SMiRT–12 / K. Kussmaul (Editor)
1993 Elsevier Science Publishers B.V.

K23/6

SEISMIC RESPONSE OF A BASE-ISOLATED BUILDING WITH HIGH DAMPING-LOW SHEAR MODULUS ELASTOMERIC BEARINGS

C.Y. Wang[1], Y.W. Chang[1], R.F. Kulak[1], R.W. Seidensticker[1]T. Kuroda[2] and M. Kobatake[2]

[1]Reactor Engineering Division, Argonne National Laboratory, 9700 S. Cass Avenue, Argonne, IL 60439, USA
[2]Nuclear Power Division, Shimizu Corporation, Tokyo, Japan

ABSTRACT

This paper deals with an investigation of seismic responses of a base-isolated building subjected to actual earthquakes. The isolation system consists of six medium shape factor, high damping, low shear modulus bearings designed by ANL and manufactured in the United Kingdom. The objective is two-fold: (1) to study the effectiveness of the isolated bearings through responses of the test building under actual earthquakes, and (2) to validate the 3-D SISEC program.

Results obtained from the earthquake observations indicate that the advantage of the base-isolation system in mitigating the acceleration of the superstructure is very pronounced. For earthquakes #42 and #44, the accelerations at the roof level of the isolated building are only 20% to 30% of the ordinary building accelerations. Also, for both ordinary and base-isolated buildings the computed accelerations agree reasonably well with those recorded.

1 INTRODUCTION

Seismic isolation is gaining attention worldwide for use in a wide spectrum of structures and critical facilities, including bridges, office buildings, hospitals, computing and telecommunication centers, as well as nuclear facilities. Today there are over 125 structures worldwide which are isolated and the numbers have been increasing steadily in the past few years. Also, substantial research efforts have been devoted to the designs, testing of isolation bearings, as well as development of analytical methods for predicting the responses of isolated structures.

An international cooperation program was initiated in September, 1988 by Argonne National Laboratory (ANL) of the USA and Shimizu Corporation of Japan for studying the response of isolated structures under actual earthquakes. Within the program agreement, Shimizu provided their test facility and earthquake data collection while ANL supplied the isolation bearings to be installed at the test facility and performed most of the analytical simulations utilizing the ANL developed 3-D computer program, SISEC (Seismic Isolation System Evaluation Code) (Wang et al., 1991).

To ensure the accuracy of the analytical simulation, recorded data of full-size reinforced concrete structures are used as the benchmarks for comparisons of code simulations with observations. Also, numerical calculations were carried out for the ordinary building, aimed at studying the relative responses of these two structures.

Two high-damping isolation systems, designed by ANL, were installed in the isolated building of the test facility. The first one, installed in April 1989, was a high shape factor, high shear modulus rubber bearing system aimed for medium and large earthquakes. From April 1989 to July 1990 thirty-seven (37) earthquakes have been recorded. Detailed responses of the test facility were analyzed and reported (Wang & Gvildys 1991; Uras 1993). The second one was a medium shape factor, low shear modulus bearing system designed for a wide range of earthquakes, including small earthquakes. This system was installed in October 1990. This paper addresses the response of the low shear modulus bearing system.

From November 1990 to March 1991, seven earthquake motions were observed at the test facility (Kuroda et al., 1991). Complete records of two representative earthquakes, #42 and #44, are used in this paper. In the analysis, 3-D models were developed for simulating the seismic responses of the ordinary and isolated structures. Correlations of observed and calculated accelerations at all instrument locations are made. The advantage of the base-isolation system in reducing the seismic accelerations is also discussed.

2 TEST FACILITY

Two test buildings, one conventionally designed and the other base-isolated, were constructed side-by-side at Tohoku University in Sendai, which is located in the northern part of Japan. The test buildings consist of two full-size, three-story reinforced concrete structures as shown in Fig. 1. The dimensions and construction details of the superstructure were exactly the same for both buildings. The buildings were constructed as rigid frame structures with outer walls made of light weight concrete panels. The test buildings were completed in May 1986.

The isolation system of the base isolated building consists of six identical bearings (Fig. 2) designed with a medium shape factor and molded with a high damping, low shear modulus rubber. These bearings are laminated composites with 12 layers of rubber and 11 layers of steel plates (shims) manufactured by Rubber Consultants, UK. Note that the U.S. bearings previously installed in the Sendai isolated building between April 1989 and July 1990 were high-shape-factor bearings (Wang & Gvildys, 1991) with 33 rubber layers and 32 shims.

