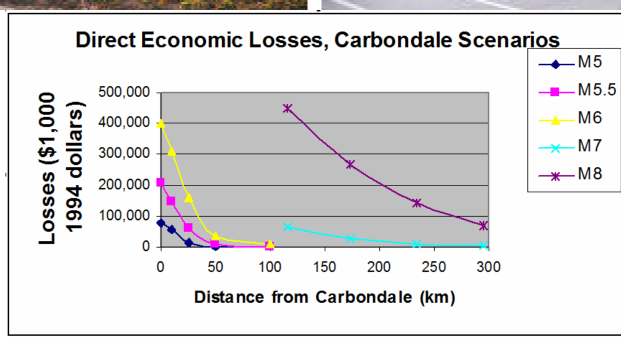
Evaluating Earthquake Risk
in Mid-American Communities



Final Report, Project SE-5
(Earthquake Loss Estimate Methods for Essential Facilities)
Mid-America Earthquake Center

Robert Olshansky, University of Illinois at Urbana-Champaign
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CHAPTER 1
INTRODUCTION

PROJECT GOAL

The goal of this research project was to provide earthquake loss estimates for two test communities, Carbondale, IL, and Sikeston, MO, using readily available methods. The results must be in a form usable by each community, and the methods must be feasible for use by other similar communities.

This project fits into a larger MAE Center program to evaluate and improve earthquake safety of essential facilities (hospitals, schools, fire stations, police stations) in Mid-America.

With a focus on essential facilities, we estimate two categories of loss:

- Direct losses to essential facilities.
- Post-earthquake demands on essential facilities, based on community-wide losses and casualties.

RESEARCH QUESTIONS

The primary objective was to tests the applicability of readily available loss estimation tools – specifically, ATC-21 and HAZUS – for providing earthquake loss estimates in typical Mid-America communities. It includes several related research questions:

1. Questions regarding use of HAZUS:

    a. How easy is HAZUS to use? What are the hardware, software, and operator requirements? How appropriate is it for use by communities in Mid-America?

    b. Does HAZUS give plausible results? (It has not yet been tested in this part of the country).

    c. How sensitive is HAZUS to the inputs of vulnerability and hazard?

2. Questions regarding integration of ATC-21 inventories with HAZUS:

    a. How feasible is it to integrate ATC-21 inventories into HAZUS? How can HAZUS best reflect the intelligence gained by doing local ATC-21 surveys?

b. How does the ATC-21 information change the output of HAZUS, as compared to using default data only? What is the value added by augmenting HAZUS with ATC-21?

3. Questions regarding the characteristics of seismic risk in Mid-America:

a. What are the expected earthquake effects in each community? What is the estimated direct damage to essential facilities? What are the expected community demands on essential facilities?

b. How are the damages and casualties distributed across the community? What is the effect of structure type? Functions? Occupancies? What are the priority candidates for retrofit or replacement?

APPROACH

Earthquake loss estimation requires the following elements:

1. *Hazard*

In order to estimate the effects of earthquake shaking, one must first specify the expected shaking levels, as well as their probability of occurrence. Accomplishing this requires identification of potential earthquake source zones and the probabilities of their generating earthquakes of various magnitudes. It then requires a model that estimates ground shaking as a function of earthquake magnitude, depth, fault mechanism, and distance from the hypocenter (these are called ground-shaking attenuation functions). We specified the earthquake sources and probabilities, and depended on the Federal Emergency Management Agency's (FEMA) HAZUS software (National Institute of Building Sciences, 1999a and 1999b) to predict the resultant earthquake shaking in Carbondale and Sikeston.

In consultation with MAE Center seismologists, we assumed the following set of earthquakes affecting Carbondale and Sikeston:

- Moment magnitude **M** 8.0 and **M** 7.0 events, evenly spaced along the axis of the New Madrid seismic zone.

- **M** 6.0, 5.5, and 5.0 events occurring anyplace in the region. We use a suite of events located at varying distances from each city: 0 km, 10 km, 25 km, 50 km, and 100 km.

