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SEISMIC BEHAVIOR OF IN-GROUND LNG STORAGE TANKS DURING SEMI-LONG PERIOD GROUND MOTION

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SUMMARY

In this study, The dynamic behavior of LNG in-ground storage tanks is discussed from the view of the practical design. Specifically, the following points are described. (1) Comparative study of the dynamic behaviors of a tank between under the semi-long period ground motion and under the short period ground motion. (2) Dynamic characteristics of the dynamic earth pressure acting on the side wall of the tank.

As a result,firstly,the fact that the tank and the surrounding ground move similarly during the semi-long period ground motion was verified. However, it is necessary to pay attention that the ratio of the maximum displacement to the maximum acceleration under the semi-long period earthquake is greater than the ratio under short period earthquake. Secondly, the dynamic earth pressure acting on the side wall of the tank is correlated not only with the relative displace-ment between the tank and the surrounding ground, but also with the absolute acceleration in the surrounding ground. The new expression of the dynamic earth pressure is proposed herein.

INTRODUCTION

Purpose In recent decades,in Japan, many cylindrical liquefied natural gas (LNG) in-ground storage tanks with radii and depths as much as several tens of meters have been constructed in alluvium grounds. And, numerous studies (Refs.1,2,3) with respect to aseismic design of in-ground tank have been Perfor-med. But, there are few studies about seismic behavior under semi-long period ground motions and about dynamic earth pressures against the side wall of the tank, because these actual data are rarely recorded. In this study, using these actual earthquake data, some examinations are carried out in order to get practical informations for aseismic design of in-ground tanks.

Earthquake observation system At the Sodegaura LNG Plant site of the Tokyo Gas Co.,Ltd., which is located facing to Tokyo Bay in Chiba prefecture, a strong earthquake observation system has been in operation since 1983. Data of over 50 earthquakes have been recorded at this site. Fig.1 shows the arrangement of the strong motion instruments of this system. Main four earthquakes shown in Table.1 are treated in this study. Semi-long period ground motions were recorded at the Nihonkai Earthquake.

The soil profile of the surrounding ground is composed of the following strata : 10m depth filled soil (N-value=10~15), 30m depth alluvium soil (N=30~50), the base soil (N>50).

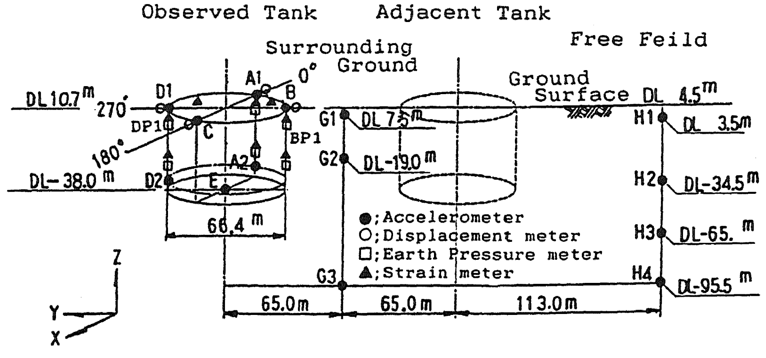

Fig.1 Earthquake Observation System

Table.1 Earthquakes used in this study

Earthquake Name	Date	M	D (km)	Δ(km)
KANTOU-NANBU	'83.2.27	6.0	72	52
NIHONKAI-CHUBU	'83.5.26	7.7	14	537
KANAGAWA-YAMANASHI	'83.8.8	6.0	22	92
TORISHIMA-KINKAI	'84.3.6	7.9	452	688

SUMMARY OF RECORDED EARTHQUAKE MOTIONS AT THIS SITE

Statistical analyses of the maximum values of recorded motions were performed. The relationship between the max. acc. on the ground surface and the max. acc. at the base (DL-95.5m), and the relationship between the max. acc. at the top of the tank and the max. acc. at the base are shown in Fig.2. Fig.3 shows the relationship between the max. disp. at the top of the tank and the max. acc. at the base.

Remarks about these figures are as follows :

(1) The amplification ratio of the max. acc. on the surface to at the base is about 3.8.

