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SEISMIC RESPONSE OF BASE-ISOLATED BUILDINGS USING A VISCOELASTIC MODEL

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1 INTRODUCTION

Due to recent developments in elastomer technology, seismic isolation using elastomer bearings is rapidly gaining acceptance as a design tool to enhance structural seismic margins and to protect people and equipment from earthquake damage. With proper design of isolators, the fundamental frequency of the structure can be reduced to a value that is lower than the dominant frequencies of earthquake ground motions. The other feature of an isolation system is that it can provide a mechanism for energy dissipation.

In the USA, the use of seismic base-isolation has become an alternate strategy for advanced Liquid Metal-cooled Reactors (LMRs). ANL has been deeply involved in the development and implementation of seismic isolation for use in both nuclear facilities and civil structures for the past decade. Shimizu Corporation of Japan has a test facility at Tohoku University in Sendai, Japan. The test facility has two buildings: one is base isolated and the other is conventionally founded. The buildings are full-size, three-story reinforced concrete structures. The dimensions and construction of the superstructures are identical. They were built side by side in a seismically active area. In 1988, the ANL/Shimizu Joint Program was established to study the differences in behavior of base-isolated and ordinarily founded structures when subjected to earthquake loading. A more comprehensive description of this joint program is presented in a companion paper (Wang et al. 1993).

With the increased use of elastomeric polymers in industrial applications such as isolation bearings, the importance of constitutive modeling of viscoelastic materials is more and more pronounced. A realistic representation of material behavior is essential for computer simulations to replicate the response observed in experiments.

2 COMPUTER SIMULATIONS

Three-dimensional space frames are employed to represent the superstructures of the ordinary building and isolated buildings. The beams, columns and girders of the buildings are represented by 3-D beam elements. No stiffness contribution is considered from the outer walls and partitions. However, the masses of these components are added into the appropriate nodal points. Three beam elements which also include the stiffness of the basement reinforced concrete wall are used to model each basement column for the ordinary building. The finite element configuration used in the simulation is shown in Fig. 1 where the three locations labeled by numbers 111, 63, and 9 indicate the elevations of the basement, first floor and roof, respectively.

As a part of the above mentioned joint program the main focus of this study is set on a comparison of the computer simulation results of two different material models with the measured response during actual earthquakes. The base-isolation bearings considered here were designed to have a frequency of 0.75 Hz at 50% shear strain. The vertical and horizontal stiffnesses are 13.6×10^5 and 961 kgf/cm, respectively.

Here, a fully three-dimensional finite-strain viscoelastic model developed by Simo and Taylor 1983, is employed to characterize the behavior of isolator bearings. In the Simo and Taylor model, the material is assumed to be isotropic in its virgin as well as in its deformed or damaged state. Volumetric and deviatoric responses are uncoupled over any range of deformation. The volumetric response is purely elastic. The proposed damage mechanism incorporates the softening behavior of rubber undergoing deformation (Mullin's effect). In the cyclic test, this translates into progressive degradation of the storage modulus with increasing maximum strain amplitude. The analytical hysteresis curve simulated by this model is given in Fig. 2.

The bilinear constitutive model is a simplified representation of the hysteretic curve for strain-softening rubber material. The linear elastic modulus is determined from the first cycle of loading in a cycling loading test, and the plastic modulus is extracted from the later stages of the same test.

The structural elements and the two constitutive models mentioned above have been incorporated in the ANL-developed computer program SISEC (Seismic Isolation System Evaluation Code) (Wang et al. 1991).

3 RESULTS AND DISCUSSION

During the testing period, thirty-seven (37) earthquakes had occurred in the Sendai area. Three of these earthquakes, No. 2, No. 6 and No. 17, are of significance for numerical simulation and comparison with observed data. Earthquake No. 6 (EQ #06) has the largest amplitude accelerations. Earthquake No. 17 (EQ #17) has the longest duration and a broad frequency spectrum. The range of frequencies in that earthquake indicates that the soil-structure interaction may be of importance. Earthquake No. 2 (EQ #02) has the same order of magnitude as EQ #06 and EQ #17. It occurred right after the installation of bearings, and the bearings were still in the virgin state. It is felt that the dynamic characteristics of the bearings can be obtained from the responses of the isolated building under those three earthquakes. Due to space limitations, comparisons among the observed response, the simulation results obtained using the viscoelastic and bilinear spring models are presented for one earthquake only, *viz.* for EQ #06.