2. *Vulnerability*

Vulnerability describes the people and structures at risk. Ideally, it requires inventory of the building stock and occupants for at least the following characteristics: building height and floor area, structure type, building age, current and replacement value of building and contents, location, foundation type, and number of building occupants.

We address vulnerability in two ways: by using default information in HAZUS, and by augmenting it with a *rapid visual screening* (ATC-21) (Applied Technology Council, 1988) survey of significant buildings. The ATC-21 survey provides information on structure type, size, location, approximate age, and ATC-21 Final Score. We surveyed the following buildings in Carbondale and Sikeston:

Essential facilities
Other public facilities (city hall, library, etc.)
Public assembly and other high-occupancy structures (theaters,churches, etc.)
Large multifamily buildings, hotels, dormitories
Health clinics, nursing homes
Large (> 5,000 sf) commercial structures

The ATC-21 data provides the basis for estimating replacement costs, based on standard construction costs in the area. In addition, county assessor data provides information regarding current value of private buildings (does not include non-taxable public buildings).

3. *Geologic conditions*

Site conditions can amplify ground-shaking, and, in some cases, can present a potential for liquefaction or landsliding. Detailed geologic maps are not currently available for Carbondale or Sikeston, nor does it appear that subsurface conditions vary significantly within either city. According to the regional map by the CUSEC State Geologists (CUSEC, 1995), Carbondale is on generally firmer soils, whereas Sikeston is on softer soils with higher potential for enhanced ground-shaking or liquefaction. For purposes of this analysis, we assumed that both are on NEHRP Site Class D, “stiff soils” (Building Seismic Safety Council, 1998, p. 34), even though Class E, “soft soils,” may well be more appropriate for Sikeston. Class D is the default used by HAZUS and the default recommended by the *NEHRP Provisions* when soil properties are unknown. For the ATC-21 evaluation, we assumed soil type SL3 (this is based on the 1985 edition of the NEHRP provisions), which conservatively assumes soft to medium stiff clays and sands.

4. *Risk = Hazard + Vulnerability*

HAZUS provides this connection. It takes hazard and vulnerability as inputs, and estimates the risk. It calculates the expected effects of a specified earthquake on the structures and population of a community. We can express this as probabilistic risk either by accounting for the probabilities of the scenario earthquakes or by using HAZUS to calculate estimated annualized risk.

BACKGROUND: CASE STUDY FOCUS ON CARBONDALE AND SIKESTON

Rationale for Case Study Approach

This project is the first in a sequence of studies focused on Carbondale and Sikeston. The purpose of focusing on Carbondale and Sikeston is to be able to perform two "deep" studies, to complement broader survey research done by others. Communities are complicated. Earthquake damages affect communities in many ways, and mitigation decisions involve trade-offs against other community issues. In particular, damage to, or repair of, essential facilities are integrally related to other community issues. By focusing a variety of studies on selected communities, we can:

- Perform detailed analyses of essential facilities and buildings at risk, and estimate potential earthquake effects.
- Identify potential mitigation actions and evaluate how they compare to other community priorities.
- Determine the willingness of key actors, in a representative community, to act in the fact of tangible risk information.

The long-term intent is to (1) describe the risk, (2) identify key actors and organizations and their concerns, (3) identify possible actions, (4) analyze costs and benefits of the actions, and (5) work with key players to determine actions that are feasible (technically, economically, politically, and socially). This project focuses on the first task: describe the risk.

Research Approach

The intent is to discover lessons that are transferable to other communities in mid-America. We hope to learn about the communities, about appropriate mitigation strategies, and about the effectiveness of existing tools for accomplishing mitigation and preparedness goals. By using existing methods, we take advantage of existing investments in user-oriented methods, and we provide for optimal transferability to other communities. As time goes on, the work will be informed by other MAE Center research, and work in these communities will help to inform MAE Center researchers of important information needed at the local level.

