A study on the seismic isolation of fast breeder reactor plant 3-D seismic isolation of reactor structure

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1. SUMMARY

Seismic load is most important for the structural design of Liquid Metal Fast Breeder Reactors (LMFBRs) because of the relatively low operational pressure of the coolant. This indicates that the reduction of earthquake excitation will result in a reduction of the structural mass and an increase of the structural reliability.

Based on the abovementioned background, the feasibility of applying a three dimensional seismic isolation to the reactor structure of LMFBR have been studied. The paper is composed of the following two parts, 1) experimental study on the force-displacement relation of the seismic isolation device 2) earthquake response analysis of a three dimensionally isolated reactor structure. The feasibility and the effectiveness of a three dimensional seismic isolation of LMFBR is shown by the study. But at the same time, it is indicated that for a more detailed analysis on the seismic behavior, the restoring force characteristics under bi-axial loading had better be taken into account in the modelization.

2. INTRODUCTION

Preceding studies on the application of seismic isolation to nuclear plants are the study by Jolivet et al, Kunar et al and Sonoda et al for example (Jolivet 1977, Kunar 1979, Sonoda 1986). But they are the studies on the horizontal seismic isolation of the nuclear reactor building. As for the reactor structure of the LMFBR, seismic isolation in the vertical direction may be also effective due to the large diameter of the reactor. Three dimensional seismic isolation is studied by a few researchers such as Huffmann, Kelly and Staudacher (Huffmann 1985, Kelly 1983, Staudacher 1985). But their studies treat the seismic behavior in a small displacement range. It is and yet essential to understand the seismic behavior of a three dimensionally isolated structure in an extreme seismic condition to evaluate its feasibility for nuclear facilities. Therefore an emphasis has been laid in the present study on the understanding of the load-deflection behavior in an extreme deformation condition.

Three dimensional seismic isolation by means of helical springs and viscous dampers at the support of the reactor structure was selected for study because of its compactness. Other method of three dimensional seismic isolation is to combine a vertical isolation of the reactor structure with a horizontal isolation of reactor building. But this method is not studied in the paper.

Tabel 1 The Loading Condition

Series	Test No.	Horizuntal Load (kN)	Vertical Load (kN)
A	1	6.2	0~28.1
	2	3.1	
	3	6.2	
	4	9.3	
	5	1.1	
B	6	0~12	28.1
	7		18.7
	8		9.3

Table 2 Dimensions of the Coil Spring

Nominal Load	160	ton
Cent. Diameter of Coil	400	mm
Dia. of Wire	100	mm
Effective Length of Coil	1400	mm
Effective Winding Number	5	turn

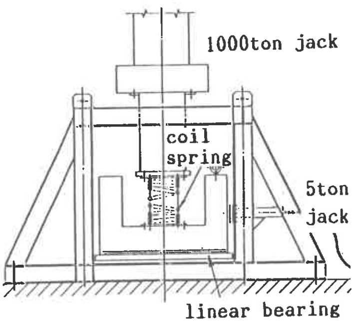

Fig 1 Schematic Illustration of Test Facility

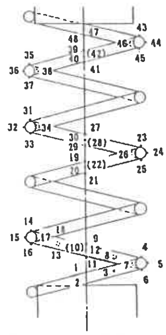

Fig 2 Position of Strain Gauges

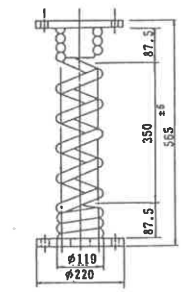

Fig 3 Schematic Illustration of Test Specimen

3. BI-AXIAL LOAD-DEFLECTION TEST OF COIL SPRINGS

3.1 Objective and composition of the test

Few test data are provided on the load-deflection relationship of helical springs in the horizontal (transversal) direction while sufficient test data are available in the vertical (axial) direction. Therefore, bi-axial load-deflection tests were performed in order to evaluate the effect of horizontal load to the vertical load-deflection relationship and vice versa. Table 1 shows the loading conditions. Fig. 1 shows the test facility. Tests are composed of the tests series A and series B. Series A comprises the vertical load-deflection tests for varied horizontal off-set displacements. Series B comprises the horizontal load-deflection tests under varied vertical initial load. Load, deflection and 162 strain components are measured in each test. Fig. 2 shows the position of strain gauges. Experimental stiffness and strain are compared to an analytical formulation and the FEM results.

3.2 Design of coil spring

The reactor structure weighing around 8,000 ton is supposed to be supported by 50 isolation devices which realize the natural frequency of 1.0 Hz in the horizontal direction and 2.0 Hz in the vertical direction. Based on the preliminary earthquake response analysis, the maximum response acceleration is estimated to be around 0.5G in the horizontal direction and 1.5G (including the gravity) in the vertical direction for an S_2 earthquake. Dimensions of the coil spring designed under the abovementioned conditions are described in Table 2. The effective hight is 1,700 mm, central diameter of the coil is 375 mm, diameter of the wire is 100 mm and the number of effective roll is five. The diameter of the wire of 100 mm is adopted because this is the maximum fabricatable diameter though a fatter wire is desirable for the increase of space efficiency. The test specimens are 1/4 scale models of the actual coil springs (Fig. 3).

