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Buckling of a Model Cylindrical Tank Subjected to Prototype Earthquakes

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INTRODUCTION

This paper includes a brief description of the correlation between the observed buckling damage of a cylindrical ground supported liquid storage tank made of steel and predictions made by an empirical approach proposed by the author. The model tank is located at Chiba Experimental Station of the Institute of Industrial Science of the University of Tokyo. As reported by Shibata et. al. {1}, the phenomenon of frequent moderate earthquake occurence at the Kwanto loam volcanic sediment was exploited in order to subject a number of model tanks to prototype earthquakes. The cylindrical tank to be studied in this paper was designed in such a way so that certain response parameters would be amplified even for moderate earthquakes in order to be easily recorded. Although a detailed description is given in references {1} and {2} a brief description of certain parameters is repeated here.

Fig. 1 depicts the basic structural characteristics of this model; it is 3800mm diameter and is filled with water up to the level of 4300mm. The tank wall thickness is equal to 1.6mm from almost all the wall height apart from the lowest shell course near the bottom with a height of 370mm that has a thickness of 3.2mm. Although there are at the bottom shell course eight anchor bolt locations these are not in use and the tank is essentially free to uplift from its reinforced concrete base that is supported to the ground by piles (Fig.1).

CHARACTERISTICS OF THE EARTHQUAKE OF 25th SEPTEMBER 1980

As discussed by Shibata et. al. {1} this model tank showed clear indications of shell wall buckling that although they were observed at a lated date they are associated with the earthquake of September 25th, 1980 that had a magnitude of M=6.1 and occured 13.3 km south-east of the Chiba Experimental Station. Most of the instrumentation connected to the model tank was over-scaled by this earthquake. However, a clear recording was obtained of the ground motion near the tank by a SMAC-Q type Strong Motion Recorder. A digitised decord was produced from a magnification of this recording and the first twenty seconds of this ground motion are depicted in the time history plots of the two horizontal and one vertical components (Figs.2,3 and 4). Based on this digitised record, response spectral curves were produced that are shown in Figs. 5,6,7 and 8.

DYNAMIC CHARACTERISTICS OF THE MODEL

Shibata et.al. {1} have also performed forced vibration tests for this model by using an unbalanced mass type exciter; in this way various low as well as high order modes were indentified. The frequency of the fundamental mode was found to be in the range from 3.6 Hz to 4.4 Hz. The frequencies of some of the higher order circumferential modes were found to be in the range from 5 Hz to 13 Hz. The magnitude of the initial imperfections of the model tank wall is not exactly known, however they are expected to be within practical tolerable limits.

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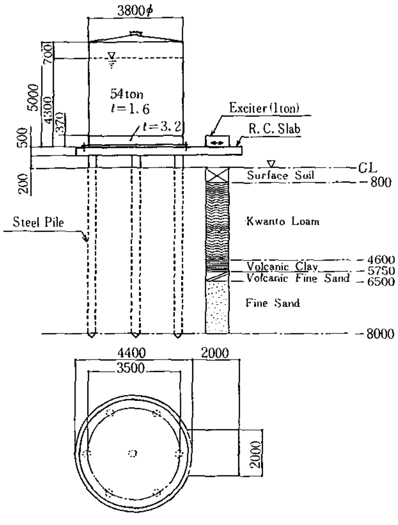

Fig.1 Model Tank
(Reproduced from {1})

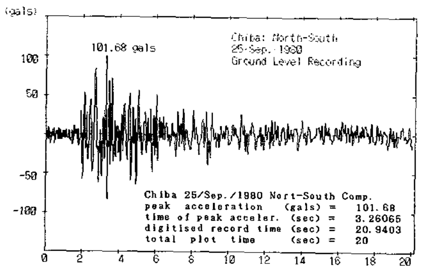

Fig.2 Digitised North-South
Acceleration Record

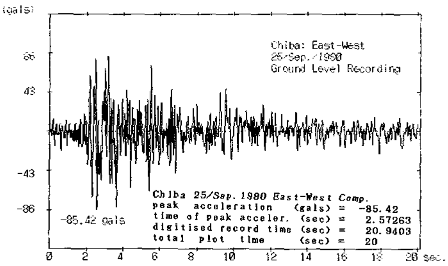

Fig.3 Digitised East-West
Acceleration Record

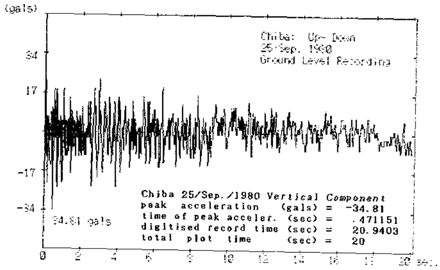

Fig.4 Digitised Vertical
Acceleration Record

EVALUATION OF THE OBSERVED PERFORMANCE

The observed shell buckling was located at the portion of the tank wall with thickness equal to 1.6 mm, approximately 410mm to 450mm from the tank bottom and 40mm to 80mm from the welding line between the buckled shell and the lowest shell course with thickness equal to 3.2 mm.

