

EARTHQUAKE OBSERVATIONS AND ANALYSES OF AN LPG TANK AND ITS FOUNDATION SOFT SOIL

by

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SYNOPSIS

Earthquake observations were projected in order to investigate the dynamic behaviors of a soft soil and an LPG tank. Much useful information concerning dynamic behaviors of the base layer, the surface layer and the tank during earthquakes was obtained. Earthquake motions of the surface layer were computed employing the multi-reflection theory in which the soil was considered to have linear viscoelastic properties. Furthermore, the tank, foundation, piles and soil were represented by a lumped-mass system, and the responses of the system were computed by applying observation records to the base layer. The computed results were compared with the observation records and the both were found to agree rather well with each other.

INTRODUCTION

Various kinds of important structures have been constructed on such deep soft soil as a land reclaimed from the sea. These structures have generally been designed on the basis of dynamic analysis including the foundation soil. In such case, there are many difficulties in deciding on a suitable analytical model and estimating the interaction effect between soil and foundation structure. In order to investigate the seismic effects of soft soil on the response of the structure, an extensive series of earthquake observations was projected for an LPG tank constructed on soft soil at Koto-ku, Tokyo.

OUTLINE OF EARTHQUAKE OBSERVATIONS

The surface layer of the site consisted of a soft silty deposit having a 38-m thickness and underlain by a stiff sandy gravel and silt formation. The S-wave velocity was about 120 m/sec within the surface layer and over 400 m/sec in the underlying stiff formation as shown in Fig. 1. The LPG tank was cylindrical in shape with a diameter of 32 m and a height of 25 m and was supported on 76 steel piles extending through the surface layer. The capacity of this tank was 12,000 kl.

Accelerometers were installed at five points on the tank, at three points vertically in the soil close by the piles and at four points vertically below the ground surface at a distance of 40 m from the nearest edge of the tank. A total of twenty-two components as shown in Fig. 1 were laid out to simultaneously take records on oscillograph charts quickly after earthquake arrival. The earthquake observations have been continued from August 1973.

RESULTS OF EARTHQUAKE OBSERVATIONS

Thirty-five earthquakes ranging from 2 to 22 gal at the ground surface have been recorded up to this time. Fig. 2 shows the distribution of the epicenters. Almost all of the epicenters of the earthquakes observed were

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located in the seismic belt along the Pacific coast of Japan. The magnitudes of these earthquakes were 7.6 or under and seismic intensities felt in Tokyo did not exceed IV in JMA scale. The epicentral distances were distributed between 10 km and 1,200 km. The focal depths ranged from 10 km to 600 km. Six earthquakes were selected from the observed earthquakes to investigate the dynamic behavior of the tank-pile-soil system. Nine earthquakes were selected to study the response of soil.

Distributions of maximum amplitude ratios are shown in Fig. 3 in which maximum accelerations of all of the points were normalized by those observed at GL-70 m. Amplification curves of the vertical series of soil along the piles were similar to those of the soil alone.

Power spectral densities were computed for the purpose of investigating the frequency characteristics of earthquake records. The frequency characteristics of earthquake waves observed at the base layer contain the characteristics of incident waves which are governed by magnitude of earthquake, location of focus, mechanism of earthquake occurrence and passage of propagating waves. It was found that the frequency characteristics at GL-70 m had a close relation to $\tan \theta$, the ratio of focal depth to epicentral distance. When the value of $\tan \theta$ was small, low-frequency components less than 1 Hz were markedly revealed in the observed waves. High-frequency components became predominant in the waves as the value of $\tan \theta$ increased. The natural periods of the surface layer were found to be about 1.2 sec for the first mode and 0.4 sec for the second mode as a result of power spectral analysis. Fig. 4 shows the power spectra of typical earthquake waves in which low and high frequency components are respectively predominant.