Selection of Communities

We sought two communities, in order to increase our chances of obtaining meaningful, transferable results. Ideally, we hoped to find one community known to be a leader in hazard mitigation, paired with a second willing community with little previous experience in this area. We also sought communities with different vulnerability and hazard characteristics, in order to better represent the range of communities in Mid-America. Figure 1-1 shows the locations of Carbondale and Sikeston in relation to New Madrid area historical seismic activity.

Because a priority was identifying communities that would be willing to work with us, we went first through the Central U.S. Earthquake Consortium (CUSEC) for nominations, then contacted the state emergency management agencies for their approval, and the agencies contacted the communities.

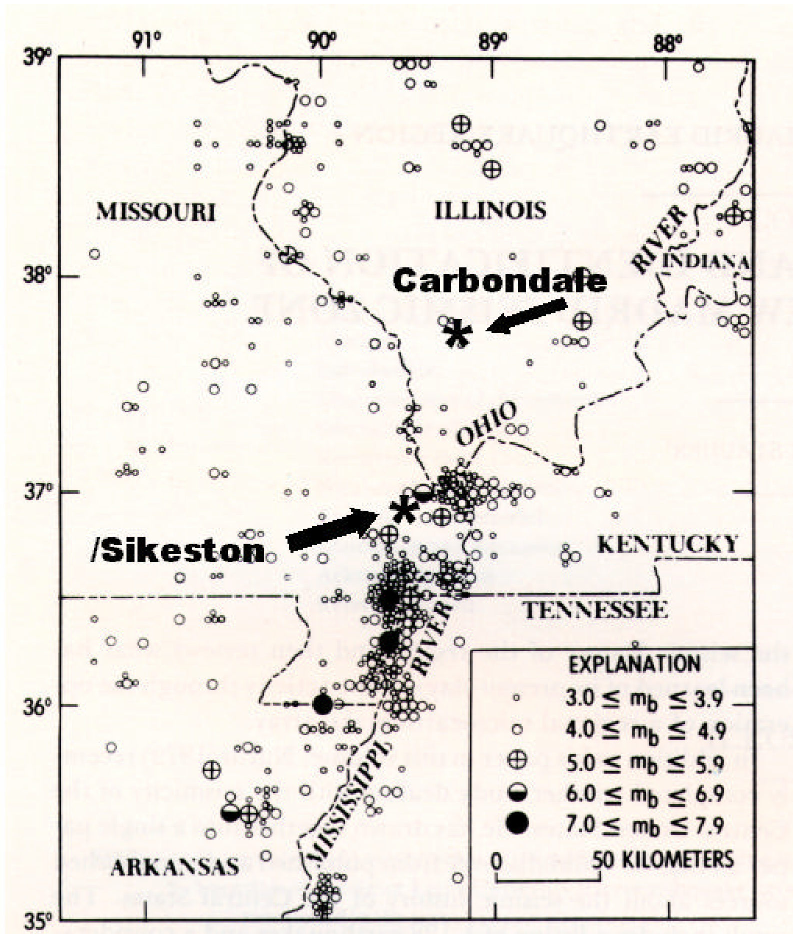

Figure 1-1. Location of Sikeston and Carbondale, with respect to 1811-1974 seismic activity (base map from Stauder, 1982).

Carbondale

Carbondale is located in Jackson County, in southern Illinois. Its population is approximately 26,000, and the population of this mostly rural county is approximately 61,000. Carbondale is the home of Southern Illinois University (SIU). With 19,000 students, its presence dominates the community. The University and other educational services employ about 40 percent of the total labor force.

Carbondale has long been known to be a leader, for communities of its size, in building code implementation, and has been concerned about its seismic risk for some time (Olshansky, 1998). For this reason, Carbondale was the first community selected in Illinois for FEMA's Project Impact program.

