Earthquake Resistant Test of New Type Glove Box (Revised)

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Abstract

1. OBJECTIVE

This earthquake resistant test is to prove new type glove boxes, planned to be used at MOX fuel fabrication plant in Japan(JMOX plant), keep the integrity of confinement and structural strength even during an earthquake. This test was intended supplement the results of “The Confirmation Test On Confinement Performance of the Improved Glove Boxes”, which were reported in the 13th SMiRT.

2. METHODS

Four full-scale models of the glove boxes were vibrated using a large shaking table. They are type A (Glove Box for pellet storage rack: 4m long×4m high×1.2m wide, 28tons), type B(Three straight Glove Boxes connected through bellows: 12.65m long×4m high×1.2m wide, 84tons), type C(Tall Glove Box: 6m long×5.6m high×1.2m wide, 45tons) and type D(Glove Box penetrated with drive shaft: 1.3m long×3.2m high×1.2m wide, 4.3tons).

Each model had support arms on its top. Support arms were anchored to the framework, which was a model of a ceiling and walls of buildings. The models are designed using the floor response spectra based on the JMOX plant design for the seismic class A. The S_1 and S_2 floor response waves were used in the test. Response accelerations, strains and displacements were measured at each vibration. To prove the confinement of the glove box during an earthquake, the model was filled with tracer gas at 0.6kPa, and gas leakage through the gaskets was measured on the surface of the model before and after the vibration. On some vibration to prove that internal pressure of the glove box was kept negative during an earthquake, the internal pressure of the model was kept at –0.3kPa by the ventilation system, and internal pressure fluctuation was measured during the vibrations. Subsequently, the linear-elastic analyses using the FEM were carried out and the results were compared with the test results to verify the effectiveness of the design analysis.

3. RESULTS

(1) The primary vibration mode was the membrane vibration of the glove box panels. The first natural frequency was approximately 10-17Hz for each model. The damping factor of the first mode lied between 1.1-2.6%.
(2) In each model, no gas leakage was detected at the S_1 and S_2 wave vibration. The maximum response acceleration being able to keep the confinement was 1700gal at the base of the model, 8300gal at the acrylic resin panel.
(3) In each model, no visible damage was found after vibrations. The maximum stress on the model was less than the yield stress for type 304 stainless steel.
(4) In type B and type C models with the ventilation system, the maximum internal pressure fluctuation was 0.09kPa(less than 0.3kPa).
(5) The response accelerations and the stresses of the analysis were found to be higher than those of the test results.

4. CONCLUSION

We see the above test models keep working even when subjected to the S_1 and S_2 earthquake, and the seismic analysis methods of the new type glove box are appropriate for designing.

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We see the above test models keep working even when subjected to the S_1 and S_2 earthquake, and the seismic analysis methods of the new type glove box are appropriate for designing.

KEY WORDS: globe box, earthquake resistant test, confinement, magnetic fluid seal, JMOX plant

