Decrement damping ratio of light equipments due to structure-equipments interaction

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1. Introduction

There are various research results that reflect the change in the behavior of the structure due to the interaction between equipments and structure. These cases corresponds to the case when the mass of the equipment is 10% or more as compared with the structure. In this case, when modeling the structure, the floor response spectrum or the floor time history acceleration reflecting the influence of the devices is reflected by the mass distribution or pointed mass. Through these method, input ground motions for the seismic evaluation of equipment were obtained.

However, few researches about interaction between light equipments and structures have been carried, because the mass of light equipments does not affect on the behavior of the structure.

In this study, to verify the effect of structure-equipment interaction of lightweight equipments installed in nuclear power plants. The shaking table test was conducted with squat reinforced concrete wall and light equipments that installed on the top slab of specimen. The damping ratio of equipments change was investigated, which changed by interaction between structure and equipments.

2. Test plan

Four of equipments and two of reinforced concrete wall were produced for the shaking table test. The details of the model used in the test and the reinforced concrete wall are shown in Fig.1. Main experimental parameters were set as type of earthquakes, natural frequency of RC wall and natural frequency of equipments

Two types of RC wall used in the test were aspect ratio of 1.0 and 0.6. The dimension of specimen with aspect ratio of 1.0 was 1500mm x 1500mm x 200mm (length x height x thickness) and of specimen with aspect ratio of 0.6 was 2500mm x 1500mm x 200mm (length x height x thickness). Compressive strength of concrete was 40MPa. For vertical and horizontal reinforcement, D13, yield strength of 497MPa rebar was used. The ratio of reinforcing bar was 0.6 for vertical and horizontal. Additional masses of 0~26 tons were installed on the top of the structure specimens to adjust the natural frequency of the structure variously.

The cabinet model was installed at the center of top

Table1. Input earthquakes information

	Type	High frequency contents	Magnitude	Other
EQ1	Artificial	With	-	UHS[1)]
EQ2	Artificial	Without	-	RG1.60[2)]
EQ3	Measured	With	5.62	
EQ4	Measured	Without	6.2	
EQ5	Measured	With	6.2	
EQ6	Measured	Without	6.2	
EQ7	Measured	Without	6.3	
EQ8	Measured	With	5.8	

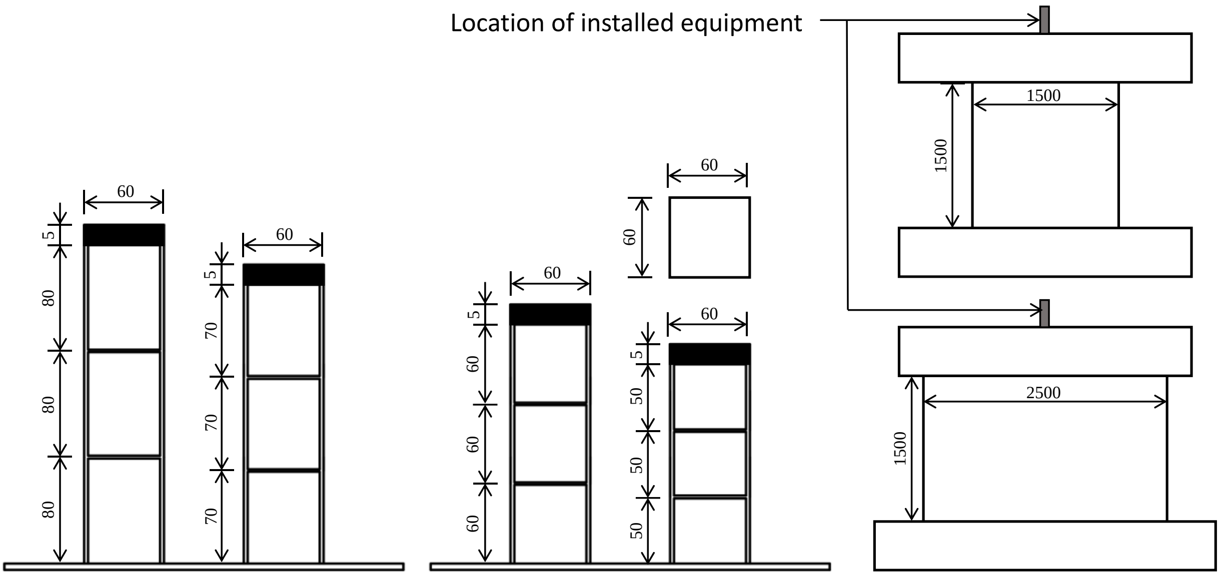

Fig. 1. Dimensions of equipments and RC walls

slab of the RC wall. The equipments were designed to exhibit a natural frequency of 20Hz ~ 40Hz, which is usually the cabinet natural frequency in nuclear power plants. Figure 1 shows the details of equipments. The height of equipements was 240mm, 210mm, 180mm, 150mm respectively, and it was made of 4-columns. Each columns were 2mm x 2mm. Each model was welded to a thick steel plate with a thickness of 5mm. The steel plate was fastened with the slab of RC walls by bolts. Iron plate of 60mm x 60mm x 5mm (width x length x thickness) were welded on the upper part of the equipments.

Eight type of earthquake waves were used for the test. The earthquake information is shown in Table1. Two seismic waves were artificial and six were measured. To prevent structural damage during the test, the PGA of earthquakes was adjusted to 0.1g. The magnitude of the actual earthquakes used is M=5.6~6.2. The used earthquakes included both near and far fault earthquake. To investigate the effect of earthquake components, four earthquakes with high frequency component was used.

The shaking table test was conducted according to the flowing procedure. EQ1~8 input was used with each change of additional mass of structure. PGA was adjusted to 0.1g to prevent nonlinear behavior.

