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SHAKING TABLE MODEL TESTS OF SLIDING GRAVITY-TYPE RETAINING WALLS DURING EARTHQUAKE

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SUMMARY

A procedure to estimate the seismic sliding displacement of the gravity-type retaining wall was studied by the shaking table model test. According to the tests, the response accelerations of the model wall and the backfilling sand wedge of the active failure decreased instantaneously on set of sliding and remained the same levels during sliding. On the basis of test results, two kinds of procedures to estimate the seismic sliding displacement which are the sliding rigid body model and the FEM model were presented. The calculated displacements were in good agreement with experimental ones of the first sliding.

INTRODUCTION

Some of the port facilities whose seismic damage levels are low can continue to function after the earthquake. It is therefore necessary to assess the quantitative extent of seismic damage to port facilities in order to take the efficient earthquake preparedness of port facilities. To achieve this objective an experimental study on the quantitative assessment of a seismic sliding wharf whose type is a gravity-type retaining wall has been done. A seismic sliding behavior of a rigid body model was already reported(Ref.1) and this study focused a seismic sliding behavior of rigid body model backfilled with the sand. This paper describes the shaking table tests of sliding retaining wall models and the method to compute the seismic sliding displacement of such structures.

GRAVITY-TYPE RETAINING WALL MODEL

The gravity-type retaining wall model in Fig.1 receives the earth pressure through an earth pressure measure board with three small-type load cells attached horizontally and two small-type load cells vertically. The loads measured by five load cells gives the resultant force of earth pressure(E), the angle of wall friction(δ) and the height of application point(h) as follows.

$$E=\sqrt{(\Sigma Fhi)^2 + (\Sigma Fvi)^2} \qquad (1)$$

$$\delta = \tan^{-1} \left(\frac{\Sigma Fvi}{\Sigma Fhi} \right) \qquad (2)$$

$$h = \frac{\Sigma Fhi \cdot hi}{\Sigma Fhi} \qquad (3)$$

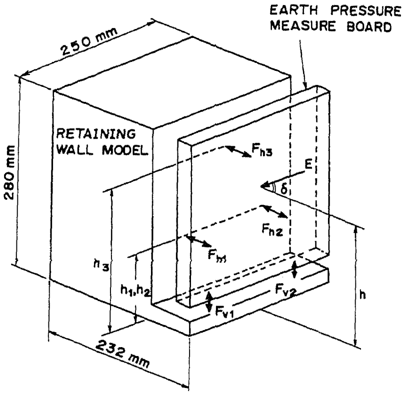

Fig.1 Retaining Wall Model

CALIBRATION OF EARTH PRESSURE MEASURE BOARD

The earth pressure measure board was calibrated with regard to the hydrostatic and hydrodynamic pressure before the shaking table test. The hydrodynamic pressure to act on the board was measured in the shaking table test of the wall model in the water. Fig.2 shows the hydrodynamic pressure of the test and that of the Westergaard's approximate formula. The measured value of the board was corrected for the inertia force of the board. On the basis of the caliblation tests the board was concluded to be reasonable for the measurement of the hydrostatic and hydrodynamic pressure.

STATIC SLIDING TEST

After the wall model was backfilled with sand, the earth pressure on the back of the wall model was measured by pulling the model with slow speed. The coefficient of earth pressure measured in the tests coincided with Coulomb's theoritical value as shown in Fig.3. Fig. 4 also shows that the failure angle of the test was in agreement with the theoretical one. On the basis of this test result it was concluded that the earth pressure measure board gives reasonable measure of the earth pressure to act on the wall model.

