Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.V)

7-9-11

STUDY ON BASE ISOLATION FOR TORSIONAL RESPONSE REDUCTION IN ASYMMETRIC STRUCTURES UNDER EARTHQUAKE MOTION

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SUMMARY

The objectives of this study are to examine torsional response characteristics of asymmetrical buildings with base isolation systems by conducting model tests on shaking table and dynamic analyses and to verify effectiveness of usage of that system. Based on these test and analytical results, effective arrangement of the base isolation system to reduce the torsional response of such asymmetrical buildings is discussed.

INTRODUCTION

Recently, several buildings with base isolation systems have been constructed and effectiveness of those systems to reduce earthquake input are reported by several observation results. However, the system is now adopted only in the regular shape building which is symmetry in stiffness and mass distribution in plan and elevation, where torsional response is negligible.

To apply this system to more general building, it is important to establish the design philosophy how to arrange the system so that the torsional effects can be minimized.

In this paper, torsional response characteristics of building models with base isolation system are described by dynamic tests and analyses.

OUTLINE OF EXPERIMENTS

Test Model The test model consists of two floors as shown in Fig.-1 and Photo.-1. The upper floor supported by four steel columns represents a building and has asymmetry in stiffness or mass disribution as follows.

1) An asymmetrical Model in stiffness distribution (Model A , Fig.-1a)
   Two pairs of different stiffness steel columns (Column L ,Column S) are utilized.

2) An asymmetrical Model in mass distribution (Model B , Fig.-1b)
   Additional mass is eccentrically attached on the upper floor supported by four same stiffness steel columns (Column M).

The lower floor has a base isolation system underneath. Two types of isolation systems are employed, one of which is four laminated rubber bearings

(Rubbers) usage only, and another is two cantilever type dampers of prestressing steel bar (Dampers) added together.

Regarding laminated rubber bearings, same stiffness rubbers are utilized to avoid stiffness eccentricity of base isolation system except Model B-3 and B-4 cases in which two different kinds of laminated rubber bearings are installed to coincide the centroid of stiffness of base isolation system with that of gravity of superstructure.

Table-1 summarizes the test models and characteristics of model components such as Weight, Column, Rubber and Damper. In this table, Model A-1 and B-1 are base fixed case for comparison usage.

Measurement Measurement systems with regard to response accelerations, displacements, input acceleration and strains of steel columns and Dampers are also shown in Fig.-1.

Testing Program One directional (X direction) input motions are applied on shaking table, where maximum accelerations are controled so that the steel column remains in elastic and Rubber deformation less than 3cm.

1) Resonance test
Natural frequencies and vibration modes of test models are examined by sine wave input motion.

2) Earthquake response test
Three earthquake waves such as El Centro 1940 NS, Taft 1952 EW and Hachinohe 1968 EW are employed where time scale is reduced to 1/2 to take account of scale effect. In this paper, El Centro 1940 NS tests are mainly explained.

RESULTS OF DYMAMIC TESTS

Hysteretic characteristic of a base isolation system Fig.-2 shows the horizontal force-displacement characteristics of base isolation systems obtained by static test in which Fig.-2a corresponds usage of only four laminated rubber bearings (Rubber 2M), while Fig.-2b two cantilever steel dampers added together.

Comparison of these two figures indicates effectiveness of the hysteretic energy absorption characteristic of prestressing steel damper.

Resonance Curve and Vibration Mode (Dynamic characteristic) Eigen values obtained from resonance tests are shown in Table-2. Fig.-3 shows the resonance curves and vibration modes of Model A-1 and A-2. A response acceleration and a torsional deformation in the first mode of base isolated system become smaller than fixed base case.

Earthquake Response Fig.-5 and Table-3 show time history response displacements of upper floor and maximum response displacements of upper and lower floors, respectively, where input motion is El Centro 1940 NS 150gal and response direction is the same of that of input. In these figure and table, N means north and indicates weaker stiffness column side for Model A and additional mass allocated side for Model B.

1) Time History Response Displacement
In fixed base cases, the displacements of the weaker stiffness columns side in Model A-1 and the additional mass allocated side in Model B-1 are larger than those of the other side, then torsional deformations occur fairly. On the other hand, in base isolated cases, the response displacements of both sides are nearly equal, and no significant torsional deformations occur.

From these results, it seems very effective to use the base isolation system for the reduction of torsional deformation of asymmetrical buildings.

2) Maximum response displacement

In case of Model A series, N side displacement is almost twice as large as S side one in base fixed case, while both side displacements are almost the same in base isolated cases. Besides, when comparing displacements of base isolation systems between Model A-2 and A-3, the displacements of Model A-3 are smaller than those of Model A-2 as a result of energy absorption effect of Dampers.