INTRODUCTION

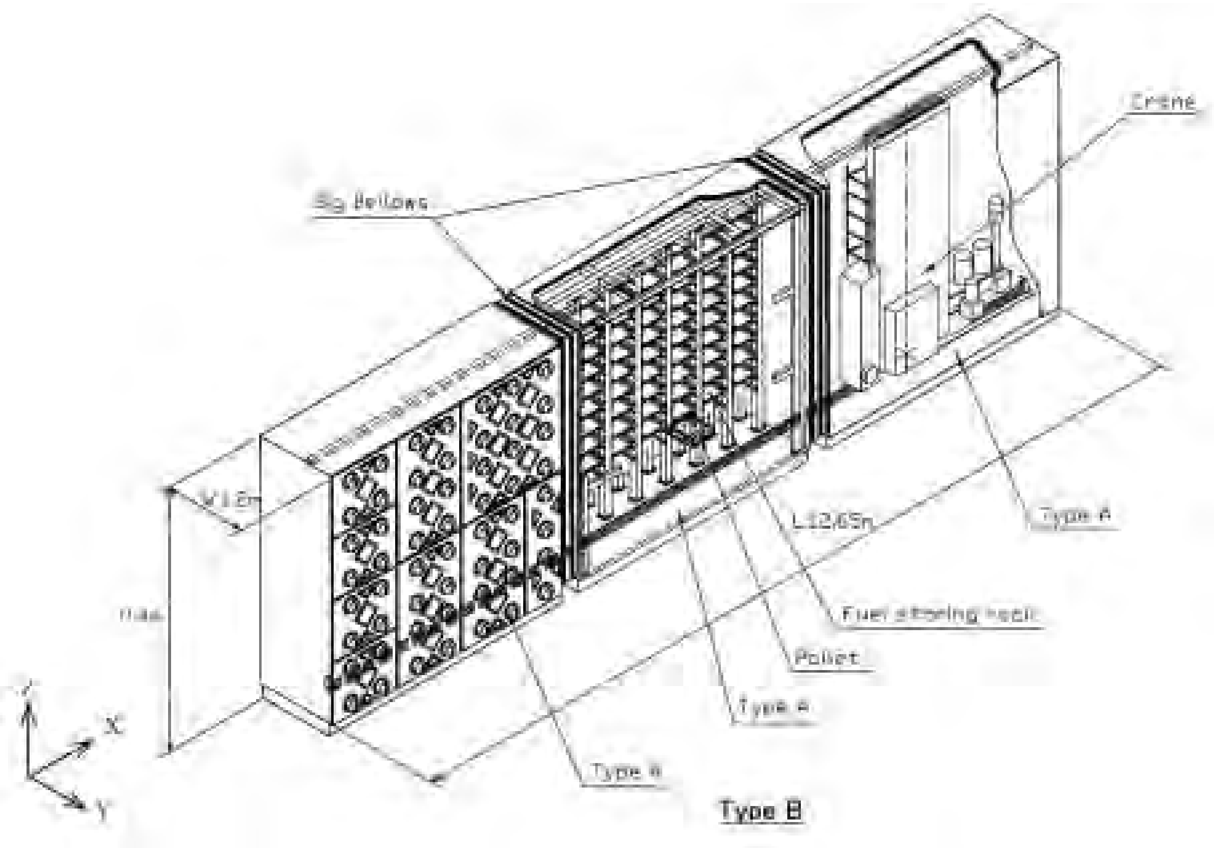
The purpose of this study is to qualify both the integrity and the confinement of glove boxes designed for a commercial Mixed Oxide (MOX) fuel fabrication plant in Japan (JMOX plant), which will be located in the Rokkasho Site near a Reprocessing Plant, Aomori Prefecture, Japan, during an earthquake.

Full-scale test-model glove boxes equipped with new structures that should be confirmed from aseismic standpoint shall be designed and fabricated. Vibration tests of these glove boxes shall be carried out for qualifying both the integrity and the confinement during an earthquake and the test results shall be reflected for design and fabrication of JMOX plant glove boxes.

TEST MODELS AND CONDITIONS

Test Models

Four full-scale models of the glove boxes were designed and fabricated for seismic class A events. Type A is the glove box with pellet storage rack (4m long×4m high×1.2m wide), and type B is the glove box connected 3 pieces of type A with two big bellows (12.65m long×4m high×1.2m wide). They will be used at the pellet storage process. Type C is named Tall Glove Box (6m long×5.6m high×1.2m wide) and type D is the glove box penetrated with drive shaft (1.3m long×3.2m high×1.2m wide). They will be used at the process for blending uranium and plutonium oxide powders. The test models are shown in Fig. 1.



