In 1989, NCEER launched a multi-year multi-disciplinary study of the seismic vulnerability of an important lifeline system. The production and delivery of crude oil is critical to every major industry and business sector in the United States. This nation’s most crucial crude oil system traverses the midwest and is subject to seismic hazards posed by the New Madrid seismic zone. To understand fully the significance of this system, particularly after major disasters such as earthquakes, it is necessary to quantify the level of seismic vulnerability of this system and the impact that may result should oil be released or disrupted. To address these questions, NCEER formed a multidisciplinary team representing researchers in seismic hazard assessment, component vulnerability analysis, system reliability analysis, and socioeconomic impact analysis. This team comprised Teoman Ariman, Tulsa University, Ricardo Dobry, Rensselaer Polytechnic Institute, Ronald Eguchi, EQE International, Mircea Grigoriu, Cornell University, Otto Helweg, University of Memphis, Howard Hwang, University of Memphis, Michael O’Rourke, Rensselaer Polytechnic Institute, Thomas O’Rourke, Cornell University, Masanobu Shinozuka, Princeton University, Kathleen Tierney, University of Delaware, and John Wiggins, EQE International. This article describes the social, economic and environmental consequences resulting from an oil spill in the New Madrid area. Questions and comments should be directed to Ron Eguchi, EQE International, at (714) 833-3303.

This study had three major objectives. First, the seismic hazard potential in the midwest required quantification. Recent seismicity data suggest that the likelihood of a magnitude 7.6 earthquake in the New Madrid region is approximately 7% by the year 2000 (Johnston and Nava, 1985).

Second, the seismic vulnerability of oil pipeline systems had to be evaluated. Vulnerability models were developed for underground pipelines and aboveground facilities to determine the likelihood of failure or damage during an earthquake. Finally, based on the seismic vulnerability of these systems, the indirect impacts caused by failure and disruption of this system were assessed. Indirect impacts included environmental damage caused by oil spillage and economic losses resulting from a disruption of oil delivery. To address these issues, multiple but coordinated research efforts were carried out by NCEER investigators.

The research plan called for investigations that focused on the following areas: quantification of seismic hazard potential, with emphasis on liquefaction hazards; seismic vulnerability modeling of underground pipelines; seismic vulnerability modeling of other oil pipeline system components, such as pump stations; system reliability analysis; environmental impact analysis; indirect economic loss analysis; and organizational and institutional response analysis to address the issues related to energy supply and distribution.

Results of the Research

The contributions from this study have been numerous. Perhaps, the most significant achievement is that a multidisciplinary research team was assembled to address a

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Post Earthquake Evaluation of Base Isolated Structures Using the 3D-BASIS Computer Program

by Satish Nagarajah

This article presents research conducted on the further development and verification of the 3D-BASIS computer program, which is part of NCEER S program in Intelligent and Protective Systems. As part of this research, correlation studies were conducted on the performance of base isolated buildings during the Northridge earthquake. Support for these studies was provided by the California Strong Motion Instrumentation Program (CSMIP). For more information, contact Satish Nagarajah, University of Missouri-Columbia, at (314) 882-0071; or Andrei Reinhorn, University at Buffalo, at (716) 645-2114 ext. 2419.

The objectives of the study presented in this article are to assess the analysis techniques used for base isolated structures – particularly 3D-BASIS; and to evaluate the effectiveness of seismic isolation. California Strong Motion Instrumentation Program (CSMIP) records (Shakal et al., 1994) of the response of the base isolated University of Southern California (USC) hospital during the Northridge earthquake provided a wealth of data for this study. The 3D-BASIS computer program was used for post earthquake evaluation of the USC hospital and the results are presented herein.

The 3D-BASIS computer program (Nagarajah et al., 1991a; 1991b) has been used for analysis and design of several base isolated buildings in California and other locations. Nonlinear analytical modeling using 3D-BASIS consists of (1) linear condensed superstructure model with three degrees of freedom per floor; and (2) the isolation system, which is modeled explicitly using nonlinear force-displacement relationships of individual isolators.

