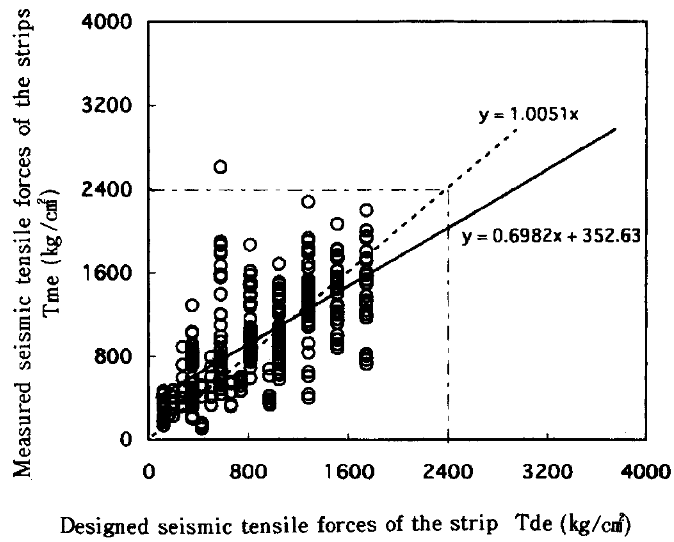


Figure 18. Measured tensile forces of the strips in the vibrations

THE EARTH PRESSURE DURING THE VIBRATION TESTS

(1) The earth pressure acting on the wall increases during the vibration. The contact pressure and the tensile forces of the strip are just the same.
(2) The contact pressure increases under the foundations of the concrete skin, however, there is not increased under the reinforced backfill.
(3) In the case of 150gal acceleration of the shaking table, the earth pressure shows apparently in the surface of layer. In this case, the acceleration of the ground surface was approximately 520 gal (figure 15).
(4) In the case of 6.0m high of the wall, the earth pressure distributes in triangle at most except the result of the 150gal acceleration over of the shaking table.
(5) The seismic earth pressure coeficient increases for the correspondence to the acceleration level (figure 16).
(6) The mean of measured tensile forces acting on the strip in the ordinary condition is almostly equal to the design value, however the tensile forces has the large variation (figure 17).
(7) The mean of the measured seismic tensile forces of the strip is almostly equal to the design value, however the seismic tensile forces has the large variation about 54% (figure 18).

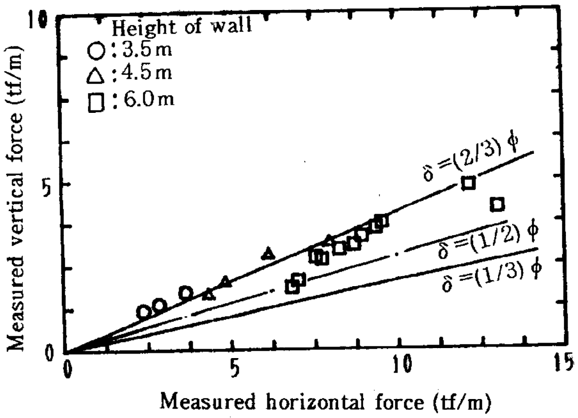


Figure 19. Seismic friction angle on the wall

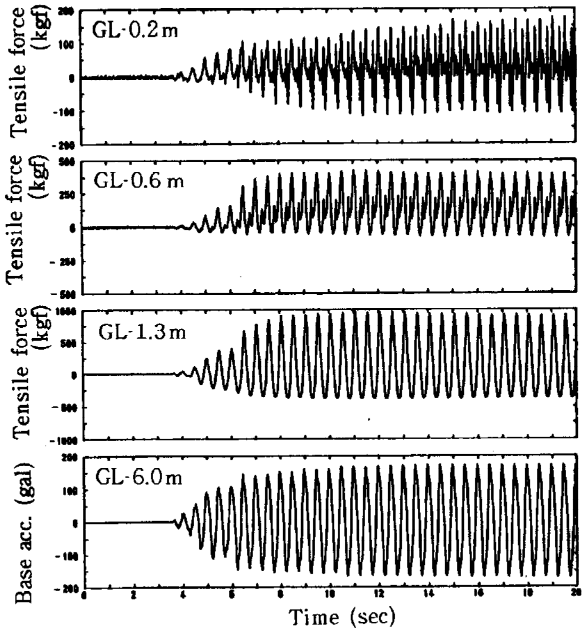


Figure 20. Performance of the tensile force of the strip in the vibrations

(8) The displacement at the skin top was 20mm in the case of 150gal acceleration on the shaking table, and the inclination of the wall is equivalent to 1/300.
(9) The deformation of the concrete skin after the vibration test was slightly remained in the front side, but the residual inclination was 1 /3000 and the extremely small value (figure 14).
(10) The seismic friction angle δ on the wall calculating from the measured horizontal force and the vertical force is the range of $\delta = (1/2 \sim 2/3)\ \phi$, ϕ: a internal friction angle of backfill materials (figure 19).
(11) The some strips in the surface layer let vibrate irregularly because of the low surcharge (figure 20).

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