Aseismic Performance of Compact Cylindrical LNG Storage Tanks

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ABSTRACT

This paper deals with the experimental and theoretical research results on the aseismic performance of both vertical and horizontal type compact cylindrical storage tanks, whose capacity is less than 250kl, for LNG satellite bases.
This research was conducted by the committee, which consisted of members from university professors, gas utility companies and fabricators in Japan and was organized by the Center for Promotion of Natural Gas, as commissioned by the Ministry of International Trade and Industry.
The testings using three one-half-scaled models of the actual tanks on the shaking tables, and the analyses using the mass-spring models for seismic performances of the tanks were made. The spring effect of the granular perlite thermal insulation was clarified, and a simplified calculation model of the tank for seismic response analysis has been established. Furthermore, the existence of the sufficient seismic analysis margin for the maximum seismic loading considered in current design was proven. And these results will contribute to establish a new design guidline.

1 INTRODUCTION

In Japan, as the use of LNG have been increased rapidly for these two decades, investigations and establishments of new guideline on the LNG storages and facilities have been developed actively as follows:

- 1979 Recommended Practice for LNG Inground Storages
- 1981 Recommended Practice for LNG Aboveground Storages
- 1986 Recommended Practice for LNG Facilities
- 1985-1988 Committee on Technical Investigation for Compact Cylindrical LNG Storage Tank
- 1988 Guideline for Compact Cylindrical LNG Storage Tank
- 1988-1990 Committee on LNG Aboveground Prestressed Concrete Storage Tank
- 1990 Guideline for LNG Aboveground Prestressed Concrete Storage Tank

The subject of this presentation is to report the result of the work conducted during 1985-1988 by the Committee on Technical Investigation of Compact Cylindrical LNG Storage Tanks. The committee was organized in the Center for Promotion of Natural Gas as commissioned by the Ministry of International Trade and Industry. The Chairman was H. Shibata, one of the authors of this paper and the Chairman of the Working Group was H. Akiyama, one of the authors of this paper. The members were composed of university professors,government officials and engineers from gas utility companies and

related companies.
The objectives of the work are as follows:

(1) To investigate the dynamic properties and to get the technical data for anti-earthquake design analysis of the tank.
(2) To clarify the effect of granular perlite insulation to the dynamic characteristics.
(3) To investigate the seismic resistant margin for safety of the tank.

2 FLOW OF RESEARCH

2.1 Preliminary Analysis

First the investigation was conducted on compact cylindrical tanks actually existing in Japan. Based on the investigation, their dynamic characteristics were analyzed. However, the dynamic properties of granular perlite were parametrically surveyed in the analysis.

2.2 Dynamic Test of Perlite

In order to grasp the static and dynamic properties of perlite as a granular material, various static and dynamic tests on perlite were carried out. These tests included compacting test, static tri-axial compression test, dynamic twisting test and shear wave travelling velocity test. Through these tests the compactibility, the static stress-strain relationship and the dynamic properties such as the elastic modulus and the damping ratio were measured quantitatively.

2.3 Vibration Test of Scaled Tank Model

Considering the results of the preliminary analysis on actual tanks and the dynamic test on perlite materials, the proto-type tanks for vibration tests were assumed. The models were designed as one half of the vertical and horizontal proto-type tanks above. The details of the vibration tests will be mentioned later.

2.4 Comparison between Test and Analysis

The experimental results were compared with those by the mass-spring model analysis, taking into account the interaction between the filled perlite and the both walls of the tanks. Various kinds of calculation model were evaluated in the view-point how they agreed with the experimental results. The design margin was examined by comparing the experiment and the elasto-plastic analysis.

2.5 Simplified Calculation Method

From the results of the model analysis the simplified equations appropriate for the practical use were derived.

2.6 Seismic Design of Actual Tank

By using the simplified calculation method the seismic safety of actual tanks was checked, and from those results the anti-earthquake design of actual compact cylindrical LNG storage tanks was established.

3 VIBRATION TEST

3.1 Model

The models are the following three one-half scaled ones the proto-types of which have the capacity of $40m^3$:

- two vertical models supported by inner and outer legs
- one horizontal model supported by inner legs and outer saddles

To check the influences of perlite filled between the both walls, the cases with perlite of density $85kg/m^3$ and $100kg/m^3$ and without perlite were experimented. Water was used instead of LNG.

3.2 Method

The experiments were conducted with respect to the items shown in Table 1. The main results are summarized from 3.3 to 3.5.