SEISMIC SLIDING TEST

Fig.5 shows a model made in the shaking table box(60cm in height, 60cm in width and 200cm in length) for seismic sliding tests. The retaining wall models

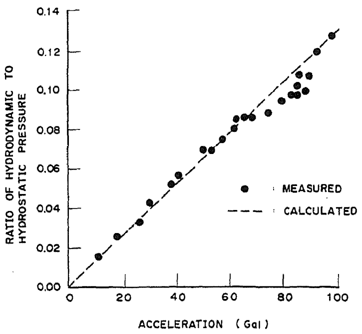

Fig.2 Calibration

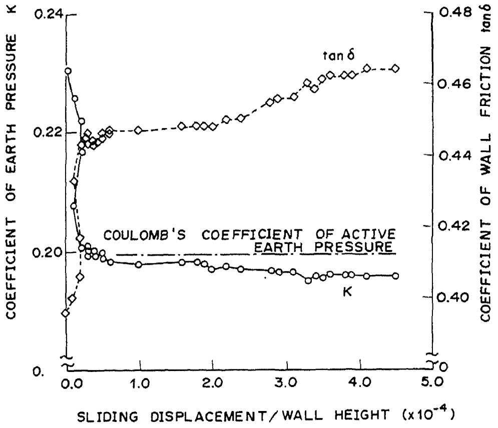

Fig.3 Coef. of Earth Pressure and Coef. of Wall Friction(Static)

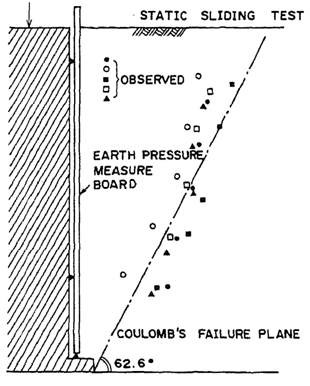

Fig.4 Failure Plane

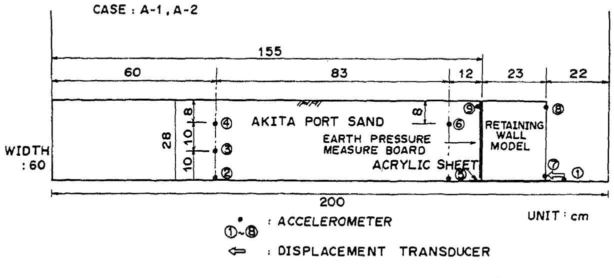

Fig.5 Seismic Sliding Test Model

Table1 Physical Properties of Sand

Item	Akita Port Sand	Takahagi Sand
Specific Gravity	2.65	2.66
Effective Size(mm)	0.11	0.90
Uniformity Coefficient	1.50	1.50
Max. Void Ratio	1.32	0.90
Min. Void Ratio	0.82	0.65

were placed on the acrylic sheet pasted on the bottom of the shaking table box, and backfilled with the sand. The backfill materials were the Akita port sand and the Takahagi sand which are the fine sand and the coarse sand respectively. Table 1 shows the results of physical properties test, and Fig. 6 shows the grading curves of the sand. The tests were conducted 7 times for the Akita port sand and 1 time for the Takahagi sand. The measurement was carried out by the accelerometers and the displacement transducer as shown in Fig.5.

Fig.7 shows a result of measurement. The amplitude of model wall accelerations decreased instantaneously at the moment to cause a sliding displacement and remained the same level during sliding. The accelerations at the surface of the sand layer near the wall (above failure plane of backfill) showed the same waveforms as the model wall. Fig.8 shows the vertical distribution of the maximum acceleration in the backfill. The acceleration of the backfill surface was not amplified as shown in Fig.8. This result shows that the backfill was shaken uniformly.

Fig.9 shows the coefficient of earth pressure and the coefficient of wall friction versus the ratio of the sliding displacement to the wall height. The coefficients of earth pressure at the start of sliding and during sliding are shown in Fig.10. It was defined that the coefficient of earth pressure during sliding was the constant value in Fig.9. The calculated values were also shown in Fig.10. The coefficients of earth pressure at the start of sliding were calculated by the following equation.

