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Study on ultimate behavior and fragility of Seismic isolated FBR plant in Japan

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1. INTRODUCTION

Regarding the design of a Fast Breeder Reactor (FBR) building, it is essential to reduce the seismic load, since the thermal load during operating is larger than the Light Water Reactor. The seismic isolation system is an effective method to do so. However, it is very important to grasp the ultimate behavior of the seismic isolation layer from the viewpoint of the assurance for the seismic safety margin of the seismic isolation system. If several isolators with small strength relatively were to rupture, the torsional response of the isolation layer would occur, and it is thought that such a torsional response would influence the ultimate behavior and the fragility (seismic safety margin) of the isolation layer.

This paper describes the results of the fragility analyses and the ultimate behavior of the seismic isolated building by three-dimensional (3-D) seismic response analyses considering the rupture phenomenon of isolators.

2. ANALYTICAL PROCEDURE

Analytical Model: As shown in Fig. 1, the object is the seismic isolated FBR building. The seismic isolation device consists of a laminated rubber bearing (hereafter "Isolator": the design vertical load of 500 tons) and the steel damper[1)]. Regarding the basic characteristics of the isolation layer, the natural periods are 1.0 second before yielding of the damper and 2.0 second after yielding in the horizontal direction, and 0.05 second in the vertical direction. The yielding strength is 0.10W (W:the sum total weight of the superstructure).

Two types of the analytical model are considered, which are the one-lumped mass models consisting of the superstructure and the isolation springs. *Model A* having 367 isolators installed in the isolation layer, which is equivalent to the actual building, is used for evaluating the fragility and the ultimate behavior of the isolation layer (the propagating rupture phenomenon to other isolators). The randomness of the rupture strength of isolators is considered. *Model B* having 25 elements (one element corresponds to 12 isolators in Model A) for investigating the torsional response is a reduced and simplified model rather than Model A.

MSS (Multi Shear Spring) model is employed for each isolator/element, which has 8 springs arranged at uniform intervals on the plane, and is possible to consider the two-directional interaction.

Mechanical Properties: Fig. 2 shows the one directional hysteresis rules of the isolator and damper. The skeleton curve slides according to the maximum response displacement in the past, and the behavior after rupture phenomenon of isolators are considered based on the experimental results[2),3)].

Rupture Criteria: As shown in Fig. 3, the rupture limit of the isolator is defined by a three dimensional rupture surface with shear and vertical strains. Rupture of the damper is not considered. As for Model A, the variation is considered as randomness of rupture criteria to be the COV (Coefficient of variation) of 10%, assuming that it is based on the Gaussian distribution. As for Model B, elements with small rupture strength are installed along the edge concentrically to increase the torsional response.

It is remarkable that the rupture phenomenon does not occur in the linear region of the isolator/element (see Fig. 2), and in this paper the unbalanced forces generated by rupture of isolator/element are converged within the current time step.

Input Ground Motion: The input ground motion "S_2" (see references 4)) contains relatively long period contents, of which the maximum acceleration and the maximum velocity are 830.94 gal and 200 kine respectively.

Analytical Parameters: List of parameters is shown in Table 1. The scaled-up intensity of the abovementioned input motion as to Model A and the input direction as to Model B are considered as parameters. Furthermore, the fragility is evaluated by employing the Monte Carlo simulation technique using 50 samplings.

3. RESULTS

3.1 Ultimate Behavior and Fragility (Model A)

The results in comparison with the two dimensional(2-D) analyses, in which the same randomness and the same input level are used, are the following:

