

Shaking Table Test on Base Isolated FBR Plant Model

Part 1 Shaking Table Test Results

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ABSTRACT

Shaking table test on seismically isolated FBR plant model is carried out. The model is three story steel frame structure supported by nine laminated rubber bearings which are reduced to a scale of 1/15. The effectiveness of base isolation system is verified through this study.

1. INTRODUCTION

Base isolation system is expected to be effective in the reduction of seismic loads and the increase of the design freedom for FBR plant. It is, however, necessary to verify the effectiveness and reliability of this system by the experimental procedure.

A series of shaking table test including the element test of rubber bearings (Ref.1) and the simulation analysis (Ref.2) are carried out. The main purpose of this study is to confirm the performance of base isolation system under earthquake in design level and the validity of response analysis method.

Three types of laminated rubber bearing - natural rubber bearing with steel damper, lead rubber bearing and high-damping rubber bearing of 1/15 scaled model of prototype - are used in this test. It can be found that they show almost same performances as the results. so in this paper, the results of shaking table test using lead rubber bearings will be discussed.

2. OUTLINE OF SHAKING TABLE TEST

2.1 Experimental Model

The prototype FBR plant using laminated rubber bearings is used for this study, and the experimental model is designed according to the similarity law as shown in Table 1.

Fig.1 shows the experimental model. This model is the three story steel frame structure with a mass of 20tonf and is supported by nine rubber bearings under each column.

Table 2 shows the design specification of lead rubber bearing in comparison between prototype and 1/15 scaled model.

It is noted that the shearing and axial forces acting on each rubber bearing are directly measured by the component force transducers which are kinds of load-cells and can measure both forces simultaneously without interference.

2.2 Input Motions

Tentative design earthquake ground motions [T.D.E.] and El Centro (1940) are used as the SMiRT 11 Transactions Vol. K (August 1991) Tokyo, Japan, © 1991

input motions. The velocity response spectra of them are shown in Fig.2 .

T.D.E. is an artificial earthquake which is formulated for this study . The level of the tentative design response spectra ($S_v, h=5\%$) in the long period region (2~10sec.) is set to 100cm/sec . (Ref.3) NS component is the predominant direction and formulated to fit this target spectra . The levels of EW and UD components are assumed to be 0.8 and 0.6 times of the target spectra respectively . The amplitude of El Centro is increased to about 2 times of recorded one in order to make its effect almost even with T.D.E.

For the input motion to the shaking table , these waves are reduced in time to $1/\sqrt{15}$ according to the similarity law and NS , EW and UD components correspond to X , Y and Z direction respectively .

3. TEST RESULTS

3.1 Response of Superstructure

To evaluate the effectiveness on the mitigation of response acceleration , both isolated and non-isolated (i.e. directly fixed on the shaking table without rubber bearings) steel frame model are subjected to the earthquake input .

The acceleration response spectra of the 2nd floor and the maximum acceleration ratio of each floor by T.D.E. (NS) are illustrated in Fig.3 . In the case of isolated model , the response spectrum has only one peak around the period of 0.5 sec. (the natural period of rubber bearing). The intensity in the region below 0.2sec., where the natural periods of most important equipments exist, is almost constant of 0.3G and remarkably lower than that of the non-isolated model . As for the ratio , it is recognized that the values of isolated model are reduced to less than 1/5 of that of non-isolated one .

Fig.4 shows the response by El Centro (NS) . Fundamentally , the tendency of response is similar to that by T.D.E. (NS) as shown in Fig.3 . Because El Centro has predominant component in short period region compared to T.D.E., the ratios are under 0.5 showing significant isolation effect and smaller than that of T.D.E.

3.2 Characteristics of Lead Rubber Bearing

A typical hysteresis loop measured on rubber bearings under T.D.E. (NS) is shown in Fig.5 compared with the element test results . The element test results are obtained from the cyclic loading tests subjected to shear strain of 100% under both static and dynamic conditions . It is noticed there is a little difference in width of loops . The loop of shaking table test is illustrated with the average shearing force of nine bearings and the relative displacement between the superstructure and the shaking table . The maximum relative displacement is 11.3mm corresponds to shear strain of 75% of the rubber bearing . It can be seen that the rubber bearing shows good performance under earthquake and the shape of loop is similar to the dynamic element test result very well .