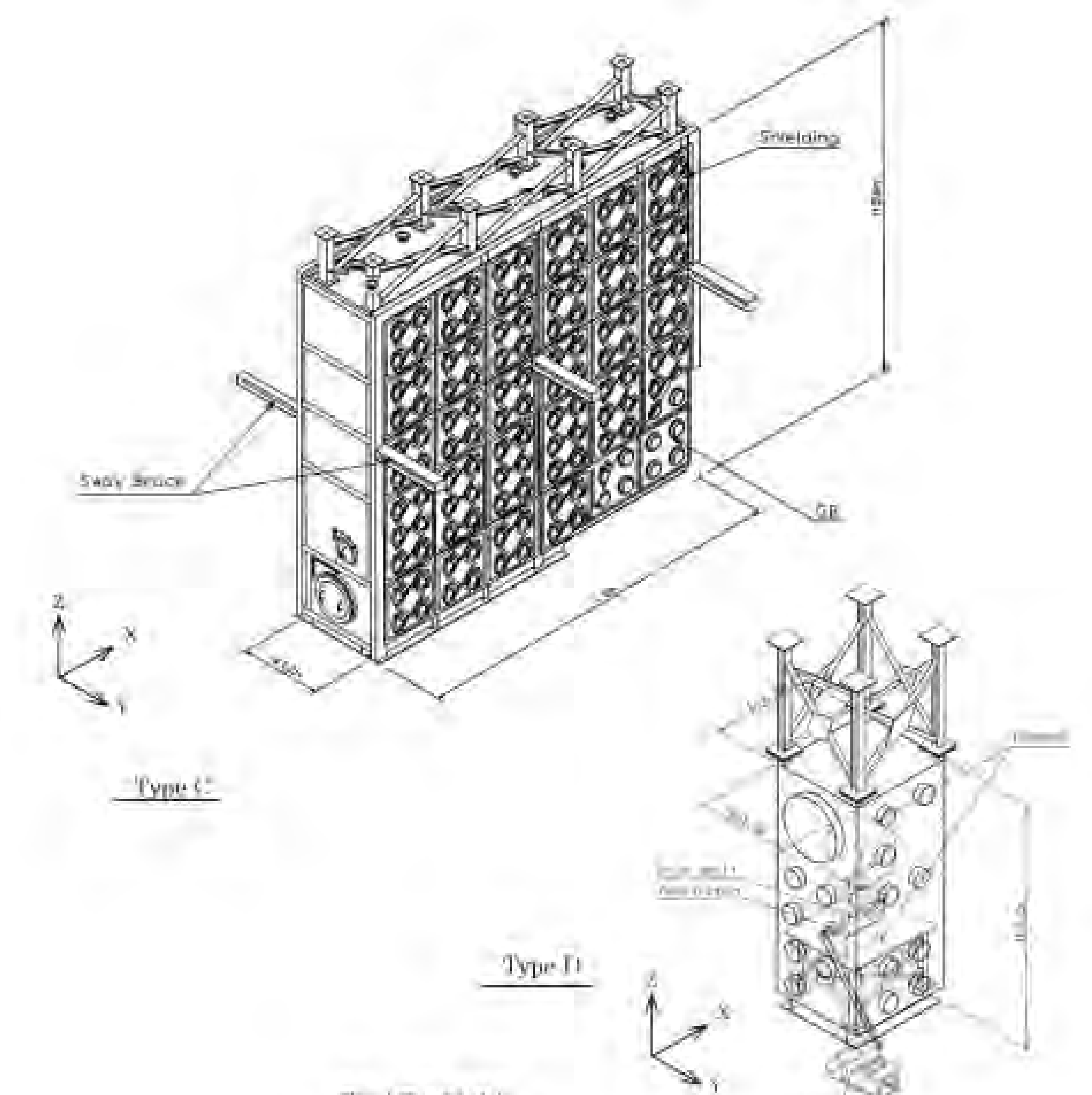


Fig. 1 Test Models.

Test-model glove boxes weigh 28tons,84tons,45tons and 4.3tons respectively.

Each model has inlet and outlet filter boxes, supports and exhaust pipes. 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 frame work is supported to a model of the JMOX plant building.

Input Waves

Horizontal and vertical input waves were prepared for this experiment. They were based on the data obtained by dynamic response analyses of the JMOX plant building using design basis earthquake ground motions S_1 and S_2. The principal items of the input waves are shown in Table 1. An example of the input wave is shown in Fig. 2. An example of the floor response spectrum is shown in Fig. 3.

