Effect of Frequency Contents of Ground Motion on Hysteretic Behavior of Steam Generator Blowdown Tank

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1. Introduction

In the records of Gyeongju earthquakes that occurred at 2016 in Korea, frequency contents show dominant above 10 Hz. The natural frequencies of nuclear power plant (NPP) equipment are mainly distributed between 10 and 30 Hz, and it may become vulnerable when an earthquake with the above characteristics occurs.

In this paper, the effect of frequency contents included in the seismic ground motion on the equipment installed on the structure was evaluated based on numerical analysis. This study expands the research results of the paper presented at the KNS Autumn Conference in 2021 [1]. The steam generator blowdown (SGBD) tank which is one of the heaviest equipment in the auxiliary building where important equipment is mainly located in the NPP was selected for the analysis.

2. Evaluation of hysteretic behavior of SGBD tank

The effect of the input seismic ground motion on the hysteretic behavior of the SGBD tank was evaluated numerically using the decoupled model of the seismic ground motion - building structure - equipment. First, the time history analysis of the auxiliary building was performed, and that of the SGBD tank was performed by applying the resulting floor acceleration obtained at the location of SGBD tank. The overall analysis was performed with commercial finite element (FE) software ABAQUS (version 2019).

2.1 Time history analysis

The time history analysis of auxiliary building was performed with 30 sets of ground motions (0.3g), material models of concrete and rebar. The real earthquake records from PEER (Pacific Earthquake Engineering Research Center) were used for seismic ground motion and scaled to match with the target response spectrum based on the selection and scaling method [1, 2]. And the 30 sets of resulting floor acceleration at the location of SGBD tank were used as inputs to the time history analysis of the SGBD tank. To obtain the nonlinear response of SGBD tank, the simplified 1 degree of freedom (DOF) lumped mass model was employed in the analysis, and the analysis was performed with two different weight conditions, empty and operating.

2.2 Results

The obtained dynamic behavior of the SGBD tank was evaluated according to the limit state of the equipment obtained from the pushover analysis of the SGBD tank. The limit state of the SGBD tank can be defined in three stages; first, anchor bolts yielding, followed by stiffener yielding, and finally skirt yielding [1]. If skirt yielding occurs, the main body of the SGBD tanks may result in collapse. For that reason, the skirt yielding was considered to be the most severe damage and selected as an evaluation criterion. The maximum displacement of the SGBD tank from the dynamic analysis was evaluated by the evaluation criteria to calculate the probabilities of failure (Table 1). As a result of the time history analysis, it was confirmed that the probabilities of failure were larger in the operating condition, but in some cases the maximum displacement in the empty tank was larger under the same floor acceleration. To confirm this effect, the additional analysis was performed.

Table I: Maximum displacement and probability of failure by each tank weight

	Empty		Operating	
	Maximum disp.	Probability of failure	Maximum disp.	Probability of failure
case1	0.50	Safe	0.43	Safe
case2	0.71	Safe	0.57	Safe
case3	0.42	Safe	0.49	Safe
case4	0.81	Safe	0.89	Fail
case5	0.71	Safe	0.79	Safe
case6	0.71	Safe	0.62	Safe
case7	0.79	Safe	0.44	Safe
case8	0.64	Safe	0.68	Safe
case9	0.38	Safe	0.64	Safe
case10	0.78	Safe	0.44	Safe
case11	0.27	Safe	0.77	Safe
case12	0.27	Safe	0.77	Safe
case13	0.42	Safe	0.49	Safe
case14	0.48	Safe	0.86	Fail
case15	0.48	Safe	0.86	Fail
case16	0.50	Safe	0.43	Safe
case17	0.38	Safe	0.64	Safe
case18	0.50	Safe	0.43	Safe
case19	0.66	Safe	0.67	Safe

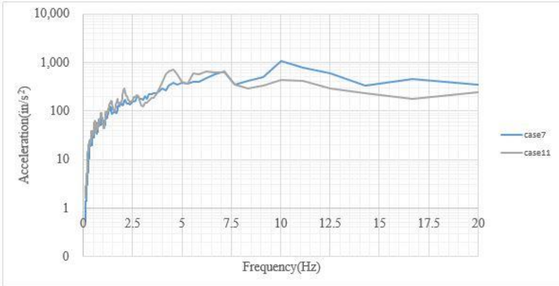
case20	0.78	Safe	0.44	Safe
case21	0.42	Safe	0.49	Safe
case22	0.64	Safe	0.68	Safe
case23	0.46	Safe	0.36	Safe
case24	0.66	Safe	0.67	Safe
case25	0.71	Safe	0.62	Safe
case26	0.38	Safe	0.64	Safe
case27	0.46	Safe	0.36	Safe
case28	-	-	-	-
case29	-	-	-	-
case30	-	-	-	-

3. Evaluation of seismic response

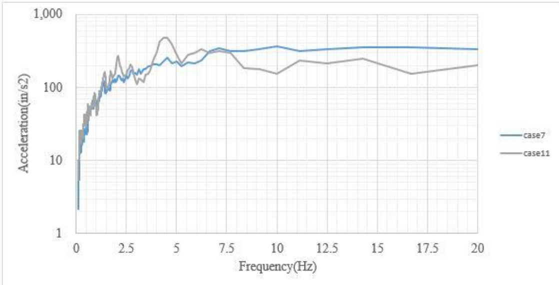
In the previous section, some results from the analysis showed that the dynamic response of the empty SGBD tank appeared higher than the tank under the operating condition. It was expected that the resonance effect occurs due to interaction between seismic ground motion and SGBD tank [3]. Therefore, the following additional studies were conducted; 1) deriving and analyzing the response spectrum of seismic ground motion and floor acceleration and 2) the dynamic analysis while changing the weights of the SGBD tank under the same floor acceleration.