The relationships among magnitude, focal distance determined by the Japan Meteorological Agency and maximum acceleration at GL-70 m were investigated. Kanai gave the empirical formula for the relation at bed rock as follows:

$$a = 10^{0.61M - (1.66 + \frac{3.60}{x})\log_{10} x + (0.167 - \frac{1.83}{x}) \times \frac{1}{T}} \quad \dots (1)$$

in which a , M , x and T represent acceleration amplitude at bed rock in gal, magnitude of earthquake, focal distance in km and period of earthquake wave in sec respectively. By using the above formula and giving the value of T as follows:

$$T = \frac{1}{2 \tan \theta + 1} \quad (\tan \theta \leq 2) \quad \text{or} \quad T = 0.2 \quad (\tan \theta > 2) \quad \dots (2)$$

the maximum accelerations were calculated for all of the earthquakes and they were compared with observed maximum accelerations at GL-70 m as shown in Fig. 5. It was found that the formulas (1) and (2) were sufficiently applicable for estimation of maximum accelerations at the base layer.

SIMULATION ANALYSIS OF SURFACE LAYER BY MULTI-REFLECTION MODEL

In order to theoretically obtain the transfer function of the surface layer and the ground motions at the corresponding observation points, the soil formation was represented by a multi-reflection model consisting of six homogeneous deposits in which the soil was considered to have linear visco-elastic properties. The frequency transfer function theoretically obtained is shown in Fig. 6 compared with that determined from the observed waves. Fig. 7 shows comparisons of waves theoretically obtained and observed at

each point. As a result, the theoretical predictions were found to agree practically well with observations.

SIMULATION OF EARTHQUAKE RESPONSE OF TANK-PILE-SOIL SYSTEM

The tank, foundation, piles and soil were represented by a series of lumped-mass systems for a simulation analysis of behaviors during earthquake. In order to decide on the most suitable analytical model, useful informations about the dynamic behavior of the tank-pile-soil system were obtained from analyses of microtremor and earthquake observations. It was found from the records on the tank that the tank was moving almost as a rigid body and the swaying and rocking motions of the foundation had a great influence on the first vibration mode of the tank. The relation between LPG level and natural period of the tank is shown in Fig. 8, which was obtained from spectrum analyses of the observation records with respect to the tank. The natural period of the tank was 0.4 sec when the tank was empty, becoming longer as the LPG level rose, and was 0.6 sec when the tank was full.

The soil and the group of piles were divided into twelve masses and the tank was treated as a rigid body as respectively shown in Fig. 9. LPG in the tank was estimated on the basis of mass fixed to the tank and a vibrating mass considering only the first vibration mode. Eigenvalues of the system were computed using the above analytical model. The natural periods of the first and second modes of the tank-pile-soil system for three LPG levels were plotted in Fig. 8 in comparison with the observation results. Fig. 10 shows the first vibration modes of the three cases.

Dynamic responses of the tank-pile-soil system were computed employing the acceleration record at GL-38 m of the "1974 Izu Hanto-oki Earthquake" as input to the deep end of the pile. The LPG level of the tank was 5.74 m in this case. The damping ratios of the soil system were assumed to be 0.01 for the first mode and 0.02 for the second mode. In the same manner, the damping ratios of the tank-pile-soil system were taken as 0.05 for the first mode of the tank and 0.01 for the vibration mode of the fluid. Fig. 11 shows the distribution of the computed accelerations in comparison with that of the observations. Computed acceleration responses are shown in Fig. 12 compared with the observed records.

As a result, it was proved that such a comparatively simple model as considered in this study may be used to explain actual behaviors of tank-pile-soil system and is applicable to engineering use.

REFERENCES

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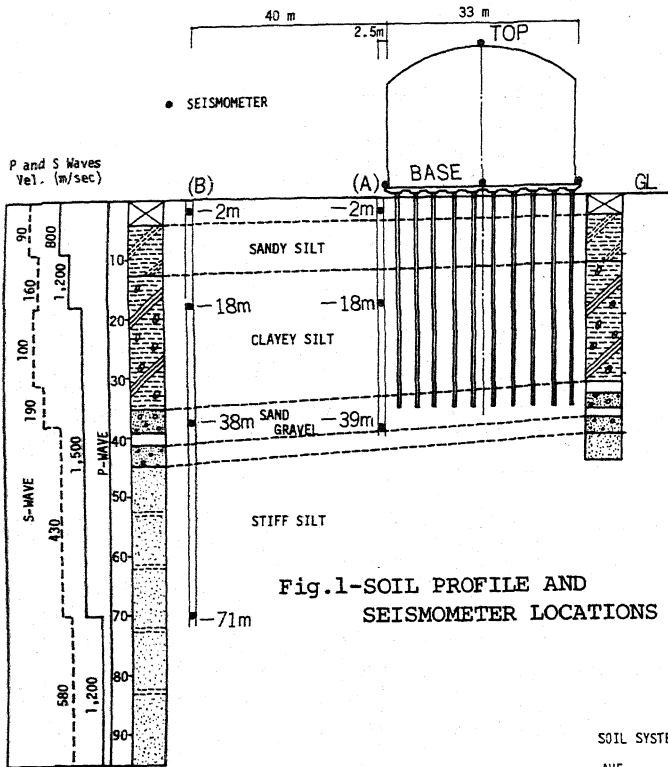