In case of Model B series, especially in base isolated Model B-2, torsional deformation is not reduced just alike the base fixed model, because the center of stiffness of the base isolation system does not coincide with that of gravity of superstructure. However, in Model B-3 and B-4, torsional deformations are more reduced, since the above two centers become close to each other.

SIMULATION ANALYSIS

Outline of Analysis Simulation analysis is conducted using shear-type vibration model as shown in Fig.-4, where two translational and a rotational degrees of freedom are provided at the center of gravity of each floor[1]. Each column stiffness is evaluated by Multiple Shear Spring model (MSS model)[2] as shown in Fig.-4 to take account of the interaction effect between two-dimensional forces beyond elastic region. Viscous damping coefficients are assumed 0.4%, 6.0%, and 0.0% for steel column, laminated rubber bearing and prestressing steel bar, respectively.

Results of Analysis Analytical results of eigen values, time history waves and maximum values of earthquake response displacement are shown in Table-2, Fig.-5 and Table-3, respectively, together with the test results. From these results, simulation analysis results provide good agreement with the test results in all cases.

CONCLUSION

Folloing are concluded through the present study :

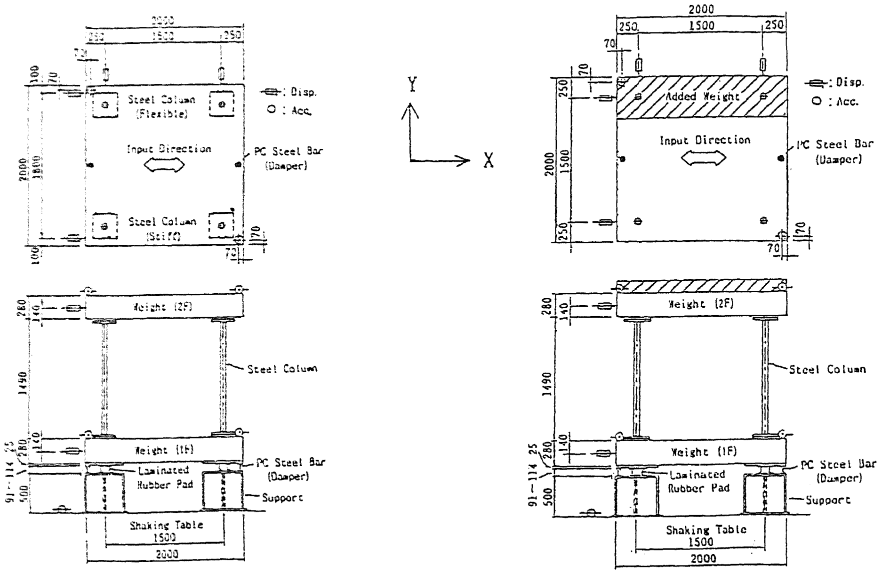
1) Base isolation system provides great promise for the reduction in torsional and lateral forces of buildings. Therefore this system may lead cost effectiveness in the construction of torsionally unbalanced building.

2) Torsional deformation can be minimized when the structural design is carried out so that the center of stiffness and strength of isolation system coincide with that of gravity of superstructure.

3) Dynamic analysis method used in this study is effective to predict the response behavior of isolated system because of a good agreement obtained between simulation analysis and test results.

REFFERENCES

1. Suzuki, T., Okada, H., etc. "Torsional Response Characteristics of Building with Base Isolation System (Part 1)," Report of the Technical Research Institute OHBAYASHI CORP. , No. 36, 67-71, Feb. (1988).
2. Wada, A., Kinoshita, M., " Elastic Plastic Dynamic 3-Dimensional Response Analysis by using a Multiple Shear Spring Model (Part 1, Parat 2)," Summaries of Technical Papears of Annual Meeting, AIJ, B, 313-316, Oct. (1985).



a. Model A (Stiffness Asymmetry Model) b. Model B (Mass Asymmetry Model)

