Journal of Japan Association for Earthquake Engineering, Vol.4, No.3 (Special Issue), 2004

SEISMIC PROVING TEST OF EQUIPMENT AND STRUCTURES IN THERMAL CONVENTIONAL POWER PLANT

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ABSTRACT: The importance of ensuring uninterrupted electric power supply was reaffirmed on the occasion of the Hyogoken-Nanbu Earthquake in 1995, when the district was affected by extended power failure. The notice has been attached to the resistance of power generation facilities to severe earthquake. The seismic proving test of equipment and structures in thermal conventional power plant was conducted.

Key Words: seismic proving test, thermal conventional power plant, shaking table test, LNG tank, tank nozzle, pile foundation of tank, boiler structure

INTRODUCTION

The importance of ensuring uninterrupted electric power supply was reaffirmed on the occasion of the Hyogoken-Nanbu Earthquake in 1995, when the district was affected by extended power failure. In Japan, there are about 50 liquefied natural gas (LNG) tanks on the ground (excluding tanks for city gas) that store LNG, one of the fuels used for thermoelectric power generation. Fortunately, none of them has been damaged by earthquake, but its importance has been attached to the resistance of power generation facilities (especially LNG tanks) to severe earthquake since the Hyogoken-Nanbu Earthquake.

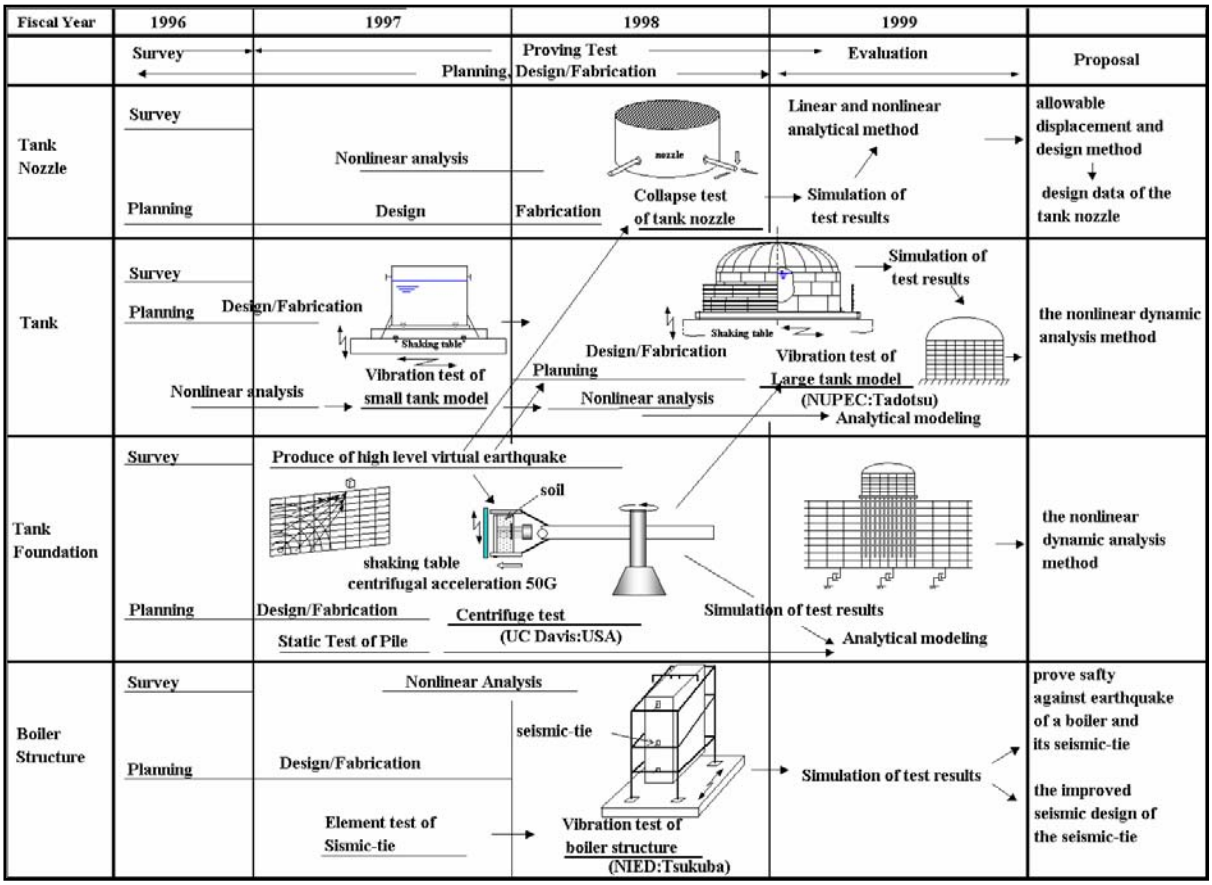
This experience has led the Ministry of International Trade and Industry (MITI) to initiate a series of surveys and tests to ascertain the resistance of thermal generating plants to severe earthquake excitation. The Ministry established a committee named **S**eismic **P**roving Test of Equipment and Structures in **T**hermal Conventional Power Plant (SPT). SPT committee had operated by Japan Power Engineering and Inspection Corporation (JAPEIC) since October 1996 until March 2000, as shown in Table 1.

