

## Comparison of SISEC Code Simulations with Earthquake Data of Ordinary and Base-Isolated Buildings

C. Y. WANG, J. GVILDYS

*Argonne National Laboratory, Argonne, IL USA*

### 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.

At Argonne National Laboratory (ANL), a 3-D computer program SISEC (Seismic Isolation System Evaluation Code) is being developed for simulating the system response of isolated and ordinary structures (Wang et al. 1991). This paper describes comparison of SISEC code simulations with building response data of actual earthquakes. To ensure the accuracy of analytical simulations, recorded data of full-size reinforced concrete structures located in Sendai, Japan are used in this benchmark comparison. The test structures consist of two three-story buildings, one base-isolated and the other one ordinary founded. They were constructed side by side to investigate the effect of base isolation on the acceleration response.

Among 20 earthquakes observed since April 1989, complete records of three representative earthquakes, #2, #6, and #17, are used for the code validation presented in this paper. Correlations of observed and calculated accelerations at all instrument locations are made. Also, relative response characteristics of ordinary and isolated building structures are investigated.

### 2 TEST BUILDING AND ISOLATION BEARING

Two test buildings, one conventionally designed and other base-isolated, were constructed side by side at Tohoku University

---

\*Work supported by the National Science Foundation, Agreement No. CES-8800871.

located in Sendai, 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 panel. The test buildings were completed in May 1986 (Kuroda et al. 1989).

Note from this figure that the ordinary building is surrounded by backfilled soil below the ground level and that the basement wall is made of reinforced concrete. The presence of soil embedment and concrete wall definitely will have certain mitigating effects on the building response. As for the isolated building, ample space is provided around the side of the basement wall to allow unrestricted movement of the superstructure. The test buildings were built in a relatively hard loam layer containing gravel, whose shear wave velocity is 310 m/sec (1017 ft/sec).

The isolation system of the base isolated building consists of six identical bearings which were designed by ANL and manufactured in the U.S. The bearings were installed by Shimizu of Japan in April 1989. These bearings are laminated composites with 33 alternating layers of high-damping rubber and steel plates (shims) manufactured by Fluorocarbon Inc., USA.

### 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. 2. 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 Shimizu Corporation

(Kuroda et al. 1989). The stiffness used in the numerical analysis is given in Fig. 3.

#### 4 RESULTS OF COMPARISON

Three representative earthquakes, i.e., #2, #6, and #17 are used here to validate the SISEC code simulations as well as to study the building response characteristics. Earthquake #2 occurred on April 28, 1989, less than twelve hours after all in-situ tests were completed; #6 earthquake occurred quite near the test buildings on June 24, 1989, and relatively had the largest magnitude; whereas #17 took place on November 2, 1989 which had the longest duration.

In simulating the responses of ordinary and isolated buildings, the X (transverse) and Y (longitudinal) component 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 those of observations.

For simplicity, comparison of observed and calculated peak accelerations at the first floor and the roof level of both ordinary and isolated buildings are given in Table 1. As can be seen from this table, the maximum accelerations obtained from recorded data and SISEC simulations agree satisfactorily with each other. Better comparison is found for the relatively strong earthquake, #6.

To study the relative response of the ordinary and isolated buildings we have found that, because of small earthquake motions and embedment of the ordinary building, the advantage of base isolation in mitigating the acceleration response is not visible. In fact, at the first floor, accelerations observed in both directions of the isolated buildings generated from earthquakes #2, #6, and #17 are higher than the corresponding values of the ordinary buildings. However, at the roof level, the advantage of isolation system in reducing the acceleration response for relatively large earthquake #6 becomes noticeable. This can be clearly seen from the results given in Table 1, where both observed and simulated accelerations of the isolated building are smaller than those of the ordinary building.

Figures 4 and 5 depict recorded and calculated transverse accelerations at the roof of the isolated buildings for earthquakes #6 and #17, respectively. Reasonable correlations of the accelerations are obtained.

#### 5 CONCLUDING REMARKS

From this comparison several conclusions can be drawn:

(1) The SISEC code can reproduce the general shape of the acceleration responses, both for the ordinary and base-isolated buildings. The analysis accurately predicts the peak accelerations and the times of occurrence.

(2) The analysis can accurately calculate the frequency characteristics of both ordinary and the isolated buildings. The computed frequencies of the ordinary building is about 3.50 and

4.20 Hz, respectively, in the transverse and longitudinal directions. The test building frequencies are about 3.60 and 4.35 Hz.

(3) For the isolated building, the agreement between the simulation and observation is better for the relatively large earthquake, #6. For small earthquakes (#2 and #17) the SISEC code generally underpredicted the peak accelerations.

(4) As anticipated, both analytical results and observed data show that the advantage of isolation system for a small earthquake is insignificant. For relatively large earthquake motion, however, such as from records of #6 earthquake, the effect of isolators in reducing the roof acceleration becomes more pronounced.

