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SYNOPSIS: A method for reducing earthquake load acting on piles by means of ground walls installed around pile foundation is proposed.
First, a shaking table test was carried out. Test specimens are 1/40 scale stractural models ,which consist of soil, piles and a building with or without ground walls. The pile head moment of the specimens with ground walls show only 60 % of that of the specimens without the ground walls. An FEM analysis was carried out for both cases and the results were compared with the test results. The comparison showed a good agreement.
Furthermore, a simplified calculation method is proposed. This method takes account of the inertia force of buildings and the earth presure to piles. The earth pressure is represented by Winkler's springs. This simplified model gives a good agreement with those experimental and analytical results and is proved to be applicable to design purposes.

INTRODUCTION

During an earthquake, piles are subjected to high shear and large moment due to the inertia force of buildings. This occasionally causes unexpected failures of piles, especially at pile heads. If some portion of this lateral load could be directly carried by earth pressure through ground walls appended to buildings, the shear and the moment at the pile heads could be reduced. In this method, the appended reinforced concrete walls are installed in the ground around pile. Those ground walls are supposed to carry a part of lateral load imposed on piles and reduce the pile moment.
First, a shaking table test was carried out. The test specimen is a 1/40 scale stractural model consists of soil, piles and a building with or without ground walls. Tested parameters are the depth of ground walls and the ratio of the resonant frequency of the building to that of the soil. The effectiveness of the walls is examined in relation to the depth of the ground walls.
Furthermore, a simplified calculation method is prposed. This method takes account of buildings and the earth pressure to piles. The earth pressure is applied to piles through Winkler's spring. This paper presents the results of the experiment and the analysis on both cases of with and without the ground walls. The depth of ground walls was chosen to 5cm, which coresponded to 2m in actual scale.

TEST SPECIMEN AND OUTLINE OF EXPERIMENTS

The original building chosen for scale models is a four-storey building suported by cast-in-place piles as shown in Figure 1. The tip of pile is located at 17m below the ground surface. The predominant frequency of the soil at the site was assumed to be 1.0Hz. The test specimens were modeled according to the similarity law shown in Table 1. The building was treated as a single-degree-of-freedom system. The models of building, foundation and

