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Experiment of Dynamic Pressure Distribution on Spent Fuel Pool Model due to Sloshing

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1. Introduction

Liquid sloshing in a spent fuel pool due to an earthquake can be the cause of nuclear fuel damage due to rack and fuel collisions caused by fluid structure interaction (FSI). Damaged fuel rods react with water to generate hydrogen, and if a loss of fluid by sloshing occurs at the same time, it can lead to a large accident such as a hydrogen explosion. In this study, sloshing dynamic pressure characteristics in a storage pool were experimentally investigated using a 1/8 scaled model of storage pool as a part of FSI in spent fuel pool seismic safety evaluation.

2. Experimental Setup

In order to study the characteristics of sloshing dynamic pressure, a test are conducted in the FAMPEX at the Korea Atomic Energy Research Institute. The dimensions of the spent fuel pool model, which is 1/8 scale of the spent fuel pool of YGN 5, are 2.15 x 1.075 x 1.3 m (height x length x width) mounted on a 2 x 2 m shake-table (Fig. 1). The pool model are made of stainless steel with a thickness of 5 mm and windows are made of fiber reinforced acrylic glass with a thickness of 35 mm in front and each side walls. The pool model contains twelve rack models. The models simulate the outer dimensions of racks and the weight of the racks with entire fuel assemblies. The dynamic pressure of liquid sloshing is measured at six points by piezoelectric pressure transmitters. Three of them are installed in the vertical center line of side wall and the rest on the rear wall. A set of three sensors is located at 1.52 m, 1.05 m, and 0.80 m height from bottom water surface. The primary variables are the free surface level, magnitude of excitation, excitation directions. Various experiments are carried out for partially-filled tanks with water height equal to 1.525, 1.296, and 0.915 m, which correspond to (*h*/*fl*) of 1.0, 0.85, and 0.6 respectively (*fl* denotes the height at scaled full fluid level and h is the liquid height). The input seismic excitation is based on the US-NRC Regulatory Guide 1.60 standard design spectra for seismic design of nuclear power plant [1]. The design spectra and extended-design spectra are generated by scaling the standard design spectra with the safety shutdown earthquake (SSE) of PGA (Peak Ground Acceleration) 0.2G which is the SSE of YGN 5 and PGA0.3G which accounts for extended design condition. The pressure response of the rectangular pool model is measured under the simulated seismic excitation which is generated by a similarity method for seismic simulation test of spent fuel pool model from the design spectra [2]. The pool model oscillates in the three horizontal direction of X, Y, and XY.

Fig. 1. Spent fuel pool model with dynamic pressure sensor.

3. Results and Discussions

Fig. 2 shows the dynamic pressure of the X(wide direction) and Y(narrow direction) wall measured by a set of three sensors along axial central line during the PGA0.2g excitation test [3]. Dynamic pressures are recorded for 30 sec including 10 sec forced excitation and 20 sec free sloshing. The dynamic pressure characteristics differ depending on the measuring time period. The pressure amplitude during the forced excitation is higher than that of the free sloshing time period in tests. The motion of the free liquid surface decays due to damping forces created by viscous boundary layers. Bottom sensors located at both walls detect the maximum amplitude of dynamic pressure in the excitation time period at every test sets. The farther away from the excitation source, the amplitude of dynamic pressure are declined. We cannot show at what water level gets the critical depth of disappearing pressure effect from natural sloshing in this test. However, from the measured results of the X-1 sensor we guess it can be the amplitude of free sloshing. On the other hand, a set of top sensors detect the maximum dynamic pressure in the free sloshing time period in every test sets. The farther away from the free surface, the amplitude are declined. We cannot show at what water depth gets the minimum saturation amplitude in this test. We wonder if it should happen near the top of the rack model.

