STUDIES ON EARTHQUAKE RESPONSES OF GROUPED UNDERGROUND TANKS IN SOFT GROUND

by

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SUMMARY

This paper reports the earthquake response problems of grouped underground tanks in soft ground with particular emphasis on the influences of grouping. The studies, based on model vibration tests and numerical simulations, analyze the interaction between grouped tanks and soft ground, and discuss an earthquake-resistant design method for grouped tanks.

INTRODUCTION

Vertical-cylinder type underground tanks with radii and depths as much as tens of meters are being constructed in large number in Japan to store petroleum or liquefied natural gas. Most of these tanks are reinforced concrete cylinders, densely grouped, and built in soft ground along seashores so that it is very important to ascertain their safety in strong earthquakes. The authors perform dynamic model tests concerning coupled vibrations of grouped tanks and soft ground and numerical simulations using FEM. The objects of the model are 6 tanks each of which is of 50,000- to 100,000-KL capacity class at spacings of 0.5 diameter. A typical ground condition of a seaside industrial district of Japan is assumed, namely, a deep and soft alluvial layer resting on a stiffer diluvial layer.

OUTLINE OF EXPERIMENT

Fig. 1 shows the outline of the model. Model ground was made of acrylamide gel. The shear modulus of elasticity of the lower layer was six times higher than that of the upper layer. Highly viscous fluid supported the side boundary of the ground to reduce the effect of wave reflection. Model tanks were made of silicone rubber except for their base slabs which were made of rigid circular plates. The diameter and depth of each tank were 35 cm and 18 cm, respectively.

The model ground only was set on a vibration table as the first step and dynamic responses to harmonic and random excitations were observed. One of the model tanks was then set in a hole dug at the center area of the model ground. The clearance between the tank wall and the hole was filled with acrylamide gel having the same stiffness as the ground, and dynamic responses to the same excitations were observed. Measurement objects were sway and rocking amplitudes of the tank, strains and deflections of the tank wall, and accelerations of several points in the ground. Then, 2, 4 and 6 tanks were set successively and tested by the same method.

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EXPERIMENTAL RESULTS

Response characteristics of a single tank The solid line in Fig. 3 shows frequency-response curves of sway amplitude, and Fig. 4 shows the distribution of amplitudes at first resonance. The following remarks may be based on the results in these figures and the results of preliminary works.

1) As dynamic interaction between the ground and the tank does not appear prominently, the sway response of the tank is more or less controlled by the response of the surrounding ground.

2) The sway amplitude of the tank is almost the same as that of the layer where the tank bottom is embedded, and the tank wall resists the movement of surface layer.

Response characteristics of grouped tanks The frequency response curve of Tank A in the 6-tank case is compared in Fig. 5 with the curves of Tank C and Tank A weighted with an iron block of equivalent weight to the liquid contained. As the curve of Tank A almost coincides with that of the weighted Tank A, the effects of inertia of the tanks are considered to be negligible and dynamic interaction between tanks does not appear prominently. There are some irregularities seen in all curves between 3 and 5 Hz. It is presumed that the response mode of the model ground was distorted by the effect of the side boundary in this frequency range.

Fig. 6 shows the relation between sway amplitude and number of tanks. The ordinate is response magnification, and results of numerical simulations using FEM (FLUSH) are also plotted in this figure. As more tanks were set, the sway amplitude of each tank became smaller.

Fig. 7 shows the mean values of maximum responses at several representative points to two earthquakes. The abscissa is number of tanks and the ordinate the ratio to the single-tank case. It is remarkable that tangential strains of the tank wall grew large when the tanks were grouped.

Deformation modes of grouped tanks Fig. 8 shows radial and relative deformations of the tank wall which were measured on the points P1 to P8 at first resonance. Three basic deformation modes are defined in the figure and their contributions to the wall deformations are pointed out in brackets under the figure.

In the case of a single tank, sway amplitude of the ground about the tank was symmetrical in the perpendicular direction and antisymmetrical in the parallel direction to the table vibration. Radial deformation due to sway [A] was then predominant.

In the case of 2 tanks, the symetric condition in the perpendicular direction was destroyed, and oval deformation [B] due to torsion grew large.

In the case of 4 tanks, the antisymmetric condition in the parallel direction also was destroyed and oval deformation [C] due to compression was added to the beforementioned [B], but phases of [C] were reverse between adjacent tanks.

In the case of 6 tanks, the deformation modes of corner tanks (Tanks C and D) were similar to the previous case, the deformation [B] due to torsion only was predominant at the middle tanks (Tanks A and B).