The equivalent stiffness (K_{eq}) and the equivalent damping ratio (h_{eq}) of lead rubber bearing calculated from the hysteresis loops are shown in Fig.6 . K_{eq} and h_{eq} in the shaking table test , symbolized by the black marks , are calculated from each maximum loop under T.D.E. of 0.5~2.3 times in acceleration amplitude and El Centro . In these cases, the total shearing force of the nine rubber bearings is used to estimate the characteristics of the isolation layer . The white marks indicate the values obtained from the element test and K_{eq} is multiplied by nine for the comparison with the isolation layer in the shaking table test . The results of dynamic element test show good agreement with the shaking table test results as well as Fig.5 . On the other hand , the results of static element test are lower than the dynamic one . It is considered that the dynamic characteristics of the isolation layer as the assemblage of rubber bearings is well expressed by the results from element test , especially in the dynamic condition . It can be also seen that both K_{eq} and h_{eq} have tendency to decrease along with the increase of deformation . The stiffness and the damping constant are specified for the shear strain of 225% . In this region , the values obtained from the test as shown in Fig.6 are satisfied the design specifications .

Fig.7 shows the comparison between the maximum response by T.D.E. (NS) and the failure

test result of rubber bearing . The limit of linearity seems to be about 250% of shear strain and the bearing ruptures in 500% after the hardening phenomenon . On the other hand , the maximum response by T.D.E. (NS) is 75% of shear strain and it is confirmed that the rubber bearing is stable during this earthquake and has enough margin for the limit of linearity . Although the response seems to be rather small for its capacity, rubber bearing should be used under the limit of linearity with appropriate margin for the design of important structure like FBR . It is because the hardening phenomenon of the rubber bearing makes the response increase .

3.3 Effect of Multi-directional Shaking

The maximum acceleration ratio of each floor and maximum relative displacement in isolation layer in X-direction under multi-directional shakings of both T.D.E. and El Centro are shown in Fig.8 and Fig.9 . Although the response acceleration and relative displacement are slightly enhanced by the multi-directional shaking compared with the uni-directional shaking , it should be said that there is no significant effect on the response in X-direction under the multi-directional shaking .

Effect on shearing and axial forces acting on rubber bearing is shown in Fig.10. The response in X-direction is not affected by the multi-directional shaking as is mentioned above , so the loops of shearing force are almost same shape . On the other hand , the variation of axial force is induced by the rocking motion of superstructure under X-directional shaking and , of course , by the vertical input motion . From these results, it is regarded that the axial force is enhanced by the multi-directional shaking due to the coupling of rocking and vertical motions . The axial forces in this figure are the dynamic components and all these amplitudes are smaller than the initial axial force at rest of 2.22ton . Thus , it can be seen that the rubber bearing is in compressive state even in multi-directional shaking .

4. CONCLUSIONS

The results of this study are summarized as follows ;

- 1) The response acceleration of superstructure and equipments is remarkably reduced by applying the base isolation system .
- 2) Stiffness and damping characteristics of lead rubber bearings as an assemblage obtained from the shaking table test are well expressed by the results from element test , especially in dynamic condition .
- 3) Rubber bearing behaves in compressive state and under the limit of linearity with enough margin during design level earthquake .
- 4) The response in X-direction is not affected by the multi-directional shaking , however , care must be taken that the axial force is enhanced by the multi-directional shaking due to the coupling of rocking and vertical motions .

Finally , it should be noted as the conclusions that the effectiveness and the reliability of base isolation system during design level earthquake are confirmed .