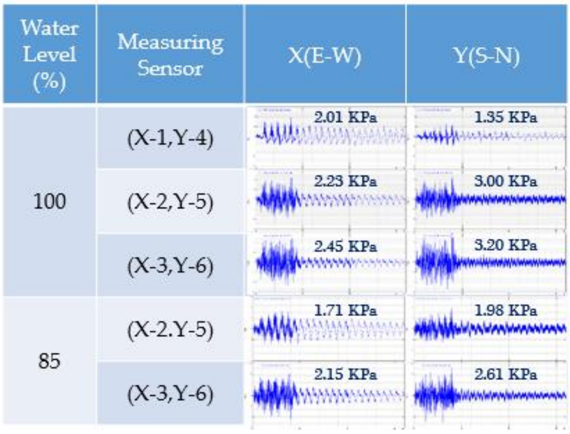

Fig. 2. Time domain dynamic pressure on the both sides of wall in XY excitation with 0.2G spectra

Fig.3 shows the spectral response of dynamic pressure measured by bottom sensors on both side walls in XY excitation with PGA0.2g and PGA0.3g seismic excitation test. The signal data is obtained for 10 seconds after the start of free sloshing.

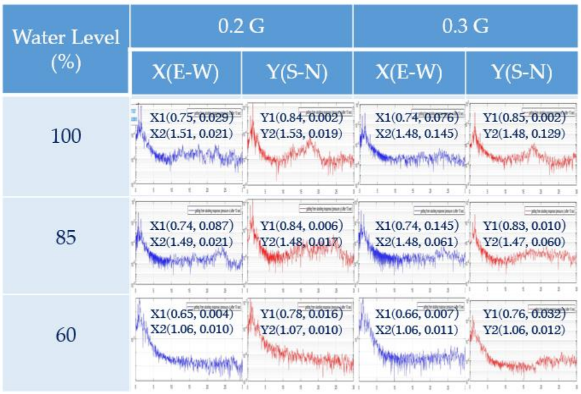

Fig. 3. Frequency domain dynamic pressure on the bottom sensors of both walls in XY excitation.

Two distinct frequency components are dominant in the measured pressure spectrum inside a pool model having an infinite number of natural sloshing frequencies. The magnitude of energy of 2nd mode on the Y directional wall is higher than that of 1st mode. The frequency of modes in 0.2G and 0.3G test are not exactly same but similar each other due to non-liner motion of fluid like fluid jump or swirling fluid motion near wall usually occurring near the natural frequency.

For a pool model, the natural frequencies of the fluid depending on the fill depth are given by:

$$w_n^2 = g\frac{n\pi}{L}\tanh\left(\frac{n\pi}{L}d\right) \qquad (1)$$

Where L is the pool model width and d is the water depth and n is the mode number. Table I shows the natural frequency of from first mode to fourth mode for the test model calculated by equation (1). 1st mode frequency of the fluid computed from the equation is not exactly same to the measured one from the test. The difference between calculation and measurement of natural frequency at the low water level is bigger than that of the high water level. Nonlinear effect of fluid is the one of the main reason of this difference. The Measured 2nd mode resonance does not exactly match with the mode of calculation. The frequency is between a certain natural frequencies.

Table I. Natural Frequency Calculation for Test Model

Water Level (%)	100		85		60	
Direction	X	Y	X	Y	X	Y
1st	0.77	0.85	0.75	0.84	0.62	0.73
2nd	1.10	1.21	1.09	1.20	1.05	1.18
3rd	1.34	1.48	1.34	1.48	1.33	1.47
4th	1.55	1.70	1.55	1.70	1.55	1.70

3. Conclusions

The sloshing dynamic pressure at the wall of spent fuel pool was measured when the 1/8 scale model of a YGN 5 spent fuel pool including storage racks and fuel assemblies was filled with water and excited with standard design spectra. The amount of fluid dynamic pressure depends on the location of the wall. The amplitude of dynamic pressure in free sloshing decreases with distance from the free surface. In this experiment, we could not identify the critical depth of disappearing pressure effect. Therefore, it is necessary to confirm the position through further experiments.

Acknowledgement

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