$$K_{AS} = K_O + (K_{AE} - K_A) \qquad (4)$$

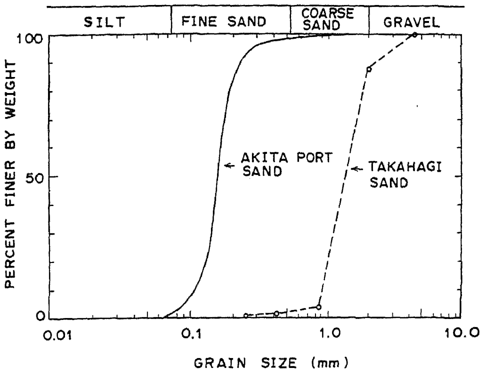

Fig.6 Grading Curves

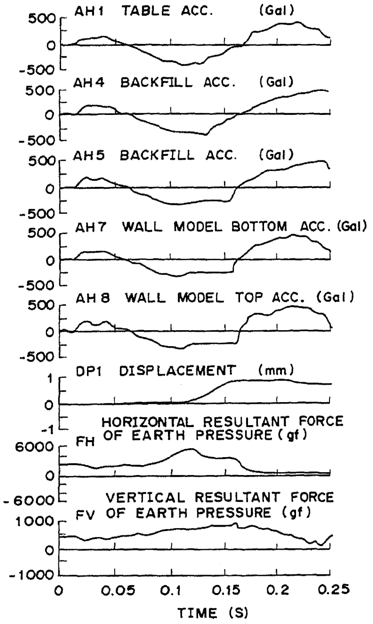

Fig.7 Result of Measurement

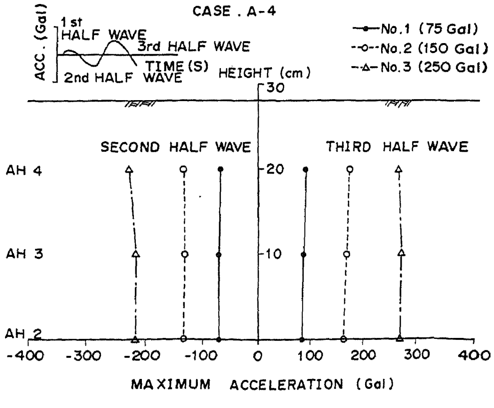

Fig.8 Acceleration in Backfill

where, K_{AS}: Coefficient of active earth pressure at the start of sliding
K_0 : Coefficient of earth pressure at rest
K_{AE}: Mononobe-Okabe's coefficient of earth pressure during earthquake
K_A : Coulomb's coefficient of active earth pressure

The coefficient of earth pressure during sliding was calculated by Mononobe-Okabe's equation. As the values calculated by Eq.(4) are in agreement with the experimental ones, it was concluded that the coefficient of earth pressure at the start of sliding is given by Eq.(4). Fig.11 shows the failure plane observed in the test. The failure angle of the test agreed with the theoretical one.

ESTIMATION PROCEDURES OF SEISMIC SLIDING DISPLACEMENT

Sliding Rigid Body Model The assumption of the computation model is that the retaining wall is the rigid body and is excited by the rigid-base translation. On the basis of test results the earth pressure on the retaining wall was assumed as follows.

- Before Sliding - The earth pressure to

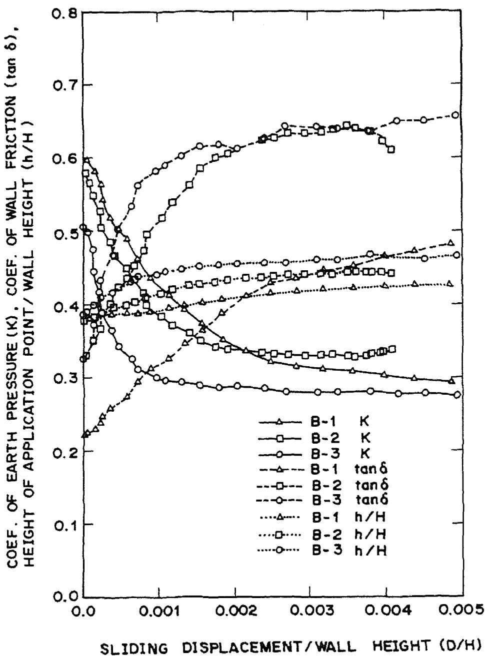

Fig.9 Coef. of Earth Pressure and Coef. of Wall Friction(Dynamic)