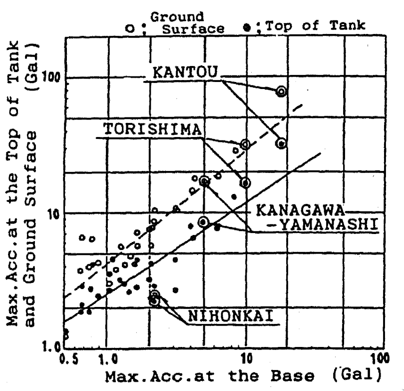

Fig.2 Relationship of Max. Acc. between at the Base and at the top of the Tank, and on Ground Surface

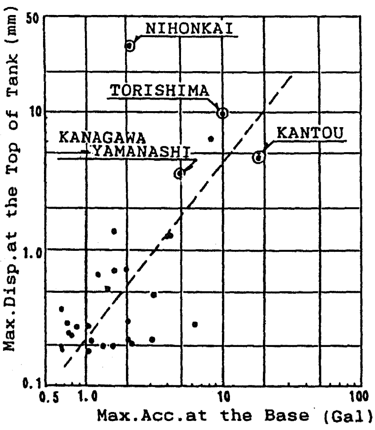

Fig.3 Relationship between Max. Acc. at the Base and Max. Disp. at the top of the Tank

(2) The amplification ratio of the max. acc. at the top of the tank to at the base is about 1.3. These facts seem to be caused by a kind of "Input-Loss" due to the structure-soil interaction effects.
(3) In the case of the Nihonkai Earthquake, the amplification ratio of the max. acc. of the top of the tank to at the base is about 1.0.

Therefore, the tank and the surrounding soil move similarly under the semi-long period earthquake motion. It is necessary to pay attention that the ratio of the maximum displacement to the maximum acceleration under the semi-long period earthquake is greater than the ratio under short period earthquake.

Distinguishment between wave groups in Nihonkai Earthquake In the ground motion of the Nihonkai Earthquake, semi-long period components (T=8~9 sec) are dominant. This is probably caused by the shallow depth of the hypocenter and the long epicentral distance of this earthquake. It was tried to distiguish between wave groups, which are , body wave and surface wave (i.e. Rayleigh wave or Love wave). Fig.4 and 5 show the horizontal and vertical particle orbits of the filtered surface ground motion and the dispersion curve of Love wave at this site.

As a result, it is understood that this ground motion is regarded as a surface wave, especially Love wave, because the particle orbit moves mainly on the horizontal plane and the predominant period coincides with the dip period of the fundamental mode of group velocity in dispersion curve.

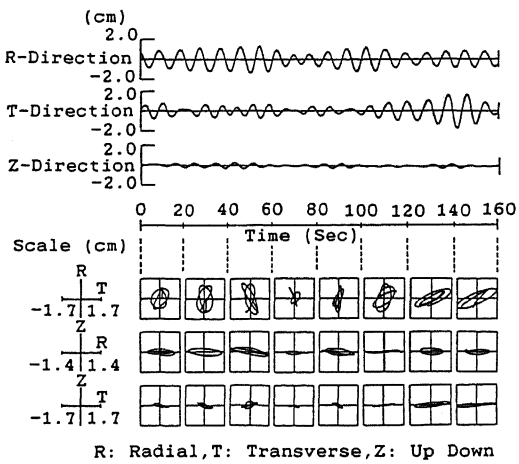

Fig.4 Particle Orbits of Filtered Wave (0.1~0.15Hz) G1

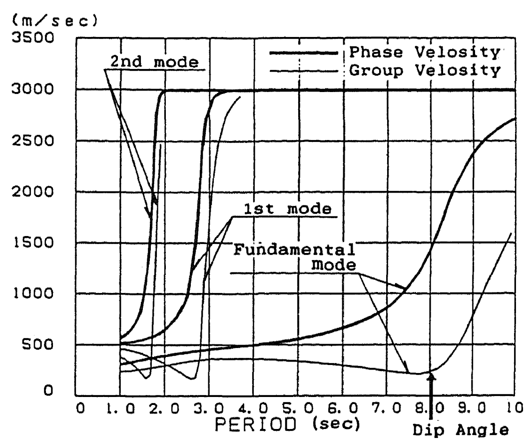

Fig.5 Dispersion Curve of Love Wave

EXERMINATIONS OF THE DYNAMIC EARTH PRESSURE

Background In aseismic design of in-ground structures, the "Seismic Deformation Method" is generally used, because it is known that dynamic behavior of in-ground structures depends on the displacement of the surrounding soil. In this method, the dynamic earth pressure is expressed by multiplying the coeffi--cient of soil reaction by relative displacement. In this study, the several examinations are carried out in order to verify this basic concept by using the actual data.

Relationships between maximum values It is shown in Fig.6 that the relationship between the maximum dynamic earth pressure on the side wall and the max. relative displacement between the tank and the surrounding ground. Fig.7 shows the relationship between the max. dynamic earth pressure and the max.

absolute acceleration in the surrounding ground. From these figures, it is found that the max. dynamic earth pressure has stronger correlation with the max. absolute acceleration rather than with the max. relative displacement. This trend seems not to be enough to explain the basic concept behind the "Seismic Deformation Method".

Characteristics of dynamic earth pressures Fig.8 and 9 show the time histories and the Fourier spectra of the top of the tank (B), dynamic earth pessure(BP1) and the surrounding ground (G1). From Fig.8, the followings are recognized:

(1) The short period components in the earth pressure time history are similar to those in the acceleration.

