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TEST OF NOZZLES AT WALL OF CYLINDRICAL TANK FOR SEVERE LOADS UNDER EARTHQUAKE

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SUMMARY

As part of a series of test for proving the resistance of thermal power plant installations to severe earthquake, static tests for nozzles installed at sidewall of cylindrical tank were conducted on reduce-scaled model of liquefied natural gas (LNG) storage tank. Test loads were reaction forces of piping affected by tank transformation, up-lifting, slipping and wall incline due to dynamic hydraulic pressure. These are the most effective loads from the result of the dynamic and static analyses of typical LNG storage tank and piping in Japan. In the test, tank was pressurized by water and load from piping was given by hydraulic jack statically in order to simulate the state of the stresses around the nozzle under earthquake. From the test result, it is considered that the typical type of nozzle on sidewall of LNG storage tank is considered as safe from leakage under the severe earthquake. Secondary, the nonlinear behavior of the nozzle in the wall of cylindrical tank, the relations between moment load and deformation or strain are obtained and compared with nonlinear FEM analysis to prove the applicability of a analyzing method.

INTRODUCTION

The importance of ensuring continuity of power supply under seismic disturbance was brought into evidence on the occasion of the Hyogoken-Nanbu Earthquake of 1995. This experience led the Ministry of International Trade and Industry (MITI) to establish a committee chaired by Emer. Prof. Shibata of University of Tokyo gathering specialists and representatives from utility companies and electrical manufacturers, to initiate the project named Seismic Proving Test of Equipment and Structures in Thermal Conventional Power Plant (SPT) to be performed in the period 1996-2000 covering a series of surveys and experiments for proving the resistance of thermal power plant installations to severe earthquake. We present four papers at 12 WCEE as the results of SPT project [Higuchi et. al., 2000], [Nishida et. al., 2000], [Tanaka et. al., 2000]

On such power plant installation - above-ground storage tanks - are the subject of study in the above project. Together with the proving tests of the tanks and the foundation performed in the above project, we pay attention to the nozzle. At the nozzle, the piping and the storage tank are connected, and under the earthquake, seismic loads both from tanks and piping will affect to the nozzles. At the nozzle under earthquake, the leakage of the contents is the main subject. There were no reports about the leaking damage from the nozzle in the above-ground storage LPG or LNG tanks, except for the bolted flange next to the nozzle of LPG storage tank by detrimental land slide due to the liquefaction near the sea side in Hyogoken-Nanbu Earthquake [The High Pressure Gas Safety Institute of Japan, 1995]. This proving test was done targeting the inlet or outlet nozzle in the bottom part of the wall of cylindrical storage tank. The example of the nozzle in LNG tank is shown in Figure 1.

The purpose of this proving test is to verify the damage mode under the earthquake and acquire the verification data of the non-linear analysis. A proposal will be done about the method for evaluate the seismic resistance of the nozzle. For this purpose, the model tank with several nozzles was made and subjected to the loading tests.

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Figure 1: Nozzle in lng above-ground storage tank

NOMENCLATURE

M: bending moment affect to nozzle, M_e : elastic limit moment at welding section of nozzle and wall (without inner pressure), M_y : moment by vertical movement of piping (positive for downward), M_z : moment by horizontal movement of piping, P_y : tank wall yield pressure $(S_h=S_y)$, *r*: radius of tank, *R*: rotation angle of nozzle, R_e : rotation angle at M_e by linear analysis, S_h : hoop stress at tank wall, S_y : yield stress, *t*: thickness of tank wall, ε : Strain of material, ε_e : Strain at yield stress.

PRELIMINARY STUDY

We studied about the load that became large with the actual tank in the earthquake to decide load conditions in the proving test [Aiba et. al., 1999]. Linear seismic response analyses were done with the typical piping and tank selected from our research on the actual conditions of the plants in Japan. As a result, a loadings to take into consideration for the proving test was selected as follows:

(1) Reaction moment due to wall inclination by the tank dynamic fluid pressure response (M_v : cyclic load).

(2) A reaction moment when the slip of the tank occurred (M_z : monotonic load).

(3) A reaction moment when the up-lift of tank occurred (M_v: monotonic load).

These loads are the reaction forces of the piping by the tank's own earthquake response. And forces from piping, such as their seismic response or the forces by the relative displacement of foundation due to the liquefaction are seem to be small. This is because, from our research, there was no LNG tank that had different foundation of the tank with the first piping support from nozzle in Japan, the influence of the relative displacement by the liquefaction was small. In addition, it is considered that the pipings in LNG plants are designed to absorb deformation by the heat and have capacities for the displacement.