According to USGS Professional Paper 1527, *Seismicity of the United States, 1568-1989 (Revised)* (Stover and Coffman, 1993), 21 earthquakes of magnitudes greater than 4.5 or intensity greater than VI are known to have occurred in southern Illinois, in an area approximately within 100 km of Carbondale. A September 1891 earthquake near Mt. Vernon, approximately 40 miles to the northeast, was estimated at body-wave magnitude 5.8 and toppled several chimneys in Mt. Vernon. The intensity at Carbondale was estimated at VI-VII. In November 1968 a magnitude (body-wave) 5.5 earthquake, centered approximately 40 miles northeast of Carbondale, affected a wide area of southern Illinois. Carbondale was affected by shaking of intensity VI to VII. According to the 1996 USGS seismic hazard maps for the Central and Eastern United States, Carbondale has a 10% probability of experiencing ground shaking of .15 to .20 g or greater in 50 years (Figure 1-2).

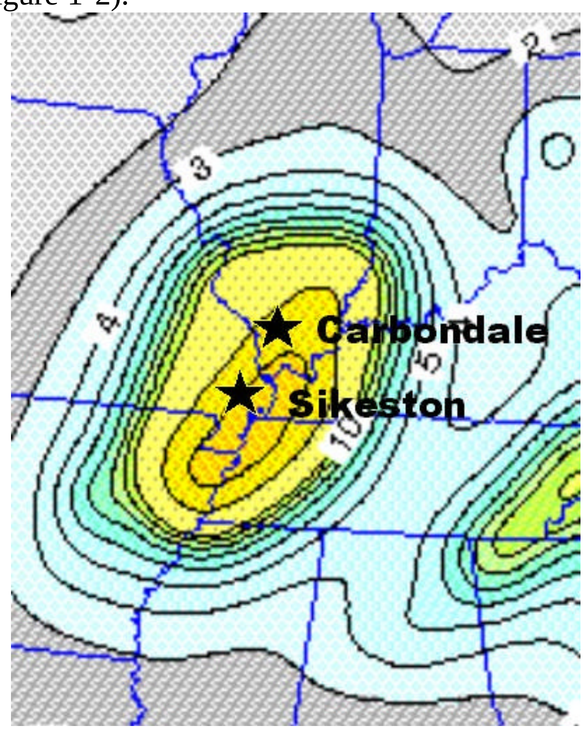

Figure 1-2. Location of Carbondale and Sikeston with respect to USGS 10% in 50-year pga map (USGS, 1996)

Sikeston

Sikeston is a city of approximately 18,000 people, mostly in Scott County, Missouri (a small part of the city is in neighboring New Madrid County). Located at the junction of Interstate Highways 55 and 57, and the intersection of the Union Pacific and Burlington

Northern railways, Sikeston is a center of retail services and manufacturing, within an agricultural region.

Sikeston is not known for being particularly active in earthquake preparedness, but they are aware of their risk and willing to consider actions to improve their preparedness. Thus, they may be representative of many communities in Mid-America.

Located in the Bootheel region of Missouri, Sikeston is quite close to the New Madrid seismic zone. According to *Seismicity of the United States, 1568-1989 (Revised)*, 16 earthquakes of magnitudes greater than 4.5 or intensity greater than VI are known to have occurred in the Bootheel region, in an area approximately within 50 km of Sikeston. More importantly, Sikeston is located at the northern terminus of the New Madrid seismic zone. An 1895 earthquake near Charleston (approximately 12 miles east of Sikeston) caused shaking of intensity VII to VIII in the vicinity of Sikeston, as well as many occurrences of liquefaction and sand blows in the area. According to the 1996 USGS seismic hazard maps for the Central and Eastern United States, Sikeston has a 10% probability of experiencing ground shaking of .20 to .25g or greater in 50 years (Figure 1-2).

CHAPTER 2
RAPID VISUAL SCREENING (ATC-21) SURVEYS IN CARBONDALE AND SIKESTON

RAPID VISUAL SCREENING (ATC-21) METHOD

Rapid Visual Screening is a method of quickly determining the seismic safety characteristics of a building. The method, developed by FEMA and the Applied Technology Council (ATC)is described in two volumes published by FEMA in 1988: A *Handbook* (Applied Technology Council, 1988a), and *Supporting Documentation* (Applied Technology Council, 1988b). It is commonly referred to as "ATC-21" from its ATC publication number.