3. Test results

3.1 Natural frequency and damping ratio

Resonance search was used to the natural frequency

Table2. Natural frequency and damping ratio

(a) structure

Set No.	External Mass (ton)	Natural frequency (Hz)	
		Aspect ratio 1.0	Aspect ratio 0.6
1	0	29.58	49.42
2	4.89	20.01	31.44
3	8.52	16.65	26.29
4	13.06	13.57	21.83
5	17.59	-	18.34
6	26.66	9.13	14.77

(b) equipment with the structure aspect ratio 1.0

No.	Natrual frequency (Hz)	Damping ratio (%)
1	39.0	0.7
2	27.1	0.4
3	25.0	0.7
4	20.7	0.5

(c) equipment with the structure aspect ratio 0.6

No.	Natural frequency (Hz)	Damping ratio (%)
1	39.3	0.4
2	30.6	0.5
3	23.0	0.6
4	22.5	0.6

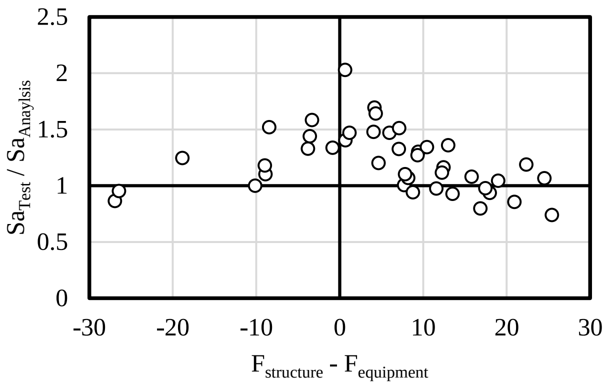

Fig 2. Maximum response acceleration of predict to test result according to frequency of structure and equipments.

of strucutres. The natural frequency of the structure was decreased with the additional mass on the top slab. The natural frequency and damping ratio of equipments wree measured by applying free vibration. Table 2 shows the natural frequencies and damping ratio.

3.2 Time history of acceleration

Based on the acceleration time history measured at the center of top slab of the structure, single degree of freedom analysis was performed for the installed equipment. Fig 2 shows the ratio of predict to test result of maximum response acceleration according to frequency of structure and equipments.

The largest error about all the shaking table test results is 2.02. It occurred at between aspect ratio 0.6 RC wall with 13.06 ton (21.83Hz) and equipment 4 (22.5 Hz). In general, the smaller the difference between the natural frequencies of the structure and the equipment, the larger the error in the analysis and the experiments.

4. The effect of structure-equipment-interaction

The damping ratio reduction equation according to the natural frequency relation of the structure and the equipment is derived by using the analytical error graph. The distribution that best reflects the results is judged to be log-normal distribution and the corresponding

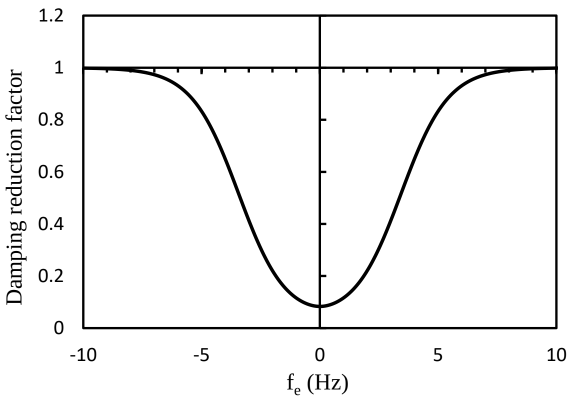

Fig 3. Damping reduction factor

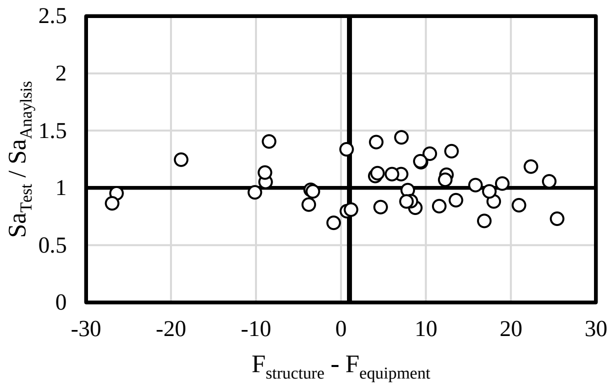

Fig 4. Maximum response acceleration of predict to test result according to frequency of structure and equipment with reduced damping ratio.

equation is changed and derived. Parameter fe is relation between the natural frequency of the structure and equipment. Eq-(1) shows that relation.

$$f_e = f_{strucutre}\left(\frac{f_{strucutre}-f_{equipment}}{f_{strucutre}+f_{equipment}}\right) \qquad \text{– Eq (1)}$$

Fig 4 shows the result of analysis by applying damping ratio reduction factor. When the damping ratio reduction factor is applied, it can be confirmed that the error is definitely reduced.

5. Conclusion

In this study, the damping ratio of equipments is reduced by a single-degree-of-freedom analysis of the equipments which is installed on the structure. At present seismic performance evaluation of equipments with coupled analysis is difficult due to the difference of damping ratio of equipments and structure. Therefore, seismic evaluation is performed by applying floor acceleration time history as the load to the equipments. There is no problem when the natural frequency difference between the structure and equipments is large. However, when the natural frequency is similar, the maximum acceleration is much different with analysis and test result. Therefore, if the natural frequencies of the structure and equipments are similar, by reducing the damping ratio at a certain rate, the reliability of the analysis is expected to be improved.

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