3 MATHEMATICAL MODELS

Three-dimensional frame models are used in numerical simulations for both convention and base-isolated buildings. In the analyses, beams, columns, and girders are all modeled by 3-D beam elements with six degrees of freedom per node to account for the translations and rotations generated from seismic events. Stiffnesses of the outer walls and partitions that are not structurally connected to the beams and girders are neglected in the calculation. However, their masses are appropriately lumped to the element nodal points, so that their inertia effects are included in the analysis.

The mathematical models of both ordinary and base-isolated buildings are given in Fig. 3. These two models are almost identical except that different modeling techniques are used for the substructure connecting the basement slab and the first floor. More specifically, the major difference (in the models) is in the middle portion of the support columns where the isolator is located. For the ordinary building, each basement column is represented by three beam elements in which the stiffness of the basement reinforced concrete wall is included. For the isolated building, on the other hand, the isolator is modeled by two spring elements; one linear spring and one nonlinear elastoplastic spring to simulate, respectively, the vertical and horizontal responses of the isolator. Two beam elements, similar to those columns of the superstructure are then utilized above and below the isolator to model the reinforced concrete pedestals.

In calculating the horizontal response of the isolator a bilinear force-displacement constitutive equation is used for the nonlinear spring element. This relationship is determined from the dynamic tests of the ANL bearings conducted by the University of California at Berkeley (Kelly, 1991).

4 RESULTS AND DISCUSSIONS

In simulating the responses of ordinary and isolated buildings, the X (transverse) and Y (longitudinal) direction accelerations observed at the center of the basement of the isolated building are utilized as input to the basement structural nodes. The computed accelerations are then compared with the recorded observations.

For simplicity, comparison of observed and calculated peak accelerations at the first floor and the roof level of both the ordinary and isolated buildings are given in Table 1. As seen from this table, the maximum accelerations obtained from recorded data and SISEC simulations agree satisfactorily with each other. In fact, for both earthquakes (#42 and #44), the deviation between the calculated and observed accelerations at both the first floor and the roof levels of the isolated building is within 21%.

To study the effectiveness of the base-isolation system, Table 1 further lists the acceleration ratio, i.e., the acceleration of the isolated building A_I divided by the acceleration of the ordinary building A_0. The advantage of the base isolation system in mitigating the seismic response is quite evident. For earthquake #42, the simulated transverse acceleration at the first floor of the isolation building is about 54% of the ordinary building, whereas in the recorded data it is about 66%. At the roof level, the advantage of base isolation becomes more pronounced. The analytical results indicate that, in the transverse and longitudinal directions, the accelerations of the isolated building are about 23% and 27% of the ordinary building. In the observation data the acceleration ratios are about 26% and 33%. This further demonstrates that as the floor elevation increases the degree of acceleration reduction also increases.

To illustrate the effect of the isolation system, Fig. 4 compares both observed and calculated accelerations in the transverse direction at the roof level for earthquake #44. As can be seen, the accelerations are greatly reduced for the isolated building.

5 CONCLUSIONS

From the results of this study several conclusions can be drawn:

(1) With the use of high damping-low shear modulus elastomeric bearings the advantage of isolation system in mitigating the acceleration response is very significant even for small earthquakes.

(2) The ANL developed SISEC code can produce the general shape of the acceleration responses of the isolated building. The analysis accurately predicts the peak accelerations and the arrival times.

(3) The ANL designed isolation bearings are very effective for reducing the earthquake hazard.

ACKNOWLEDGMENTS

This work was supported by the U.S. National Science Foundation, Agreement No. CES-8800871.

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Table 1. Comparison of accelerations of isolated and ordinary buildings

			Ordinary Bldg., A_O		Isol. Bldg., A_I		Accel. Ratio, A_I/A_O	
Eq. No.	Loc.	Dir.	Obs. (gal)	Cal. (gal)	Obs. (gal)	Cal. (gal)	Obs.	Cal.
42	Roof	T	7.18	6.96	1.87	1.59	0.26	0.23
		L	7.29	7.16	2.46	1.94	0.33	0.27
	1st Floor	T	2.10	2.45	1.39	1.33	0.66	0.54
		L	2.79	3.58	1.90	1.70	0.68	0.47
44	Roof	T	8.73	8.56	1.44	1.34	0.16	0.16
		L	5.43	5.27	1.09	0.86	0.20	0.16
	1st Floor	T	1.66	1.95	1.19	0.97	0.71	0.50
		L	1.43	2.05	0.93	0.76	0.65	0.37