The good agreement between the analytical predictions and the observed data lend credibility to the SISEC formulation and numerical technique used for calculating the seismic system response.

#### REFERENCES

Wang, C. Y. et al. (1991). System Response Analyses of Base-Isolated Structures to Earthquake Ground Motions, Trans. SMIRT-11, paper K26/6, August 18-23, Tokyo, Japan (to be published).

Kuroda, T., Saruta, M. and Nitta, Y. (1989). Verification Studies on Base Isolation Systems by Full-Scale Buildings, ASME, PVP, Vol. 181, pp. 1-8.

Kuroda, et al. (1989). Unpublished information.

Table 1. Comparison of Observed and Calculated Maximum Accelerations for Earthquake Data #2, #6, and #17

Eq. No.	Dir.	Maximum Acceleration, in/sec <sup>2</sup>									
		I.B.					Ordinary Building				
		Bsmt.		1st Fl.			Roof		Isolated Building		
		Obs.	Cal.	Obs.	Cal.	Obs.	Obs.	Cal.	Obs.	Cal.	Obs.
2	T	3.1	3.6	3.7	10.8	10.6	5.0	4.7	8.8	6.7	
	L	4.2	3.6	5.7	10.2	10.3	6.6	6.6	13.0	9.3	
6	T	13.1	14.8	12.1	41.9	53.5	15.1	15.9	24.7	19.3	
	L	7.4	8.3	9.0	29.5	25.1	12.9	15.4	19.8	18.1	
17	T	3.8	4.1	5.0	16.3	18.9	10.1	12.9	22.7	19.1	
	L	5.1	5.1	5.4	11.8	12.6	9.5	14.6	14.6	18.3	

T: Transverse (X)

L: Longitudinal (Y)

