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Behavior of the cantilever retaining wall under seismic loadings

Mikio Futaki
Building Research Institute, Ministry of Construction, Japan

Osamu Sakaguchi
Kinki University, Japan

ABSTRACT; This paper deals with a experimental study on a real scale cantilever retaining wall for seismic loadings.Nowadays the construction of housing lots is very popular in Japan.A Precast concrete retaining wall is well used for the rationalization in this construction work.Then, the vertical wall is strongly requested for the slope topography due to the expensive price of land.The present paper aims to investigate the safety and to evaluate the force acting on the wall for seismic loadings.

1 INTRODUCTION

A number of research papers have been reported since a pseudo-static method developed in 1924 by Okabe (Okabe 1924).In the study of the interaction between soils and structures, model tests are performed in general, because of the difficulties in conducting the prototype test. It is very difficult to satisfy modelling laws in the test regarding as the stresses in the ground. Recently,the centrifuge model test has become a very useful manner in the research of soil structures (Schofield 1981).Using the centrifuge model test, it can be satisfied similarity between models and prototypes.This test method ,however,is not enough in the case of the problems depending on the frequency.

There are two types of retaining walls in the design on the bases of their failure mode, which are gravity retaining walls and cantilever ones. As for the gravity retaining walls,a number of tests have been performed by using the shaking table.As mentioned before,We can not evaluate satisfactorily the test results from the common shaking table test (O-hara 1979).In the design of the cantilever retaining walls,the Rankine theory are used well in static problems,However,we have few useful ideas in dynamics. In particular,inertia force is very important because inertia force changes with the location of the image surface of the backfill.In general, earth pressures must be overestimated in the case taking account of the vertical image surface at the heel of the wall in dynamics. Furthermore, it has been reported that displacement of the wall reduces the earth pressures in dynamics (Farrokh 1983).

2 TEST EQUIPMENT AND TEST METHOD

Fig-1 shows the scheme of the test equipments.This investigation was performed by using a large shear box,which has the structure divided into 20 stories with 16 guide rollers between each story not to restrict the shear deformation of soils when soils are vibrated horizontally. The scale of this shear box is 5 m(height)

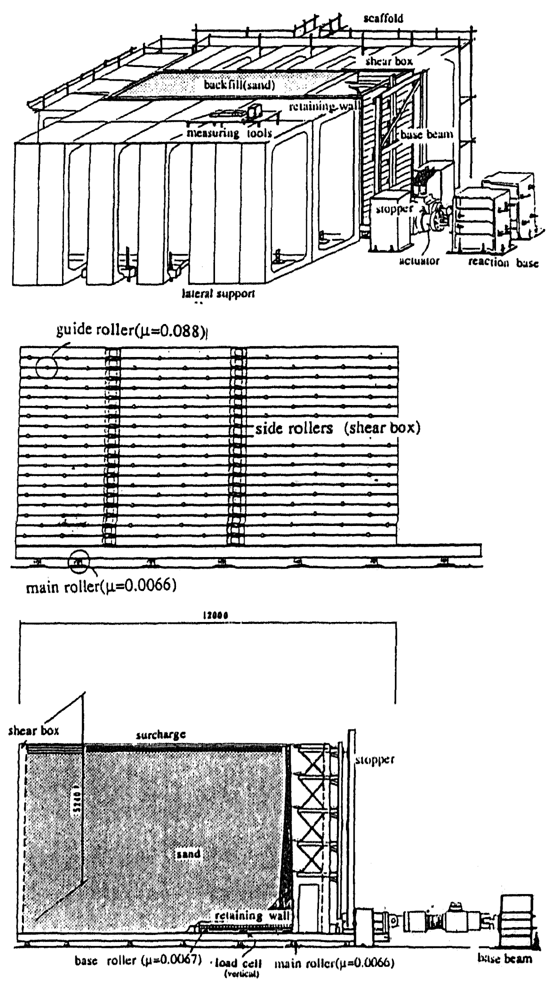


Figure 1. The scheme of the equipments

x 2.4 m(width) x 10 m(length). The shear box is placed on the base floor supported by 147 main rollers and also supported in the both lateral sides with 80 side rollers.A prototype cantilever retaining wall with the backfill of sand is installed in the shear box . The shear box whose weight is about 200 tons with the backfill sands was vibrated in one direction by two actuators. As the retaining wall is also supported on rollers ,we can measure directly the total horizontal force and the total vertical force acting on the wall by the load transducers. As presented in this figure, it can be seen that the each coefficient of friction for the roller (μ) is very small,respectively.

