

## An Earthquake Analysis of an Existing Structure in the Southeast Region of the United States

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### Summary

*Earthquakes can and do happen in the Southeastern United States. In areas where earthquakes are likely to occur, knowledge of where and how to build structures can be helpful in reducing property damage. In this study, a detailed earthquake analysis of an existing high-rise structure located in the southeast region of the United States is performed. The analysis is based on the effects of past earthquakes in the Eastern United States. The probability of structural and nonstructural damage due to displacements imposed by seismic excitations was approximated through fragility curves. Repair costs were estimated based on the probability of exceedance of each damage state. Passive control devices were used to improve the response of the building and to reduce the extent of damage. Findings of this study will be used to educate both students and professionals on the importance of earthquake hazard in the southeast region.*

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### Background

While hurricanes have historically been the main cause of damage to structures located in the Eastern and Southeastern United States during the June-November period, the probability of earthquakes in this region cannot be ignored. Believe it or not, earthquake hazard is prevalent in this area. Figure 1 shows the seismic hazard map for the Eastern United States. Of this area, South Carolina, Tennessee, Arkansas, Missouri, and Kentucky have a high probability of earthquake occurrence.

Although most earthquakes occur at the boundaries of tectonic plates (e.g., California), they can occur in inner zones. This is most likely caused by the build-up of strains from pressures developed at the plate boundaries (Hu 1996). The most notable events of this type were the New Madrid earthquakes of 1811-1812 and the Charleston earthquake of 1886. The four New Madrid earthquakes were the largest intraplate earthquakes in the world. The Mississippi River changed its course, the land surface sunk to form new lakes and the violent shaking snapped off trees. The Charleston earthquake, whose maximum intensity and magnitude were equal to X and 7.3, respectively, caused damage for an estimated \$5,000,000 and was felt as far as 160 km away from the epicenter. This was the most damaging earthquake ever to strike the Eastern United States. To date, there have been more than 60 earthquakes in the Charleston area. On April 13, 1998, a small earthquake of magnitude 3.9 shook Kershaw County, SC, and on May 8, 2001, the Monticello Reservoir experienced a 3.26 magnitude earthquake. The quake was felt throughout the whole state.