Table 1 Items in Vibration Test

Item		Measurement	Note
Preliminary test	Grain-size distribution test	Grain-size distribution before and after vibration tests	Grain-size change due to vibration
	Static test	Strain of supports	Relationship between earthquake forces and support strains
Free vibration test		Acceleration of inner and outer tanks	Natural frequency and damping ratio
Sweep test		Acc. and disp. of inner and outer tanks, Strain of supports, Pressure of perlite	Natural frequency, natural modes and damping ratio
Earthquake response test	Design level	ibid	Response amplification factor and interactive force between walls
	High level	ibid	Behavior after support yielding
	Horizontal Vertical	ibid	Influence by vertical motion

3.3 Vibration Characteristics of Tank

As shown in Fig. 1, the inner and outer tanks of the vertical tank models vibrate almost in the same phase and nearly to one degree of freedom system, although there are slight differences between both response waves. On the other hand, in the horizontal tank model as shown in Fig.2, both inner and outer tanks vibrate almost in accordance with the earthquake wave, which are alike rigid-body response motions.

3.4 Effect of Perlite

Among various effects of perlite on the vibration behaviors of tank, the most important one is the spring effect. It means that the perlite filled between both walls of inner and outer tank plays a role to combine both tanks as a whole, as shown in Fig. 3. From this viewpoint, the effects of perlite are expressed as follows:

(1) The Young's modulus of perlite is estimated to be at least 5 kgf/cm^2.
(2) The filled of perlite increases the natural frequency of tank almost by 10% in the case of vertical tank, but do not so much in the case of horizontal tank.
(3) The horizontal seismic force of the inner tanks transmitted to the outer tanks through the perlite approximately by 30% in the case of vertical tank, but by 10% in the case of horizontal tank.
(4) The transmission of horizontal seismic force through the perlite becomes more significant when the inner supports are yielded.

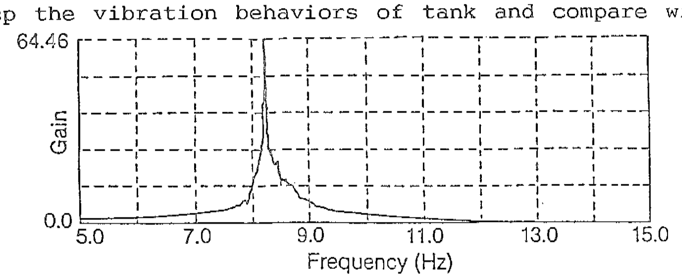
3.5 Seismic Safety Margin of Tank

The models were designed at the level 0.27g of the horizontal input acceleration. In the tests the behaviors of tank were investigated against the input acceleration up to 0.8g over the design level. Even in such situations the models could stand in satisfactory condition, however the inner supports were yielded partly.

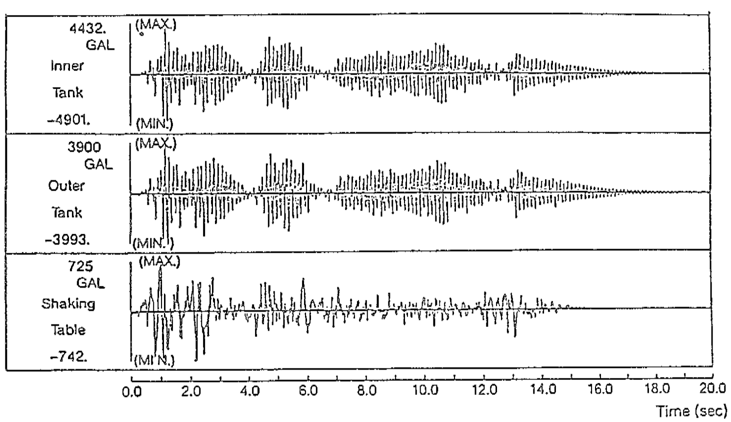
4 METHOD OF ANALYSIS

4.1 Fine Analysis

First, in order to grasp the vibration behaviors of tank and compare with



(a) Sweep Test



(b) Earthquake Response Test

Fig. 1 Results of Vibration Test (Vertical Tank)

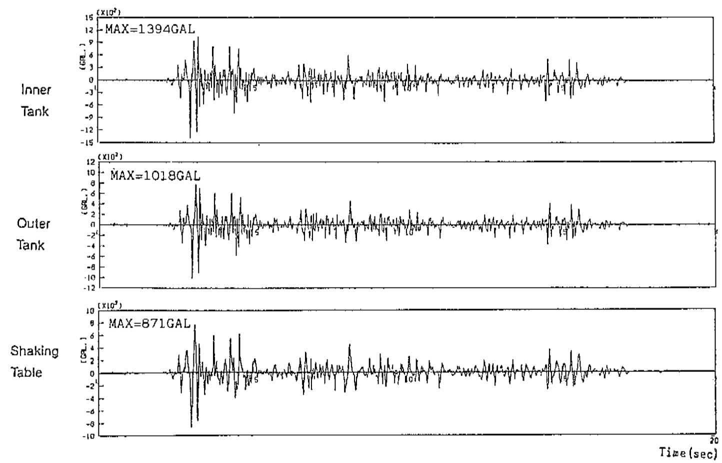


Fig. 2 Result of Vibration Test (Horizontal Tank)

the experiments, fine analysis models with six degrees of freedom were adopted, as shown in Fig. 4. However, by comparing the theoretical results with those of experimental it was found that the response of tanks is near to the one degree of freedom system and it may be replaced to by more simplified method.