2.1 Cantilever retaining wall and test grounds

The scheme of the retaining wall is also presented in Fig-1 or Fig-3.This is a precast concrete cantilever retaining wall,which has the shape of 5 m (in height),1.84m (in width) and 3 m (in base length).The sand is used as the backfill and the physical properties of the sand are presented in Table-1.

Table 1. The psychical properties of the sand

Specific gravity	2.733
Maximum void ratio	0.993
Minimum void ratio	0.650
Water content	7.0 %
Internal friction (triaxial)	31.5 (degrees)
Uniformity coefficient	2.52
sand content	95 % and more

Fig-2 shows the results of triaxial compression test carried out at three different relative densities of this sand with a natural water content.From this test results,we can get the internal frictional angle of 31.5 degrees for the sand .However,as this value is obtained from axial symmetric stress condition as usual way,it should be revaluated for the plain strain condition in the case of this test .Judging from the past investigation on fractional angle of sands ,the value of internal frictional angle in plain strain is larger about 10% and more than in triaxial compression test (Tatsuoka,F,1986,etc.). Therefore,we used here the value of 34.6 degrees in plain strain condition to evaluate the test result .

2.2 The measurements.

The measurements of 48 sensors were stored once on memories in dynamic strain amplifiers and were saved on a Hard disk by a micro computer to evaluate the behavior of the retaining wall with the back fill.Fig-3 shows the locations and the kinds of sensors. As mentioned before, the retaining wall is supported on the rollers.Therefore,we can get the force acting on the wall directly. Moreover, transducers to measure earth pressures are also installed on the wall as in the usual way.To evaluate the stability of the retaining wall, 9 load cells are placed under the base in 3 lines.Other sensors are acceleration transducers,displacement transducers and new developed shear strain meters(Okawa 1989).

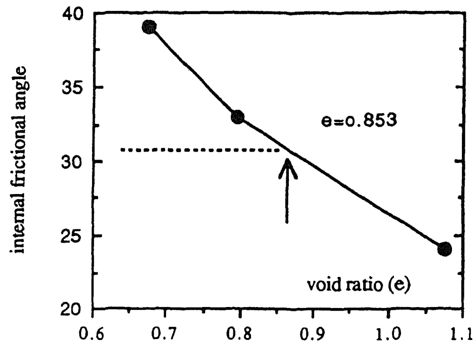


Figure 2. Frictinal angle vs void ratio

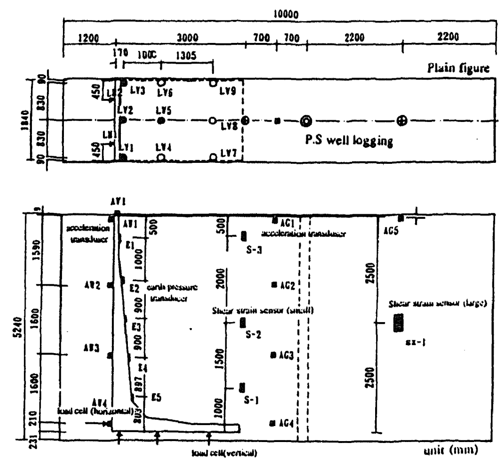


Figure 3. The location of the sensors

2.3 The condition of seismic loading

In this investigation,three types of vibration tests were performed.First,the retaining wall are vibrated harmonically at different frequency (1.0 to 5.0Hz) with the amplitude of (+-)0.2m/m in the displacement of the base floor to find the natural frequency of this equipment. Second,a actual earthquake wave(TAFT-NS) is examined ,and then ,the wall is vibrated with the constant frequency by the increased loads step by step.