Fig. 1-SOIL PROFILE AND SEISMOMETER LOCATIONS

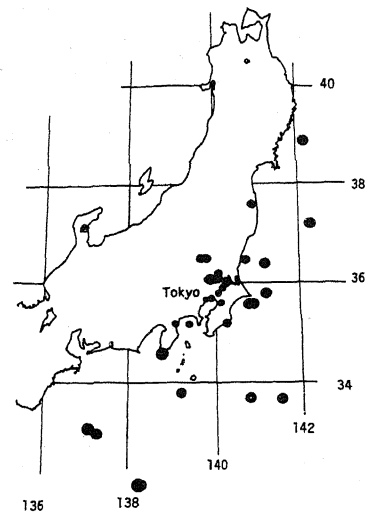


Fig. 2-DISTRIBUTION OF EARTHQUAKE EPICENTERS OBSERVED

Fig. 3-DISTRIBUTION OF MAXIMUM AMPLITUDE RATIOS

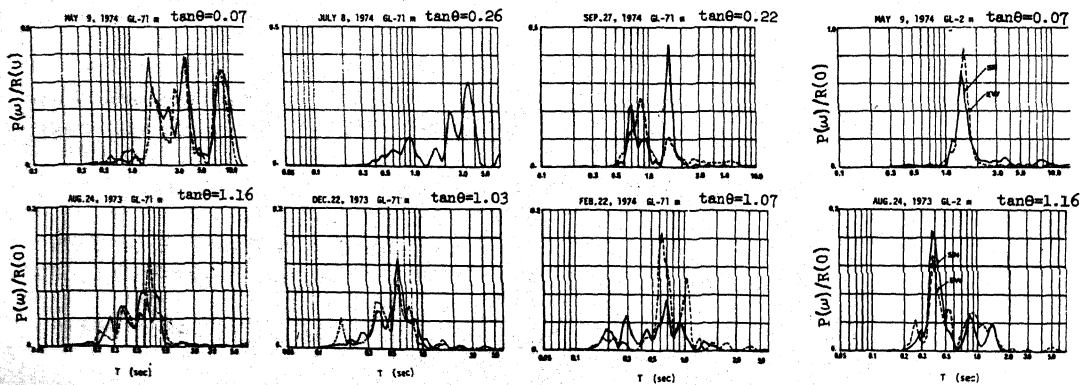
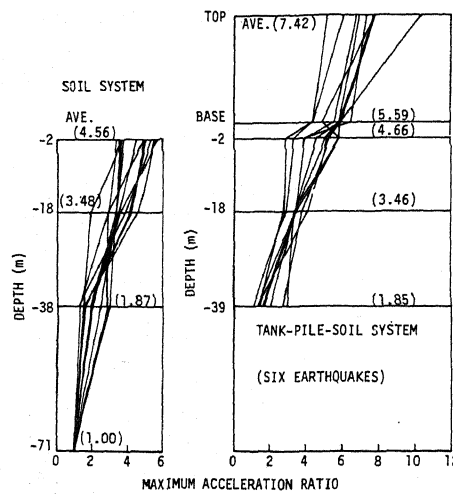