Fig.-1 Asymmetry Test Models

Table-1 List of Experiment Models

Specimen		Column	Rubber	Damper	Refferences	
Stiffness Asymmetry Model	Model A-1	Column S Column L	— —	—	Fixed-Based Model (Elastic)	Weight · 1st floor weight : W_1=3.12t · 2nd floor weight : W_2=2.89t · Added weight : W_3=1.18t Stiffness of Column · Column S : k_H=0.164t/cm · Column M : k_H=0.289t/cm · Column L : k_H=0.556t/cm Rubber (Laminated Rubber Bearing) Material:Natural Rubber · Rubber 2M : k_H=37.0kg/cm * Diameter:80mm , Height:75.0mm · Rubber 3M : k_H=59.2kg/cm * Diameter:100mm , Height:89.4mm *Stiffness k_H changes slightly under Working Load Level. Damper (Cantilever Type) Material:PC Steel Bar Diameter:11mm , Length:75mm Yielding Disp.:5mm
	Model A-2	Column S Column L	Rubber 2M Rubber 2M	—	Isolated Model	
	Model A-3	Column S Column L	Rubber 2M Rubber 2M	○	Isolated Model (Elasto-Plastic)	
Mass Asymmetry Model	Model B-1	Column M Column M	— —	—	Fixed-Based Model (Elastic)	
	Model B-2	Column M Column M	Rubber 3M Rubber 3M	—	Isolated Model (Elastic)	
	Model B-3	Column M Column M	Rubber 3M Rubber 2M	—	Isolated Model (Elastic)	
	Model B-4	Column M Column M	Rubber 3M Rubber 2M	○	Isolated Model (Elasto-Plastic)	

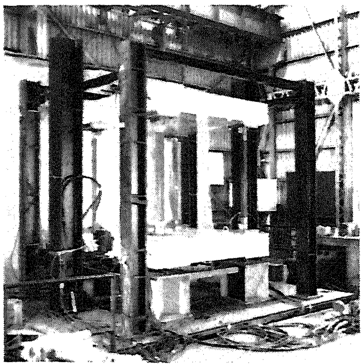
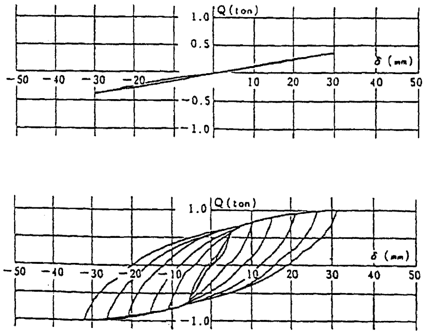


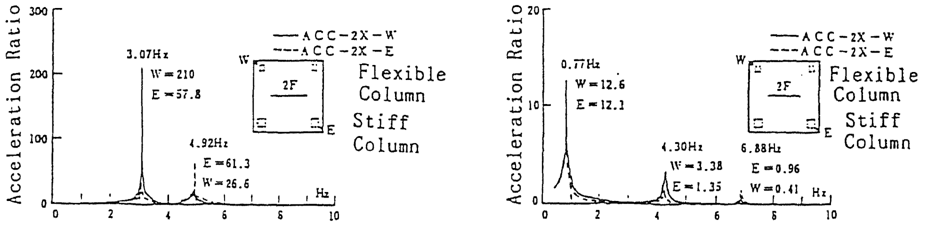
Photo.-1 Model A (Stiffnes Asymmetry Model)



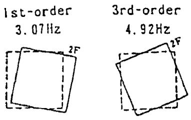
a. Rubber 2M

b. Rubber 2M + Damper

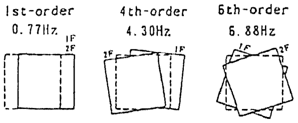
Fig.-2 Horizontal Force - Disp. curve (Static Test)



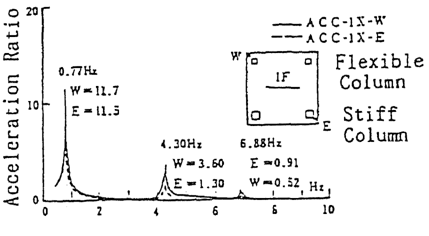
Fixed Base Model (A-1)



Fixed Base Model (A-1)



Fixed Base Model (A-2)



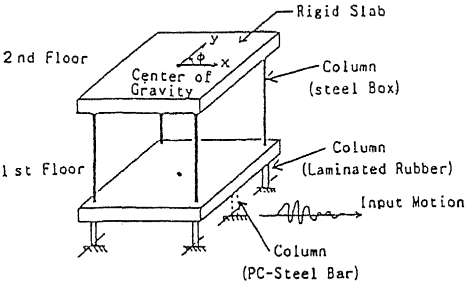
Base Isolation Model (A-2)

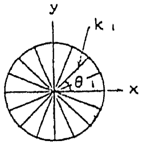
Fig.-3 Resonance Curve and Vibration Model (Model A)

Table-2 Results of Eigen Value

Specimen		Vibration Mode (Hz): 1st.	2nd.	3rd.	4th.	5th.	6th.
Stiffness Asymmetry Model	Model A-1	3.07	-	4.92			
		3.02	3.52	4.91			
	Model A-2	0.77	-	-	4.30	-	6.88
		0.771	0.773	1.00	4.27	4.94	6.88
Mass Asymmetry Model	Model B-1	2.55	-	3.64			
		2.55	2.67	3.56			
	Model B-2	0.88	-	-	4.14	-	5.67
		0.881	0.915	1.21	4.02	4.20	5.63
	Model B-3	0.83	-	-	4.15	-	5.62
		0.830	0.831	1.06	4.01	4.17	5.57