- The response acceleration wave at the center of gravity by the 3-D analyses is a little greater than by the 2-D ones, and it is considered that the difference is attributable to the influence of modeling between 2-D and 3-D. However, as for the response displacement wave (see Fig. 4) and the velocity wave, both 2-D and 3-D results are almost the same.
- As shown in Fig. 5, the rupture phenomenon occurs at roughly 14.8, 19.2 and 24.7 seconds. It is also proved obviously by analyses that the propagating rupture phenomenon, which might cause all isolators to rupture, is not observed[3)], even if several isolators were to rupture.
- As the input level is increased, the torsional response becomes greater. However the maximum torsion is insignificant, since the average relative displacement between the corners of the base-mat (68 m) is 5 cm (even the maximum value is at most 19 cm) at the input level of 2,100 gal (2.53S_2).
- The fragility of the isolation layer is shown in Fig. 6. The fragility curves are estimated based on the relationship between the maximum input acceleration and the rupture ratio (in the range 10% to 50%). As it is observed that there is little difference between the rupture patterns of 2-D and 3-D as shown in Table 2, it is shown that the influence of the torsion is insignificant. Furthermore, the isolation system has a very large seismic safety margin against the design-base earthquake(S_2).

3.2 Torsional Response (Model B)

- The torsional response becomes greater, as the degree of the input direction is larger (see Fig. 7). At the input level of 2,200 gal (2.65S_2), the element rupture phenomenon propagates to other elements, the displacement at the corner is forced to enlarge by the torsional response, as shown in Table 2. However, it is not observed that the partial rupture phenomenon causes the propagating rupture of the isolation layer in such a case, since there is some different phase between the displacement response of the superstructure and the torsional response of the isolation layer as shown in Fig. 8.
- Regarding the influence on the floor response spectra due to the torsional response, as shown in Fig. 9, the increase of the floor response at the corner (Element No.25) is observed to be large, but at the center to be small in comparison with results by the 2-

D, where the torsional response is not considered. The floor response at the corner (Element No.5) is smaller than at the other corner (No.25), though the displacement response at Element No.5 becomes larger than at Element No.25. It is considered that the response acceleration at Element No.5 becomes small, as the derivative (secondary) acceleration due to the torsion might cancel the response acceleration of the building (at the center), as shown in Fig. 10.

- The results of the input direction of 0 degree reaches all the rupture, in which the torsional response does not occur (see Table 2). Therefore, it is remarkable that the rocking response of the building has a significant influence on the ultimate behavior (safety margin) rather than the torsional response of the isolation layer.

4. CONCLUSIONS

From the results of the seismic response analyses considering the rupture phenomenon of isolators, the torsional response occurred by the partial rupture, the ultimate behavior, and the fragility of the isolation layer are estimated. Conclusions are as follows.

- In the case that the rupture criteria is given randomly to each isolator (Model A), the torsional response value is clarified to be insignificant. Accordingly, the influence on the ultimate behavior (propagating rupture phenomenon) and the fragility curve of the isolation layer are recognized to be inconsiderable. Furthermore, it is confirmed that the isolation layer of the FBR building has an appreciable seismic safety margin against the tentative design-base earthquake(S_2).
- Even if the torsional response becomes greater due to the partial and concentrative rupture (Model B), neither the drastic increase of the displacement response nor the propagating all rupture phenomenon by the torsion are observed, since there is some different phase between the displacement and the torsional response. Regarding the influence on the response of the superstructure, the floor response spectra at the corner is greater or less than at the center. However the influence on the spectra at the center due to the torsional response is insignificant. Furthermore, it is proved that the rocking response of the building has a significant influence on the ultimate behavior (safety margin) rather than on the torsional response of the isolation layer.