2.4 The kinds of tests.

Seven kinds of vibration tests were conducted continuously for the specimen. The conditions of each test are presented in table-2. In this investigation,we take into account of dead load on the surface of the ground and the coefficients of springs for sliding of the base. In case3,the rollers under the wall are restricted not to work to investigate the influence of the condition for input motion. Case7 is just the same as case1,except for more excitation in case7.

Table 2. The condition of each test

	Dead load	Spring constant for sliding
case1	0	infinity(roller free)
case2	1	infinity(roller free)
case3	1	infinity(roller fixed)
case4	1	2k(roller free)
case5	1	k(roller free)
case6	1	(1/3)k(roller free)
case7	0	infinity(roller free)
	(ton/m^2)	k=4.6(ton/mm)/m

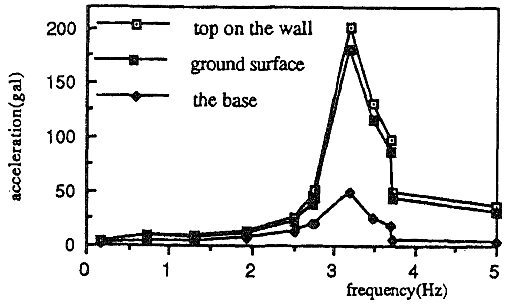


Figure 5. Acceleration spectrum (case1)

3 TEST RESULTS

3.1 Force acting on the wall and deformation before the vibration test.

Fig-4 shows the relationship between the forces acting on the wall(in vertical and in horizontal) and the steps of the backfill constructions, resulting that both of the total forces increase with the ground height. Calculating the ratio of the horizontal force to the vertical force in respect to the increment, we can obtain the value of 0.42. Otherwise, from the Jaky equ. Ko=1-SinØ';

here , Ko; coefficient of earth pressure at rest,

Ø'; internal frictional angle in effective

we can also get a similar value of Ko=0.43.

On the other hand ,the displacement at the top of the wall is about 1.2m/m after finishing the ground construction.Regarding as the dynamic properties of the ground, we get $160kgf/cm^2$ up to 1m depth and $310kgf/cm^2$ below 1m depth from the surface as the shear modulus,which were calculated from shear velocity obtained by P.S well logging in the shear box.

3.2 Vibration test results

Fig-5 shows a example of acceleration spectrum in case1 derived from the sweep vibration test,resulting that the predominant frequency is about 3.5 Hz in this case, which is similar to the natural frequency of this ground calculated from soil mass and the shear modulus. Fig-6 shows examples of time histories of measurements which are ground accelerations,horizontal force, vertical force,shear strain,earth pressure, displacement of the wall and so forth in the tests.In the figures initial value of each