Table 1 Principal Input Wave Characteristics

Wave		FRS1	FRS2
Max. Acceleration(gal)	Horizontal	409.0	478.2
	Vertical	148.0	200.5
Duration(sec.)		38.2	17.4

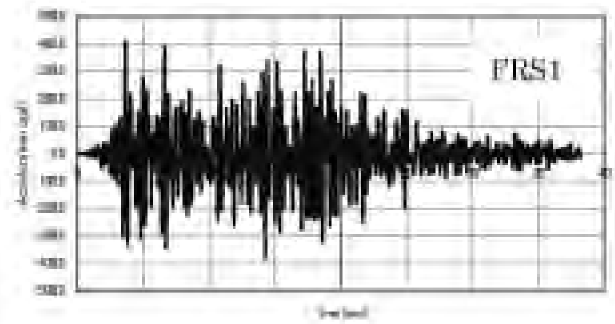


Fig. 2 Example of Input Wave

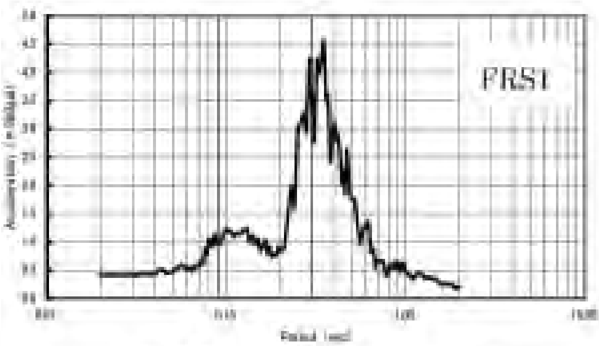


Fig. 3 Example of Input Spectrum

METHODS

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 quakeproof of the 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 5Hz and 30Hz in 5 minutes. The acceleration of the input vibration was 50 gal.

(2) Seismic wave vibration test

To prove the glove box works during an earthquake, the models were filled with tracer gas. Before and after the vibration, the tracer gas leakage was measured by a detector on the outside of the models. The response acceleration, strain, displacement and internal pressure fluctuation were also measured.

The vibration forces were set at three levels. They were classified into level S_1, level S_2 and the endurance limit level (above S_2). The endurance limit level vibration was 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.

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 eigen value analysis. The fundamental natural frequency and the mode were compared with the experiment.

2) the simulation analysis 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 ±10% in the periodic domain. The damping factor was taken as 1% for all modes. When the response of each mode was superimposed, the "Square Root of the Sum of the Squares" (SRSS) method was employed.

We used the F.E.M. program, GT-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〔1〕〔2〕. The boundary conditions were given to mach the experiment setting.

RESULTS

Vibration Characteristics

The natural frequencies of test models were measured in the preliminary tests and results are shown in Table 2. Damping factor of the first mode for all models lied between 1.1% and 2.6%.

Seismic Wave Vibration Test

(1) Confinement performance

For all models, no gas leakage was detected at level S_1, S_2 and the endurance limit level.

In the type A, the maximum response acceleration still confining the gas was 1656gal at the base of the model, 5291gal at the model frame, and 5755gal at the stainless steel panel. In the type B, the maximum response acceleration still confining the gas was 1154gal at the base of the model, 4302gal at the model frame, and 8016gal at the stainless steel panel. In the type C, the maximum response acceleration still confining the gas was 1065gal at the base of the model, 4457gal at the model frame, and 8384gal at the acrylic resin panel. In the type D, the maximum response acceleration still confining the gas was 1660gal at the base of the model, 1867gal at the model frame, and 2459gal at the acrylic resin panel.

Especially, for the magnetic fluid seal unit of the drive shaft, the confinement performance had already confirmed as a unit test 〔3〕, but we have got the maximum response acceleration still confining the gas in the state of building it into a glove box. The maximum response acceleration is 974gal at the base of the model, 1099gal at the penetration.

(2) Structural strength

For all models, the stresses due to vibration were less than the allowable stress limit at level S_1, S_2 and endurance limit level. The maximum stress was 168N/mm^2 on the type B model, and 156N/mm^2 on the type C model at 1.6 times excitation of level S_2. Both are less than the yield stress (205N/mm^2)

for type 304 stainless steel. In each model, no visible damage was found after vibration tests.

In addition, for the type A and B model, internals such as a crane and racks had no damage and the pallets loaded with mock pellets did not dropped from the rack at level S_1, S_2 and endurance limit level.