(2) The earth pressure time history contains also the long periods components.

(3) The Fourier spectrum of the earth pressure has two peaks, one is about 0.1Hz and the other is about 2.0Hz. The former coincides with the predominant frequency of the disp. spectrum, and the latter coincides with that of the acc. spectrum. Consequently, characteristics of the dynamic earth pressure have both characteristics of the acceleration and the disp-lacement. Similar characteristics can be found in Fig 9,but not so clear.

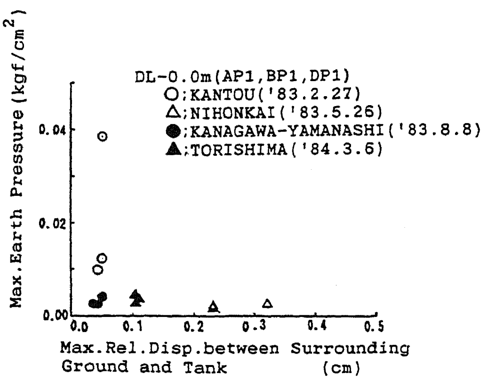

Fig.6 Relationship between Max. Earth Press. and Max. Relative Disp.

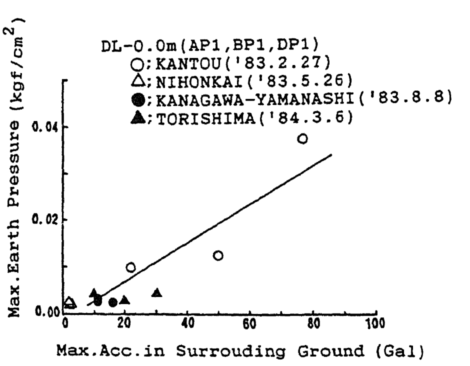

Fig.7 Relationship between Max. Earth Press. and Max. Acc.

New expression of the dynamic earth pressure Fig.10 shows the correlation between the earth pressure and the relative displacement by using filtered time histories (1.0-3.0Hz), and Fig.11 shows the correlation between the earth pressure and the absolute acceleration by using filtered time histories (1.0-3.0Hz). They have strong correlations. Therefore,the dynamic earth pressure should be a function of both the relative displacement and the absolute acceleration.

$$P = k \cdot y - m \cdot x$$

where,
- P : dynamic earth pressure (kgf/cm^2)
- k : coefficient of soil reaction (kgf/cm^3)
- m : added mass factor ($kgf \cdot sec^2/cm^3$)
- y : relative disp. (cm)
- x : absolute acc. (cm/sec^2)

CONCLUSION REMARKS

Two aspects of the aseismic design of the in-ground tank were examined. As a result,the following conclusions are obtained.

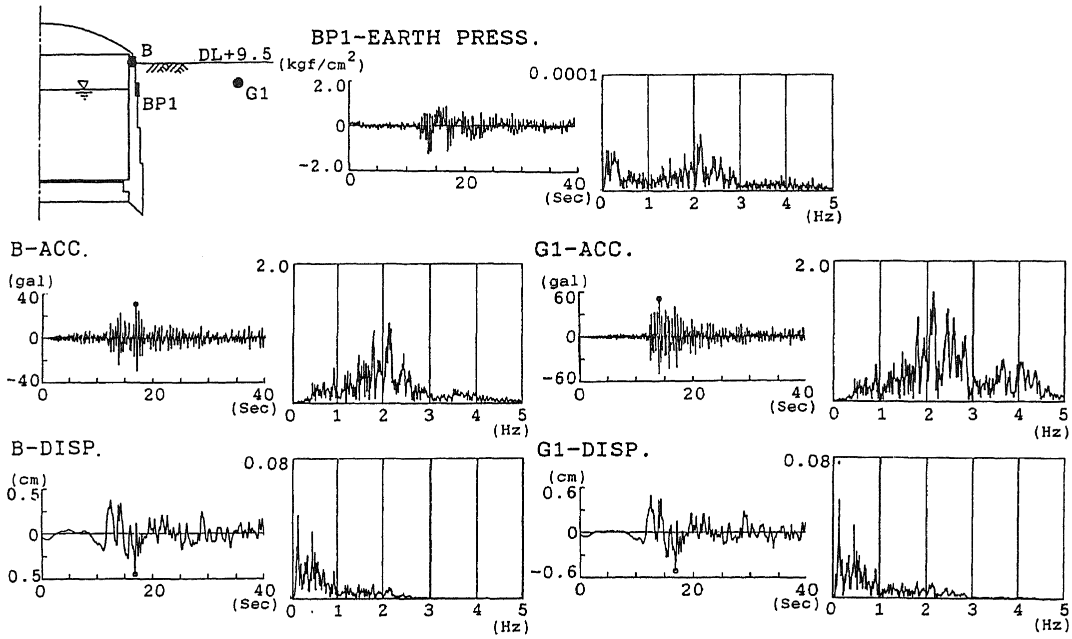

Fig.8 Time Histories & Fourier Spectra of KANTOU-NANBU(1983.2.27)