The Rapid Screening Procedure is performed via a sidewalk survey of the building. The Handbook provides the inspector with background information and data required to complete a standard Data Collection Form (Appendix B). The inspector determines a Basic Structural Hazard score, then adds or subtracts Performance Modification Factors, based on observed seismic-related defects. The result is a final Structural Score value, **S**, of about -1 to about +6, with higher **S** scores corresponding to better seismic performance. The result is a ranking of surveyed buildings into two categories: those with acceptable life safety risk, and those that should be studied further. The **S** scores are related to the probability of major damage, defined as damage exceeding 60 percent of the building value[1]. For example, an **S** score of 1 indicates a probability of major damage

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[1]According to the Manual (p. 53), the "Basic Structural Hazard Score reflects the estimated likelihood of a typical building of that category sustaining major damage, given its seismic environment (see ATC-21-1, Appendix B, for details). Major damage means that repairs would cost approximately 60 percent of the building's value (not including land or site improvements). This value of 60 percent was selected because it often results in the building being a total economic loss and, more importantly, it is about the threshold where life-safety (i.e., building collapse) begins to become a serious hazard."

More specifically, according to Appendix B of the Supporting Documentation (p. 103), "The Basic Structural Hazard (BSH) is defined for a type or class of building as the negative of the logarithm (base 10) of the probability of damage (D) exceeding 60 percent of building value for a specified NEHRP Effective Peak Acceleration (EPA) loading (reflecting seismic hazard) as:

$$BSH = -\log_{10} [Pr(D \exists 60\%)]$$"

Furthermore, the same definition holds for the Structural Score **S**, which is the resultant score from adding or subtracting Performance Modification Factors to the BSH. That is,

$$\mathbf{S} = -\log_{10} [Pr(D \exists 60\%)$$

What does ATC-21 mean by "given its seismic environment"? It divides the nation into three seismicity areas, based on the 1985 NEHRP map areas (Building Seismic Safety Council, 1985): High (areas 5,6,7), Moderate (areas 3,4), and Low (areas 1,2). The user selects the appropriate ATC-21 form to complete, based on the area's of 1 in 10, **S**=2 corresponds to a probability of 1 in 100, **S**=3 corresponds to a probability of 1 in 1,000, and so on. If a building has an S score of 2 or less, ATC-21 recommends that it be further investigated by a professional engineer experienced in seismic design.[2] We used this information to devise an additional way of evaluating the seismic risk to a building, given its seismic environment. If 10^{-S} equals the probability of major damage, then 10^{-S} times the building floor area gives some indication of the amount of floor area likely to be subject to major damage; this is a way to weight the damage probability by the size of the building. Although this value does not have a specific meaning, it is a useful relative indicator of damage potential, and it can indicate the approximate proportion of the building stock that is at risk. We call this quantity the "risk floor area."

It is important to understand the strengths and limitations of this method. Its strength is that it can be done quickly and inexpensively, allowing a community to develop a list of potentially hazardous buildings. The weakness is that it does not substitute for a detailed engineering analysis. It is meant to be an initial screening. The goal is to broadly identify *most* of the potentially seismically hazardous buildings, at a relatively modest expenditure of time and effort. A more detailed inspection and analysis is needed in order to determine an individual building's actual degree of life-safety hazard.

The method is designed for all common building types. The ATC-21 manual specifically addresses the following building types:

W	Wood buildings of all types
S1	Steel moment resisting frames
S2	Braced steel frames
S3	Light metal buildings
S4	Steel frames with cast-in-place concrete shear walls
C1	Concrete moment resisting frames
C2	Concrete shear wall buildings
C3/S5	Concrete or steel frame, with unreinforced masonry infill walls
TU	Tilt-up buildings
PC2	Precast concrete frame buildings
RM	Reinforced masonry

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seismicity. According to the maps included in ATC-21, Carbondale is in a Moderate area, whereas Sikeston is High (Appendix C).