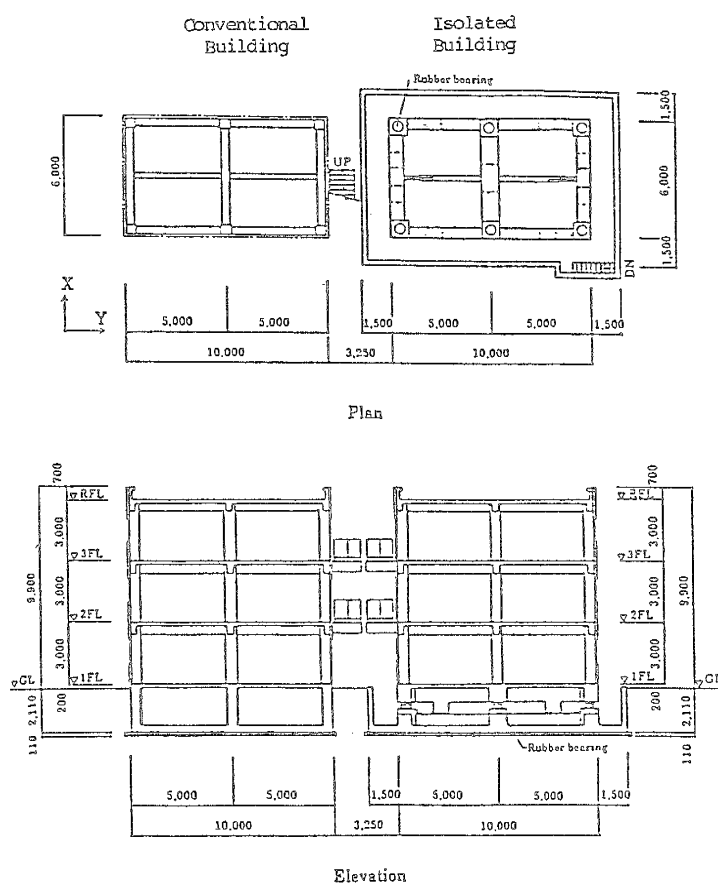


Fig. 1 Plan and Elevation of Test Buildings

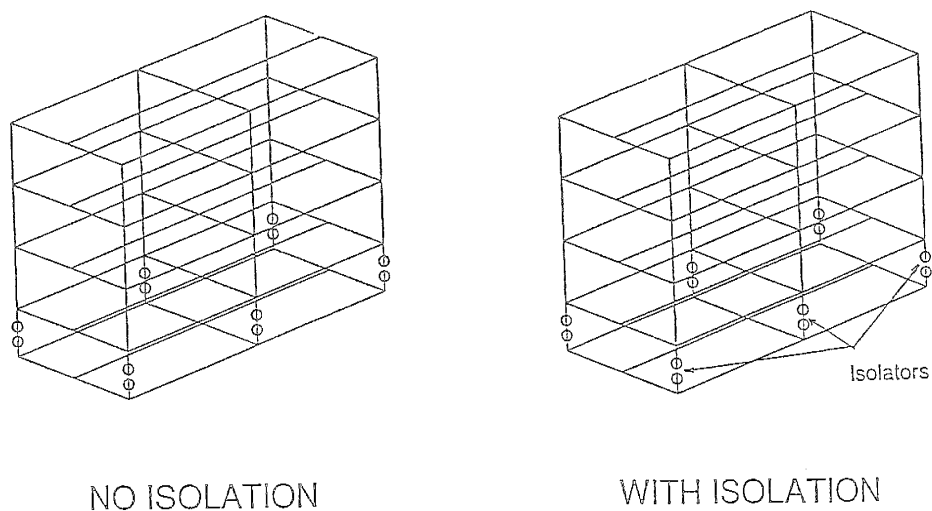


Fig. 2 Mathematical Model of Ordinary and Isolated Buildings

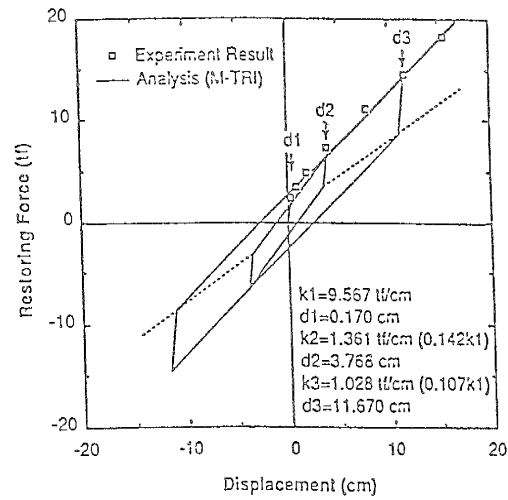


Fig. 3 Analytical Parameters for Simulating Isolator Horizontal Response

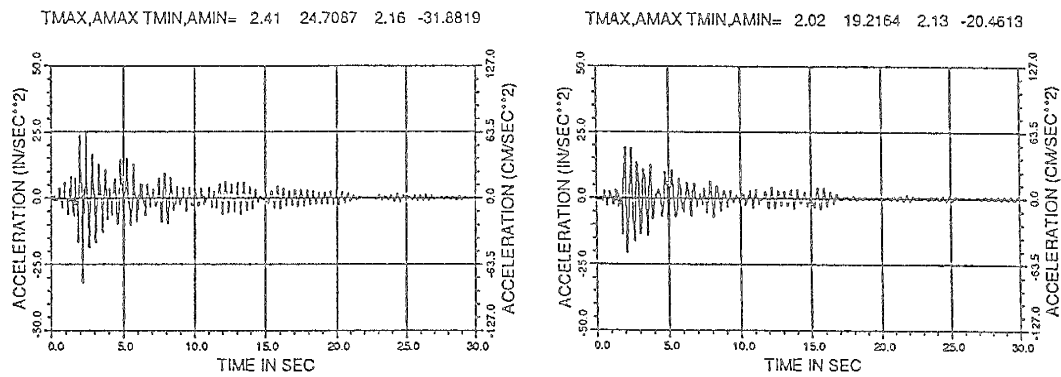


Fig. 4 Comparison of Transverse Accelerations at the Roof of the Isolated Building for Earthquake #6 (left: observed, right: calculated)

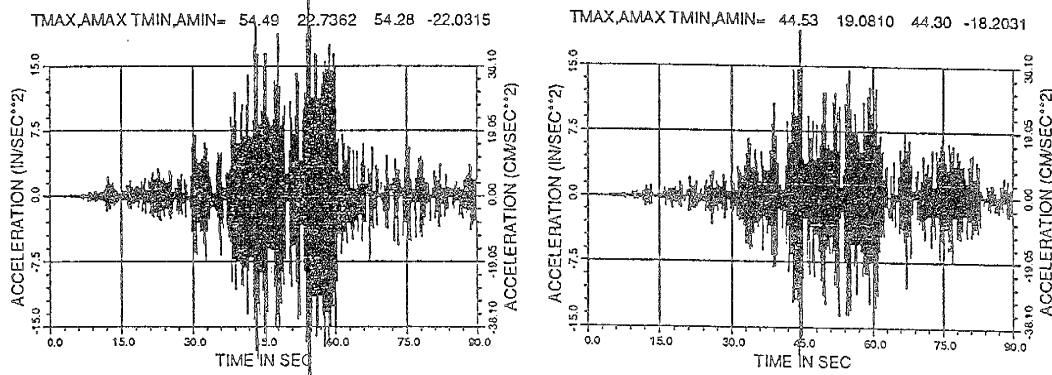


Fig. 5 Comparison of Transverse Accelerations at the Roof of the Isolated Building for Earthquake #17 (left: observed, right: calculated)