Earthquake Resistance Test of Full-Scale Glove Box

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1. INTRODUCTION

A glove box used at nuclear facilities must confine radioactive materials. High airtightness and negative internal pressure are used to prevent leaks. The allowable leakage rate of air is 0.1 % vol/hr or less at the pre-service inspection. The negative pressure value is kept at -30 mm H_2O in normal operation.

The glove box structural strength and its confinement reliability during an earthquake are major concerns. The verification of aseismic analysis methods and assumptions for a glove box are thus of great importance.

Data on the dynamic behavior of giant glove boxes was recently obtained in large shaker experiments.

This paper describes these experimental results and the appropriateness of aseismic analysis methods used in current design.

2. TEST MODELS AND CONDITIONS

2.1 Test Models

The test models were two typical glove boxes (with and without shields). They were designed for seismic class B events. The design acceleration is horizontally 0.36G. Both models are 3,650 mm high x 3,000 mm wide x 1,000 mm thick. Their weights are 3.6 tons for the no-shielding model and 6.8 tons for the shielding model. Test models are shown in Fig. 1.

Each model has two inlet filter boxes, two exhaust filter boxes and their supports, two exhaust pipes, and inlet and outlet valves. Mock-up trestles standing by themselves are in the model.

Each model has support arms on its top. The support arms are anchored to the framework. The framework is supposed to a model of the nuclear facility buildings.

2.2 Input Waves

Horizontal and vertical input waves were prepared for this experiment. They were based on the data from the aseismic design committee of the Standardization Program for a Light Water Reactor. They were "maximum possible earthquake" (S1) and "maximum credible earthquake" (S2).

Four artificial seismic waves (obtained by dynamic response analyses of three reference nuclear facility buildings) were used as horizontal inputs. These waves were developed by using the response spectrum covering all the second floor response spectra of the above mentioned buildings. An example of the response spectrum is shown in Fig. 2.

Vertical acceleration components of S1 and S2 were used for the vertical inputs.

The input waves are shown in Table 1. Examples of the floor response spectra are shown in Fig. 3.

3. METHODS

3.1 Vibration Test Methods

Vibration tests consisted of preliminary tests and seismic wave vibration tests. The preliminary tests were conducted to obtain the vibration characteristics of the glove boxes. The seismic wave vibration tests were conducted to prove aseisimisity of glove box strength and confinement.

(1) Preliminary test

The sinusoidal wave vibration test was performed by applying an automatic sweeping vibration, i.e., the swept sine band between 5 Hz and 30 Hz in 5 minutes. The acceleration of the input vibration was 0.05G.

(2) Seismic wave vibration test

To prove the glove box works during an earthquake, the models were filled with 5% freon R-12 gas (CCl_2F_2). Before and after the vibration, freon gas leakage was measured by a freon gas detector on the outside of the models. The response acceleration, strain, displacement and internal pressure fluctuations were also measured.

The vibration forces were set at three levels. They were classified into level I (1/2 S1), level II (S1), and the endurance limit level (S2 and above).

The endurance limit level vibrations were conducted to investigate the seismic margin of the models. The test was thus carried out raising the acceleration to the limit of the shaking table.

3.2 Aseismic Analysis Methods

The three-dimensional beam model for the finite element method (F.E.M.) is commonly used in glove box aseismic design. The design is based on linear-elastic analysis.

We verified the methods to estimate analytically the dynamic characteristics of a glove box by

1) an igen value analyses. The fundamental natural frequency and the mode were compared with the experiment.
2) the simulation analyses of the seismic vibration experiment was conducted by a time-history modal analysis. The response acceleration and stress values at key model locations were compared with those of the experiment.
3) a seismic margin assessment was conducted for a glove box design. The analysis was carried out by the spectrum modal method. The design input spectra were prepared by broadening raw spectra $\pm$ 10% in the frequency domain. The damping value was taken as 1% for all modes. When the response of each mode was superimposed, the "Square Root of the Sum of the Squares" method was employed.

We used the F.E.M. program, ICES-STRUDL. In conducting these analyses, the stiffness of acrylic resin panels and shielding panels were neglected. We considered only their mass. The side, upper, and bottom board of a glove box were considered as a brace whose rigidity was equal to their in-plane rigidity. The boundary conditions were given to match the experiment setting.

4. RESULTS

4.1 Vibration Characteristics

In the preliminary tests the first natural frequency of the no-shielding model was 13.8 Hz and the damping value of the first mode was 3.5%. Those of the shielding model were 13.3 Hz and 2.8%.