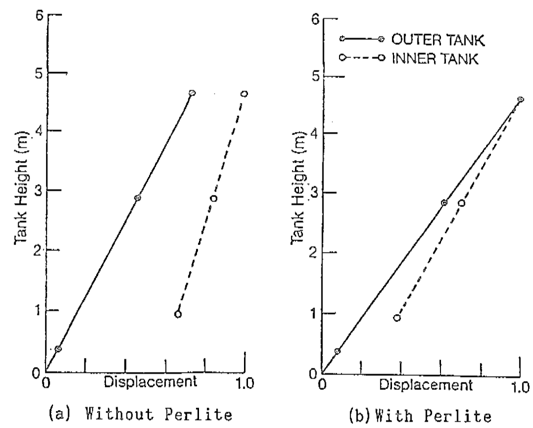


Fig. 3 Vibration Modes of Vertical Tank

4.2 Simplified Analysis

The simplified analysis model finally proposed for the seismic design is illustrated in Fig. 4, too.
These are derived from considering the vibrational characteristics of tank, in which the simplifying to the one degree-of-freedom system is enough and the dynamic effect of perlite may be assumed to be rigid. If it should be necessary to be considered, the fine analysis has only to be applied.

5 CONCLUSION

From these three years research project, the following conclusions are obtained for the anti-earthquake design of compact cylindrical LNG storage tanks.

(1) A simplified response calculation method for anti-earthquake design of compact cylindrical LNG storage tanks is proposed, including the effect of granular perlite insulation.
(2) It is clarified that the granular perlite insulation shares the seismic force partically, and it is expected that the granular perlite insulation decreases the seismic force acting on the supports of the inner tank.
(3) It is verified that these types of tanks have the sufficient seismic resistant margin, if designed based on the guideline.

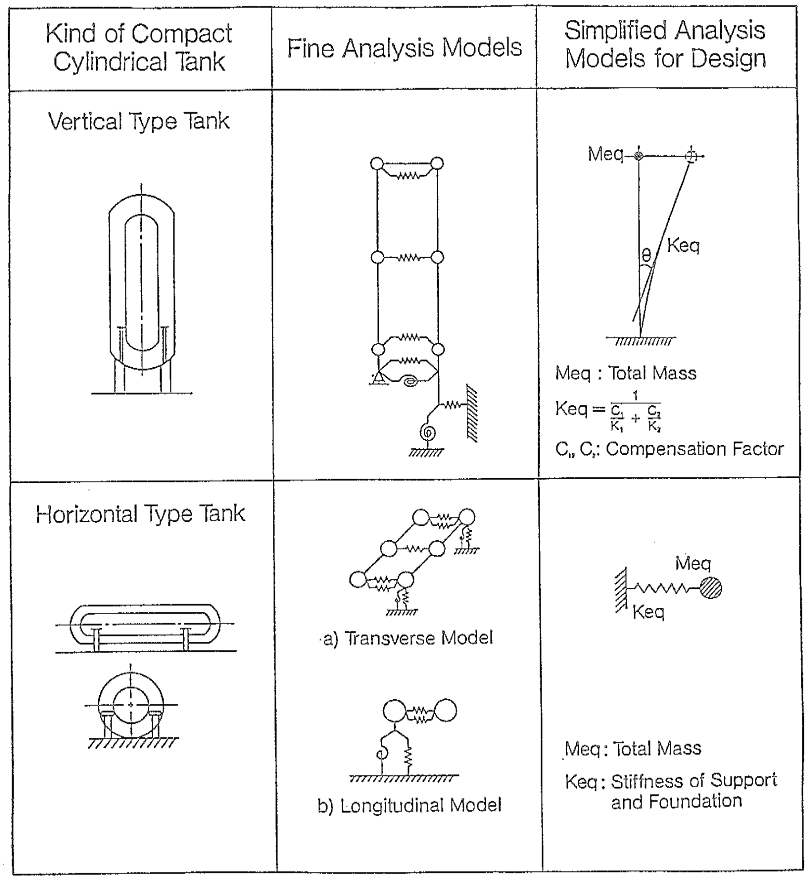


Fig. 4 Analysis Models for Anti-Earthquake Design

6 ACKNOWLEDGEMENTS

This research work was conducted with the heavy cooperative works of the members in the Committee on Technical Investigation of Compact Cylindrical LNG Storage Tanks in the commission of the Ministry of International Trade and Industry (MITI). The authors express their sincere appreciations to the helps of all the related people.