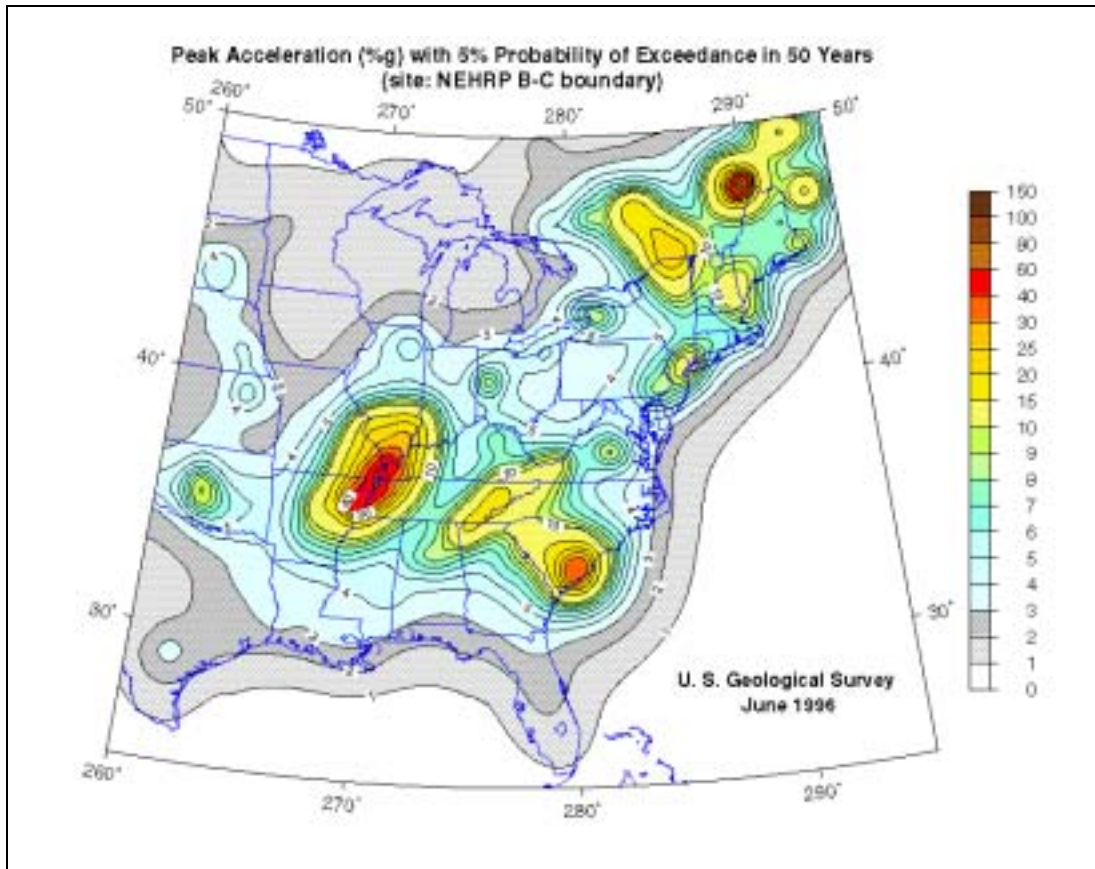


Figure 1. Seismic hazard in the Eastern United States

The probability of another event like the 1886 earthquake occurring somewhere in the Eastern United States is equal to 40-60% in the next 30 years (Nishenko and Bollinger 1990, Sibol et al., 1990). Mitigation of the effects of earthquakes is no longer a goal in earthquake-prone areas only. Therefore, there is a need to develop a methodology to guide future decision-making regarding seismic hazard.

The primary objective of this study is to analyze the effects of an earthquake on an existing structure constructed in the Southeastern region of the United States. This research also aims to relate building motion to probability of damage, which can be used to obtain approximate amounts of earthquake damage in terms of monetary cost. In addition, this study is intended to develop a methodology for the reduction of structural and nonstructural damage.

### Literature Review

Recent advancements in structural dynamics have allowed civil engineers to better understand and control the vibrations of civil engineering structures due to earthquakes. This knowledge allows engineers to more readily control the vibration of high-rise structures caused by natural hazards such as earthquakes and hurricanes. Social and economic impacts of natural disasters are continually increasing due to factors such as population growth, increasing capital investment in urban areas and the inevitable increasing number of older buildings with time (Liu 1996). Therefore, there is a

growing need to mitigate the effects of natural disasters on civil engineering structures. In recent years, civil engineering applications of methods for structural control have been developed (Fujino et al., 1996).

Passive control is a widely used method of structural control. Passive control devices include base isolators and tuned mass dampers. Other passive devices are liquid column vibration absorbers and gyrostabilizers (Chang and Hsu 1998, Higashiyama et al., 1998). Base isolation was utilized in an experiment conducted on a 4-story building in Santiago, Chile. The experiment showed that the base isolation system was effective in reducing the building's peak acceleration (Moroni et al., 1998). In recent years, tuned mass dampers have been installed in a number of buildings worldwide to reduce building vibration. A tuned mass damper has been installed in the Citicorp Center in New York City (Peterson 1980).

## **Methodology**

The structure considered for this study is the Turlington building located in downtown Tallahassee. It is a federal building housing the Florida Department of Education and Board of Regents. Therefore, it falls into the occupancy class "governmental structure." Although this study focuses on South Carolina, a structure located in Florida was chosen because building designers were accessible and because the structure was designed using a regional building code (SBC). The present worth of this building is \$39,624,000.

Since the structure consists mainly of 3-bay frames, the dynamic behavior of one frame can be considered representative of the dynamic behavior of the whole structure. A 2-D finite element model of one of the N-S frames was developed. Since torsion effects were not considered, 3-D analysis was not necessary. The model has 104 nodes and 312 DOFs. Each node was assigned three DOFs: horizontal displacement, vertical displacement and rotation. Nodes were also assigned at splice locations at floors 4, 6, 8, 10, 12, 14, and 16. The model has 154 elements separated by beam-to-column connections at each node. The number of DOFs of the model was reduced using a Guyan reduction technique but the relevant dynamic characteristics of the full model were maintained (Spencer et al., 1998). The damping matrix was determined from the reduced mass and stiffness matrices.

