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EXPERIMENTAL AND ANALYTICAL STUDY ON CROSSOVER PIPING SYSTEM IN SEISMIC ISOLATION FBR PLANT: (I) MAIN STEAM PIPING

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1. INTRODUCTION

In the design of crossover pipings between a seismic isolated and a non-isolated buildings of FBR plant, large relative displacement caused by design basis earthquake are imposed on the pipings. A main steam piping, which sustains a high steam pressure in the elevated temperature range, is required to be designed as the crossover piping in the seismic isolated FBR plant that we considered. The design method for the main steam crossover piping was investigated in this study. As a result of the study, it is found that a main steam crossover piping with some reduced stiffness seismic supports and viscous type dampers would be preferable to accomodate large relative displacement in the seismic events.

To confirm the applicability of the conventional design analysis method and the stress evaluation method to the crossover piping, the seismic tests on the main steam piping system was conducted. A 1/2 scale main steam piping model was used in the experiment. The seismic isolated building model was simulated by steel block supported by rubber bearings and installed on a shaking table.

The test results were compared with both predictions by the time historical analysis method and by the modal analysis method. Response spectrum defined on the shaking table and on the seismic isolated building model were used for the modal analysis. The stress evaluation method for the crossover piping was discussed focusing on the stress classifications and allowable limits. Design margines of the design analysis methods for crossover piping was evaluated by comparing with stress measured in the piping.

2. DESIGN OF THE MAIN STEAM LINE CROSSOVER PIPING SYSTEM

The piping layout of main steam line of the seismic isolated FBR plant is shown in Fig.1[1]. The design temperature and design pressure of the piping are approximately 500℃ and 190 atg respectively. Maximum relative displacement (± 390 mm) between the seismic isolated building and non-isolated building appear in the extreme design basis earthquake (S_2). In order to establish the structural integrity of the crossover piping, following considerations on the material and the seismic supports are added to conventional piping design.

- Piping material : High strength at elevated temperature range is required. In this study, Mod.9Cr-1Mo steel is applied.
- Seismic supports: Coil springs are used to avoid resonance with the seismic isolated building, and velocity proportional type oil dampers are required to reduce seismec responce of the piping system.

A 1/2 scale seismic test model was designed considering the shaking table size. A similarity law was applied to the model piping to simulate the stress appeared in the actual crossover piping under seismic events. The schematic figure of the seismic test piping is shown in Fig.2. The seismic isolated building modelled with an 20 tons of inertial mass structure, supported by four rubber bearings, was connected to the test piping rigidly by weld. The vibrational characteristics of the building model was adjusted by stiffness of the rubber bearings and dampers attached to the seismic isolated building model.

3. EXPERIMENTS

Experiments on following three items were condcted in the facility of the National Research Institute for Earth Science and Disaster Prevention in Tsukuba.

3.1 STATIC LOAD TEST

Static load was applied to the test piping model by the oil actuator and the displacements and strains of the piping were measured. The measured data was put into comparison with analytical results.

3.2 SINUSOIDAL SWEEP EXCITATION TEST

Frequency response functions were measured at various location of the piping system by sinusoidal sweep excitation. Resonance frequencies, mode shapes and damping ratios of each modes were evaluated from the results. The measured data were put into comparison with analytical results.

3.3 SEISMIC EXCITATION TEST

The piping system was excitated at the maximum design basis earthquake (S_1) and the extreme design basis earthquake (S_2) level, and displacements, accelerations and strains of the various locations of the piping system were measured. The data measured in the test were put into comparison with analytical results. Maximum acceleration of the shaking table and maximum relative displacement between the shaking table and the seismic isolated building model are shown in Table 1.

4. NUMERICAL ANALYSES

Static analysis on relative displacement, complex eigen value analysis and time historical response analysis (direct integral method) were conducted using FEM beam elements model and compared with measurements. The FEM analytical model is shown in Fig 3. Stiffness of the coil springs and damping coefficient of the oil dampers evaluated by element tests were applied to the analytical model. The stiffness and damping coefficient of the seismic isolated building model were also evaluated by the building model element test and applied to the analytical model. Since these components showed linear deformation characteristics, linear analysis methods was applied to the piping analyses.

