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STUDY ON ULTIMATE BEHAVIOR OF BASE ISOLATED REACTOR BUILDING

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1. INTRODUCTION

In a high-seismic country such as Japan, it is important for the practical use of a base isolated plant to comprehend the seismic safety margin. In this study, the ultimate behavior of a base isolated reactor building beyond the design level was investigated using dynamic non-linear analysis in which the design seismic motions with increased amplitude were used. And the effects of the different stiffnesses used in the model of laminated rubber bearing on the ultimate behavior of a base isolated reactor building were also verified.

2. ANALYSIS METHODOLOGY

2.1 Structure

The structure of interest was the base isolated FBR reactor building. The building was planned so as to have low center of gravity and wide basemat to overcome low tensile capacity of the laminated rubber bearing, or to reduce tensile force due to seismic overturning moment.[1] For the isolation devices, the laminated rubber bearings (160 cm in a diameter and 22.5 cm in total thickness of rubber sheet) with a 500 tonf load rating and the Steel Dampers which formed a part of the seismic energy absorption device were provided. Fig.1 gives a summary of this base isolated reactor building.

2.2 Input Seismic Motion

The input motion consisted of seismic waves (S2 level) which contained long period components, as known to have the most influence on the base isolated structures. Fig.2 shows the response spectrum and the acceleration time history of S2 seismic motion.

2.3 Analysis Model

The analysis model is presented in Fig.3. The superstructure was modeled by shear-flexural beams with lumped-masses, where nonlinearity of shear stiffness of RC members was taken into account. The isolation layer consisted of a single horizontal spring and 19 vertical springs. The soil foundation was assumed to be the hard rock with Vs=1500m/s and modeled by sway and rocking springs. The non-linear rocking spring was used taking account of the up-lift of the basemat.

2.4 Modeling the Isolation Devices

The horizontal spring in the isolated layer consisted of the non-linear characteristics of the laminated rubber bearing and these of the Steel Damper. The horizontal restoring force characteristics of the laminated rubber bearing was modeled by the polygonal lines as shown in Fig.4. In addition, a slip phenomenon in which the value for the horizontal displacement ($\delta 1$) at the beginning stage of the hardening increased due to the influence exerted by cyclic loading was modeled by a repetition influence factor α .[2]

The restoring force characteristics of the Steel Damper was modeled by R-O model as shown in Fig.5.[3]

The vertical springs in the isolated layer, consisting of the laminated rubber bearing, have one non-linear characteristic. The restoring force characteristics of the laminated rubber bearing in the vertical directions were assumed to be asymmetrical (stiffness of the compression side was different from stiffness of tension side) and non-linear, as shown in Fig. 6.[2]

2.5 Cases for Analysis

Tables 1 and 2 show the cases for analysis.

Seismic response analyses were carried out by using the seismic motion amplified by 1.0 ~ 2.75 times the S2 seismic motion in order to determine the ultimate behavior of the base isolated reactor building.

Sensitivity analysis was performed to verify the effects of different stiffnesses used in the model of the laminated rubber bearing on the ultimate behavior of the base isolated reactor building. In sensitivity analysis, the seismic motion of 2.25 x S2 was input, and the values of stiffness in the hardening zone as shown in Fig.7 and the value of the repetition influence factor α were changed.

3. RESULTS

3.1 Seismic Response Analysis

Fig.8 shows the distribution of maximum response acceleration and the maximum response displacement under the influence of seismic motion with varying amplification. Fig.9 gives the relationship between the shear force and the horizontal displacement in the isolated layer (the laminated rubber bearings plus the Steel Dampers) when 2.75 x S2 seismic motion was input. As the amplification was increased, the effect of minimizing the response acceleration by the isolation devices diminished and the response acceleration of the steel structure on top of the reactor building increased. This is because the hysteresis curve of the laminated rubber bearing moves from the linear region into the hardening zone as the seismic motion increases, and the response of the building increases as the response in the short period increases.

Fig.10 shows the maximum response value in the shear force versus the horizontal displacement for the laminated rubber bearings. The hysteresis curves moved from the linear region into the hardening zone when 1.5 x S2 seismic motion was input, and the maximum horizontal displacement increased approximately in proportion to the amplification of input seismic motion. Above the level of 2.0 x S2, the displacement at the beginning stage of the hardening increased due to the effects of repetition, and the skeleton curve began to slip.