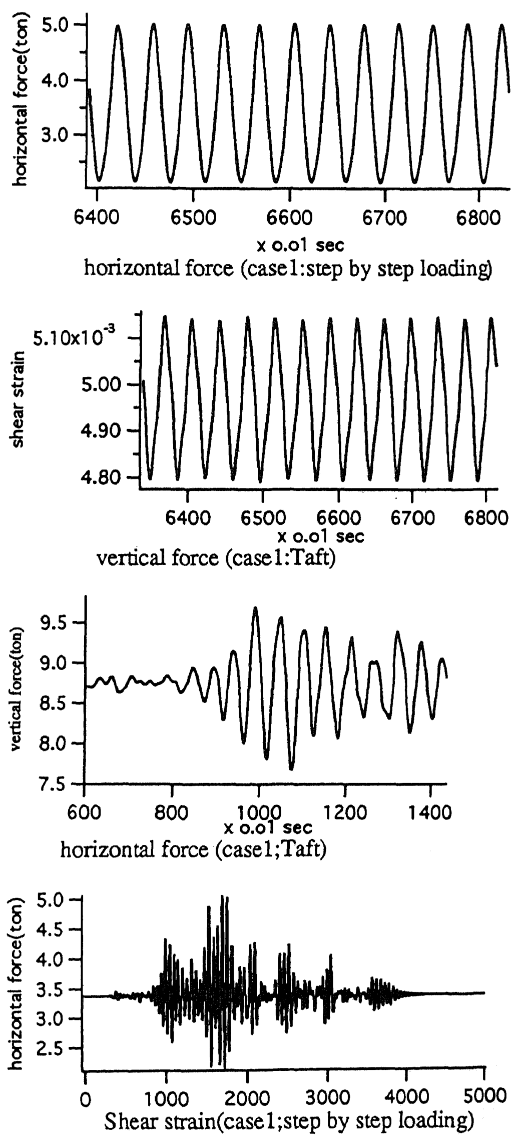


Fig 6. Examples of time histories

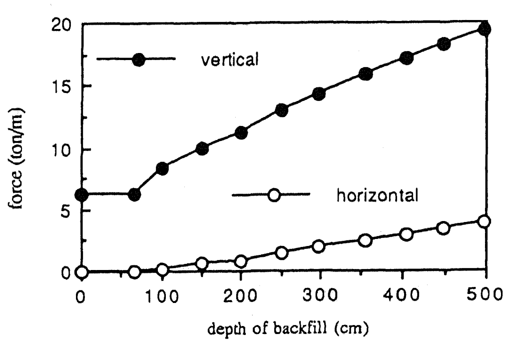


Figure 4. forces acting on the wall

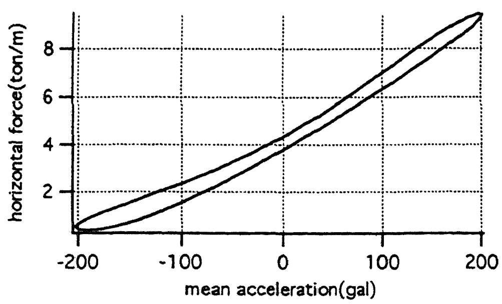


Fig 7. Horizontal force (case1)

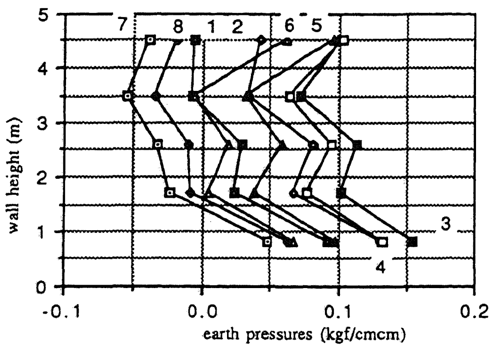


Fig 8. The distribution of earth pressures

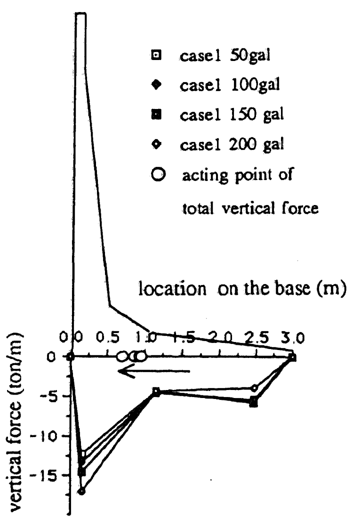
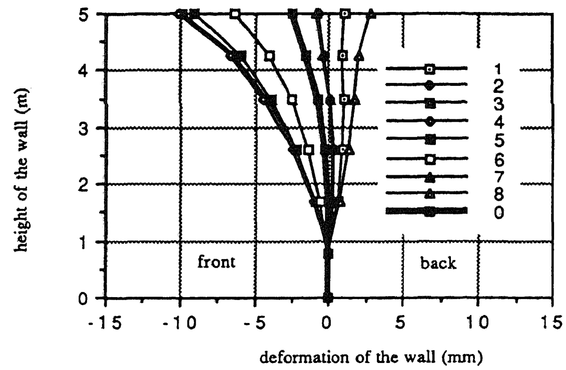


Fig 9. The distribution of vertical force(ton/m)

measurement is the value at the beginning of the ground construction.

1) Horizontal force

The relationship between the total horizontal force measured directly in front of the wall and the mean acceleration of the ground of case1,is presented in Fig-



Fifure 10. deformation of the wall (case1)

7.Hereinafter, we use the mean acceleration in the presentations of test results,because the amplitudes of accelerations are different in the depth of the ground.It is found that the total horizontal force increases in proportion to the mean acceleration in the ground(positive in active condition).This relation is the similar in the passive ground condition.We could also found the increasing of the horizontal force due to the dead load on the ground surface in case2.However ,the magnitude of the horizontal force is not so large as expected results that the dynamic horizontal force shall be obtained from the dynamic earth pressures adding inertia force of the wall.