Two conventional seismic analysis methods, the enveloped response spectrum analysis and the milti-response spectra analysis were conducted. Here, the equivalent damping ratio in these response spectra was determined by weightening the modal damping ratios and the participation factors. The stresses obtained by two response spectrum analyses methods were combined with the stresses in the piping by the relative displacement to evaluate total stresses in the piping during seismic excitations.

5. RESULTS OF THE EXPERIMENT AND THE NUMERICAL ANALYSES

5.1 STRESS BEHAVIOR IN THE PIPING UNDER STATIC LOAD

Comparison between mesurements and analysis results of the displacements and stresses in the piping system caused by relative displacement are shown in Table 2. Stresses of the experiment were evaluated from axial and circumferential strains of fhe piping using the formula of plane stress fields. Agreements between measurements and analized values were excellent. Therefore, it was concluded that the piping behavior under relative displacements can be sufficiently predicted by the linear static analysis.

5.2 VIBRATIONAL CHARACTERISTICS

Comparison between measurements and numerically analized values of the resonance frequencies and damping ratios are shown in Table 3. Here, the first mode is dominant frequency of the seismic isolated building model. Responses in the second, therd and sixth mode were too low to measure during the experiments. It is due to their large damping ratios and small participation factors. Other resonance frequencies and damping ratios agreed with analysis results. Therefore, it is also concluded that vibrational characteristics of the piping system can be sufficiently predicted by the complex eigenvalue analysis.

5.3 SEISMIC RESPONSE CHARACTERISTICS

Comparison between measurements and numerically analized time histories of the piping system at S_2 level excitation are shown in Fig.4. Sufficient agreement between measurements and analized time histories of displacements, accelerations and stresses were observed during excitation. Disagreement between measured and analized maximum responses of piping displacements, accelerations and stresses are less than 10%.

The stresses by seismic excitation were devided into stresses caused by relative displacement and stresses caused by inertial force. Each stresses in the time history form are shown in Fig.5. From this figure, it is founded that apporoximately 70～90% of the piping stresses are caused by relative displacement between the seismic isolated building model and the shaking table.

In the conventional design method of the piping system, the stresses by inertial force and the stresses by relative desplacement were analized by response spectrum analysis and static analysis respectively. The applicability of this conventional design method to the crossover piping was considered. Response spectrum defined on the shaking table and on the seismic isolated building model are shown in Fig.6. The damping ratio of each spectrum is assumed to be 4.3%, which is the equivalent damping ratio of the piping system evaluated by the complex eigenvalue analysis. Two response spectrum analysis methods were considered to evaluate stresses caused by inertial force. One was the stress evaluation by using a enveloped response spectrum, other is by using multi-response spectra. The stress evaluation results by both methods are shown in Table 4. From theses results, the stresses obtained from the enveloped response spectrum analysis are approximately 1.7 times of the stresses measured, whereas the stresses by the multi-response spectra analysis are 1.4 times of the measurements. Therefore, it is concluded that even for in the crossover piping design, the conventional design method based on response spectrum analysis and static analysis on ralative displacement gave conservative stress evaluation.

6. CONCLUSIONS

The seismic tests on the main steam crossover piping system of the seismic isolated FBR plant was conducted, and the following results were obtaind;
[1]The seismic response of the crossover piping under seismic events can be

precisely predicted by linear type time historical response analysis.
[2]Under seismic events, the stresses caused by relative displacement are dominant in the crossover piping.
[3]The stresses of the crossover piping system can be conservatively evaluated by combining response spectrum analysis results and static analysis results on relative displacement.

7. ACKNOWLEDGEMENT

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REFERENCES

[1]Watanabe,Y et al. (1992). Design Study of Piping System to Accomodate Large Displacement of Sismic Isolation FBR Plant. Proc. 1992 Fall Meeting of the Atomic Energy Society of Japan,575.