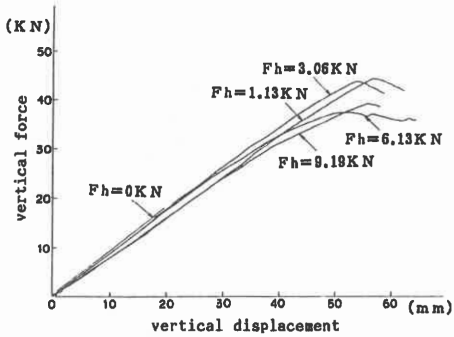

Fig 4 Results of The Test Series 1

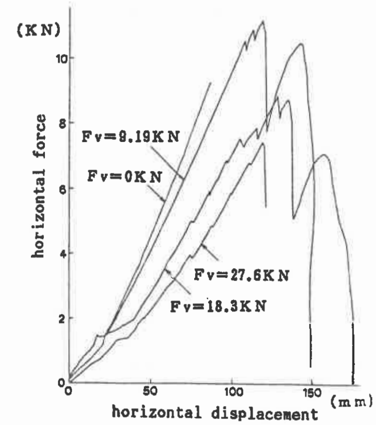

Fig 5 Results of The Test Series 2

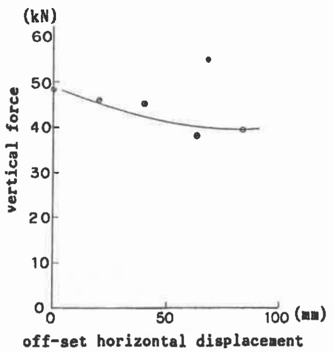

Fig 6 Maximum Vertical Tolerable Load For Different Horizontal Off-Sets

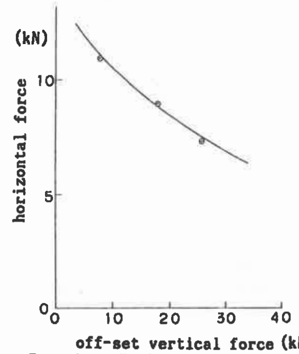

Fig 7 Maximum Horizontal Tolerable Load For Different Vertical Off-Sets

3.3 Results of load-deflection test

Fig. 4 represents the results of the tests series 1, Fig. 5 represents the test series 2. The dotted lines denote the FEM analysis taking into account the geometrical non-linearity in the large deformation range. The arrows denote the stiffness estimated by the analytical formulation.

Series 1 The deviation of the vertical stiffness for varied horizontal off-set displacements is $\pm 10\%$ and it does not show any obvious tendency as a function of the off-set. So, the effect of horizontal off-set can be neglected for design purposes. The relation between the vertical load and deflection is linear up to a certain extent. After that point, the vertical load does not increase while the vertical displacement increases. The behavior after the maximum load is explained as following. Because the horizontal actuator is load-constant type, it fractured the coil spring after the P-δ effect of the vertical load canceled the horizontal restoring force of the spring. Decrease of the horizontal restoring force corresponding to the increase of the vertical load also assures the explanation. Common fracture mode of the coil spring under the load combination of Series 1 is the loss of horizontal restoring force. Fig. 6 shows the maximum load for different horizontal off-sets. The maximum load decreases weakly corresponding to the increase of the horizontal off-set. The linear load-deflection relationship and the fracture mode indicate that the geometrical non-linearity plays an important role compared to the material non-linearity in the load-deflection behavior.

Series 2 Fig. 5 indicates that the horizontal stiffness decreases with the increase of the vertical load. Horizontal load-deflection curve can be approximated by two straight lines. The increase of the stiffness in the large deformation is cause by the touching of spring wires each other. The fracture mode in the Series 2 was the fracture at the welding of the wire end. Fig. 7 shows the maximum horizontal loads for different vertical loads. Maximum horizontal load decreases with the increase of the vertical load.

Preliminary earthquake response analysis estimates that the maximum load for a spring will be around 10 ton horizontally and 30 ton vertically for an S_2 earthquake. Extrapolating the test results by using the law of simslarity, the maximum tolerable load of the actual isolation device will be 15 ton horizontally and 45 ton vertically at the same time. It is presumed therefore, that the coil spring has enough resistance (safety margin is 1.5) to be used as a seismic isolation device.

4. EARTHQUAKE RESPONSE OF THREE DIMENSIONALLY ISOLATED REACTOR

4.1 Determination of earthquake input

It is widely acknowledged that the input earthquake motion has a predominant effects on the earthquake response of seismically isolated nuclear facilities. Nevertheless, the design earthquakes for nuclear facilities which are used currently in Japan can not be relied as for its so called long period components (one to 10 seconds) because of insufficient observation data. On the contrary, they have enough reliability for their short period components. In the light of the abovementioned situation, an extensive earthquake observation is currently on the way. But it still does not supply with enough reliable data for the determination of the long period components of design earthquake waves. Therefore, an observational earthquake motion which had been obtained at a firm rock site at the occasion of a large earthquake was adopted for design earthquake in the study. The waveform is shown in Fig. 8, response spectrum is shown in Fig. 9. The amplitude of the observational earthquake motion was raised for the analytical use by more than ten times so as the maximum acceleration becomes 300 gal.