4.2 Seismic Wave Vibration Test

(1) Confinement performance

For both models, no gas leakage was detected at level I, level II, and the endurance limit level.

In the no-shielding model, the maximum response acceleration still confining the gas was 5.28G at the base of the model, 12.0G at the model frame, and 30.2G at the acrylic resin panel. In the shielding model, the maximum response acceleration was 2.97G at the base of the model, 4.17G at the model frame, and 10.4G at the stainless steel panel.

During vibration at level I, the maximum fluctuation of the model internal pressure was $\pm$ 6.77 mm H_2O for the no-shielding model, and $\pm$ 12.9 mm H_2O for the shielding model. The internal pressure was confirmed to keep negative during an earthquake, if the pressure was kept at -30 mm H_2O at normal conditions.

(2) Structural strength

For both models, the stresses due to vibration were less than the allowable stress limit at level I, level II, and the endurance limit level. The maximum stress on the no-shielding model was 17.1 kg/mm^2 (less than the yield point for austenite stainless steel). The maximum stress on the shielding model was 11.1 kg/mm^2 (less than the yield point for mild steel).

4.3 Verification of Design Analysis

(1) Appropriateness of finite element model

By an igen value analyses, the first natural frequency was 14.1 Hz for the no-shielding model and 14.2 Hz for the shielding model. The igen values of both the experiments and the analyses were fairly coincident. Then the simulation of test results were conducted by time-history modal analysis. The response values of the simulation were relatively close to those of the test results.
The analytical model thus appears appropriate for the catculation of glove box vibration characteristics.

(2) Evaluation of the design analysis

In comparing the seismic wave vibration test and the design analysis conducted by the floor response spectrum modal method, we found the response acceleration and the stress values are significantly higher than those of the test results at the key locations.

The maximum acceleration obtained by the design analyses was close to those of the experiment on both models. The safety margin for the no-shielding model was 2.2 times the minimum acceptable values. The safety margin for the shielding model was 2.6 times the minimum acceptable values.

The vibration characteristics of the no-shielding model are shown in Fig. 4. The maxima response of the experiment are shown in Table 2. The comparison of the analyses and the experiment are shown in Table 3.

5. CONCLUSIONS

We see the two test models keep working even when subjected to level I, level II, and the endurance limit level. It has been shown the three-dimensional beam model (usually carried out by F.E.M. linear analysis) can estimate the dynamic behavior of the glove box. The analysis using the 1% modal damping value and the $\pm$ 10% broadened response spectrum calculate the value for a full safety margin. We have confirmed the method is reasonable for a design analysis of a glove box.

6. ACKNOWLEDGEMENT

This work was sponsered by the Science and Technology Agency of Japan in the fiscal year 1985 to 1987. The authors thank the Test Executive Committee for their helpful discussions and criticisms.

Table 1. Principal Items of Input Wave

(a) Horizontal

	S1	S2
Near Field	Name : FS1N	Name : FS2N
	Max. Acc.: 0.65G	Max. Acc.: 0.85G
	Max. Vel.: 26 Kine	Max. Vel.: 24 Kine
	Max. Disp: 3.5 cm	Max. Disp: 2.5 cm
Far Field	Name : FS1L	Name : FS2L
	Max. Acc.: 1.00G	Max. Acc.: 1.80G
	Max. Vel.: 50 Kine	Max. Vel.: 71 Kine
	Max. Disp: 3.6 cm	Max. Disp: 4.2 cm

(b) Vertical

	S1	S2
Near Field	Name : S1N-UD	Name : S2N-UD
	Max. Acc.: 137.8 gal	Max. Acc.: 252.7 gal
Far Field	Name : S1L-UD	Name : S2L-UD
	Max. Acc.: 121.5 gal	Max. Acc.: 229.7 gal

Table 2. Maximum Response of Seismic Vibration

(a) no-shielding model

	Input wave	Table acc. (G)	Can acc. (G)	Panel acc. (G)	Can stress	
					Ex. data	Allow.
Level I	1/2FS1N	0.424	1.29	3.18	1.87	19.6
	1/2FS1L	1.02	3.17	7.39	3.39	19.6
Level II	FS1N	1.21	4.36	9.30	5.20	19.6
	FS1L	2.91	5.51	13.6	8.50	19.6
Endurance limit level	FS2N	1.24	3.71	10.2	5.70	44.8
	FS2L	4.51	8.85	20.6	15.8	44.8
	1.7FS2N	2.71	9.52	21.5	15.2	44.8
	1.1FS2L	5.28	12.0	30.2	17.1	44.8