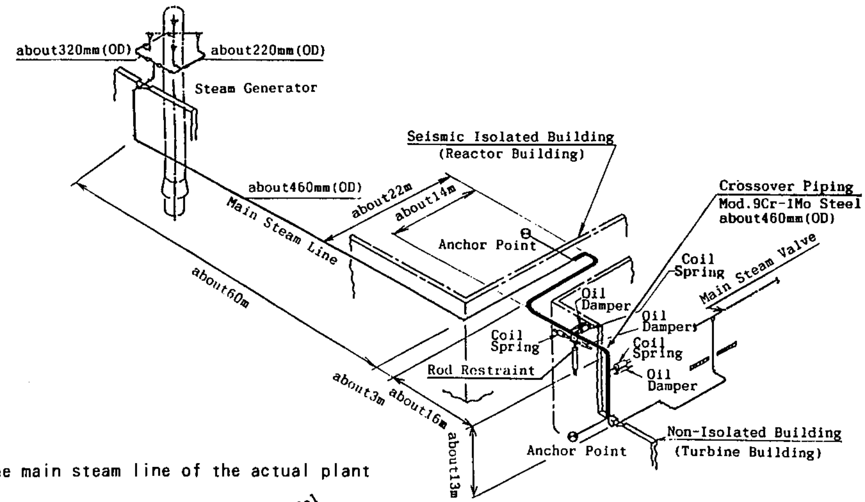


Fig. 1 Layout of the main steam line of the actual plant

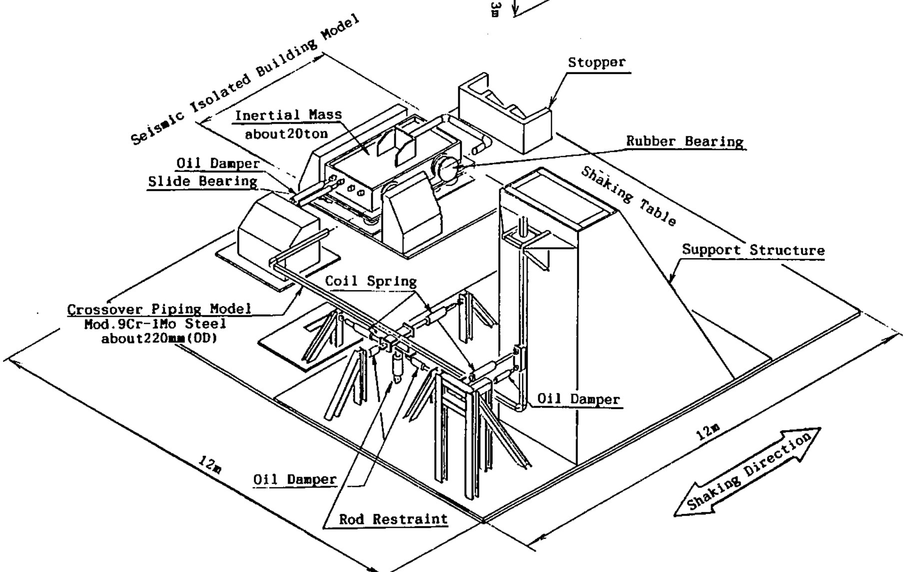


Fig. 2 Layout of the seismic test model

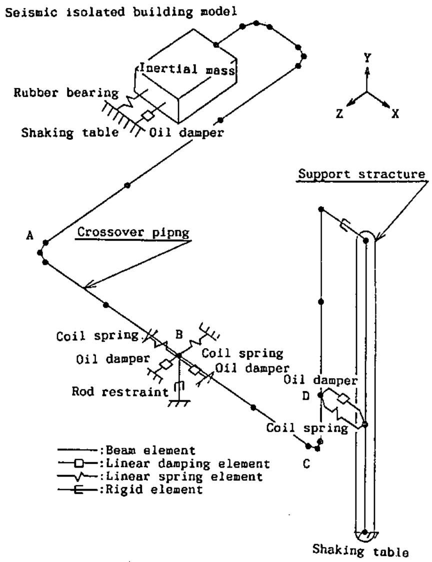


Fig. 3 Analytical model

Table 1 Maximum inputs of the seismic excitation test

Seismic level	Maximum accelaration of the shaking table (G)	Maximum relative displacement between the shaking table and the isolated building model (mm)
S1	1.1	65
S2	1.7	195