Two types of control devices were considered: passive tuned mass damper and base isolators. The devices were designed considering the natural frequency of the uncontrolled structure. The tuned mass damper was incorporated at the top floor of the structure, while the base isolation system was modeled by adding supplemental masses at the base of the first story columns and by modeling rubber bearing pads between the new floor masses and the ground.

In this study, the HAZUS approach for damage assessment was followed, according to which estimates of earthquake damage in buildings can be made given the building type and the level of ground motion. Damage functions or fragility curves are used to define the probability of reach or exceedance for different damage states given the peak building response. Damage states include slight, moderate, extensive, and complete damage.

According to the building types presented by HAZUS, the structure considered in this study is labeled as S1H, which means high-rise steel moment frame with 8+ stories. This kind of structures, like others, might experience both structural and non-structural damage.

Economic loss is derived from building damage estimates. These estimates, which depend on the structural type and/or the occupancy class, are expressed in terms of the probability of occurrence of a particular damage state. Using inventory information and economic data, monetary loss can be derived from the damage state probabilities. Building repair and replacement costs are estimated as the product of the floor area of each building type within the given occupancy class, the corresponding probability of occurrence of the given damage state, and repair costs of the building type per square foot for the given damage state.

## **Results**

Three input loads were considered for this analysis. The first input load used in the analysis is the acceleration record of the 1988 Saguenay earthquake (Quebec, Canada), whose magnitude and intensity were equal to 5.9 and VII, respectively. This event was the largest earthquake in Eastern North America in 53 years. The next input load is a magnitude 7.3, “Charleston-like” synthetic ground acceleration, which was developed by the Engineering Seismology Laboratory at the University at Buffalo using a stochastic model. The final input load considered for the analysis is a synthetic representation of the New Madrid earthquakes that shook the western part of Tennessee in 1811-1812. The magnitude 8 earthquake is one of the largest ever felt in the United States.

For each control approach considered (i.e., tuned mass damper and base isolation), the uncontrolled response of the structure was compared with the controlled response. Results proved that the control methods were successful in reducing the floor displacements of the structure. The tuned mass damper was found to be more effective in reducing the response of the upper floors, while base isolation was most effective in reducing the response of the lower floors. Overall, separation of the superstructure from its foundation (base isolation) achieved higher reductions of building motion.

Static analysis was performed and accurate approximations of the structural response were obtained considering the first five modes only. The probabilities of damage for the five modes were used to approximately calculate the cost of damage to the structure. In the worst-case scenario, a magnitude 8 earthquake will damage 30% of a structure such as the one considered in this study (i.e., the building designed without seismic provisions) and repairs will cost \$12,000,000. Structures located in the low seismic zone of South Carolina might experience as much as \$10,000,000 worth of damage if exposed to a large magnitude earthquake. These amounts are considerable compared to the \$7,000,000 damage expected in High-Code design regions such as California. While none of the seismic designs considered made the structure resilient to damage, consideration of seismic effects always reduce the likelihood of structural collapse and personal injuries.

## **Conclusion**

Cost of damage repair can be reduced by as much as 70% by incorporating either a TMD or a base isolation system. The TMD was not as effective as the base isolation system in reducing the damage to the post-earthquake model. Control devices not only reduce the response of the structure to earthquakes but also reduce the amount of damage. Therefore, control devices might be a good supplement for existing structures designed without considering seismic provisions and located in regions with seismic history.

## Future Work

Consideration of nonstructural damage and damage to the building contents due to ground accelerations might be important and should be considered in further studies. In addition, 3-D models might be necessary to perform more realistic analyses. While this study considered structural damage caused by strong ground motion only, future work should account for other causes of damage. The methodology developed in this study should also be used to evaluate damage caused by other phenomena such as hurricanes.

## Acknowledgements

This research was carried out under the supervision of Professor Makola M. Abdullah, and supported in part by the Multidisciplinary Center for Earthquake Engineering Research.

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