BEHAVIOR OF UNDERGROUND TANK DURING EARTHQUAKES

BY

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SYNOPSIS

The authors have conducted earthquake observations of an underground tank constructed on a reclaimed land. By making reference to the results of the earthquake observations, a method of earthquake response analysis was proposed for this type of tanks, using a new mathematical model, in which the tank is assumed as a cylindrical structure on an elastic foundation of the ground. The strain obtained by this new method have a good agreement with the observed strain during the earthquake.

1. Earthquake Observation

The general view of the underground tank where earthquake observations were carried out is shown in Fig. 1. It is a reinforced concrete structure of a cylindrical shape which is of 24m in inner diameter and 10.3m in depth. The side wall and the bottom slab are 90cm and 20cm thick respectively. The soil profile, N-value and the seismic wave velocities are shown in Fig. 2.

The layer between EL+4.5m~EL+1.75m is reclaimed with sand and gravel. The alluvial layers between EL+1.75m~EL-11.0m are composed of sand and silt with the N-value of 5~10. The diluvial layers between EL-11.0m~EL-50.0m are composed of silt and gravel. The sand stone at EL-50.0m is considered to be the seismic bedrock.

The fundamental natural period of the surface layer above the sand stone is presumed to be about 0.90sec. from the results of the micro-tremor observations and the seismic wave velocities.

The location of accelerometers, strain meters and earth pressure meters are shown in Fig. 1. Seven accelerometers were installed at the top and the bottom of the tank, while two accelerometers were placed on the ground surface and on the bedrock 24.0m away from the tank. The acclerometers are the moving coil type with a natural period of 0.20 sec..

Thirteen strain meters were installed on the inside of the tank's wall. These strain meters were newly developed and measure the changes in the distance between two scale points which are set 1.0m apart on the side wall of the tank.

Fig. 4,6 show the records of an earthquake which occured on November 30, 1974 (M=7.6, Depth=420km, $\triangle$=510km), while Fig. 8,9 show the record of an earthquake which occured on November 16, 1974 (M=6.1, Depth=40km, $\triangle$=270 km).

Dynamic characteristics of the underground tank and the ground obtained by the earthquake observations are summarized below:

(1) The acceleration wave forms at the observation points of A2 and A7 on the tank are very similar to that at the point A1 on the ground sur-

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face (Fig. 4). Further more, as shown in the power spectra (Fig. 5), the dominant periods of the acceleration at the point A2 and A7 also agree with those at the point A1 and any dominant period of the tank's vibration itself cannot be found which is due to the tank's inertia force. According to the power spectra the magnitude of the accelerations on the tank (A2, A7) with the periods 0.93sec., which can be considered to be the fundamental periods of the surface layer during this earthquake, are smaller than that on the ground surface (A1) on account of the rigidity of the tank which resists the deformation of the ground. The dominant period 4.55sec. of the acceleration can be considered to be caused by the vibration of the water in the tank. It almost concides with the peirod of 5.13sec., which is calculated from the water depth of 2.0m at the time of the earthquake.

(2) The vertical displacement at the points A6 and A8 have almost the same magnitudes and the opposite phase to each other, shown in Fig. 10, and this shows that the rocking motion of the tank is considerablely large during the earthquake.

(3) As shown in Fig. 7, the predominant periods of the strain almost agree with those of the acceleration on the ground surface and this result shows that the motion of the ground is a decisive factor for the strain of the tank.

(4) Fig. 6 shows the strain records at the observation points S2, S7, S9, S11, S12 (circumferential strains) and S3, S5, S8, S10, S13 (vertical strains). As shown in Fig. 1. the observation points S2 and S12 are on the Y-axis, facing to each other and the point S7 is on the X-axis, perpendicular to the Y-axis. The strains at the points S2 and S12 have very similar wave forms and almost same phases. On the other hand, the strain at the point S7 has the opposite phase to these strains. Further more, the points S5 and S10 are set on the walls, which are perpendicular to each other, and the vertical strains at these two points have also the similar wave forms with opposite phases. The results mentioned above indicate that the tank is deformed elliptically during the earthquake.