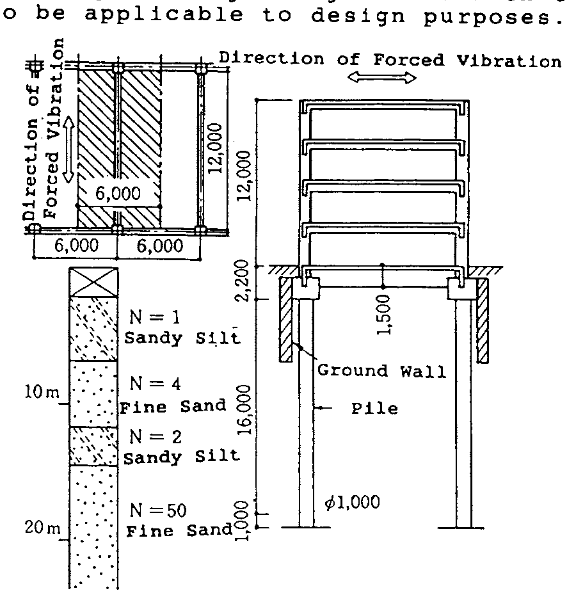

Fig.1 Original Building for Test Specimen

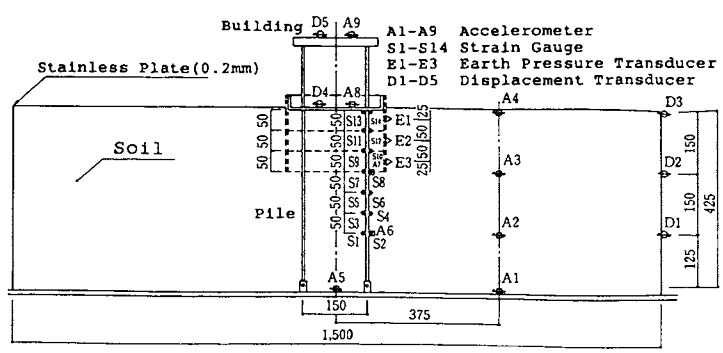

Fig.2 Set-up of Specimen and Instrumentation

Table 1 Similarity Law

Items	Dimension	Unit	Similarity Ratio
Length	L	cm	1/40
Acceleration	LT^{2}	cm/sec^{2}	1/1
Time	T	sec	1/6.3
Velocity	LT^{1}	cm/sec	1/6.3
Density of Soil	ML^{3}	$kgsec^{2}/cm^{4}$	1/1.4
Force	MLT^{2}	kg	$1/8.96X10^{4}$
Weight	M	$kgsec^{2}/cm$	$1/8.96X10^{4}$
Stress	$ML^{1}T^{2}$	kg/cm^{2}	1/56
Modulus of Elasticity	$ML^{1}T^{2}$	kg/cm^{2}	1/56
Strain	—	—	1/1
Bending Rigidity	$ML^{3}T^{2}$	$kgcm^{2}$	$1/1.43X10^{8}$

piles were made of steel. Each pile has a fixed head and a hinged tip. The soil model was made of a mixture of polyacrylamide and bentnite. This material had been confirmed to be elastic. The dimension of the soil model is 1.5mX1.0mX0.425m. Figure 2 illustrates the set-up of the specimen and instrumentation. The shaking table tests were carried out with use of sine wave ranged from 3Hz to 50Hz. The maximum acceleration given to the soil is 10 Gal.

COMPARISON BETWEEN 3D-FEM ANALYTICAL AND EXPERIMENTAL RESULTS

Method of analysis

Response analyses in frequency domain were carried out using three dimensional FEM. The analytical model was illustrated in Figure 3. Solid elements were used for the ground. Beam elements were used for the building and the piles. Plate elements were used for the foundation and the ground walls. The element size was decided to 1/4 of the wave length of 2nd natural frequency. Steady state response was calculated from 0.5Hz to 50Hz. The material property used for analysis are described in Table 2. The Rayleigh damping coefficient was decided by spectrum fitting method.

Results of analysis

Figure 4 shows experimental and analytical acceleration response at each of the top of building. The foundation and the ground surface for both case of with and wituout ground walls. The acceleration responses of the two cases are almost same. Peaks at 6.2Hz and 19.4Hz are the 1st and the 2nd natural frequency of the soil. Peaks at 9.9Hz and 10.4Hz correspond to the sway mode of the foundation. The peak at 11.6Hz is caused by the horizontal motion of the building. In analyses, the 1st and the 2nd peaks of the soil apeard, while only one peak at 11.6Hz was observed in the building. Figure 5 shows the distribution of acceleration response and the pile's moment at the resonance points of the soil and the building. At the resonance point of the soil(6.2Hz), acceleration in the soil and the building without ground walls is similar to the in case of experimental results. But in case of with ground walls, analytical results are a litle larger than experimental results. The pile's moment is largest at the pile head and it decreases in proportion to the depth. The reason for this is that not only the inertia force of the building but also the compulsory

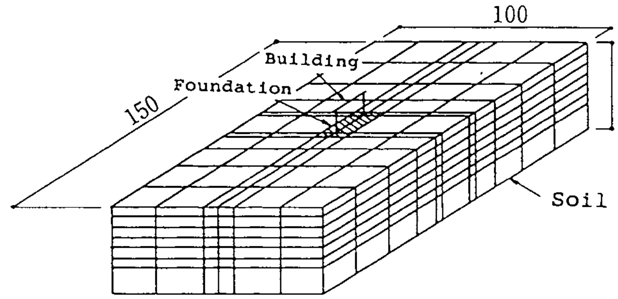

Fig.3 Analysis Model

Table 2 Material Properties Used for Analysis

Member	Young's Modulus (kg/cm^{2})	Shear Modulus (kg/cm^{2})	Poisson's Ratio	Density (kg/cm^{3})	Damping Facter (%)	Area (cm^{2})	Inertia Moment (cm^{4})
Soil	—	1.42	0.48	$1.2X10^{3}$	3.0	—	—
Pile	$2.1X10^{6}$	—	0.29	$7.9X10^{3}$	3.0	0.75	$3.9X10^{3}$
Foundation	$2.1X10^{6}$	—	0.29	$7.9X10^{3}$	3.0	—	—
Column	$2.1X10^{6}$	—	0.29	$7.9X10^{3}$	3.0	0.35	$2.9X10^{4}$
Building	$2.1X10^{6}$	—	0.29	$7.9X10^{3}$	3.0	19.5	3.7