We also calculated the size of load from the typical tanks and pipings in Japan. Cyclic load range of seismic response will not exceed two times of elastic limit load. In case of the up-lift and the slip of tank, the maximum load will be two times of elastic limit load because the piping connected to the nozzle will become the plastic limit first when the moment load become two times of the elastic limit load.

PROVING TEST

The range of the loads in the test was decided from the estimated result of the loads shown above. The cyclic load range of the test considered the wall inclination response was made two times of the elasticity limit load (M_e) . And for the slip and the up-lift of the tank, more displacement was affected in the proving test. This is because we paid attention to the strength and the non-linear behavior to be compared with the analysis of the nozzle at the storage tank in the proving tests and not for the piping which strength and the behavior has been studied in the past and the design method have already established.

Test tank

The tank for the test is made as shown in Figure 2 (a). The main dimensions of the tank are shown in Table 1. The diameter of the tank was 3870mm of about 1/15 of the actual tank. WEL-TEN590RE (Nippon Steel) was selected for the material of the tank that could obtain as a thin material that a yield stress became near to the actual 9% Ni steel. The wall thickness was 2.3 mm to fit r/t to the actual tank as much as possible.

The shape of the nozzle of the test tank is shown in Figure 2 (b). The diameter of the nozzle was made scaled to the diameter of the test tank and the actual tank. And as mentioned above, the thickness of the piping connected to the tank was increased than the scaled model of actual tank, for increasing the equivalent strength not to break during the test.

Test cases

The test cases are shown in Table 2. In the tests of the monotonous loadings, case-1 to 3, rotation angle at the nozzle by the load from piping was made to be over 0.1 radian. It was about 4 times of the elasticity limit displacement, which was calculated by the linear FEM analysis, to clearly reveal the nonlinear behavior in the monotonous loading

In the test that considered the cyclic loading of seismic response, case-4 and 5, a ratio with the yield stress and the stress by the piping load or the internal pressure was made to correspond to the actual tank.



(a) Shape of test tank

(b) Nozzle of test tank

Figure 2: Test Tank

	actual tank	test tank
Material	9%Ni	WEL-TEN590RE
Standard Yield Stress (MPa)	590	450
wall thickness (mm)	28.3	2.3
Diameter of tank (mm)	59500	3870
Radius/thickness (r / t)	1051	841
Diameter of nozzle (mm)	900	58.5

Table 1: Main dimensions of test tank

Table 2: Test cases

Case	Type of	Direction	pressure	loading	subject
	Loading		(MPa)	range	
1	monotonous	$+M_y$	0	0.1rad	Lift-up of tank
2	monotonous	Mz	0	0.1rad	Slip of tank
3	monotonous	Mz	0.27 P _y	0.1rad	Slip of tank
4	cyclic	$\pm M_{y}$	$0 \Leftrightarrow 0.54 P_y$	$2M_e \times 10$	Wall inclination
5	cyclic	$\pm M_y$	0.27P _y	$3M_{\rm e} imes n$	Fatigue

Case-1

Case-1 was the test which partial up-lift of the tank was presumed. As a reaction force by the lift, downward moment $(+M_y)$ was loaded, and return after up-lifting was also took into consideration, a displacement was returned to the zero finally. Internal pressure became a zero because it is the negative side of the dynamic fluid pressure that the tank lifts, and the dynamic fluid pressure was exclude from the hydrostatic pressure. On the present assumption, the hydrostatic pressure and a dynamic fluid pressure are exactly equal (see Table 1).

Case-2

Case-2 was the test which a tank slip was presumed, and a moment (M_z : Horizontal direction) was loaded. Internal pressure was made as zero so that it could compare it with next case.

Case-3

Case-3 was the test that the slip of the tank was presumed, and a sideways moment (M_z) was loaded. For it was considered that a side slip became the biggest in the position of 90 degree from the earthquake direction, the internal pressure in the test was made equivalent to the hydrostatic pressure $(0.27P_y)$ and considered that the influence of the dynamic fluid pressure is ignored at that position when tank slipped.

Case-4

Case-4 was the test of simulating the repetition of the wall inclination by the dynamic fluid pressure in the earthquake. The cyclic load range due to the wall inclination was made 2 times of an elasticity limit load according to Table 1 and the loads were same in both positive and negative sides. The cyclic range of the inner pressure was made its hoop stress to 0.53 of the yield stress. The fluctuation of pressure and a piping load due to the dynamic fluid pressure took it into consideration as shown in Figure 3.