(5) The vertical strain at the point S8 is less than the circumferencial strain at the same point (S7), but in the case of S3 and S2, the vertical strain is about 1.5 times of the circumferencial strain. From these results, it is pointed out that the vertical strains have the comparable magnitude with the circumferential strains and the studies of not only the circumferencial strains but also the vertical strains are necessary for the aseismic design of underground tanks.

(6) The cbservation points S11 and S12 are set on the same vertical line, and the point S11 is 3.0m below the ground surface while the point S12 is 9.0m below. The circumferential strains at these two points have almost same magnitudes and phases. This result shows that the tank is deformed uniformly along the vertical line in the case of the shallow tank as this.

2. Method of Numerical Analysis

A new mathematical model was proposed for the practical design of underground tanks, taking only the main factors into account that had influences upon the behavior of the tank during earthquakes. The dynamic analysis of the underground tanks was carried out on the following assumptions:

(1) It is assumed that frequency characteristics of the ground motion is not influenced by the presence of a tank.

(2) The inertia force of the tank is not considered in the analysis since its effect upon the dynamic strain of the tank can be considered to be small from the results of earthquake observations.
(3) The deformation of the ground around the tank is calculated by shear vibration of the surface layers above the rock by assuming that the tank is absent.
(4) The deformation and the strain of the underground tank are calculated from the displacement of the surrounding ground by considering that the tank is a cylindrical structure on the elastic foundation of the ground.

3. Comparison between the Observed and the Calculated Strain

To examine the adequacy of this new numerical method, the strains during the earthquake (November 30, 1975) were calculated and were compared with the observed strains. In the present analysis the vibration of the water was neglected since the water depth was only 2.0m and the influence of the water upon the strain of the tank was comparatively small.

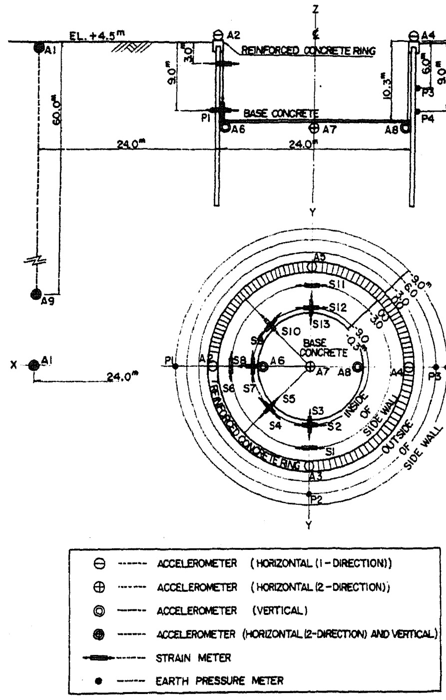
The distribution of the displacement of the ground around the tank was assumed as shown in Fig. 12. The present tank was constructed in the new reclaimed ground, filled up two years ago, which was next to an old reclaimed ground filled up about ten years ago. The tank is located in 14m to the old ground, or so near that the displacement of the old ground has some influences upon the stresses of the tank. From the results of the micro-tremor observations on the ground surface arround the tank, it was presumed that the predominant periods of the new and the old ground were almost same but the amplitude of the earthquake motion on the old ground was about 80% of that on the new ground.

The displacement of the new reclaimed ground was calculated by the fundamental shear vibration of the surface layer on the sand stone using a multiple-mass-model. The S-wave velocities of each layer were revised in order that the calculated fundamental period of the ground became to be 0.93sec. which was obtained by the earthquake observation. The damping ratio was assumed to be 5.0%. As the input seismic waves, the acceleration records in the X and Y directions on the sand stone were used. Fig. 11 shows the finite element model and the elastic moduli of the tank and the coefficient of the subgrade reaction.