In the longitudinal direction, the input acceleration of the Earthquake #6 has one dominant frequency of 2.23 Hz. The maximum response amplitude for the first floor of the viscoelastic model is 25% greater than the observed one. The results of the bilinear model yields a 22% larger amplitude (Figs. 3 and 4). The frequency spectrum of the viscoelastic model derived from the time history computations through FFT yields a response frequency of 2.23 Hz for the first floor and the roof whereas the observed frequency is 2.27 Hz. It should be noted that a comparably large peak is found at 2.40 Hz both in the observed and computed frequency spectra. The dominant frequencies for the bilinear case are 2.23 Hz for both floors.

Similarly, in the transverse direction, comparably large peaks (dominant frequency at 2.57 Hz) are encountered in the input record. The first floor maximum response amplitude from the viscoelastic model is 15% smaller than that of the observed. Bilinear model yields 18% smaller results. In the viscoelastic model, both the first floor and the roof have a computed frequency of 2.30 Hz. However, the observed data yields 2.07 Hz for the first floor and 2.17 Hz for the roof with several closely-spaced frequencies in 2.07-2.42 Hz range. The frequencies obtained with the bilinear model are 2.13 Hz and 2.17 Hz for the first floor and the roof, respectively.

4 CONCLUSIONS

The comparison of results shows that the viscoelastic model can predict the actual behavior of highly-filled rubber material used in isolator bearings rather accurately. However, the effectiveness of this model is somewhat dependent on the input spectrum. When the spectrum of the input motion has a clear dominant frequency, the simulation results are in excellent agreement with the experimentally observed data. When the input motion has a wide range of frequencies and no visible dominant frequency exists in the spectrum, the maximum response predicted by the model is shown to be off about 30%. However, the frequency of the superstructure is well retained in the simulations.

The bilinear model originally proposed is found to be fairly effective. However, the performance of the viscoelastic model in most of the test cases presented here is better than that of the bilinear model. The reliability of the viscoelastic model over the bilinear model is also consistently higher. However, the implementation of the viscoelastic model depends on the availability of two types of test data: cyclic shear and relaxation tests. This is different in the bilinear case, where the data needed to construct the bilinear model are derived only from cyclic shear tests. Thus, the bilinear model becomes very attractive when the relaxation data is not available for the rubber material. Nevertheless, it is highly recommended that the viscoelastic model be used in the future seismic response analysis if all the required data of cyclic shear and relaxation tests are available.

ACKNOWLEDGMENTS

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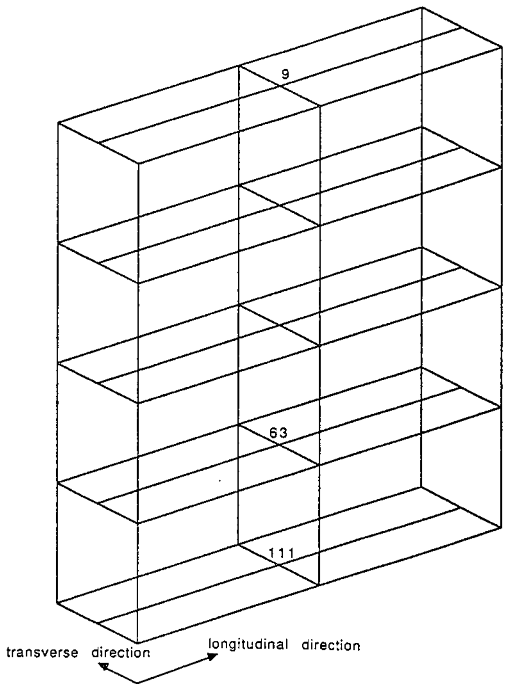