Fig.11 shows the maximum response value in the axial force versus the vertical displacement for the laminated rubber bearing. At the level of 1.5 x S2 a tensile force started to act on the laminated rubber bearings, and at the level of 2.75 x S2 the vertical displacement exceeded the turning point of the stiffness in the tension side.

Fig.12 shows the maximum response value in the axial strain versus the shear strain for the laminated rubber bearing. With input seismic motion greater than 2.0 x S2, where the skelton curve of the laminated rubber bearing moved into the hardening zone, the tensile axial strain increased and at the level of 2.75 x S2 the tensile axial strain exceeded the assumed breakage bound. However, since the reactor building as studied herein had a low center of gravity, the tensile axial strain at the level of 2.75 x S2 was small and about 10%.

3.2 Sensitivity Analysis

Fig.13 shows the comparison of each case in the maximum response.

Even when the stiffness in the hardening zone was varied by ± 20%, the changes in the maximum response acceleration at the support level of the reactor vessel, in the maximum horizontal displacement of the laminated rubber bearing, and in the maximum shear strain of the lowest story of the reactor building were within ± 5%. The effects of different stiffnesses in the hardening zone on maximum response were also small.

If the repetition influence was disregarded (α = 0), the maximum response acceleration at the support level of the reactor vessel and maximum shear strain on the lowest story of the reactor building increased by about 18%, and the maximum horizontal displacement in the isolated layer decreased by about 8% This leads to the conclusion that the repetition influence factor can have some effect on the maximum response. However, when the repetition influence factor α was assumed 0.50, the change in maximum response from the basic case (α = 0.45) was small, being within ± 2%.

4. CONCLUSIONS

In this study, the ultimate behavior of a base isolated reactor building was investigated using dynamic non-linear analysis by using the seismic motion amplified by 1.0 ~ 2.75 times the S2 seismic motion. And the effects of the different stiffnesses used in the model of the laminated rubber bearing on the ultimate behavior of a base isolated reactor building were verified by the sensitivity analysis. The results obtained by these studies may be summarized as follows.

i) With increased amplification of the imput seismic motion, the histeresis curves moved into the hardening zone and the response of the reactor building increased. However, the laminated rubber bearings remained undamaged at the level of 2.75 x S2 seismic motion. Therefore, the base isolated reactor building as studied herein had the sufficient seismic safety margin.

ii) It was understood that the repetition influence factor had some effect on the ultimate behavior of a base isolated reactor building, but the difference in the response was a little less than ± 20%.

5. ACKNOWLEDGMENTS

This study was carried out as a part of the FBR common research of the electric power companies in Japan, having useful advices and suggestions by professors and specialists.

Reference

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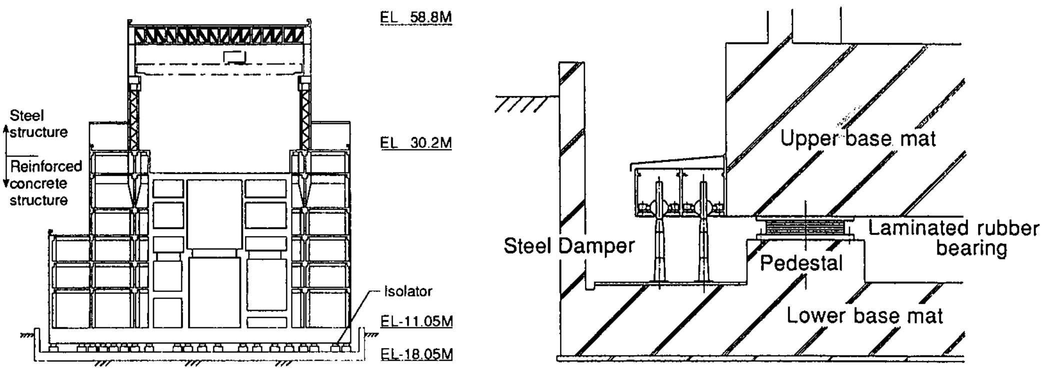
[3]Shirahama,K.et al.(1992)"Study on Concept of Seismic Isolation Type Plant for FBR (Part 20 Simulation Analysis of the Experiment on the Steel Damper)", Summaries of Technical Papers of Annual Meeting AIJ,Vol B,pp.1587-1588