3.1 Generating the response spectrum

To confirm the relationship between the response of the SGBD tank and the seismic ground motion, the response spectrum of seismic ground motion and the floor response spectrum was derived (Fig. 1). The response spectrum was generated from the time history acceleration of case 7 and case 11. In case 7, the dynamic response of the empty condition is larger than the operating condition, and in case 11, the response is larger as the weight increases. In the response spectrum generated from each seismic ground motion, a peak response appears at 10 Hz in case 7, and a peak response appears at 4.5 Hz in case 11. In the floor response spectrum, case 7 shows a peak response at 10 Hz, and case 11 shows a peak response at 4.5 Hz. The natural frequency of the empty SGBD tank is 10 Hz, and that of the SGBD tank under operating condition is 6 Hz. That is, in case 7, the seismic ground motion has a peak response at 10 Hz, which is the natural frequency of the empty SGBD tank, and also has a maximum response at 10 Hz even after the seismic ground motion is input to the auxiliary building. Therefore, it can be vulnerable at the conditions considered to be safe due to the resonance.



(a) Seismic ground motion

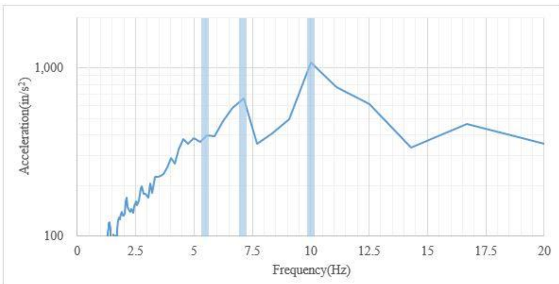


(b) Floor acceleration

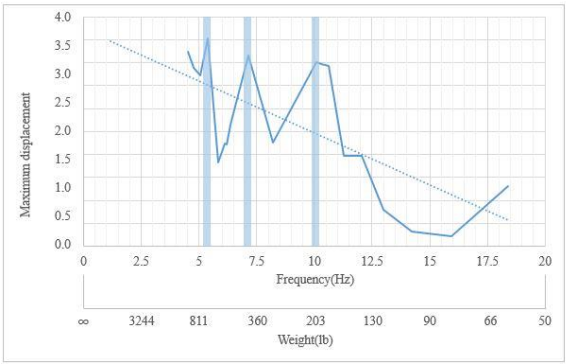
Fig. 1. Response spectrum

3.2 Seismic response evaluation

As a result of generating the response spectrum derived from the seismic ground motion and the floor acceleration, it was confirmed that the frequency contents of the seismic ground motion affects the dynamic response of the SGBD tank. In this chapter, time history analysis was performed under the same floor acceleration while increasing the weight of SGBD tank, and the maximum displacement according to the weight of the tank was evaluated. As a result, as the weight increased, the maximum displacement of the SGBD tank increased, but it was confirmed that the maximum displacement also increased at the frequency at which the peak appeared in the response spectrum (Fig. 2 (a)). That is, the response tends to increase as the frequency decreases, but the response increases sharply at the frequency where the peak occurs in the response spectrum.



(a) Floor response spectrum of case 7



(b) Maximum displacement according to the SGBD tank weight

Fig. 2. Comparison of floor response spectrum and analysis results

4. Conclusions

In this study, the effect of seismic ground motion on SGBD tank was evaluated with numerical approach. To investigate the interaction of seismic ground motion - building structure - equipment, the time history analysis of auxiliary building was performed first with 30 sets of seismic ground motion, material models of concrete and rebar. And the floor acceleration obtained at the location of the SGBD tank was used as an input to the time history analysis of the SGBD tank. The hysteretic behavior obtained from the analysis of the SGBD tank was evaluated by the skirt yielding considered as the most severe damage among the limit states of the tank to obtain the probability of failure. Analysis was performed with empty and operating conditions according to the amount of water in the tank, and the probability of failure was large in the operating condition. However, in some conditions (e.g. case 7), when the same floor acceleration was applied, the dynamic response was large in the empty condition which is the lighter weight. This is due to the resonance effect that occurs when the main frequency contents of the floor acceleration due to the associated seismic ground motion contains the natural frequency of the empty SGBD tank. In addition, in the evaluation of the maximum displacement while increasing the weight at the same floor acceleration of case 7, the response was larger as the weight increases (that is, as the frequency decreases), but dynamic response sharply increases at the frequencies with peak response appeared in the response spectrum. In conclusion, seismic ground motion may include a peak response at natural frequency of equipment, which may be amplified in the floor acceleration and it can be lead the critical damage to the equipment. Therefore, it is necessary to evaluate the dynamic response of equipment considering the interaction between seismic ground motion - building structure - equipment.

REFERENCES

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