Figure 1. Finite Element Mesh

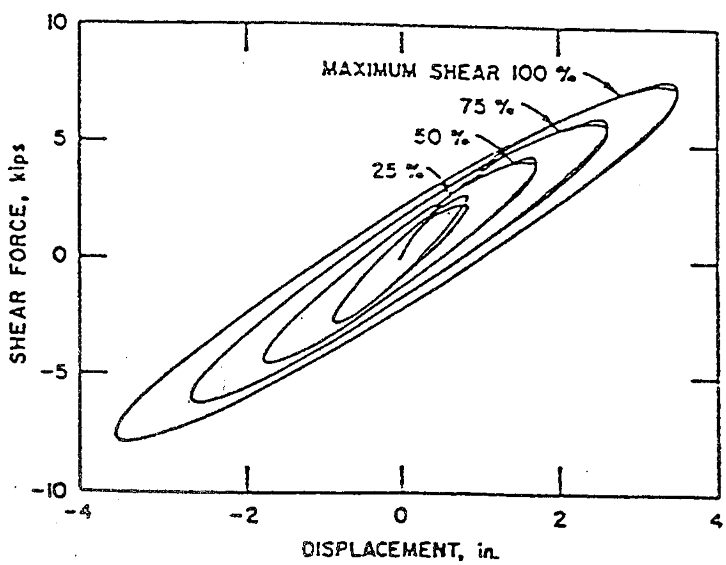

Figure 2. Analytically Simulated Hysteresis Curve

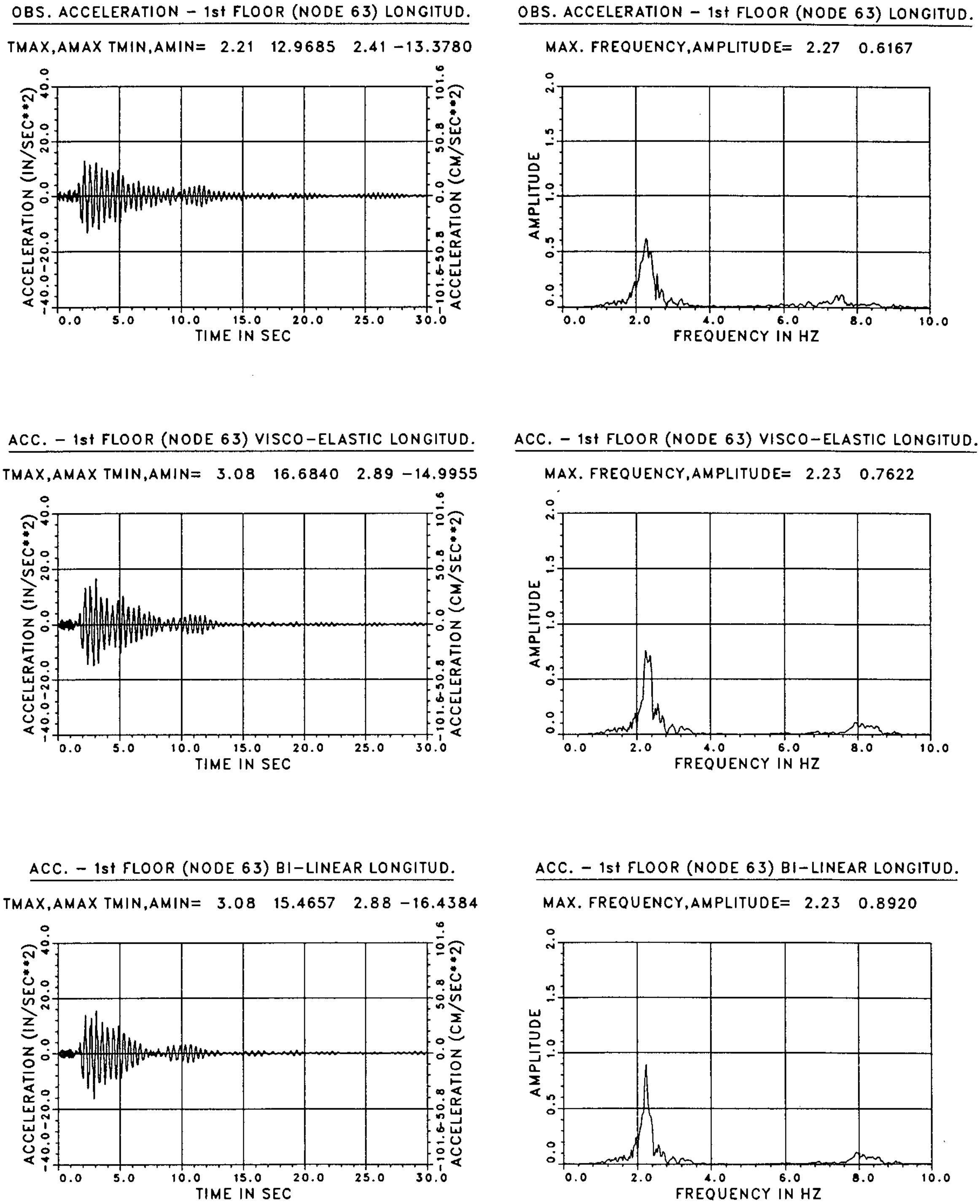

Figure 3. Comparison of Simulation Results with Experimental Observation - First Floor