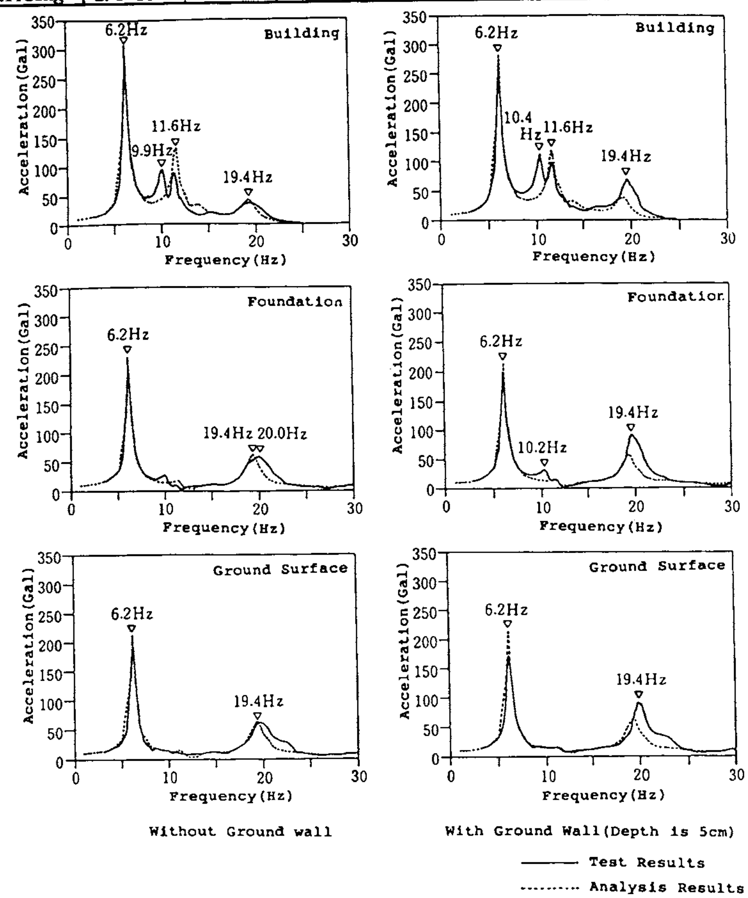

Fig.4 Results of Acceleration Response

force from the soil act on a pile. The pile head moment of the specimen with ground walls shows 60% of that of the specimen without the ground walls, although the analytical results give slightly larger value than the experimental results. At the resonance point of the building(11.6Hz), as for acceleration at the top of the building, analytical results are larger than the experimental results. The moment distribution along the pile axis varies from a positive value to a negative one, depending on the distance from the ground surface, as given by Chang's formura. The pile head moment dicreases to 60% in case that the ground walls exist.

ANALYSIS BY THE SIMPLIFIED MODEL

Comparison between experimental and calculated results

Figure 6 shows comparison between the pile moment distribution in experiment and calculated results by Chang's formula. Acording to Chang's formula, the moment distribution along the pile axis varies from a positive value to a negative one, depending on the distance from the ground surface. The test result for the 1st vibration mode of the soil shows only a positive value all through the pile length. For the 1st vibration mode of building, the calculated result shows a good agreement with the test result. As for the 1st vibration mode of the soil, both the inertia force of the building and the earth pressure act on the pile. But at the 1st vibration mode of the building, the inertia force of the building is dominant.

Method of analysis

This analytical method was introduced to estimate the force which act on to the pile from the soil at the 1st mode of the soil. A static 2-dimensional elastic analysis was adopted in this method. Piles and earth pressures are represented by beam elements and Winkler's springs respectively. The analytical model was shown in Figure 7. The inertia force of the building was applied to the pile head and the earth pressure was given to the pile through the soil spring. The distribution of the earth pressure to the pile was assumed to be similar to the 1st mode shape obtained from the test result. Pile moment and displacement were calculated according to the flow chart shown in Figure 8. At first, the inertia force of the building was applied to the pile head, and the displacement of the foundation was calculated. The difference between this value