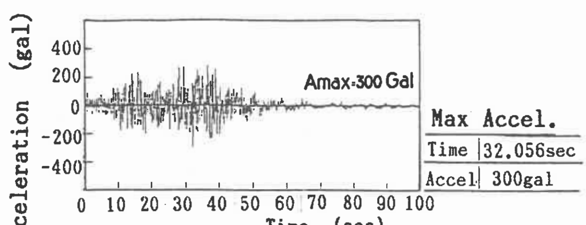

Fig 8 Waveform of Imput Acceleration

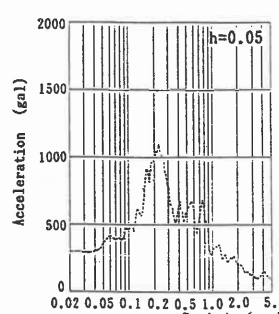

Fig 9 Response Spectrum of Imput Acceleration

Table3 Natural Frequencies and Partipation Factores

model	period (sec)	frequency (Hz)	participation factor
1	4.54	0.22	1.386
2	2.49	0.40	0.564
3	1.83	0.55	−0.233
4	1.50	0.67	0.299
5	1.23	0.81	0.006
6	1.07	0.94	−0.128
7	1.02	0.98	−0.060
8	0.21	4.71	−0.857
9	0.20	5.07	−7.579
10	0.16	6.11	−0.552

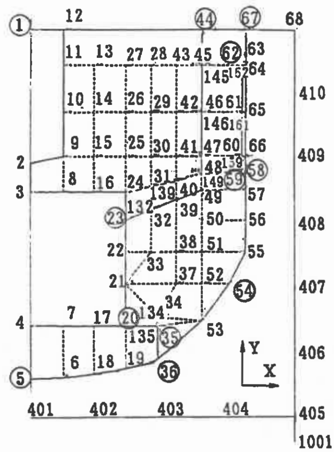

Fig 10 Axi-symmetric Analysis Model

Table 4

Node No.	Acceleration (Gal)	Displacement (cm)
1	295	1.82
44	295	1.82
67	295	1.82
5	307	1.95
36	295	1.82
55	235	1.35
58	219	1.29
20	274	1.62
35	274	1.62
23	228	1.30
59	219	1.29
62	272	1.54

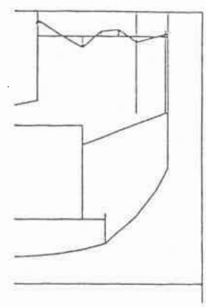

Fig.11 The First Sloshing Mode

4.2 Earthquake response of reactor structure

Fig. 10 shows the axi-symmetric model used for the response analysis. Liquid sodium is modelized by an added mass matrix taking the gravity effects into account. As shown in Fig. 11, the first sloshing mode appears at 0.22 Hz and the first vibration mode appears at 1.22 Hz (6th mode). At the 6th mode a coupling of sloshing and reactor structure vibration is distinguished. This is one of the important characteristics in the vibraiton mode of the three dimensionally isolated reactor structure. For the higher modes, the coupling is not obvious.

The maximum accelerations shown in Table 4 are not different much each other throughout the reactor which indicates that the reactor sways as a rigid body during earthquakes also. There is a weak amplification of accleration through the reactor vessel. But it is rather due to the rocking motion of the reactor structure according to the vertical deformation of the isolation devices than due to the deformation of the reactor vessel itself. Vertical acceleration is also reduced by the seismic isolation. But the vertical accleration at the periphery of the roof-deck is higher than that at the center. Compared to the earthquake response of a non-isolated case, the horizontal maximum acceleration is reduced from 2 G to 0.3 G (0.15) and the vertical maximum acceleration is reduced from 1 G to 0.2 G (0.2). That enables the reduction of the thickness of vessel from 50 mm to 20 mm yet increasing the structural margin.

Fig. 12 Sloshing Time History

The sloshing time history is shown in Fig. 12. Maximum wave height reaches 0.8m but because sloshing pressure is much lower than that of the fluid structure interaction,it is not inpedimental from the point of view of the structural design.

5. CONCLUSION

Feasibility of a three dimensional seismic isolation of the reactor was studied through the experiments on coil springs and the seismic response analysis of the reactor structure. The load-deflection test on the coil spring has shown that it could be possible to use coil springs as three dimensional seismic isolation device but the coupling effects of horizontal and vertical loads on the horizontal restoring characteristics had better be tested more intensively for a more detailed evaluation. The response analysis has indicated that the three dimensional seismic isolation is effective for the reduction of seismic load but an interaction between sloshing and isolated reactor have to be taken into account properly.

6. REFERENCE

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