The inner pressure and the up-down direction moment (M_y) from the piping, the reaction force of the piping due to the wall inclination is fluctuated together. When the dynamic fluid pressure was a positive, the upward moment $(-M_y)$ was loaded and when the dynamic fluid pressure was a negative, the downward moment (M_y) was loaded. The number of cycles was made to 10, estimated as the major cycles in the severe earthquake.

O: Simulate Point



Note: Ps: equivalent to hydrostatic pressure. Pd: equivalent to dynamic fluid pressure.

Figure 3: Cyclic loading method in case 4

Case-5

Case-5 was the test for estimate the fatigue strength. The constant pressure and the cyclic moment (M_y) were loaded. The range of loading was made 1.5 times to the case-4, as more severe condition. The test was done until the leakage will occur. Inner pressure was made constant equivalent to the hydrostatic pressure because it was considered that there were few influences of a fluctuation in pressure against fatigue.

TEST RESULTS

The appearance of the test is shown in Figure 4. A relation between the moment and the rotation displacement at the nozzle as a result of case-1 to 4 are shown in Figure 5. The notes on the results are mentioned below.



Figure 4: Appearance of test



Figure 5: Relations between the moment and the rotation displacement at the nozzle

Case-1 to 3

The strength never declined during the experiment, and the buckling, the crack opening of the welded section, and the leak weren't seen. In other words, it didn't meet yield strength and any failure was appeared at this range of displacement.

In case-1, when a displacement was returned to the zero, a negative reaction force appeared because of the remaining displacement. In Case-2 and 3, few remaining displacement was seen with the wall after the experiment.

In case-2, reaction force became larger than case-2. It was the effect that the internal pressure increased the stiffness of the wall.

Case-4

The rotation displacement was arisen when the moment are zero because the piping which loaded in this test was made free during the inner pressure was loaded. In other words, this rotation displacement was arisen due to the inclination of the wall by the internal pressure. The results is seemed as a linear and regular. The un-stability like ratcheting didn't occur as a result of the experiment. The nozzle seemed to be safe under the severe earthquake.

Case-5

In the case-5, the leak appeared from the welded section of the nozzle and the wall at 287 times of loading cycles as a result. It is considered that the number of this cycle is highly exceeding the cycles in the earthquake.

COMPARISON WITH THE ANALYSIS RESULT

Both linear and the non-linear analyses of the tests were done with the analysis model which showed it in Figure 6. In nonlinear analysis, the analysis program MARC was used in consideration of the material nonlinearities and the geometric nonlinearities. The stress-strain curves of the materials were simplified as elastic-perfectly plastic. The yield stresses were obtained by the material tests.

The comparisons with the test results and the non-linear analysis results of case-1 to 3 with the ratio to the linear analysis results are shown in Figure 7 and Figure 8. Figure 7 shows the relation between moment load and rotation angle of nozzle. Figure 8 shows the relation between moment load and strain at the edge of nozzle, that is a welding part of nozzle and wall.







Figure 7: Relation between moment load and rotation angle of nozzle



Figure 8: Relation between moment load and strain at nozzle edge.

The analysis results correspond with the test results well. The analysis method seems to be practical.

The relation of deformation and load shown in Figure 7 shows that the tendencies of the tests were seem to be calculated properly except the returning path of case-3. We think this as a future theme.

The relation of strain of the edge of nozzle and load shown in Figure 8 shows that the strain at this part does not increase even if it exceeds yield strain in both experiment and analysis. We think this is because the plastic hinge have occurred at another part and the stress redistribution have risen. And this stress redistribution is the reason why reaction force never falls down when the deformation exceeds the elasticity limit.

CONCLUSION REMARKS

A series of tests and analyses was concluded as follows.

(1) The major seismic loadings of the nozzles at the bottom in the wall of cylindrical above-ground storage tank under the severe earthquake are considered as the reaction moments due to wall inclination by the tank dynamic fluid pressure response, slip of the tank and up-lift.

(2) Even if the nozzle in the wall of cylindrical tank is subjected to the displacement loading exceeds the elasticity limit displacement, the reaction force of the nozzle never falls down.

(3) Under the estimated cyclic loading due to dynamic response of the tank, the nozzles are seemed to be safe.

(4) Behavior of nozzle on the cylindrical tank shell is mostly simulated by nonlinear analysis.

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