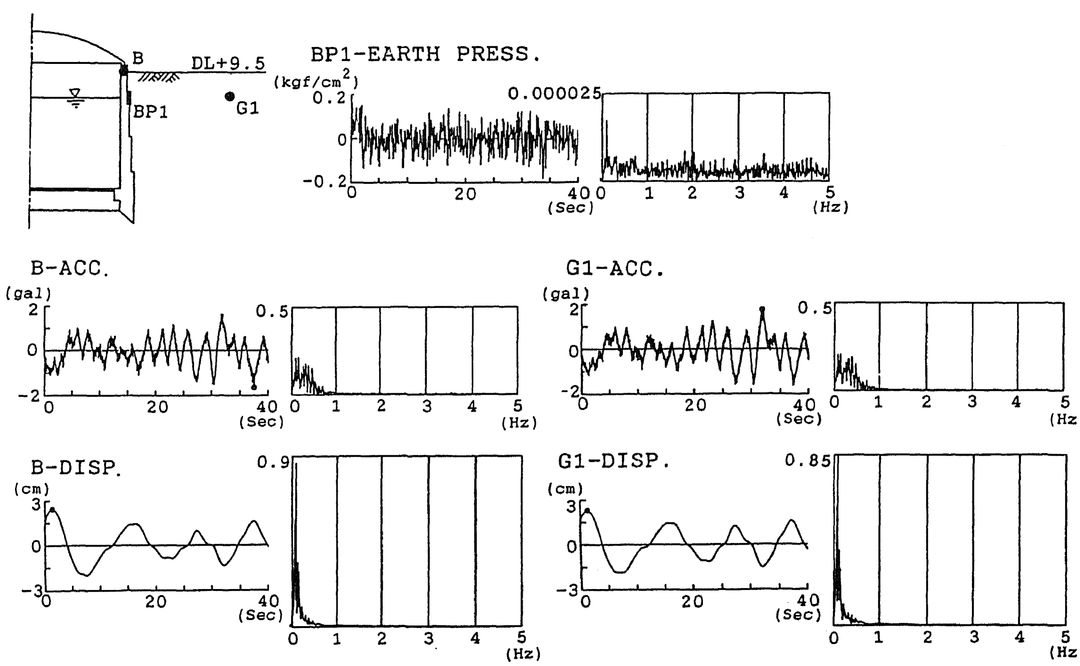

Fig.9 Time Histories & Fourier Spectra of NIHONKAI(1983.5.26)

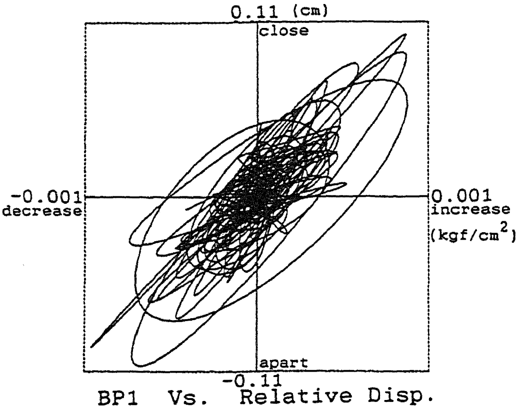

Fig.10 Relationship between Earth Press. and Relative Disp.

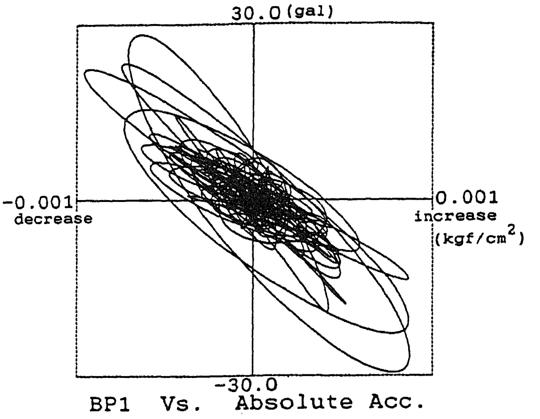

Fig.11 Relationship between Earth Press. and Absolute Acc.

(1) In the aseismic design of in-ground tanks, the semi-long period ground motion is not significant without for sloshing problem. However, in the design of the plumbing system, this semi-long period ground motion has to be taken into account.

(2) The dynamic earth pressure against the side wall of the tank is correlated not only with the relative displacement, but also with the absolute acceleration. And, the new expression of the dynamic earth pressure is proposed.

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