5. ACKNOWLEDGMENT

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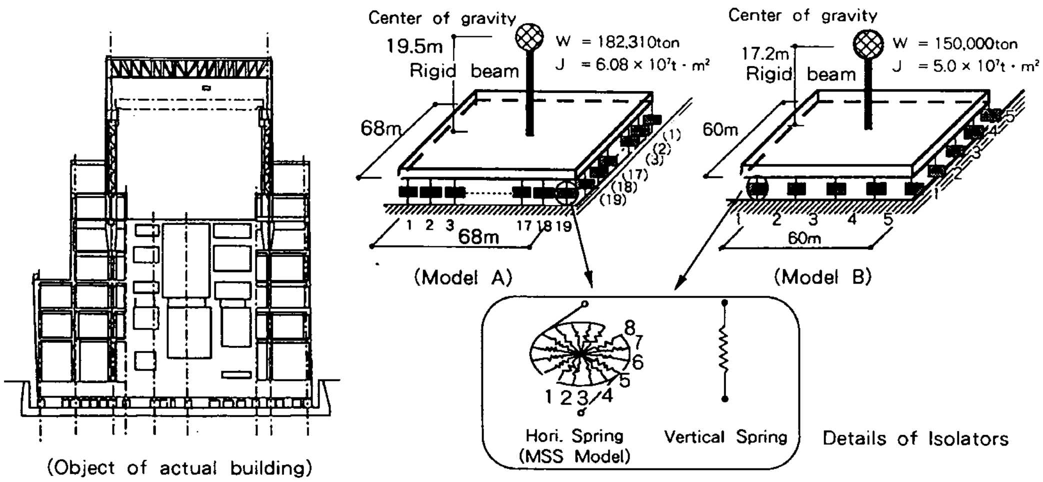
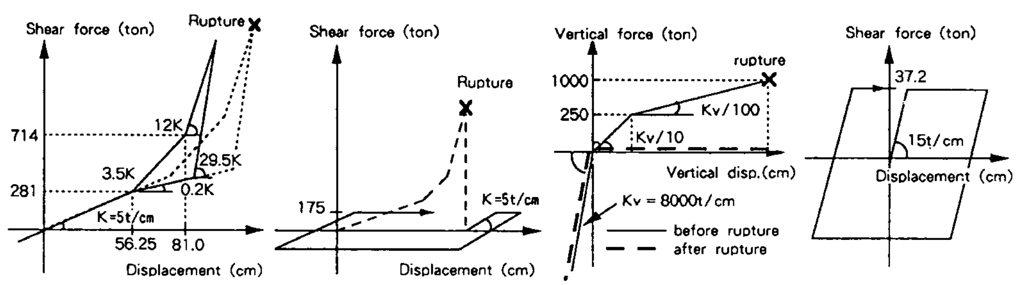


Fig. 1 Analytical model.



(a) Horizontal rule for isolators (b) Horizontal rule after rupture for isolators (c) Vertical rule for isolators (d) Horizontal rule for dampers

Fig. 2 Mechanical properties of isolation device.