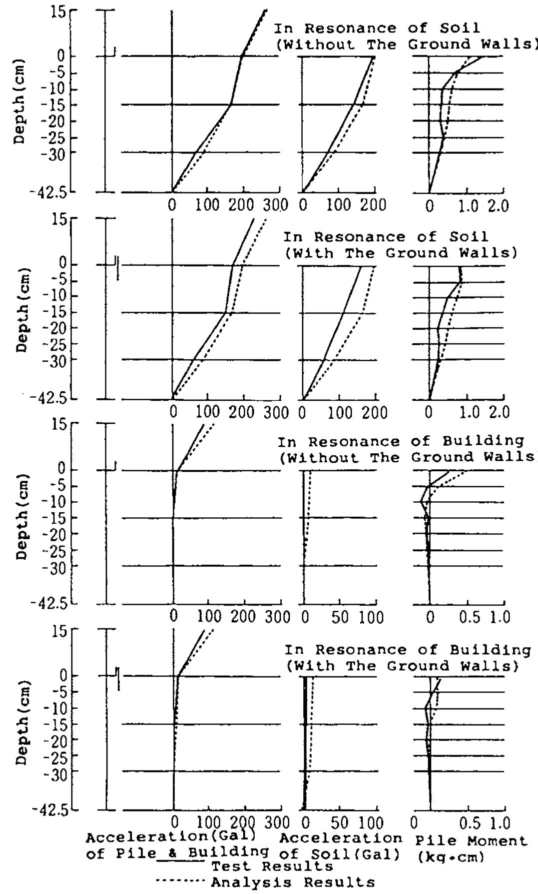

Fig.5 Distribution of Response

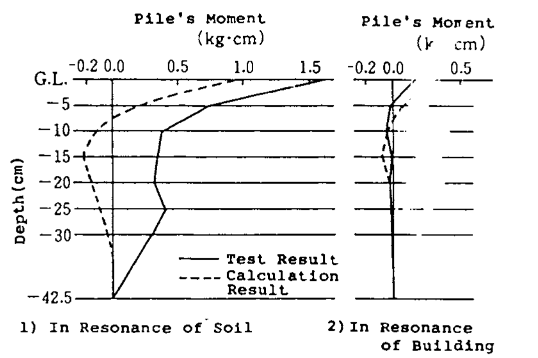

Fig.6 Distribution of Bending Moment by Past Calculation Method

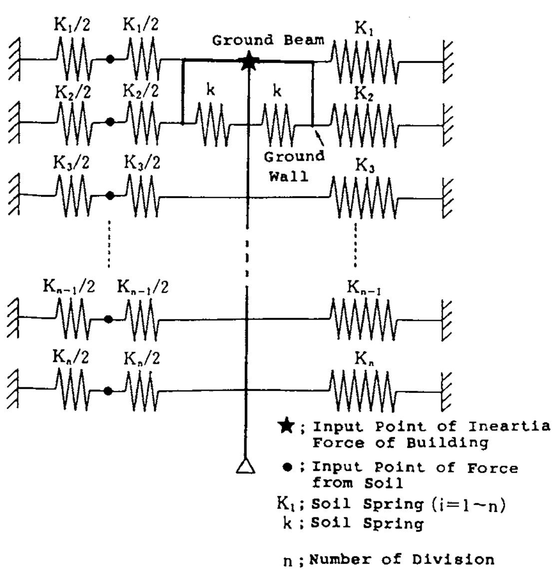

Fig.7 Simple Analysis Model

and the test result value was assumed to be the effect of the earth pressure. Next, the foundation displacement due to an imaginal unit earth pressure was calculated. Comparing the difference and the imaginal displacement the magnification facter α was derived. The pile moment due to the imaginal unit earth pressure was multiplied by the facter α and then it was added to the original moments due to the inertia force of building. Thus, the pile moment could be estimated, taking account of both the inertia force and the earth pressure. Material properties used for analysis are described in table 3. The stiffness of soil spring was determind by Mindlin's method.

Results of analysis

Figure 9 shows the result of analysis in case of without ground walls. 1) is the distribution of the pile moment when only the soil pressure acts to pile. 2) is the distribution of the pile moment when only ineartia force of the building acts on pile head. 3) shows the total moment distribution. The calculated results well agreed with the test results. The pile head moments of 1) and 2) are nearly the same. But change in the moment near the pile head length is smaller in 1) than in 2). So, the inertia force of buildings affects the shear of pile head more than the earth pressure. Figure 10 shows the distributions of the moment and the shear force in both case of 5cm and 10cm depth of ground walls models. The calculated results well agreed with the test results. And, the effectiveness of the ground walls can be easily understood through this simplified calculation model.