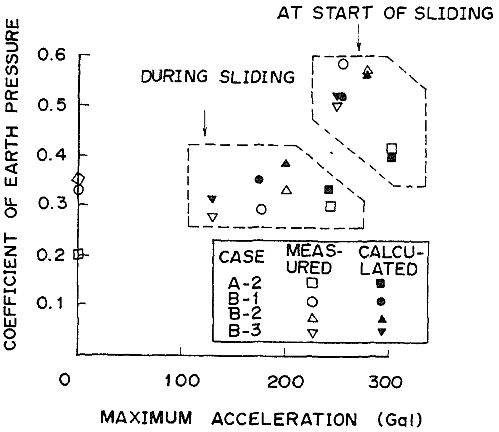

Fig.10 Coef. of Earth Pressure before and after start of sliding

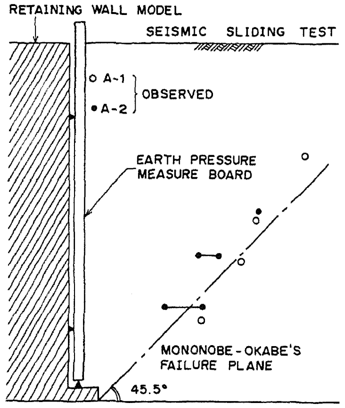

Fig.11 Failure Plane (Dynamic)

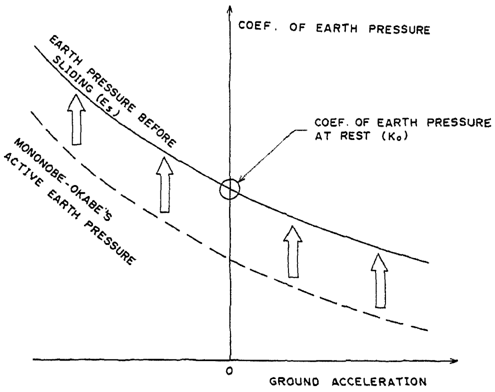

Fig.12 Coef. of Earth Pressure to Start Sliding

act on the retaining wall before sliding is assumed to be Es in Fig.12 which parallels the Mononobe-Okabe's earth pressure and equals the earth pressure at rest for the seismic coefficient of zero. The sliding starts when the horizontal force to act on the retaining wall exceeds the friction force of the wall bottom, that is

$$Es \cdot \cos\delta - M \cdot Ah > \{ Es \cdot \sin\delta + M \cdot (g+Av)\} \cdot fs \qquad (5)$$

where, δ is the angle of wall friction, M is the mass of retaining wall, fs is the static coefficient of wall bottom friction, g is the acceleration of gravity and Ah and Av are the horizontal ground acceleration and vertical one, respectively.

- During Sliding - Supposing the soil wedge slides on the failure plane given by the Mononobe-Okabe's equation, the relation between the earth pressure to act on the wall during sliding and the acceleration of retaining wall is given by the balance of force and the conformity condition of the displacement. This failure plane is assumed to be fixed during sliding. The earth pressure Ed obtained by the above method is supposed to act on the retaining wall during sliding. The equation of motion during sliding is

$$M \cdot Awh = Ed \cdot \cos\delta - \{Ed \cdot \sin\delta + M \cdot (g+Av)\} \cdot fd \qquad (6)$$

where, fd is the dynamic coefficient of friction and Awh is the acceleration of retaining wall. As Ed is the function of Awh, the above equation is solved for Awh.

When the relative velocity of retaining wall to the base becomes zero, the retaining wall stops sliding. Then the coefficient of friction turned to be the initial static coefficient of friction and the earth pressure reduced to Coulomb's active earth pressure.

Fig.13 shows the comparison between measured and calculated time histories. The calculated time histories for the first sliding was good agreement with the measured ones. The main reason why the calculated result for the second sliding is different from the measured one is supposed to be that there is a possibility of change in the static coefficient of friction after the first sliding.