(b) shielding model

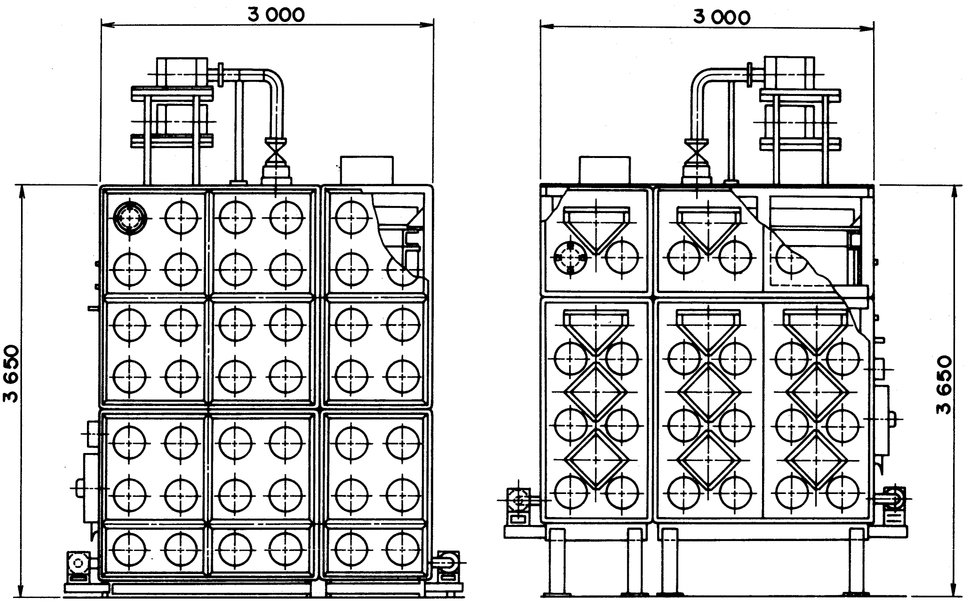
	Input wave	Table acc.(G)	Can acc.(G)	Panel acc.(G)	Can stress		Leg stress	
					Ex. data	Allow.	Ex. data	Allow.
Level I	1/2FS1N	0.424	0.874	2.11	0.398	19.6	2.05	25.0
	1/2FS1L	1.02	2.15	5.25	1.07	19.6	4.67	25.0
Level II	FS1N	1.21	2.38	6.76	1.47	19.6	5.63	25.0
	FS1L	2.91	6.98	10.4	2.80	19.6	11.1	25.0
Endurance limit level	FS2N	0.942/0.350	1.47	2.47	1.11	44.8	2.79	36.9
	FS2L	2.09/0.423	3.42	5.18	3.76	44.8	6.22	36.9
	2.5FS2N	2.08/0.740	3.17	6.05	3.50	44.8	6.72	36.9
	1.3FS2L	2.97/0.560	4.40	6.72	5.69	44.8	7.62	36.9

Hor./Ver.

Table 3. Comparison of the Analysis and the Experiment

	Max. acceleration (G)									
Location	17	20	21	22	23	25	26	30	32	Table
Design	2.53	1.34	4.08	4.56	1.33	4.90	3.78	1.57	1.56	1.08
Experiment	1.71	1.73	2.03	3.63	1.64	3.92	2.47	1.27	1.34	1.08
Simulation	1.52	1.08	2.00	2.35	1.08	2.12	1.86	1.09	1.09	1.08

	Max. stress (kg/mm^2)									Allowable stress
Location	15	20	24	32	36	70	82	84	86	(kg/mm^2)
Design	5.77	2.47	5.71	6.11	4.51	2.50	6.11	7.79	4.51	19.6
Experiment	1.47	0.38	1.38	1.45	0.32	0.39	2.70	0.80	0.41	19.6
Simulation	4.38	1.75	3.59	3.52	2.85	1.79	3.47	5.17	2.88	19.6