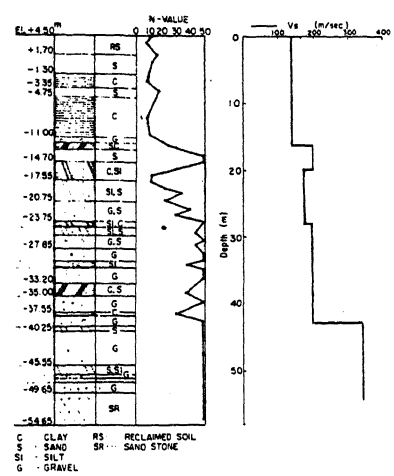
Fig. 13 and Fig. 14 show the time histories and the power spectra of the circumferencial strains (S2, S7, S9, S11, S12). The wave forms of the calculated strains have a good agreement with those of the observed strains except the vibration with high frequencies. The calculated vertical strains have same phase with the observed strains but their magnitude are almost 1/2 of the observed.

4. Conclusion

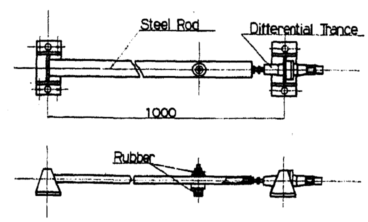
(1) The frequency characteristics of the strains of the tank were very similar to that of the acceleration of the ground and any dominant period which was related with the tank's inertia force could not be found except the vibration of the water in the tank.
(2) The tank was deformed elliptically during the earthquake.
(3) The vertical strains of the tank wall had a comparable magnitude with the circumferential strains.
(4) The strains calculated by using a new mathematical model had a good agreement with the observed strains.



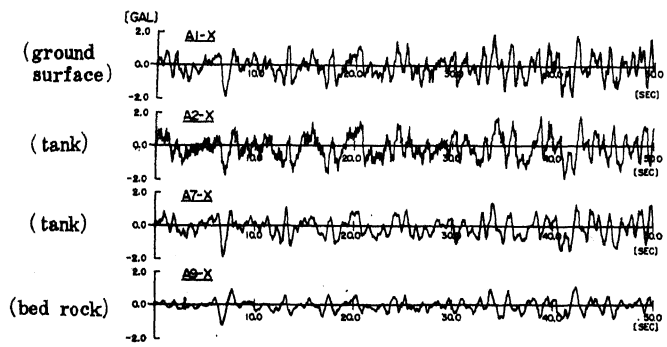
Fi9-1 General View and Locations of Accelerometers and Strain Meters