Note: T: Transverse L: Longitudinal

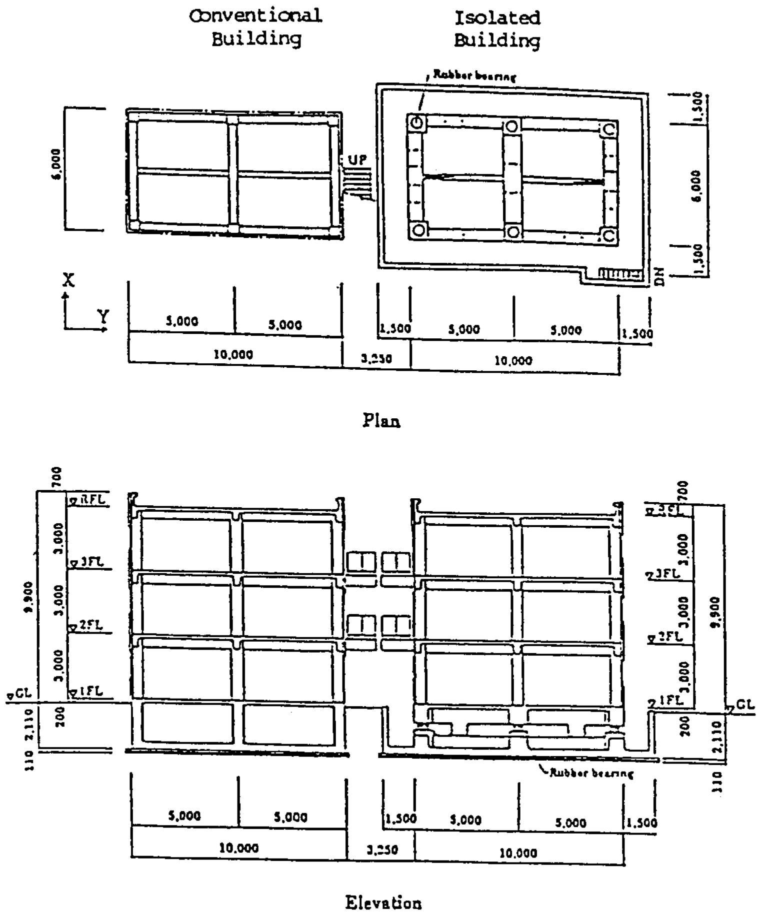


Fig. 1 Plan and Elevation of Test Buildings

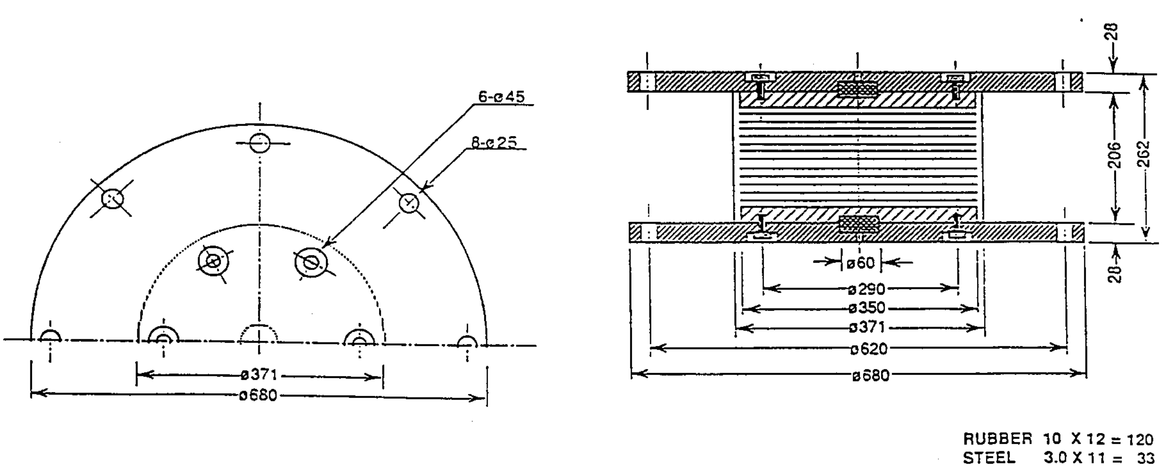
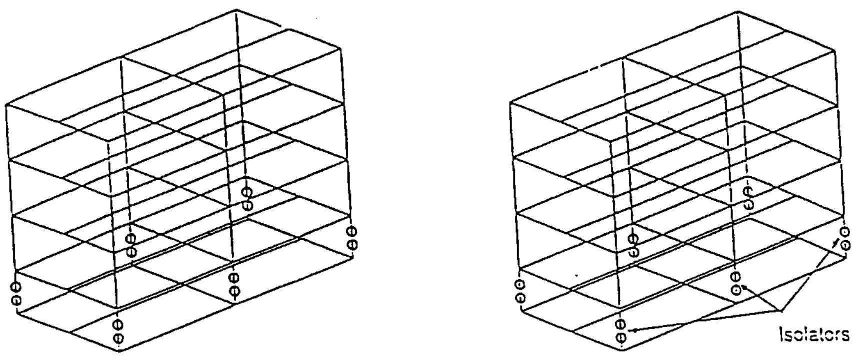
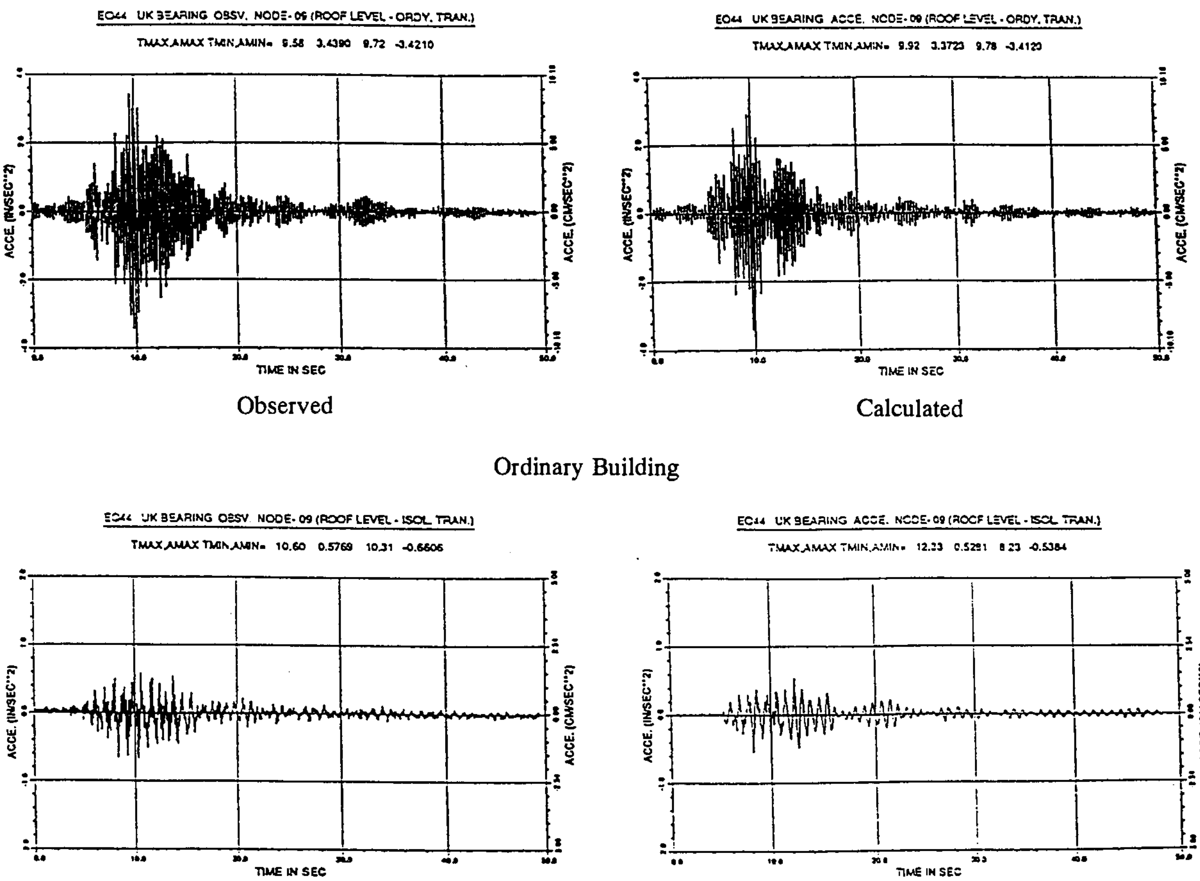


Fig. 2 Bearing Dimensions (unit: mm)



NO ISOLATION WITH ISOLATION

Fig. 3 Mathematical Model of Ordinary and Isolated Buildings



Observed Calculated

Ordinary Building

Observed Calculated

Isolated Building

Fig. 4 Comparison the Observed and Calculated Transverse Accelerations at the Roof Level (Eq. #44)