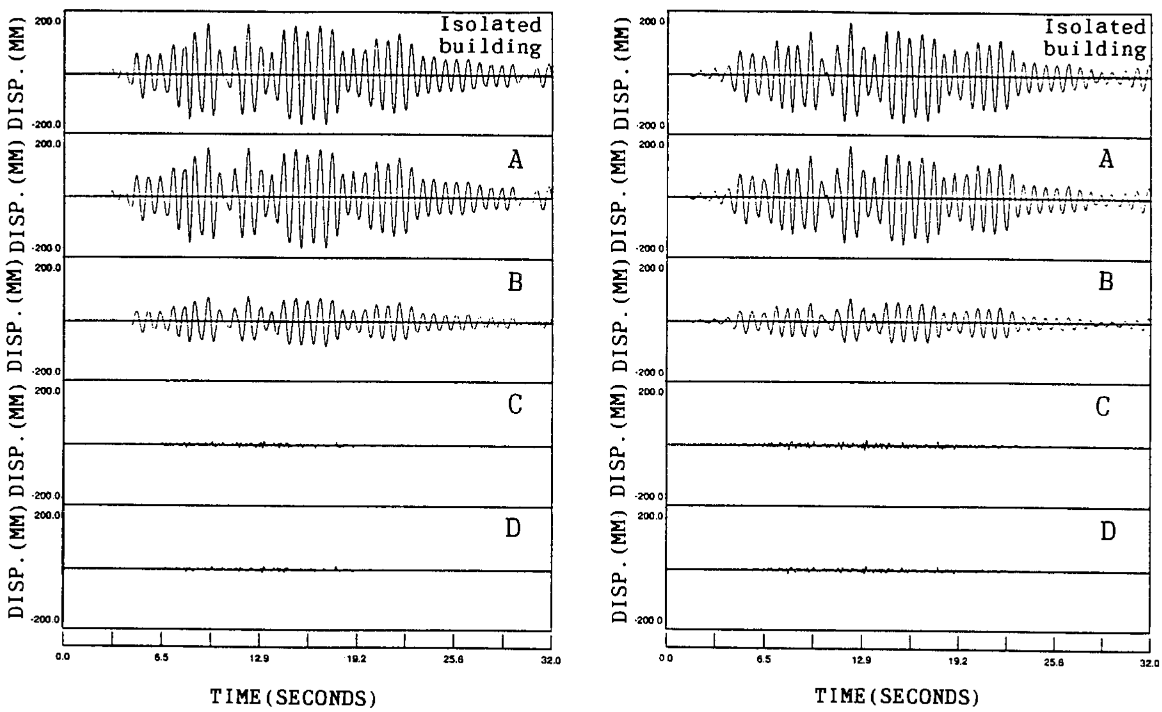
Table 2 Behavior of the piping system under relative displacement

Displacement of the isolated building model (mm)	Piping displacement (mm) A Exp.	A Ana.	B Exp.	B Ana.	Piping stress (Kgf/mm^2) A Exp.	A Ana.	B Exp.	B Ana.
+285	+272	+276	+129	+123	24.2	26.0	9.1	10.1
-284	-272	-276	-125	-122	25.6	25.9	9.6	10.2