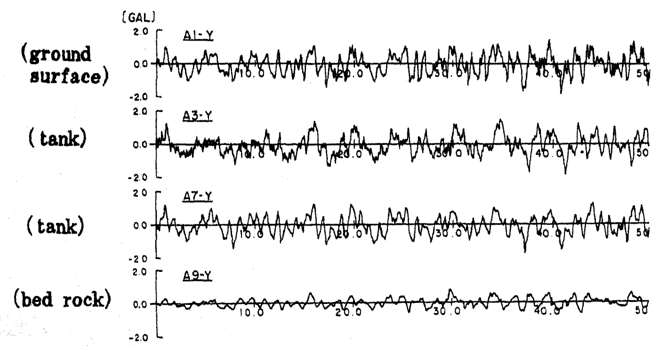
Fi9-2 Soil Profile



Fi9-3 Strain Meter

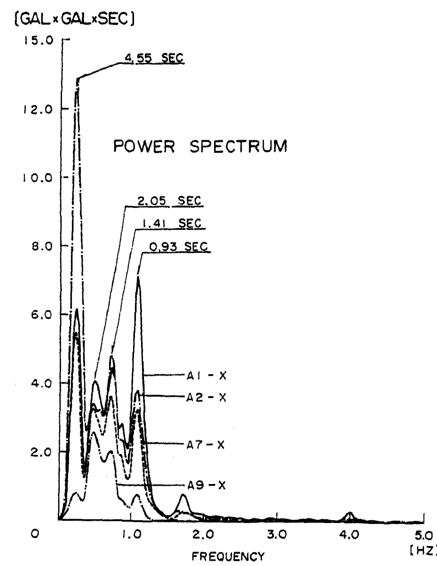


(a) X-direction

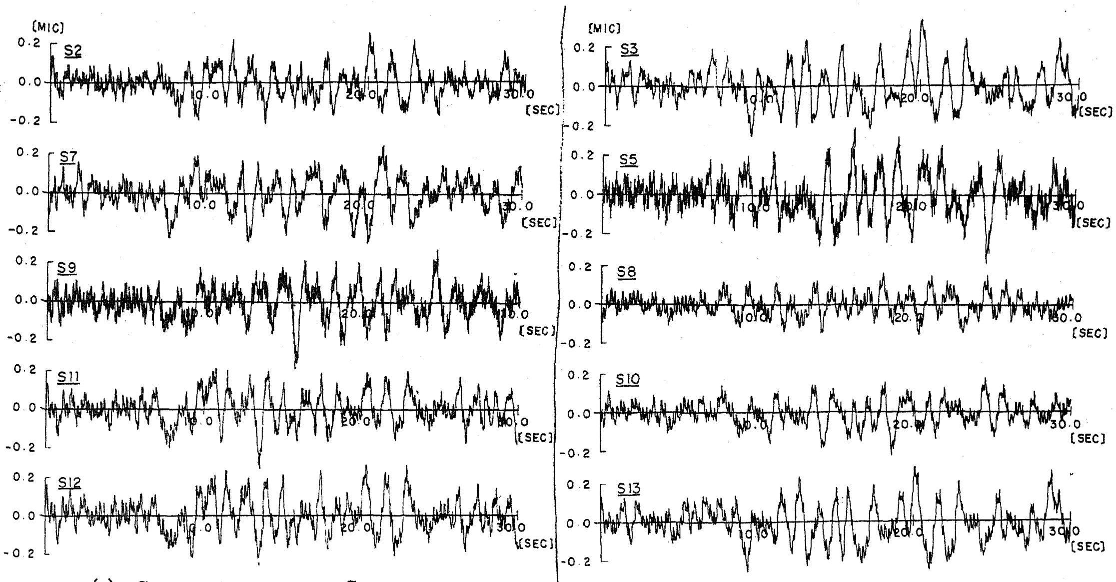


(b) Y-direction

Fi9-4 Acceleration Records (Nov. 30,1974)



Fi9-5 Power Spectra of Acc. (X-direc.) (Nov. 30,1974)



(a) Circumferential Strain (b) Vertical Strain

Fig-6 Strain Records (Nov. 30, 1974)