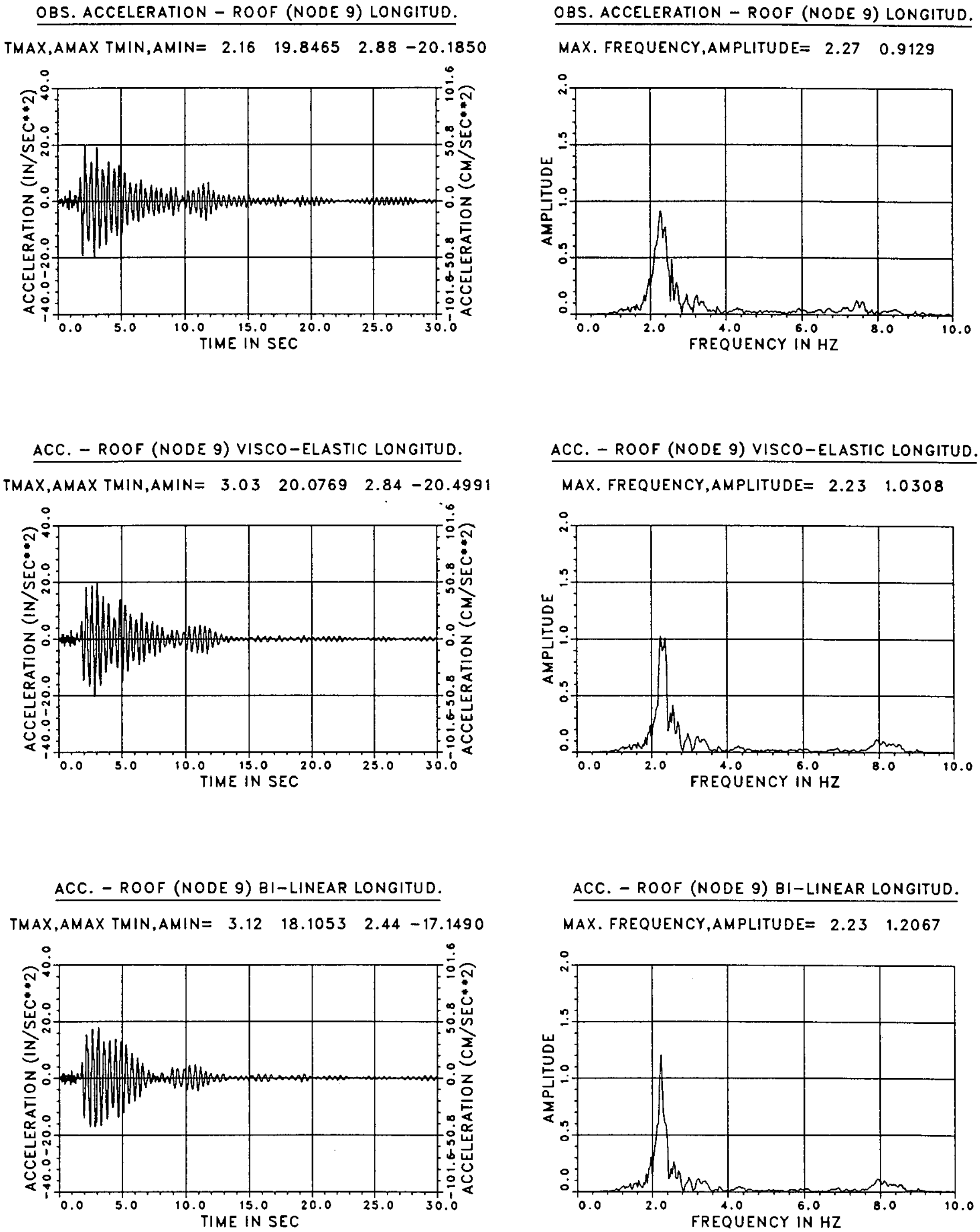

Figure 4. Comparison of Simulation Results with Experimental Observation - Roof