The seismic proving test of equipment and structures in thermal conventional power plant was carried out. LNG storage tanks installed on the ground (tank, tank nozzle, pile foundation of tank) and boiler structures were selected as the subjects of SPT. In the seismic proving test, vibration tests and analysis were conducted. Based on the results of the analyses and the evaluation of test results, the analytical methods were established for the following:

- Dynamic behavior of the liquid-filled tank in severe earthquakes
- Dynamic behavior of tank-pile-soil interaction in severe earthquakes
- Collapse mode of the tank nozzle
- Dynamic characteristics of seismic tie of the boiler structure

Then the seismic evaluation on the LNG tank and boiler structures was performed by the above. With the comprehensive evaluation of tests and analyses, the seismic capability of LNG tank and boiler structures was assessed for severe seismic excitation.

Table 1 Seismic Proving Test on Equipment and Structures of Conventional Thermal Power Plant



SEISMIC PROVING TEST

Tank

Vibration tests and analyses have been conducted to prove the safety of LNG tanks under severe earthquakes and to establish an analysis method for nonlinear behavior of a tank. Under a severe earthquake, the focus of nonlinear behaviors of a LNG tank was on the elephant foot bulge (EFB) and side slipping. Small tank model tests were conducted. Based on the results obtained from the small model tank tests, dynamic testing was performed on a large tank under conditions closer to the actual plant. The 1/8 actual tank size model (Photo 1), made of steel, measured 8 m in diameter and 3.89 m in wall height. Plate thickness was 4.5 mm for wall and for the bottom periphery (0.5 m wide band), and 20 mm for the main central part. The bottom plating was thickened in this part by bolting it to the shaking table floor. The anchor straps prevented uplift. A large tank model test using the large shaking table of the Nuclear Power Engineering Corporation (NUPEC) at Tadotsu was carried out. Comparison of the results of FEM analysis with test results substantiated the applicability of nonlinear FEM analysis to

nonlinear tank behavior. The studies on storage tanks covered the nonlinear phenomena of EFB which affects the lower part of tank wall and lateral slip of the tank body, regarding which verification was sought on the validity of the form applied for analyzing these nonlinear phenomena.

Tank Foundation

Survey of the previous studies on seismic records and design seismic ground motions were conducted. Thus, the severe earthquake motion for the seismic proving tests was set up. In the test of the tank foundation, the large centrifuge earthquake simulator of University of California at Davis was used to carry out a series of shaking table tests under 50*g* centrifugal acceleration on the 1/50 scaled tank structure with piled foundation constructed on the model multi-layered ground. The test model was shown in Photo 2. It was found out that the piled foundation used for LNG tank structure could be used or remain functional even after a severe earthquake. The reliability of the nonlinear response analysis to ground and foundation response during the severe earthquake and the applicability of the previous design method for pile foundation under the severe seismic load were evaluated. As an analysis from the above, 2-D FEM method and nonlinear frame method were proposed.