<u>Finite Element Model</u> The separation and sliding between soil and structure in the finite element model were simulated by the joint element(Ref.2). Fig.14 shows the finite element model. In this calculation the failurte plane of backfill observed in the test was given in advance. As shown in Fig.15, the calculated

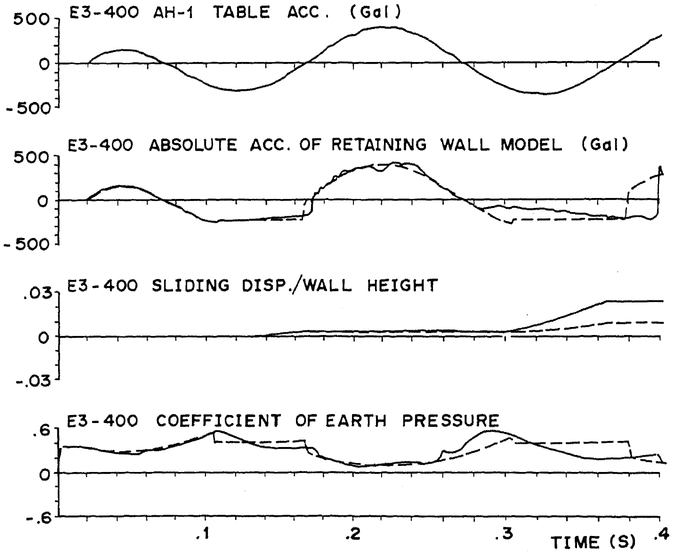

Fig.13 Comparison between Measurement and Calculation(Rigid Body Model)

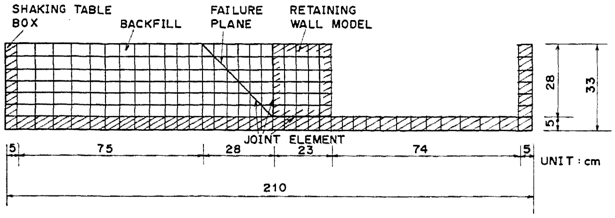

Fig.14 FEM Model

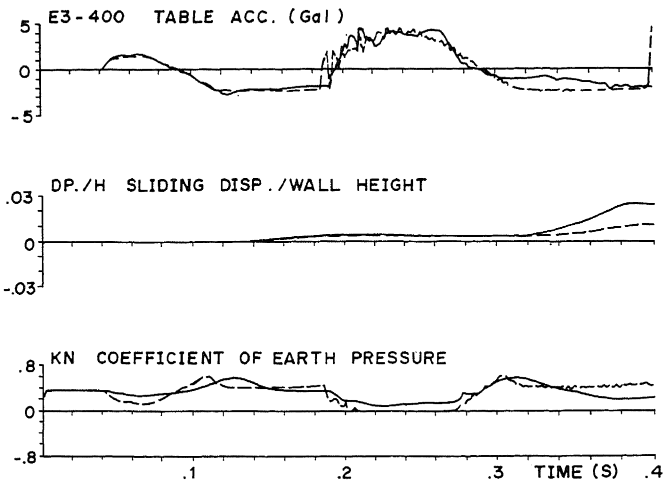

Fig.15 Comparison between Measurement and Calculation(FEM)

time histories were good agreement with the measured ones.

CONCLUSION

On the basis of the shaking table test results of sliding gravity-type retaining wall model, the calculation methods of seismic sliding displacement were presented. The investigated results are as follows.

1)It was confirmed that the active earth pressure during earthquake to act on the sliding model of the retaining wall was measured accurately by the earth pressure measure board used here.

2)The amplitude of model wall accelerations decreased instantaneously at the moment to cause a sliding displacement and remained the same level during sliding.

3)The acceleration at the surface of sand layer near the wall (above failure plane of backfill) showed the same waveforms as that of the model wall.

4)The procedure to estimate the sliding displacement of the gravity-type retaining wall with consideration of the Mononobe-Okabe's active earth pressure during earthquake gave the same values as the test results, and it was concluded that this method is usefull to estimate the sliding displacement of the gravity-type retaining wall during earthquake.

REFERENCE

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2. Toki, K., Sato, T. and Miura, F.,"Separation and Sliding between Soil and Structure during Strong Ground Motion", Proc. of JSCE, No.302, 31-41, (1980)