The USC hospital is an eight-story, steel braced frame, base isolated building, as shown in figure 1. The seismic isolation system consists of 68 lead-rubber isolators and 81 elastomeric isolators (see figure 1). The building has been extensively instrumented by CSMIP (Shakal et al., 1994); the sensor locations are also shown in figure 1. A detailed model

Figure 1: USC Hospital Superstructure, Isolation System Details and Sensor Locations (CSMIP Station No. 24605) (Continued on Page 16)
of the superstructure was developed using ETABS (Wilson et al., 1975), with rigid floor slab assumption. ETABS uses six degrees of freedom (DOF) per node with three degrees of freedom per node slaved to the master node at the center of mass of the floor; hence, in the condensed model, only 24 DOF (8 floors x 3 DOF per floor) are retained for modeling the USC hospital. Eigenvalues and eigenvectors of the condensed model from ETABS were used in modeling the superstructure with 3D-BASIS. The dynamic characteristics from ETABS were further verified by comparison with system identification results (Nagarajaiah et al., 1995). Elastomeric isolators were modeled in 3D-BASIS using a nonlinear force-displacement relationship based on prototype bearing test results for the USC hospital.

The response of the USC hospital to the Northridge earthquake (foundation level acceleration CHN 5 and CHN 7, see figure 1) was computed using the nonlinear analytical model. Figure 2 shows a comparison between the recorded and computed response in the EW and NS directions; absolute accelerations and relative displacements at sensor locations shown in figure 1 were compared. The figure shows that the correlation between the computed and recorded response was good — both in phase and amplitude (except for the roof acceleration in the NS direction in one peak cycle of motion). Figure 3 shows the recorded and computed displacement and acceleration profiles at times of peak base displacement, peak acceleration, peak structure base shear (above base), and peak drift. The accuracy with which the analytical model captures the displacement response as shown in figure 3 is notable; there are, however, differences in acceleration response, which may be due to the complexity of the analytical model. Correlation of recorded and computed time histories and profiles demonstrate the accuracy of the analysis techniques and the nonlinear models used in 3D-BASIS. Identical results were obtained when 3D-BASIS-TABS (Nagarajaiah et al., 1993; Reinhorn et al., 1994) was also used.

The time history of the response shown in figure 2 indicates that the isolators yield (the yield displacement is 0.34 inch or 0.86 cm) and the isolation system responds in the inelastic range for a significant portion of the time history with a period of ~1.3 to 1.5 seconds. The peak ground acceleration
was 0.163 g in the EW direction and 0.37g in the NS direction. The peak acceleration at the base was 0.073g in the EW direction and 0.13g in the NS direction. The peak acceleration at the roof was 0.158g in the EW direction and 0.205g in the NS direction. The accelerations were deamplified because of base isolation. Figure 4 shows a comparison between the computed peak response envelopes of the base isolated USC hospital and probable response if the building was fixed-base. The benefits of seismic isolation become clear by examining the peak story shear and peak story drift envelopes, in both cases, in the EW and NS direction. The superstructure remains elastic in the base isolated case; however, the fixed-base structure will yield.

Furthermore, the higher mode effects were dominant in the fixed-base case; whereas, in the base isolated case, the higher mode effects were not as dominant. The changes in stiffness after the fifth floor, because of setbacks, were the cause for these higher mode effects; this is clear in the displacement and acceleration profiles in the NS direction, presented in figure 4. The profiles in figure 4 are at instants of occurrence of the peak acceleration, peak structure base shear (above base), and peak drift, in the base isolated and fixed-base case. In figure 4, examination of the displacement profile reveals that when the peak structure base shear occurs, in the base isolated building, the isolation mode is dominant. Further results of the evaluation of the effectiveness of the seismic isolation can be found in Nagarajaiah et al., 1995.

Figure 3: Recorded and Computed Displacement and Acceleration Profiles at Instants of Occurrence of the Peak Base Displacement, Peak Acceleration, Peak Structure Base Shear (above base), and Peak Drift in the EW and NS Directions

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Figure 4: Comparison Between Base Isolated and Fixed-based Case: (1) Normalized Peak Story Shear and Drift Envelopes in NS and EW Directions; (2) Displacement and Acceleration Profiles at instants of occurrence of the Peak Acceleration, Peak Structure Base Shear (above base), and Peak Drift in the NS Direction

References