(a) Section (b) Isolation Devices

Fig.1 Summary of base isolated reactor building

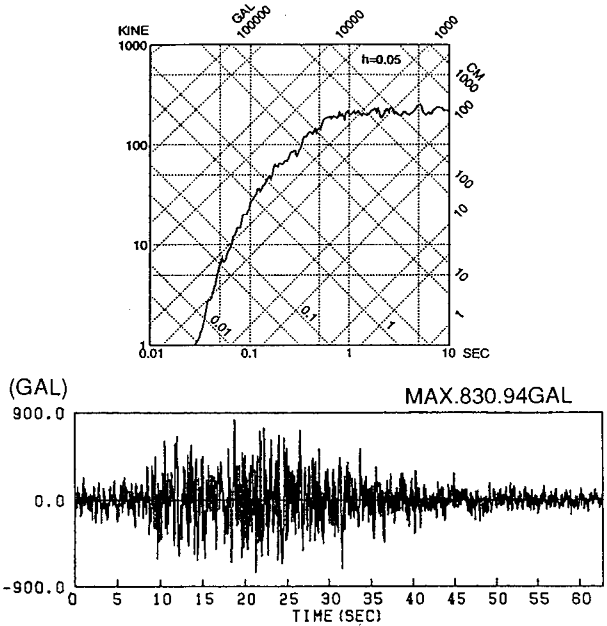


Fig.2 Input seismic motion (S2)

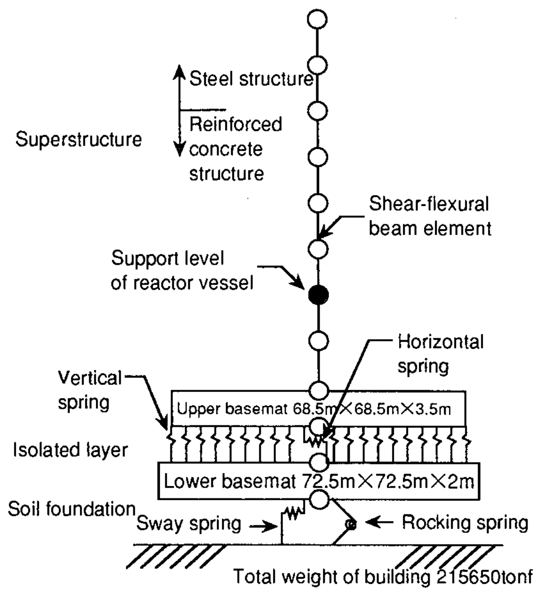
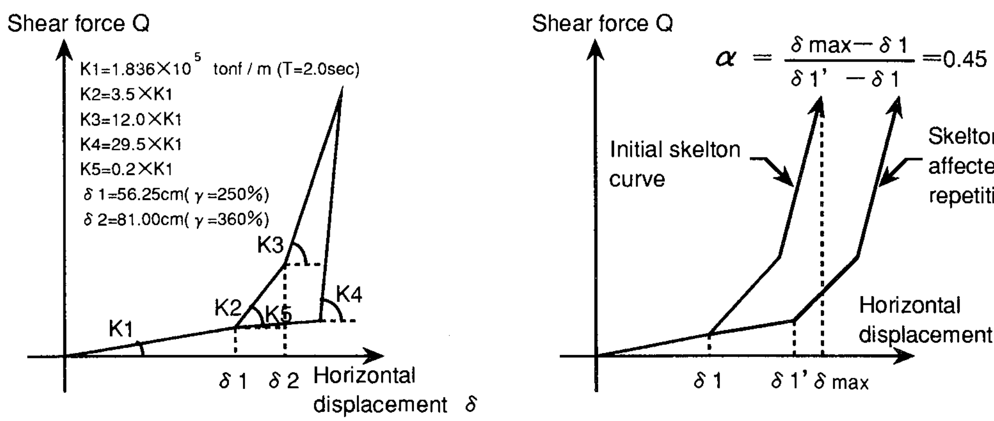
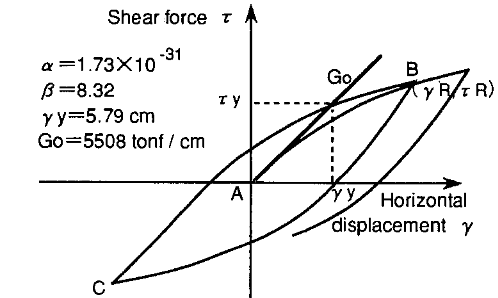


Fig.3 Analytical model



(a) Hysteresis curve (b) Repetition influence factor α

Fig.4 Horizontal restoring force characteristics of laminated rubber bearing



$$\gamma = \frac{\tau}{Go}\,(1+\alpha\,|\,\tau\,|^{\beta-1})$$

$$\frac{\gamma-\gamma R}{2} = \frac{\tau-\tau R}{2}\cdot\frac{1}{Go}\,(1+\alpha\,|\frac{\tau-\tau R}{2}|^{\beta-1})$$