These tendencies appeared in the observed tangential strains of the tank walls. In the case of a single tank, normal strain was predominant and the strain distribution matched the mode of sway [A]. In the cases of 4 and 6 tanks, normal strains rather were decreased and bending strains which matched the modes of [B] and [C] grew very large.

CONCLUDING REMARKS

1) The response of the ground chiefly controls the responses of grouped tanks as in the case of a single tank. It is considered that peculiar resonance phenomena due to dynamic interaction between grouped tanks will hardly occur during earthquakes.

2) The grouped tanks exert a grouped force to resist and to restric the movements of surface layers of the ground.

3) Each tank in the group is unsymmetrically loaded by the ground due to the influence of neighboring tanks. Because of this, in-plane lateral oval deformations of tank walls are predominant, and tangential strains of the walls are larger than for the case of a single tank.

4) The lateral deformations of the walls are of three modes, namely sway, oval deformation due to torsion, and oval deformation due to compression. Earthquake stresses of the walls should be estimated considering combinations of these modes in the case of grouped tanks.

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Simularity	
Length	1/150
Density	1/1.7
Shear Wave Velocity	1/50
Time	1/3
Acceleration	1/16.7
Deformation	1/150
Strain	1/1

Material Constants	
ground	Vs m/s
Top Layer	1.97
Middle L.	2.68
Bottom L.	4.81
Tank	E kg/cm²
Wall	130.
Vs S-Wave Velocity	
E Young's Modulus	

Table 1 Simularity & Material Constants

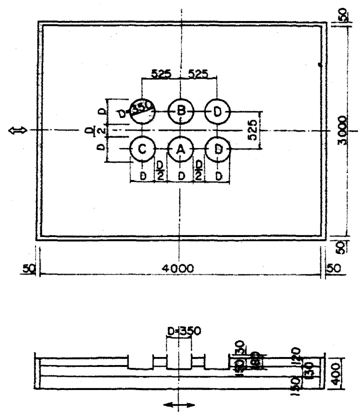

Fig. 1 Outline of Model Tanks and Soil Layers

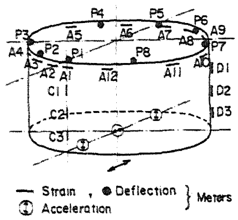

Fig. 2 Location of Meters

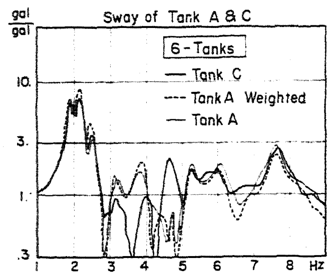

Fig. 3 Frequency Response Curves

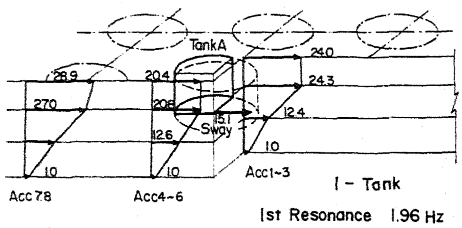

Fig. 4 Acceleration Amplitudes of 1-st Resonance (Soil Layer Acc.1-8 & Tank)

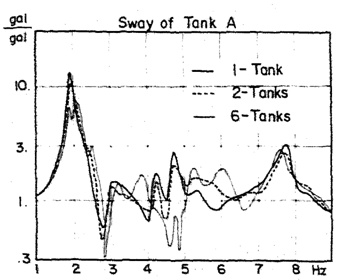

Fig. 5 Frequency Response Curves

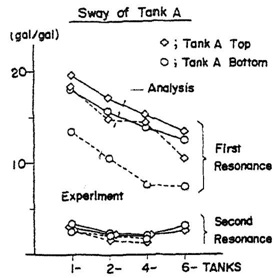

Fig. 6 Sway Amplitude vs. Number of Tanks under Harmonic Excitation

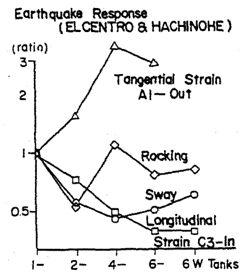

Fig. 7 Max. Amplitude vs. Number of Tanks under Earthquakes

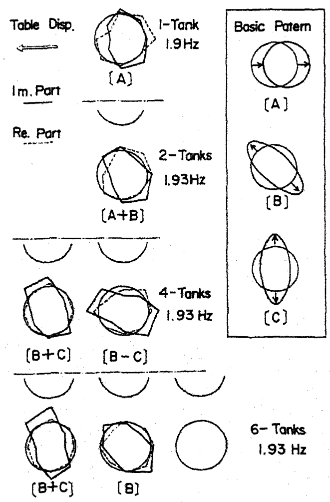

Fig. 8 Radial Deformation of Tanks under Harmonic Excitation