(3) Internal pressure fluctuation

During vibration at both level S_1, S_2 the maximum fluctuation of the model internal pressure was 0.090kPa for the type B model, and 0.088kPa for the type C model. The internal pressure was confirmed to keep negative during an earthquake, if the pressure was kept at –0.3kPa at normal conditions.

Verification of Design Analysis

(1) Appropriate of finite element model

By eigen value analyses, the natural frequencies for all models were shown in Table 2. The eigen values of the experiments and the analyses were fairly coincident. A comparison of vibration characteristics is shown in Fig. 4.

Table 2 Comparison of Natural Frequencies

Model	Vibration Direction	Natural Frequencies(Hz)		
		Test	Simulation	Design
Type A	X	17.4	18.0	17.2
	Y	13.0	12.2	12.1
Type B	X	10.3	11.0	10.7
	Y	9.3	9.4	9.8
Type C	X	15.1	13.9	13.8
	Y	9.8	9.6	9.6
Type D	X	17.4	17.9	18.0
	Y	23.5	21.0	20.8

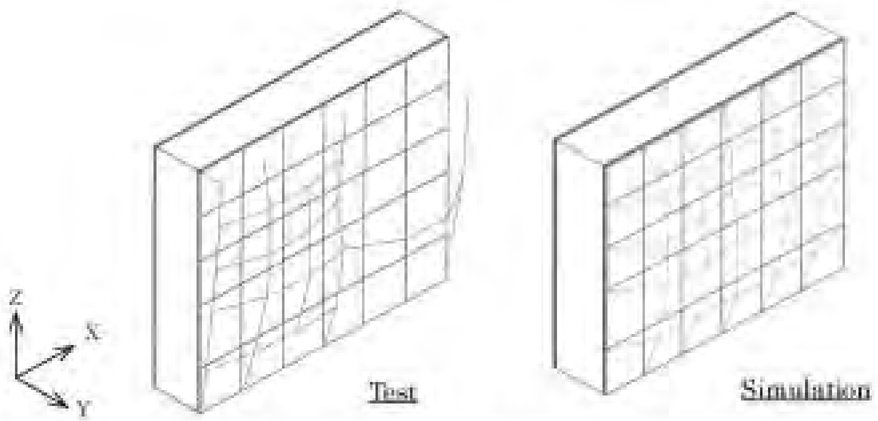


Fig. 4 Comparison of Vibration Characteristics

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 calculation 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 accelerations and the stress values are significantly higher than those of test results at the key locations. Comparisons of the analyses and the test results are shown in Fig.5 and Fig. 6. The analytical method thus appears appropriate for the glove box design analysis.