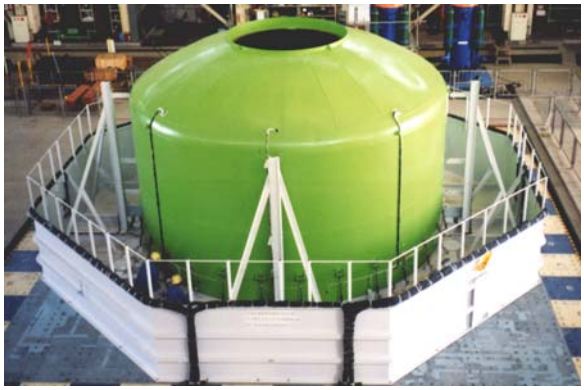


Photo 1 Vibration Test of Large Tank Model

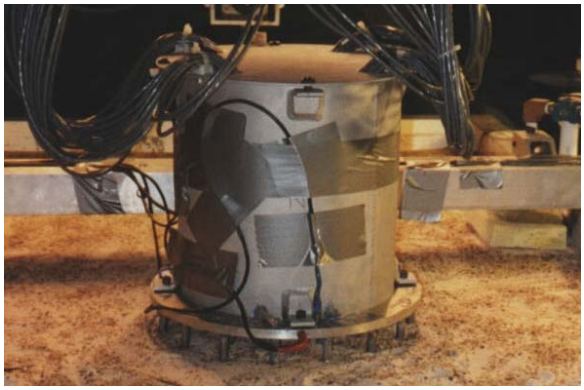


Photo 2 Centrifuge Test of Tank Foundation

Tank Nozzle

Research of the earthquake damages and calculation of the stress at nozzle were conducted. Damage modes of nozzle were estimated. The reaction moment due to the inclination of the tank wall by the dynamic fluid pressure and the movement of the pipe by the slip and the up-lift of the tank were selected as a loading for the proving test.

As a part of a series of proving test, static tests of the nozzle were conducted. The diameter of the tank was 3870mm, which is about 1/15 of the actual tank size as shown in Photo 3. From the test result, it is considered that the typical type of nozzle is considered as safe from leakage under the severe earthquake. The nonlinear behavior of the nozzle, the relations between moment load and deformation or strain were compared with FEM analysis to prove the applicability of an analyzing method. The linear analysis method using Bijlaard's theory and nonlinear FEM analysis considering material nonlinearity and geometrical nonlinearity are a useful tool for the design of nozzle.

Boiler Structure

An actual boiler is suspended from the top of the support structure for unrestrained thermal expansion during operation. In order to restrain horizontal movement during an earthquake, they are connected at certain points by the seismic ties. Seismic ties are important devices for the seismic design of a boiler structure. These functions are to protect the boiler from damaging pressure parts by energy dissipation due to inelastic deformations of the tie. Furthermore, the characteristics of ties and their arrangement give great influence to seismic response of the overall structure.

In the proving test of boiler structure, elementary tests were conducted to investigate the behavior of seismic ties. The vibration tests were carried out by using a scaled model of boiler structure (8.3m in height, 4m in width and 4m in depth) on the large shaking table of the National Research Institute for Earth Science and Disaster Prevention (NIED) at Tsukuba. Test model was shown in Photo 4. It has been confirmed that seismic ties possess almost the same dynamic characteristics, sufficient deformation capability and enough durability against severe earthquake. A softening of seismic ties and efficiency of optimum design method were proposed.

Photo 3 Collapse Test of Tank Nozzle

Photo 4 Vibration Test of Boiler Structure

CONCLUSIONS

With the comprehensive evaluation of these tests and analyses, the seismic capability of LNG tank and boiler structure was assessed. The results and proposal of the seismic proving test of tank, tank foundation, tank nozzle and boiler structures are summarized as follows:

Tank
- Prove the safety of LNG tank under severe earthquake
- Evaluation and proposal of the nonlinear dynamic analysis method of the tank

Tank foundation
- Prove the seismic performance of tank foundation during severe earthquake
- Evaluation and proposal of the nonlinear dynamic analysis method of soil-structure interaction

Tank nozzle
- Confirm the damage mode of the tank nozzle
- Proposal of the analytical method of the tank nozzle

Boiler structure
- Prove safety of seismic ties in the boiler structure
- Proposal of the design method of seismic tie and softening method of boiler structure

The results of the SPT project have been reported in 50 papers (19 papers were in Japanese and 31 papers in English). These papers are listed in References.

ACKNOWLEDGMENT

These tests and analysis had been planned, and were being pursued, under the SPT Committee. The Committee Chairman, Professor Emeritus Heki Shibata of the University of Tokyo, the tank-subcommittee Chairman, Professor Hiroshi Akiyama of Nihon University, the boiler-subcommittee Chairman, Professor Kohei Suzuki of Tokyo Metropolitan University and members of the Committee had been accorded unreserved guidance and invaluable advice in the course of planning and implementation of the work. The present authors express their grateful appreciation of the invaluable assistance afforded to them in their work.

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(Submitted: June 5, 2004)
(Accepted: June18, 2004)