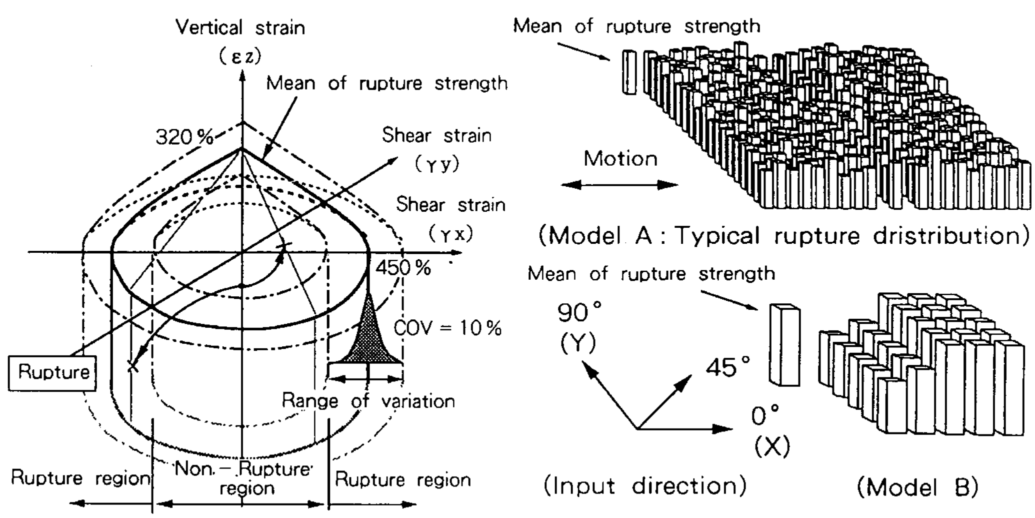


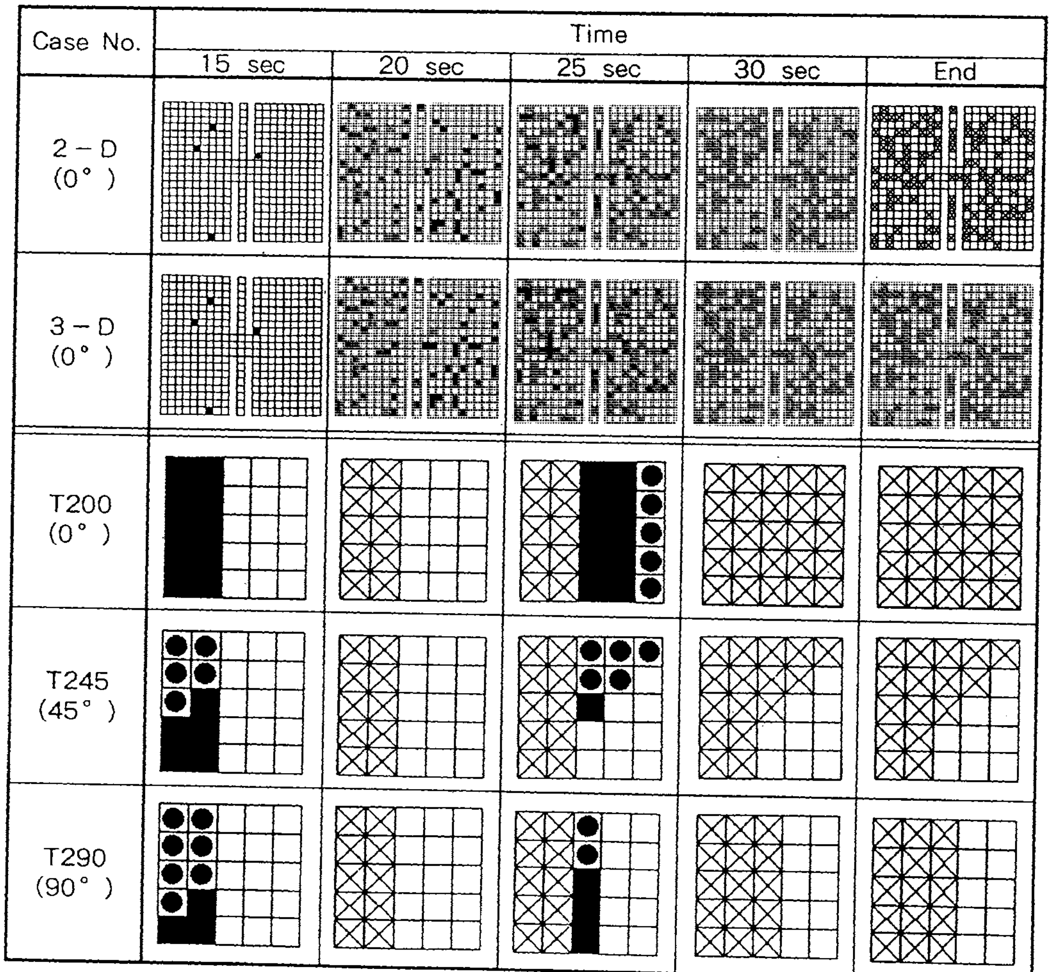
Fig. 3 Rupture criteria.

Table 1 List of parameters

Case No.	Input acceleration (gal)	Input direction (degree)	Remark
X170	1,700	0	Model A (50 Samplings)
X180	1,800	0	
X190	1,900	0	
X200	2,000	0	
X210	2,100	0	
T100	1,900	0	Model B
T145	1,900	45	
T190	1,900	90	
T200	2,000	0	
T245	2,000	45	
T290	2,000	90	

(Note) Two dimensional analyses with the same condition as three dimensional analyses are conducted, in which the torsional response is not considered.

Table 2 Typical Rupture Patterns



□ Rupture has not occurred yet.
⊡ Rupture by combination of tensile and shear strains occurred.
■ Rupture by combination of compressive and shear strains occurred.
⊠ Rupture has already occurred.