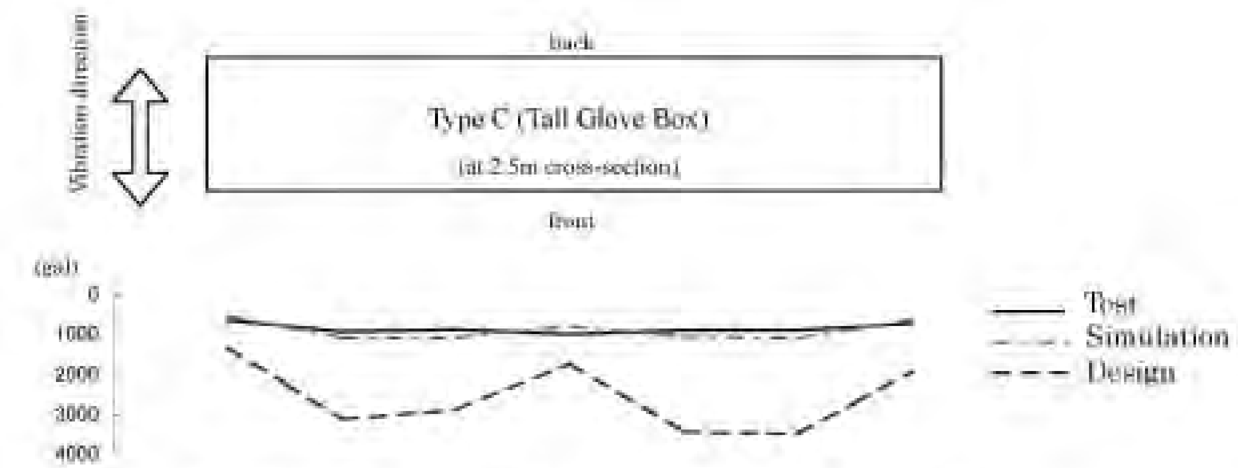


Fig. 5 Example of Response Acceleration Distribution at FRS1

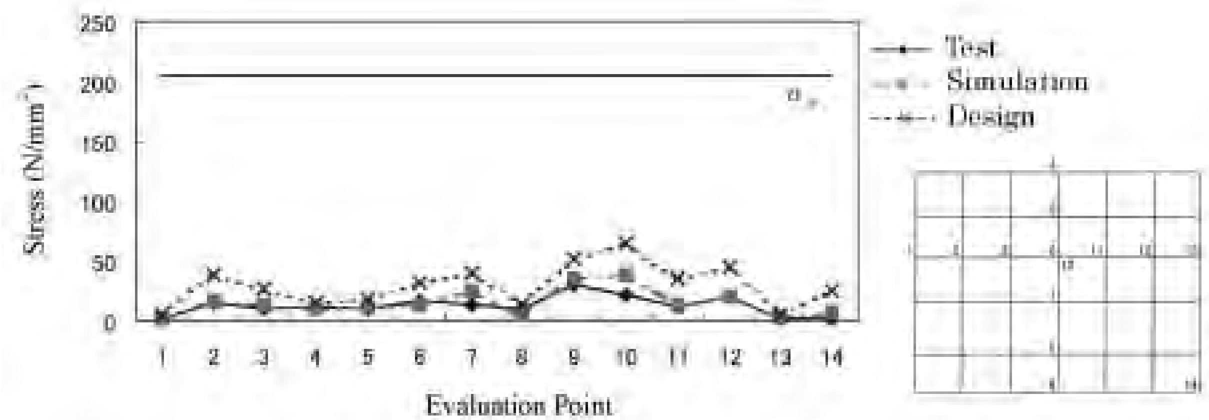


Fig. 6 Example of Stress Distribution at FRS1

CONCLUSION

We see all the test models keep working even subjected to level S_1, level S_2 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 factor and the ±10% broadened response spectrum calculate acceleration and stress with safety margin. We have confirmed the method is appropriate for the design of the glove box of JMOX plant.

Examples of the maximum response accelerations to establish confinement of glove boxes are shown in Table 3.

Table 3 Maximum Response Acceleration Values to Establish Confinement

Glove Box	Specimens	Acceleration(gal)	Input Wave
Glove Box with pellet storage rack	Stainless Steel Panel with Glove Port	5755	FRS2
	Frame	5291	FRS2
	Glove Box Base	1656	FRS2
Glove Box connected 3 pieces of type A with two big bellows	Stainless Steel Panel with Glove Port	8016	FRS2
	Frame	4302	FRS2
	Glove Box Base	1154	FRS2
Tall Glove Box	Acrylic Resin Panel with Glove Port	8384	FRS2
	Frame	4457	FRS2
	Glove Box Base	1065	FRS2
Glove Box penetrated with drive shaft	Acrylic Resin Panel with Glove Port	2459	FRS2
	Frame	1867	FRS2
	Glove Box Base	1660	FRS2
	Magnetic Fluid Seal Unit	1099	FRS2

NOMENCLATURE

S_1 - maximum possible earthquake, - ;

S_2 - maximum credible earthquake, - ;

σ_y - yield stress, N/mm^2;

ACKNOWLEDGEMENT

This study was performed as a joint study of The Japan Atomic Power Co., Hokkaido Electric Power Co., Inc., Tohoku Electric Power Co., Inc., The Tokyo Electric Power Co., Inc., Chubu Electric Power Co., Inc., Hokuriku Electric Power Co., The Kansai Electric Power Co., Inc., The Chugoku Electric Power Co., Inc., Shikoku Electric Power Co., Inc., Kyushu Electric Power Co., Inc. and Japan Nuclear Fuel Ltd. Nuclear Fuel Industries, Ltd. was the technical supporting company for this study. This study was also sponsored by Ministry of Economy, Trade and Industry.

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