Upper row values ; experiment , Lower row values ; analysis , - ; not measured





k_i : Stiffness of i element (Elasto-Plastic)

K : Stiffness of Column

Δx, Δy : Deformation Increment

ΔP_x, ΔP_y : Force Increment

$$\begin{Bmatrix} \Delta P_x \\ \Delta P_y \end{Bmatrix} = \begin{bmatrix} K \end{bmatrix} \begin{Bmatrix} \Delta x \\ \Delta y \end{Bmatrix}$$

$$\begin{bmatrix} K \end{bmatrix} = \begin{bmatrix} \Sigma k_i \cos^2 \theta_i & \Sigma k_i \cos\theta_i \sin\theta_i \\ \Sigma k_i \cos\theta_i \sin\theta_i & \Sigma k_i \sin^2 \theta_i \end{bmatrix}$$

a. Vibration Model · b. Evaluation of Column Stiffness

Fig.-4 Analytical Model

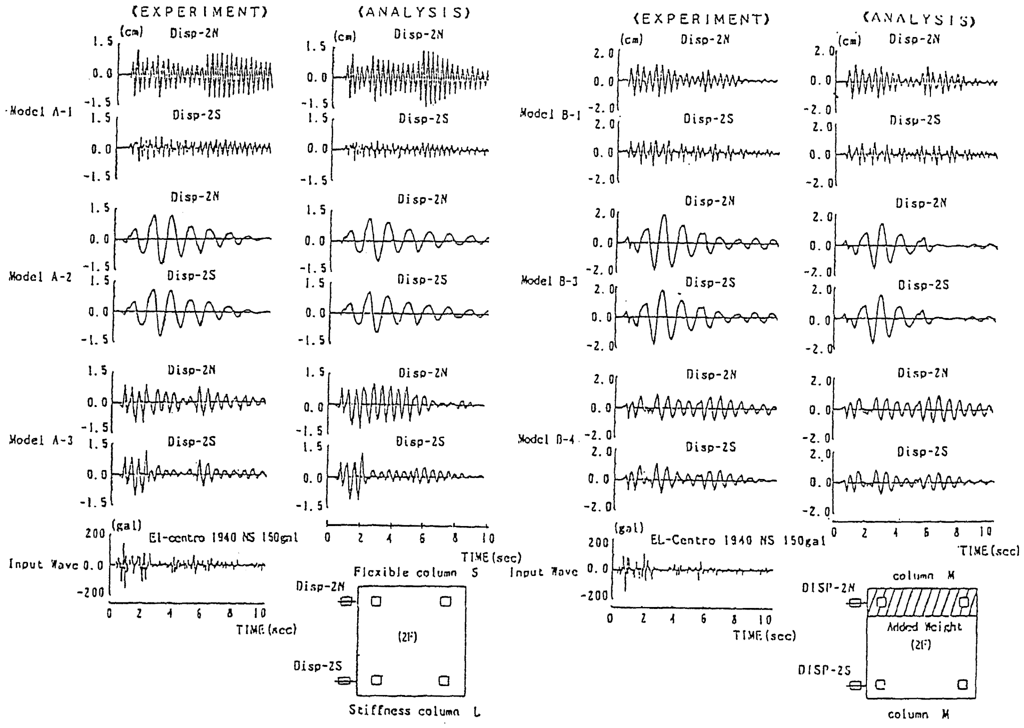


Fig.-5 Experimental and analytical Results of earthquake response

Table-3 Maximum Displacements of earthquake response

Specimen			Experiment(cm)		Analysis(cm)	
			1F	2F	1F	2F
Stiffness Asymmetry Model	Model A-1	N side	-	1.223	-	1.325
		S side	-	0.653	-	0.578
	Model A-2	N side	2.089	2.494	2.048	2.212
		S side	2.081	2.498	2.025	2.117
	Model A-3	N side	0.870	1.043	0.901	1.199
		S side	0.855	1.163	0.936	1.135
Mass Asymmetry Model	Model B-1	N side	0.010	1.119	-	1.015
		S side	0.013	0.871	-	0.789
	Model B-2	N side	1.969	2.209	1.993	2.172
		S side	1.349	1.500	1.220	1.337
	Model B-3	N side	1.651	1.875	1.457	1.639
		S side	1.639	1.797	1.432	1.570
	Model B-4	N side	0.607	0.929	0.604	0.927
		S side	0.721	1.099	0.615	0.822

(El Centro 1940 NS 150gal input)