2)Earth pressures

The distribution of earth pressures on the wall during seismic loading are plotted in Fig-8,resulting that the distribution of the earth pressures are far from triangular.The calculated total horizontal force from the distribution of the earth pressures is smaller(about a half) than the force measured directly.The way using earth pressure transducer in dynamic test has a few problems ,which are the scatter of earth pressures on the wall and the influence of shear stress on the surface of the transducer.

3) Vertical force

Fig-9 demonstrates the distribution of the vertical forces on the base of the wall in one cyclic loading.The change of vertical force almost developed at the toe part of the base but not so much at the heel. This is different from the condition of the general design of the cantilever wall. Regarding as this point, the rigidity of the base of the wall is significant.

4)The deformation of the wall.

The deformation of the wall are plotted in Fig-10 during one cyclic loading, resulting that the wall deformations tend to incline in the front side,and shows a residual tendency of this deformation.From the result of accelerations measurements,the wall might be deformed much the same as the ground deformations.However, the top of the wall is separated from the ground in the exciting vibration .

5) The safety for the sliding.

The safety for the sliding of the wall can be estimated by the ratio of the total horizontal force to the total

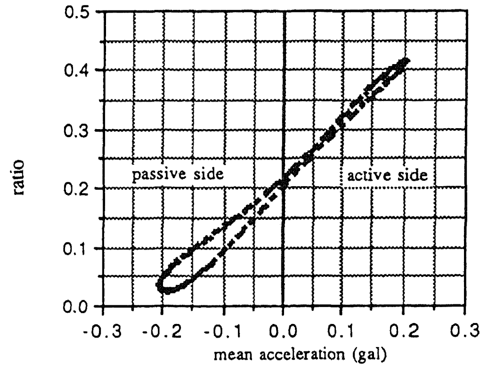


Figure 11. The ratio horizontal force to vertical force

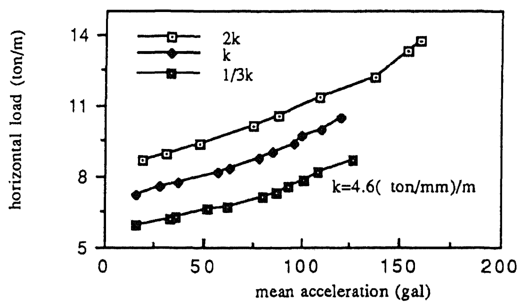


Figure 12. Influence of the spring constant

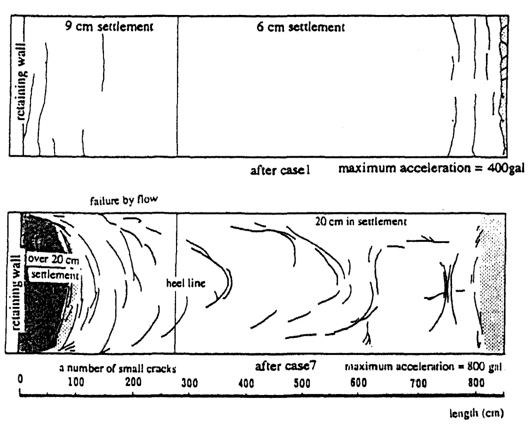


Figure 13. The state of the cracks on the wall

vertical force. Fig-11 shows the relationship between the ratio and the mean acceleration of the ground. As mentioned before,both forces vary with the accelerations.The relationship between the ratio and the acceleration presents the hysterisis loop for seismic loading ,and is almost proportion to the acceleration.In this figure,calculated ratio from Monnobe and okabe method are also plotted. The difference between the two is about 20% at most for the average ground acceleration of 200gal.