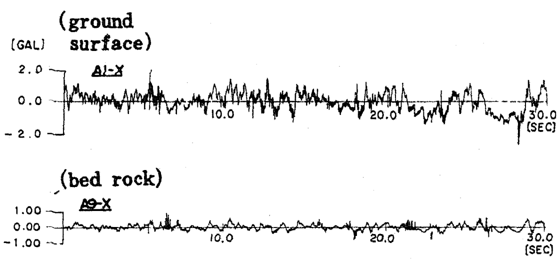
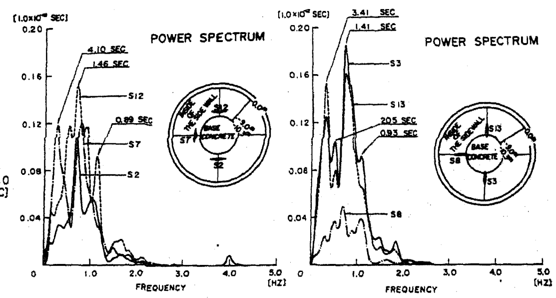
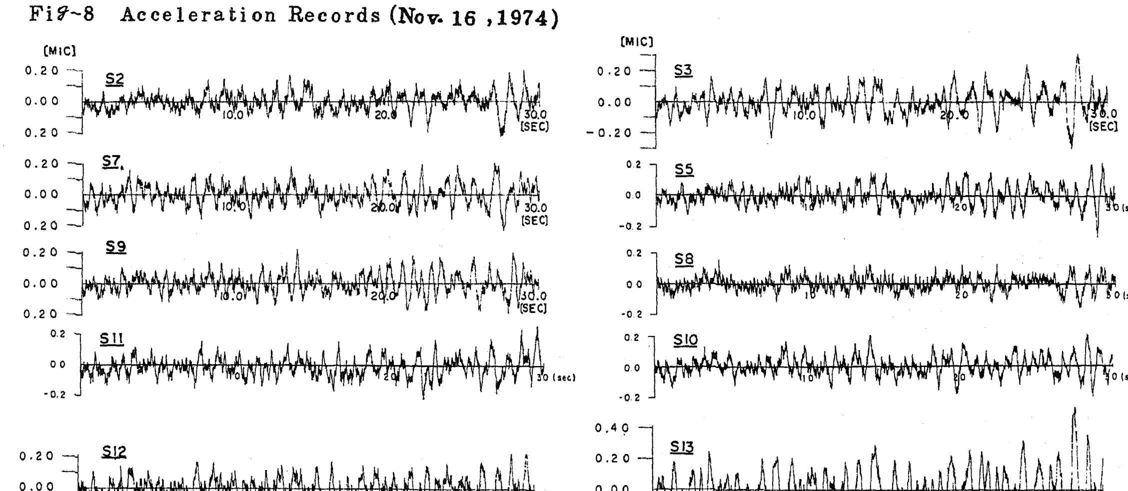


Fig-8 Acceleration Records (Nov. 16, 1974)



(a) Circumferential (b) Vertical

Fig-7 Power Spectrum of Strain records



(a) Circumferential (b) Vertical

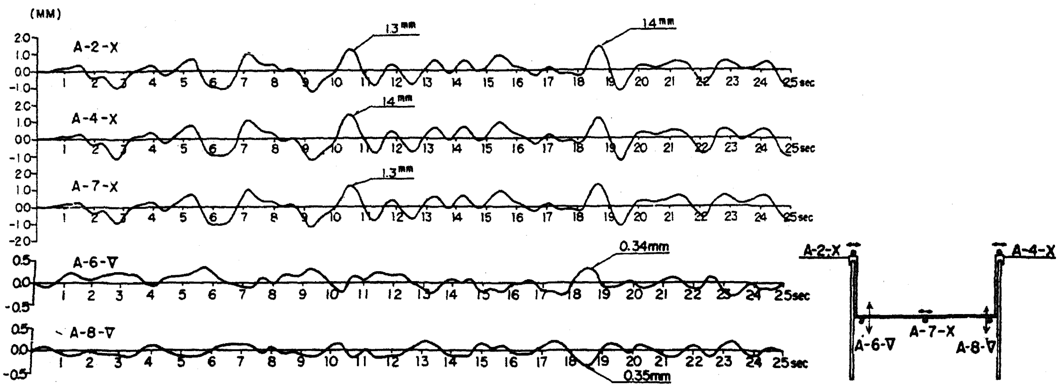


Fig-10 Displacement Records (Sep.27,1974)