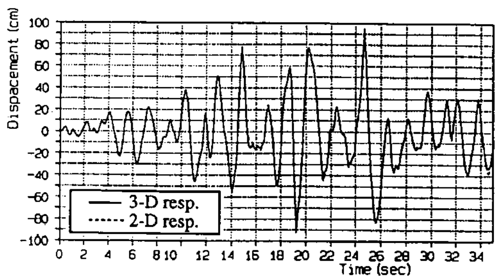


Fig. 4 Comparison of diplacement response between 2-D and 3-D.

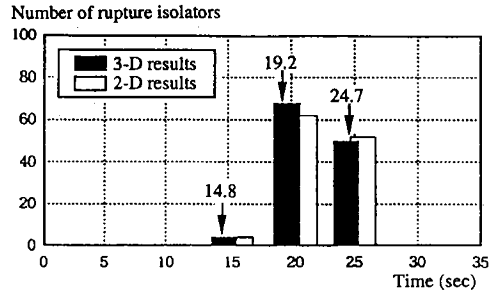


Fig. 5 Occurrence time of rupture and rupture number

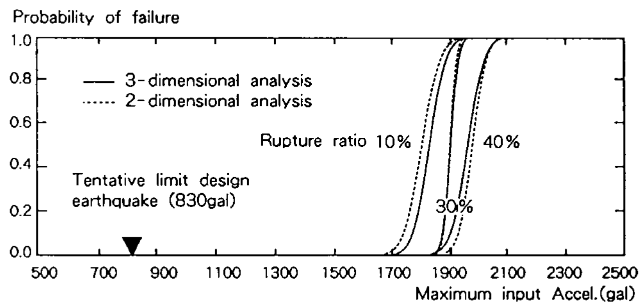


Fig. 6 Fragility curve of isolation layer.

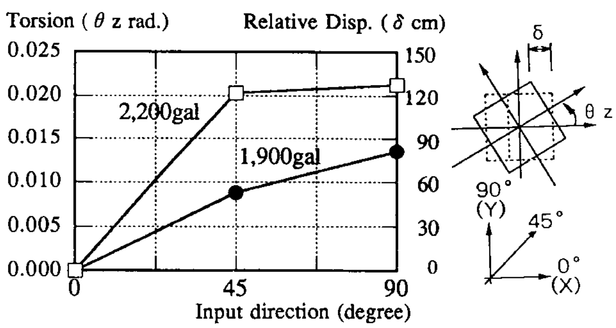


Fig. 7 Relationship of input direction and maximum torsional response.

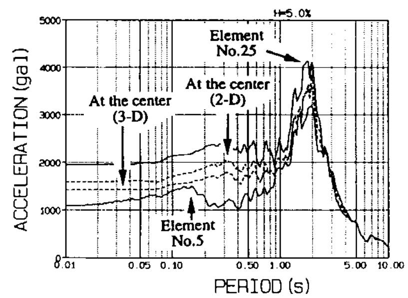


Fig. 9 Comparison of floor response spectrum between the center and the corner.

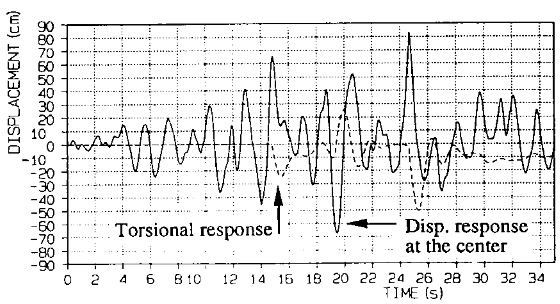


Fig.8 Comparison between displacement response and torsional response at the center.

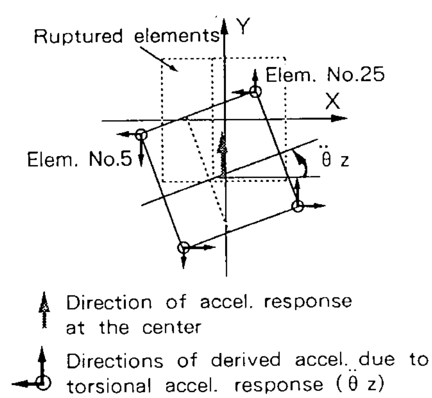


Fig.10 Concept of derivative acceleration due to the torsion.