Table 3 Resonanse frequencies and damping ratios of the piping system

Mode number	Resonanse frequency (Hz) Experiment	Resonanse frequency (Hz) Analysis	Damping ratio (%) Experiment	Damping ratio (%) Analysis	Participation factor (--)
1	1.3	1.3	4.4	5.0	2.17
2	---*	4.0	---*	13.5	0.04
3	---*	5.3	---*	19.7	0.07
4	7.1	6.4	0.6	0.1	0.01
5	11.3	11.2	1.7	3.5	0.02
6	---*	12.8	---*	7.6	0.05
7	13.4	13.3	1.0	0.8	0.04
8	15.2	14.0	0.6	0.1	0.02
9	16.8	16.4	4.2	4.1	0.98
10	18.1	20.3	1.2	1.5	0.03

*:These modes were not measured because the damping ratios are large and the participation factors are small.



a. Experiment

b. Numerical analysis

Fig. 4 Time historical seismic response of the piping system (S2 level)

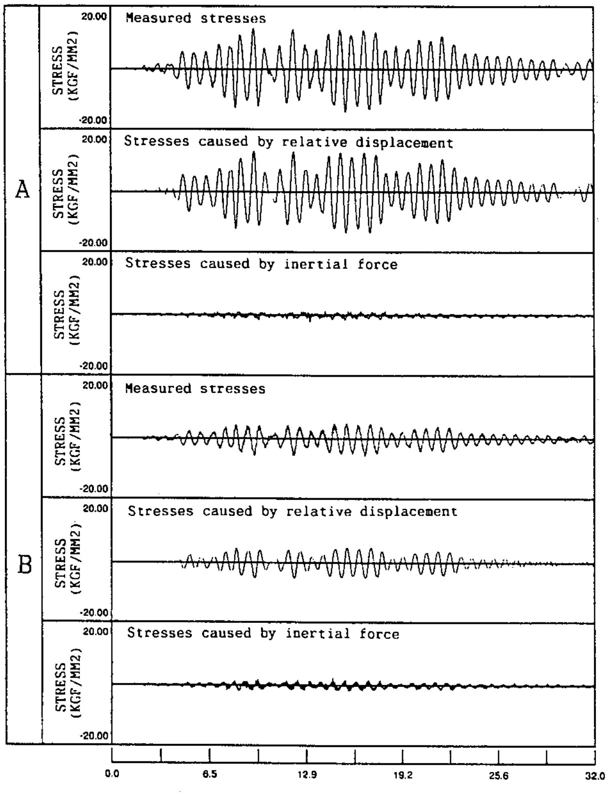
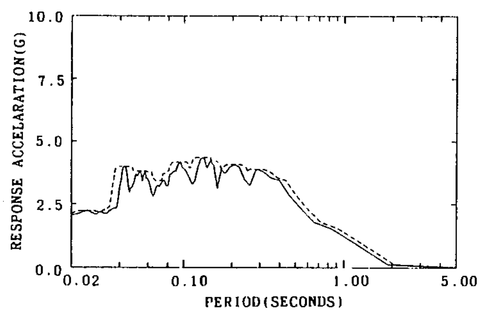
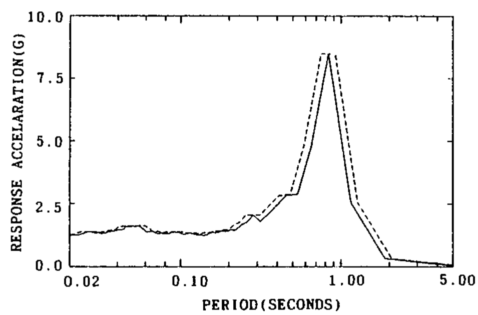


Fig. 5 Devided stress time histories of the piping system



a. Shaking table



b. Seismic isolated building modei

Fig. 6 Response spectrum

Table 4 Stress range evaluation results of conventional design analysis (S2 level)

Location	Experiment	Time historical analysis	Multi-response spectrum analysis + Statically relative displacement analysis	Enveloped response spectrum analysis + Statically Relative displacement analysis
A	31.8	35.2 [1.1]*	42.2 [1.3]*	48.0 [1.5]*
B	14.5	14.4 [1.0]*	20.2 [1.4]*	25.2 [1.7]*

*: The number in [ ] show the ratio of the analyitical value to the experimental value.
The unit of stresses is Kgf/mm^2 .