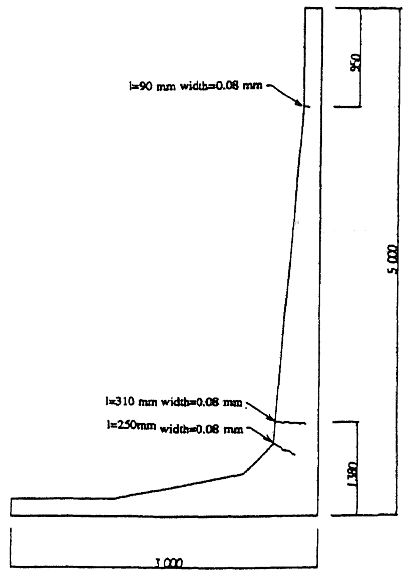


Figure 14. The state of the cracks on the wall

6)The influence of the coefficient of the spring to slide.

Permitting the slide of the wall to some extent, it has been pointed out that the earth pressures acting on the wall decreases .It is very important to the wall stability. To investigate the influence of the displacement of the wall by sliding, three kinds of spring coefficients were used with the change of the springs attached to the front of the wall on the roller.Total horizontal forces are plotted for each spring constant(2K,K,1/3K; K=4.6 ton/mm/m) in Fig-12.Since these test were conducted from large spring coefficient(2k) to weak one in turn,the larger displacement was developed in this order,resulting that the horizontal force at the beginning of each test decreased in the same order. Then,in case 7,the condition of sliding is changed to be fixed again,and it can be seen that the horizontal force recovered to much the same as value in case1.However,it seems that the amplitude is similar from case4 to case6 during excitation.

7)Observation of the ground surface after the test.

Fig-13 shows the state of the ground surface after the case 7.There existed some cracks up to 200gal of ground acceleration due to the settlement of the ground only near the wall. In case 7(where the average acceleration is more than 600gal on the ground surface).We can find cracks far from the wall and the uniform settlement of the ground. Judging from the location of cracks and the traces,these cracks must be developed by the deformation of the wall .

8) Observation of the wall

Fig-14 presents the scheme of cracks on the wall at the end of the test. There are a few cracks at the most dangerous section and the upper part of the wall due to the bending moment.Then,the width of the residual cracks is about 0.08m/m. However,it seems that the real residual width of cracks after the vibration is a little

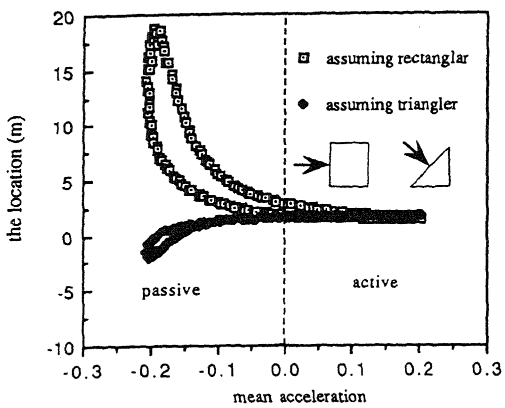


Figure 15. The location of earth pressure acting on

more,because this is the value after removing the soils from the backfill.Taking account of this test results,the design of this wall was change to be more rigid ,taking into account of endurance of the wall.

9)The location of the earth pressure acting on the wall

Assuming the location of the surface on which earth pressure works,we can calculate the height of earth pressure acting on from measurements of the horizontal force and the vertical force.Fig-15 presents the location of the earth pressures on two assumed surfaces during one cyclic loading.It seems that Coulomb slip surface is more acceptable than the Rankine image surface during excitation.because of less errors from the agreeable location of 1/3 of the wall height in both of active and passive condition.

4 .CONCLUSIONS

A Dynamic vibration test on a prototype cantilever retaining wall was conducted by using a large shear box.Based on test results,the following conclusions can be obtained.

(1)The horizontal force is in proportion to the average acceleration of the ground.

(2)Though the distribution of the vertical force under the base tends to concentrate in the front of the wall base,The degree of concentration is not so large as the calculation based on the assumption of rigid base.

(3) The ratio of the horizontal force to the vertical force is proportion to the mean acceleration of the ground .

(4)It is more acceptable to assume that the earth pressures also acts on the potential sliding surface of the Coulomb wedge in the cantilever retaining.

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