Fig.5 Restoring force characteristics of steel damper

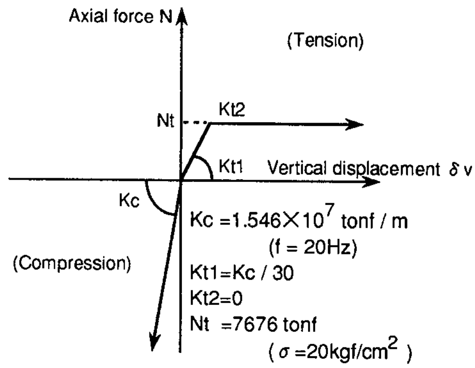


Fig.6 Vertical restoring force characteristics of laminated rubber bearing

Table 1 Cases for seimic response analysis at ultimate behavior

Case No.	Input seismic motion
1	1.0 × S2
2	1.5 × S2
3	1.75 × S2
4	2.0 × S2
5	2.25 × S2
6	2.5 × S2
7	2.75 × S2

Table 2 Cases for sensitivity analysis (Seismic motion of 2.25× S2 input)

Case No.	Stiffness in hardning zone	Repetition influence factor α
Basic case	K2 , K3	0.45
I − 1	1.2 K2 , 1.2 K3	0.45
I − 2	0.8 K2 , 0.8K3	0.45
II − 1	K2	0.0
II − 2	K2	0.50

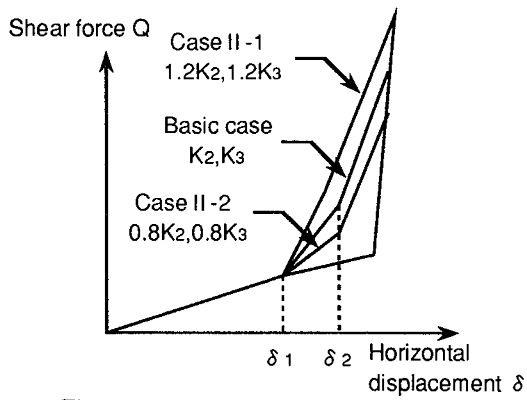
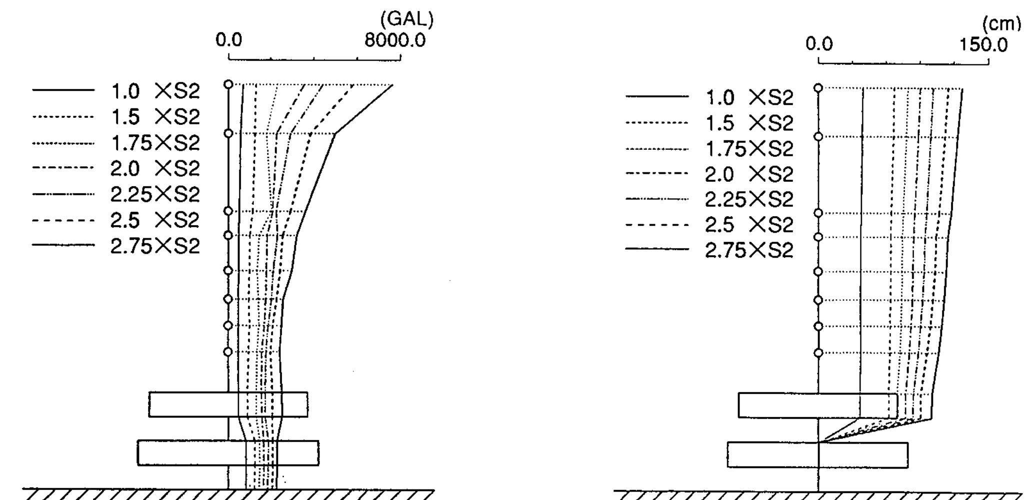


Fig.7 Stiffness in hardening zone for sensitivity analysis



Distribution of maximum response acceleration

Distribution of maximum response displacement

Fig.8 Maximum response

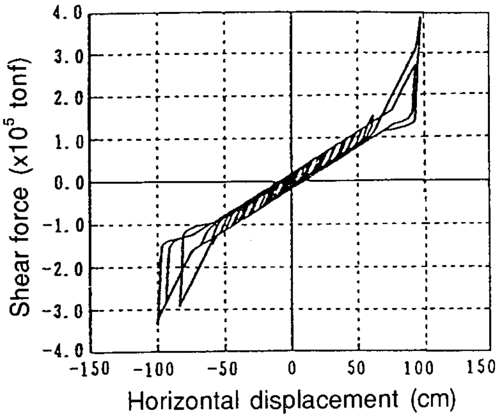


Fig.9 Relationship between shear force and horizontal displacement in the isolated layer (Case7 : 2.75× S2)