5. ACKNOWLEDGMENTS

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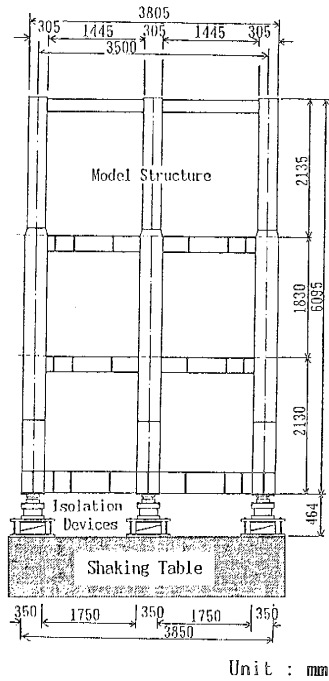


Fig. 1 Experimental Model

Table 1 Similarity law

Parameter	Similitude
Length (L)	$L_p / L_m = \lambda = 15$
Acceleration (α)	$\alpha_p / \alpha_m = 1$
Force (F)	$F_p / F_m = \lambda^2 = 225$
Stress (σ)	$\sigma_p / \sigma_m = 1$
Strain (γ)	$\gamma_p / \gamma_m = 1$
Time (T)	$T_p / T_m = \sqrt{\lambda} = 3.87$

p:prototype . m:model

Table 2 Design Specifications of LRB

Item	Prototype	Model
Loading Weight (tf)	500	2.22
Hori. Spring Const. (tf/cm)	5.036	0.336
Natural Period (sec)	2.0	0.52
Diameter (cm)	160	10.7
Rubber Layers (cm×number)	0.9×25	0.06×25

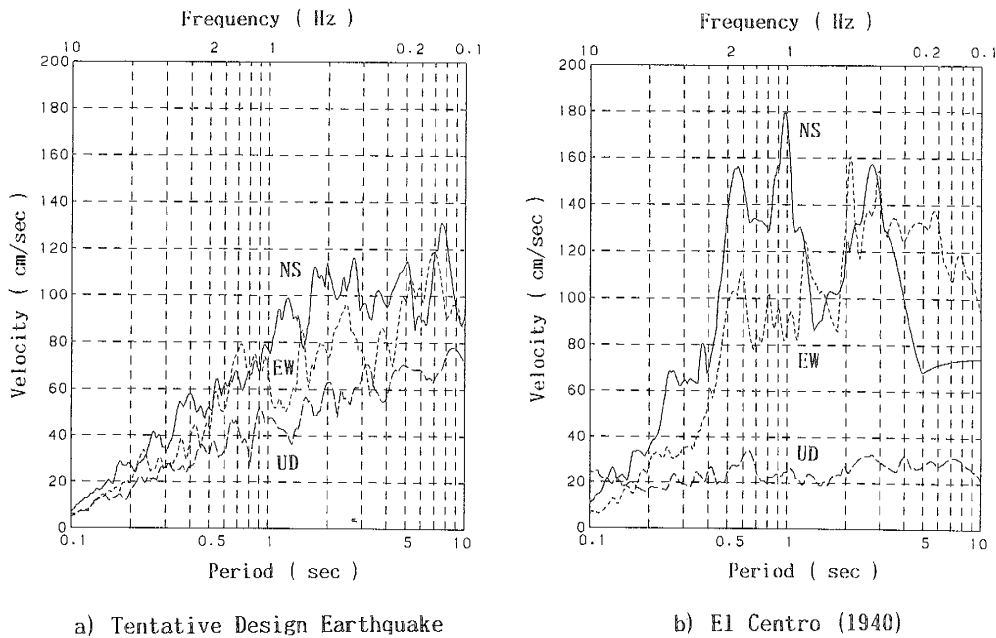
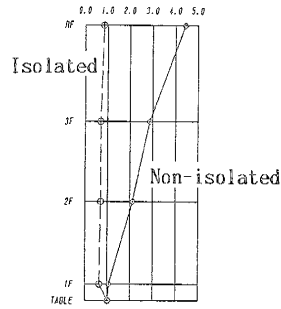
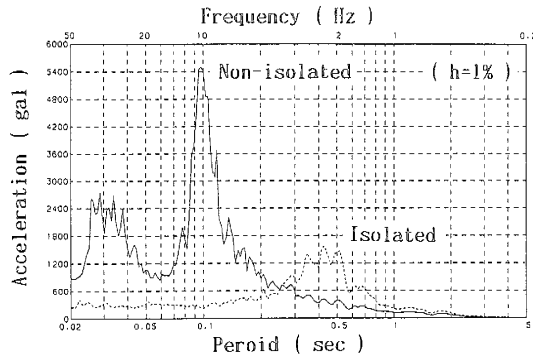
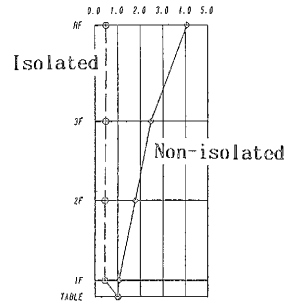
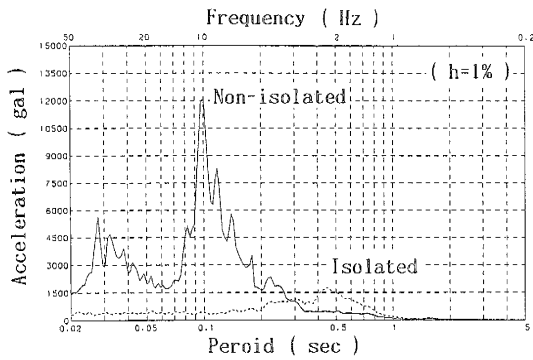