no-shielding model shielding model

Fig. 1 Test Modles

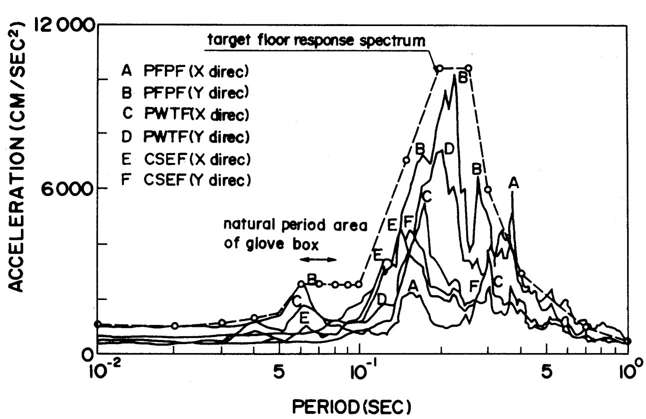


Fig. 2 Example of the Target Floor Response Spectrum

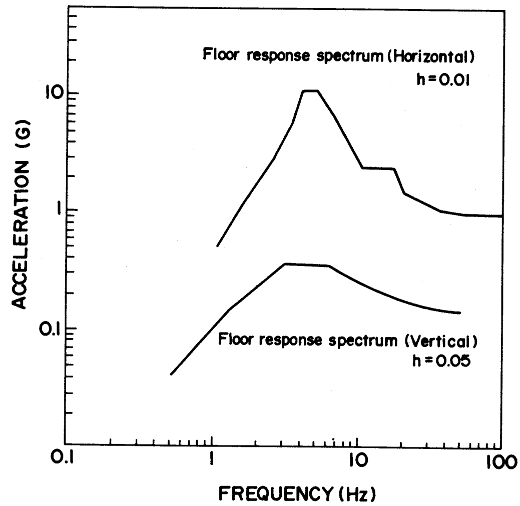
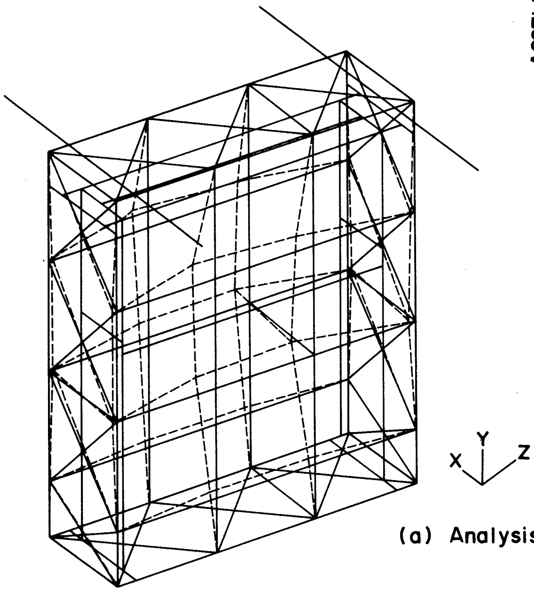
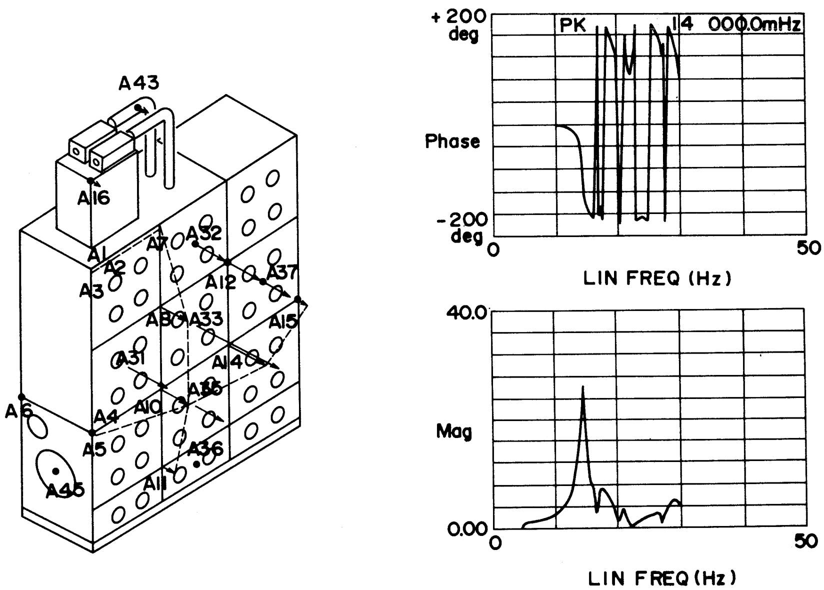


Fig. 3 Examples of the Floor Response Spectra for Input



(a) Analysis



(b) Experiment

Fig. 4 Vibration Charactristics of the No-shielding Model