Fig. 4-POWER SPECTRA OF TYPICAL EARTHQUAKES

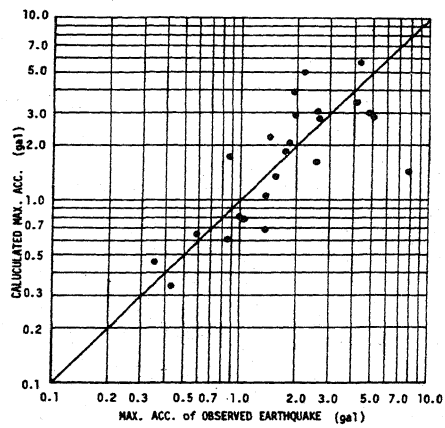


Fig. 5-COMPARISON BETWEEN OBSERVED AND CALCULATED MAXIMUM ACCELERATIONS AT GL-70 M

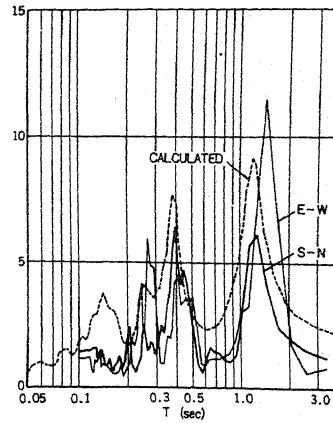


Fig. 6-FREQUENCY RESPONSE FUNCTION OF THE SURFACE LAYER

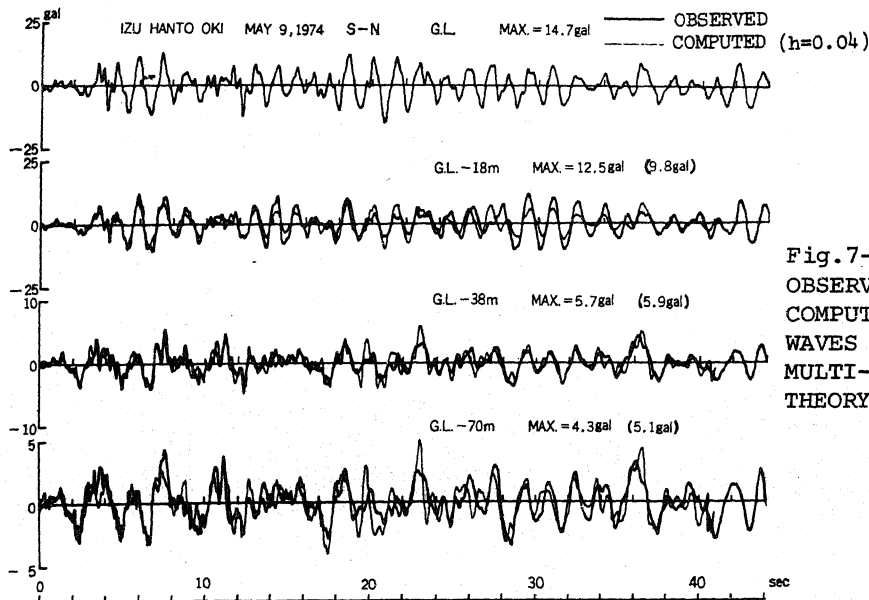


Fig. 7-OBSERVED RECORDS AND COMPUTED ACCELERATION WAVES BY THE USE OF MULTI-REFLECTION THEORY

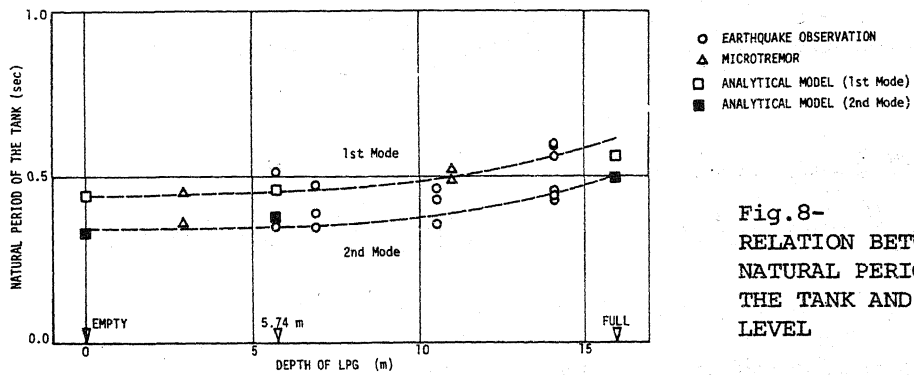