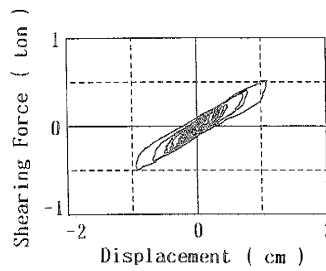
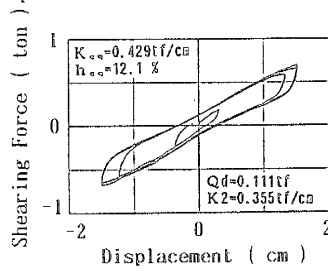
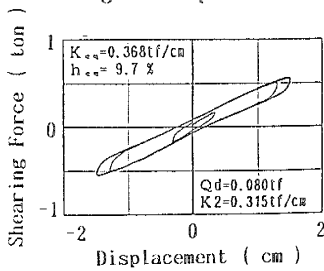
Fig. 2 Velocity Response Spectra of Input Motions (h=5%)



a) Acceleration Response spectrum of 2nd Floor b) Maximum acceleration Ratio
Fig.3 Comparison of Response Between Isolated and Non-isolated [T.D.E.]

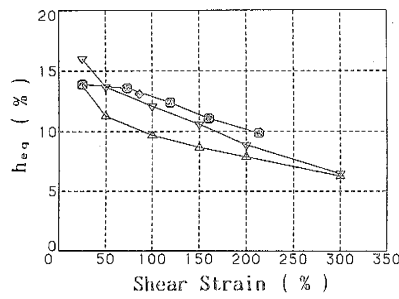
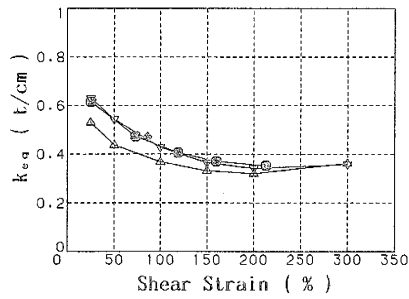


a) Acceleration Response spectrum of 2nd Floor b) Maximum acceleration Ratio
Fig.4 Comparison of Response Between Isolated and Non-isolated [El Centro]



a) Element Test (Static) b) Element Test (Dynamic) c) Shaking Table Test

Fig.5 Comparison of Hysteresis loop



■ Shaking Table Test (T.D.E.)
◆ Shaking Table Test (El Centro)
▽ Element Test (Static)
△ Element Test (Dynamic)