The procedure proposed my Manos {3} is employed to evaluate the wall stability of the model tank. For this purpose values of the Ceq coefficient were obtained for shell wall thicknesses assuming in both cases the same liquid height. The results are listed in Table **1**. As proposed in reference {3} in order to evaluate the earthquake tank wall stability the values of the Ceq coefficient must be compared with relistic estimates of the impulsive acceleration coefficient (Cex). The stability criterion is expressed by equation 1.

$$Ceq/Cex > 1 \qquad (1)$$

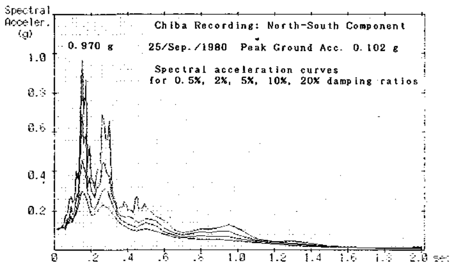

Fig.5 Acceleration Response Spectra North-South Component

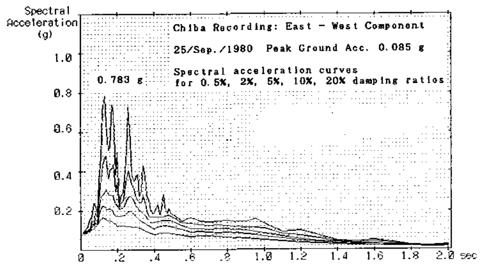

Fig.6 Acceleration Response Spectra East-West Component

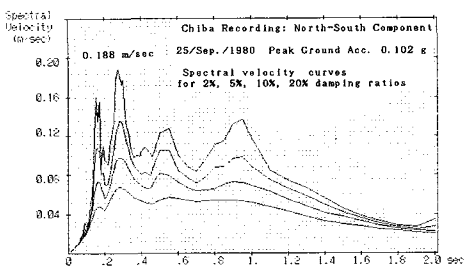

Fig.7 Velocity Response Spectra North-South Component

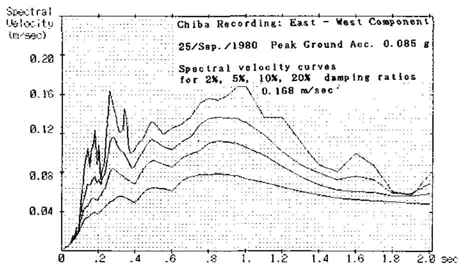

Fig.8 Velocity Response Spectra East-West Component

In the case of the earthquake of September, 1980 two values of Cex are obtained, namely (Cex)peak and (Cex)EPA, using the digitised record and employing an amplification factor of 4.3 {3}. (Cex)peak is obtained by multiplying this amplification factor with the square root of the sum of the squares (SRSS) of the peak acceleration of the two horizontal components whereas (Cex)EPA is obtained by multiplying 4.3 with the SSRS of the effective peak acceleration values of the two horizontal components. These Cex values are also listed in Table 1 together with the values of the corresponding rations representing the stability criterion values (equation 1). As can be seen from this Table the above stability criterion is successfull in predicting the buckling of the shell with thickness equal to 1.6 mm as well as the safe performance of the shell with thickness equal to 3.2 mm.

Table 1 Evaluation of the Earthquake Performance by the Ceq stability coefficient

	Ceq (g)	(Cex)peak (g)	Ceq / (Cex)peak	(Cex)EPA (g)	Ceq / (Cex)EPA	Remarks
Thickness of Shell 3.2 mm	2.198	0.571	3.849>1	0.516	4.260>1	failed
Thickness of Shell 1.6 mm	0.513	0.571	0.898<1	0.516	0.994<1	failed

CONCLUSIONS

1. The correlation between the expected performance of the tank wall by the approach proposed by the author and the observed performance is very good.

2. The change of wall thickness at the level of 370mm from the ground is a discrepancy between the model tank and prototype tanks. Its influence on the observed performance is not covered by the present study.

3. This model tank facility at Chiba Experimental Station provides very useful information for studying the behavior of liquid storage tanks subjected to prototype earthquake conditions.

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