Fig. 8-RELATION BETWEEN NATURAL PERIODS OF THE TANK AND LPG LEVEL

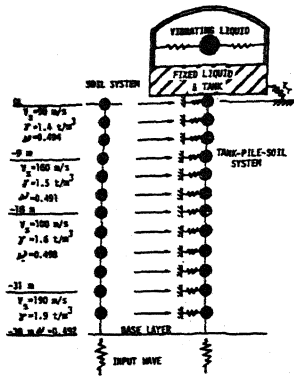


Fig.9-ANALYTICAL MODEL OF SOIL AND TANK-PILE-SOIL SYSTEM

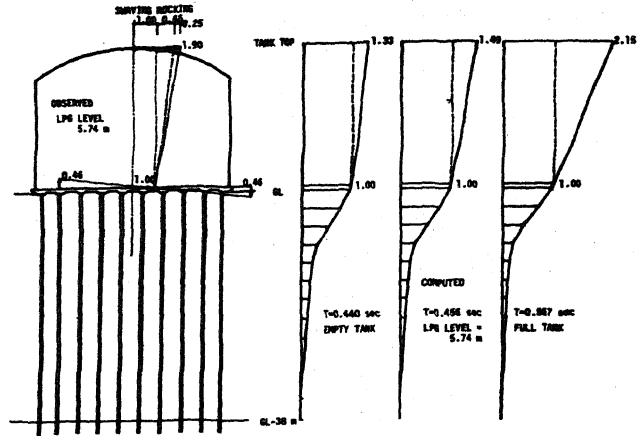


Fig.10-VIBRATION MODES OF ANALYTICAL MODEL AND OBSERVED MODE

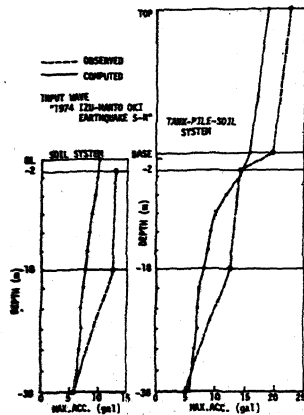


Fig.11-DISTRIBUTION OF COMPUTED AND OBSERVED MAXIMUM ACCELERATIONS

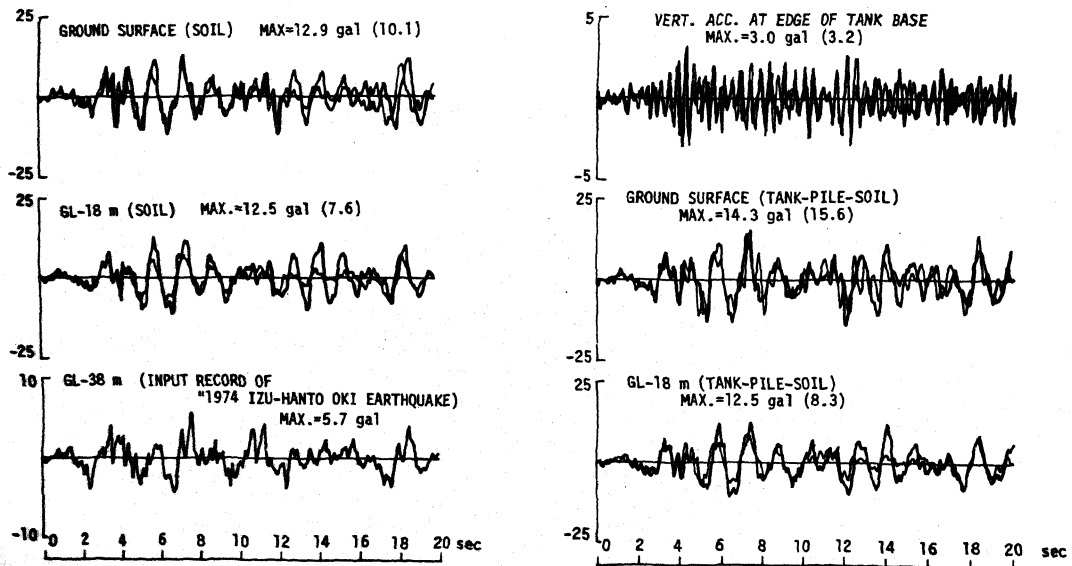


Fig.12-COMPUTED AND OBSERVED ACCELERATION WAVES OF THE TANK-PILE-SOIL SYSTEM