Fig.6 Comparison of $k_{e,q}$ and $h_{e,q}$

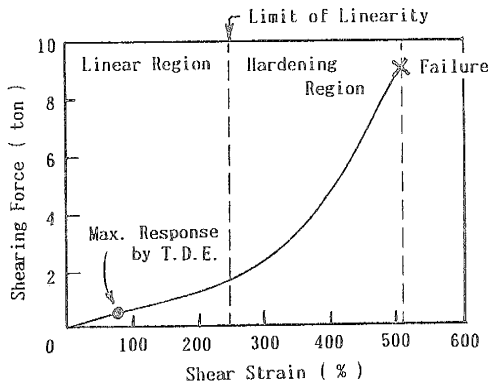


Fig. 7 Comparison between shaking table test and Element Failure Test results

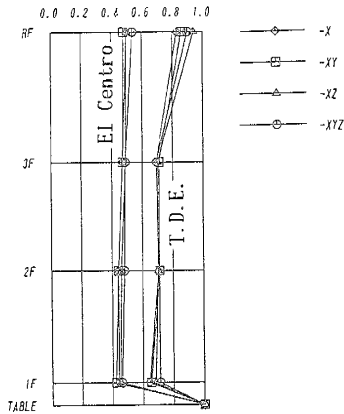


Fig. 8 Effect of Multi-directional Shaking (Maximum Acceleration Ratio)

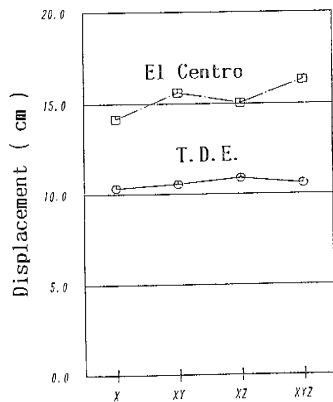


Fig. 9 Effect of Multi-directional Shaking (Maximum Relative Displacement)

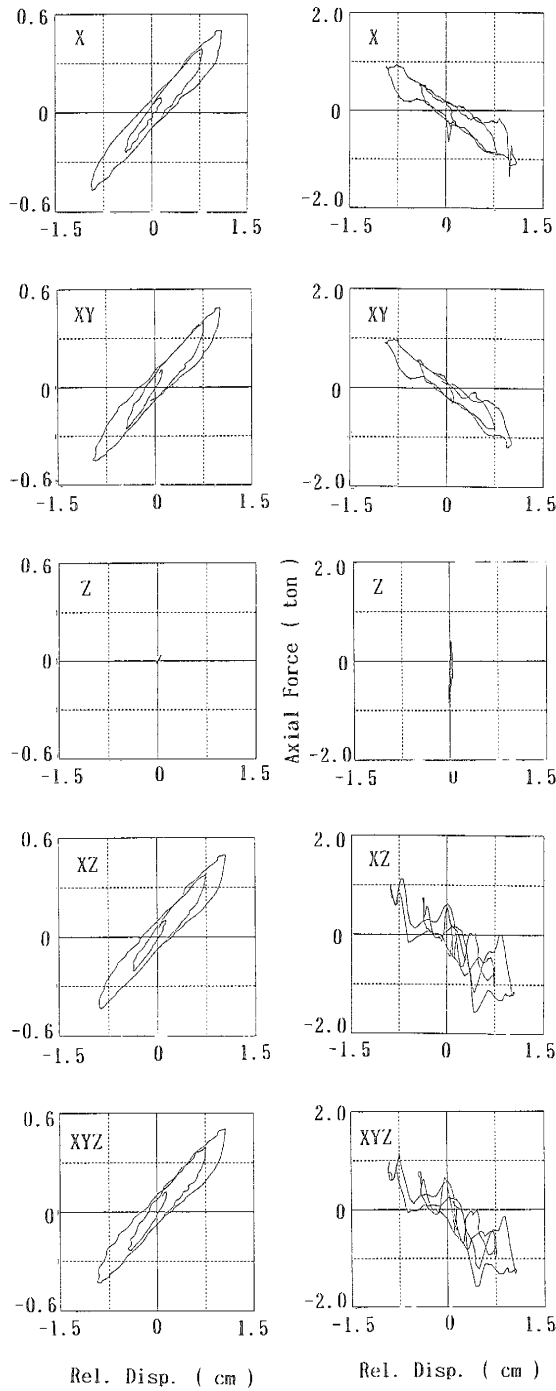


Fig. 10 Effect of Multi-directional Shaking (Shearing and Axial Force, T.D.E.)