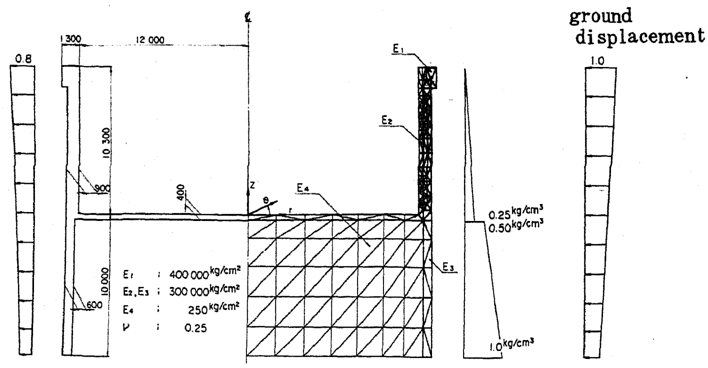


Fig-11 Numerical Analysis Model

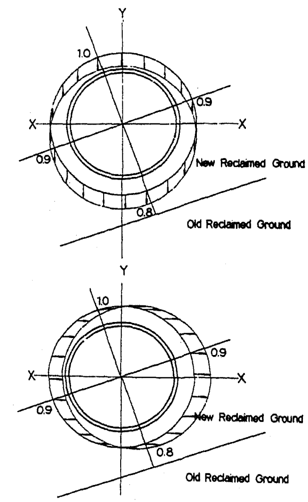


Fig-12 Distribution of Ground Displacement

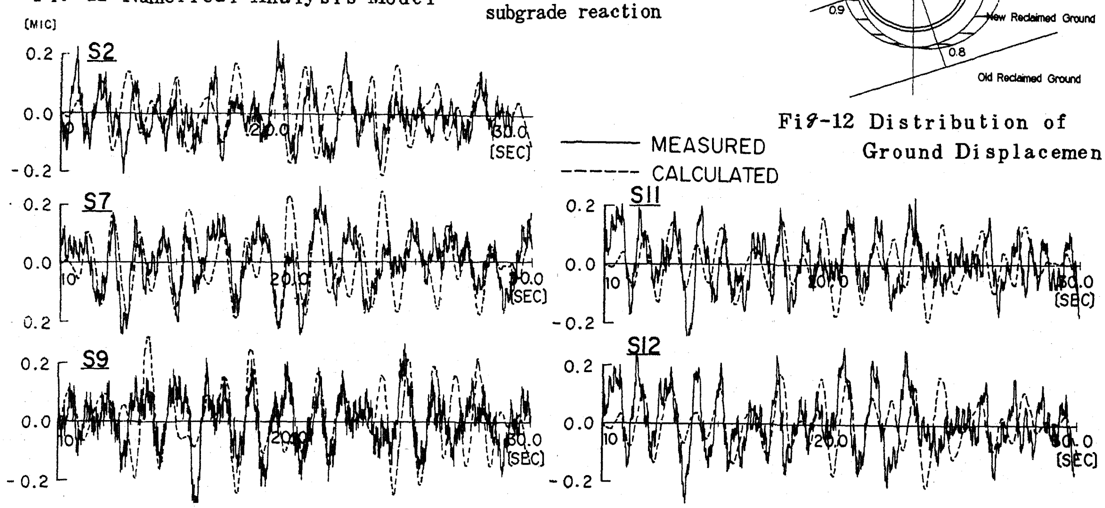


Fig-13 Calculated Strain Records (Nov. 30,1974)

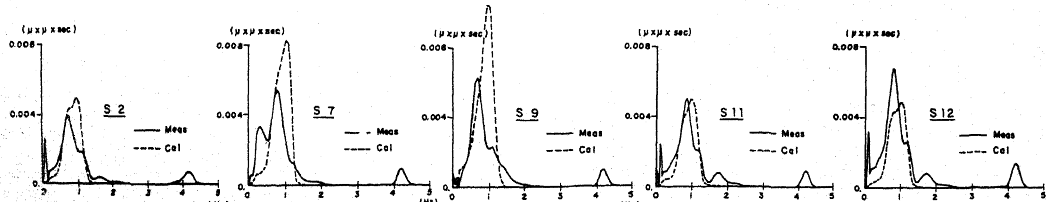


Fig-14 Power Spectra of Strain Records