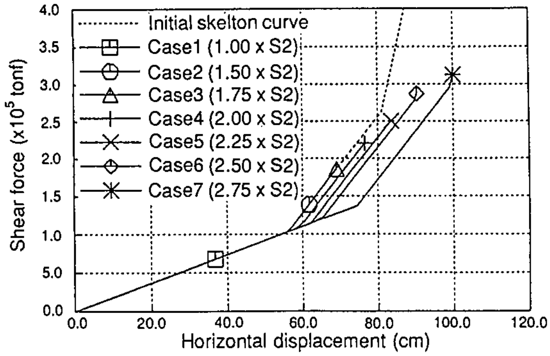


Fig.10 Maximum response value in shear force versus horizontal displacement for laminated rubber bearing

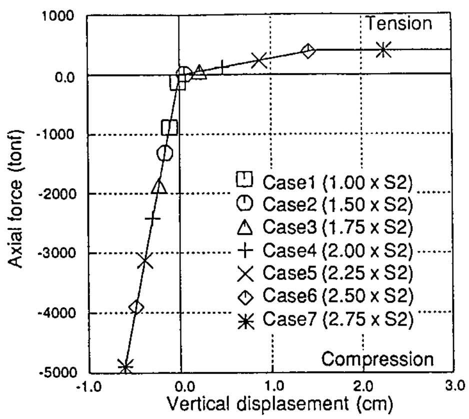


Fig.11 Maximum response value in axial force versus vertical displacement for laminated rubber bearing

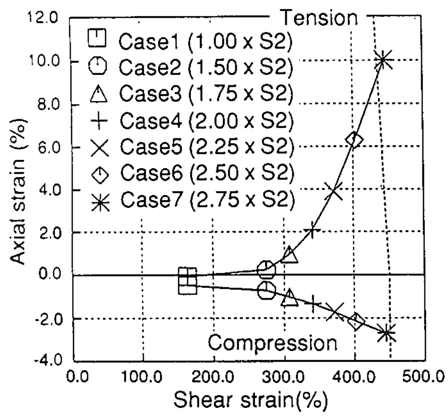


Fig.12 Maximum response value in axial strain versus shear strain for laminated rubber bearing

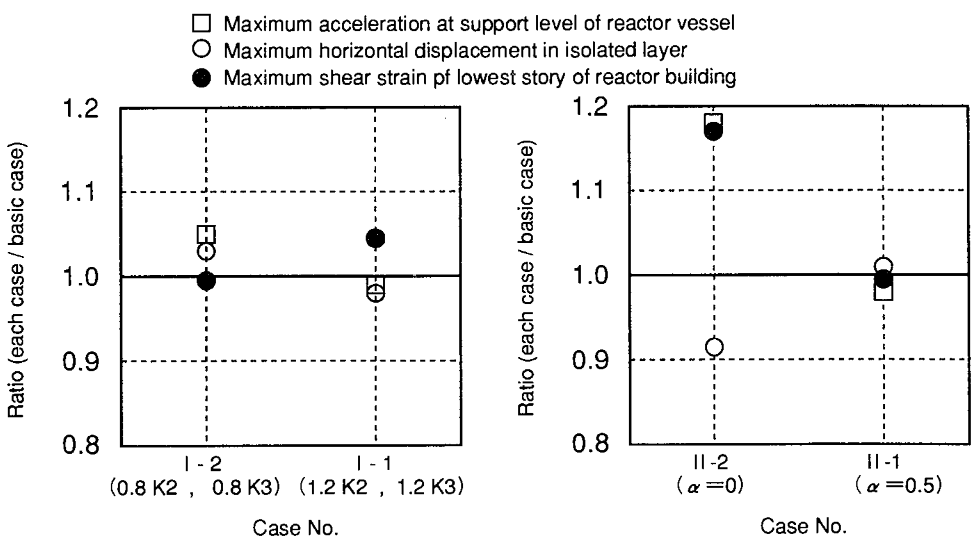


Fig.13 Comparison of each case with basic case in maximum response