CONCLUSIONS

Shaking table tests were carried out using a 1/40 scale model. A 3-D FEM analysis was carried out to examine the results of the shaking table tests. Furthermore, the simplified calculation method was introduced. This method is useful to easily estimate the moment and the shear force acting on piles, taking account of both the inertia force of the building and the earth pressure. This method could be also adopted to examine the effectiveness of the ground walls appended to buildings. The analytical results were summarized as follows;

1) The results of frequency response analysis well agreed with the test results at the 1st and 2nd eigen-frequencies of the soil.
2) At the 1st frequency of the soil, The calculated acceleration well agreed with the test results in case of with the ground walls model. But, calculated values were a little larger than the test results in case of without the ground walls model.
3) At the 1st frequency of the soil, the pile moment showed positive values all through the pile length. But, at the 1st frequency of the building, the moment varies from a positive value to a negative one, depending on the distance from the ground surface.
4) The calculated results using this simple model well agreed with the test results. This model could be also applied to the model with the ground walls. The calculated results well agreed with the expermental results.

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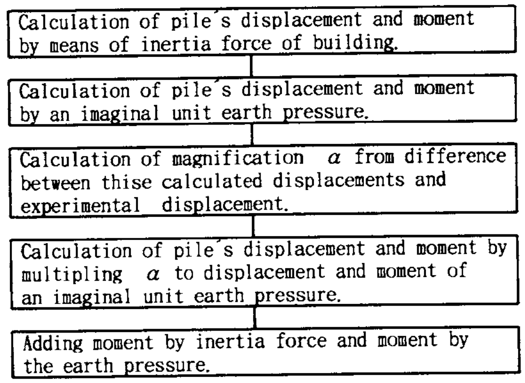

Fig. 8 Flow Chart of Analysis

Table 3 Material Properties Used for Analysis

Input Items		Data
Pile's Length	(cm)	42.5
Pile's Width	(cm)	1.5
Number of Division		17
Pile's Young's Modulus X Area	(kg)	$7.9X10^{5}$
Pile's Bending Rigidity	($kgcm^{2}$)	$4.1X10^{3}$
Soil's Shear Modulus	(kg/cm^{2})	1.42
Soil's Poisson's Ratio		0.48
Soil's Density	(kg/cm^{3})	$1.2X10^{3}$
Displacement of Foundation	(cm)	0.14
Inertia Force of Building	(kg)	0.21

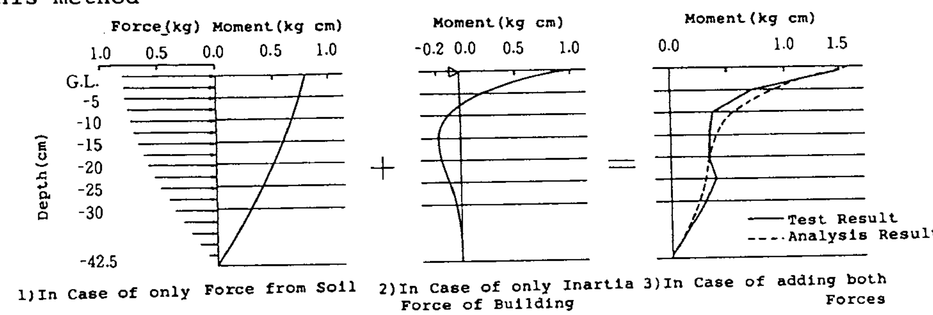

Fig.9 Analysis Result(Without The Ground Walls)

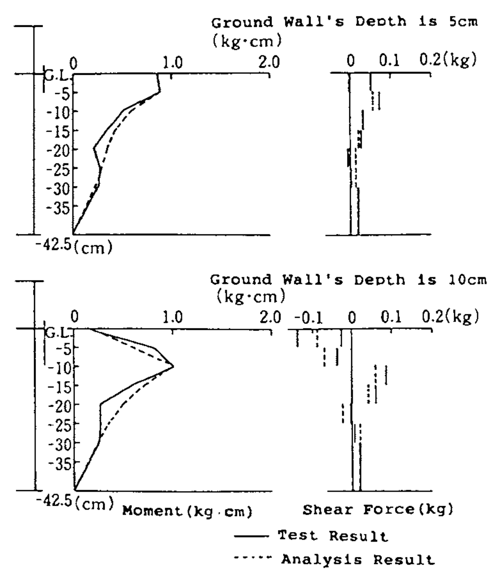

Fig.10 Analysis Results by Simple Model