[2] "...present design practice is such that an **S** of about 3 is appropriate for day-to-day loadings, and a value of about 2 or somewhat less is appropriate for infrequent but possible earthquake loadings. Thus, until and unless a community considers the cost-benefit aspects of seismic safety for itself, an **S** of about 2.0 is a reasonable preliminary value to use within the context the RSP to differentiate adequate buildings from those potentially inadequate and thus requiring detailed review. Use of a higher cut-off **S** implies greater desired safety but increased costs; use of a lower value of **S** equates to increased seismic risk and a lower short-term cost (prior to an earthquake)." (ATC, 1988, p. 151).

URM Unreinforced masonry

The Handbook then describes methods for determining:

- Number of stories and total floor area
- Age of building
- Use type
- Occupancy
- Non-structural falling hazards
- Type of structure
- Modifiers:
  - Poor maintenance
  - Vertical irregularity
  - Soft story
  - Torsion
  - Plan irregularity
  - Pounding
  - Large heavy cladding
  - Short columns
  - Benchmark year for seismic design
  - Soil profile

To account for expected seismicity of the area, the surveyor selects one of three basic data forms to use, depending on whether the location is in a low, medium, or high seismicity region, according to maps in the Handbook.

USE OF ATC-21 BY LOCAL COMMUNITIES

Local building officials and emergency service personnel can learn to survey buildings in their communities. In 1991, the Central U.S. Earthquake Consortium contracted with EQE Engineering and Design to conduct a pilot training program in ATC-21 Rapid Visual Screening. The purpose was to test the feasibility of teaching non-engineers the ATC-21 method, in order to use local government agencies for rapid, low-cost earthquake building hazard surveys. Approximately 30 local officials from the Central U.S. attended a two-day training seminar, and practiced the method on nearby buildings. Officials were primarily personnel from city building, fire, police, and other emergency service departments. Following the training, participants from Evansville, Indiana, and Cape Girardeau, Missouri, then evaluated 162 buildings in their own communities.

A licensed Structural Engineer then visited the two cities and checked 32 of the assessments in each city. The purpose was to verify the adequacy of the pilot training program. The Structural Engineer and the surveyors agreed on 27 out of the 32 forms in Cape Girardeau and 31 of the 32 forms in Evansville.

This test was successful. Conclusions included:

1. Local officials can effectively learn the ATC-21 method in a two-day seminar.

2. The method requires 30 minutes or less per building.

3. Based on the limited sample, the method results in assessments sufficiently accurate for initial screening.

The Central U.S. pilot training program showed that local officials can employ the ATC-21 method with fairly good accuracy. The seminar provided them with adequate tools and knowledge to accurately screen dozens of buildings per day per person.

As a result of the pilot program, the project managers estimated that the typical building department of a typical town of 10,000 people can screen all critical facilities in their jurisdiction within a day, all their commercial buildings within a few days, and could make judgments regarding the seismic vulnerability of the housing stock within a few days. Thus, most towns can screen their buildings, using existing personnel, in a relatively small amount of time. With two days of training, and several days of surveying, existing staff can screen all the buildings in a town. If preferred, the screening can be performed over several weeks or months, squeezed in as time is available.

INSPECTOR TRAINING AND RELIABILITY OF ATC-21

The ATC-21 method has inherent limitations because it is based on visual survey of the building, and often only the exterior of the building. For this reason, a low Structural Score, **S**, should not be construed as a final verdict on the building, but only a suggestion "that the building requires additional study by a professional engineer experienced in seismic design" (ATC, 1988, p. 1). Furthermore, this means that the data are most usefully viewed in aggregate. For this reason, we do not publish the individual building survey results but only summaries of the inventories.

Although the ATC-21 manual states that it is suitable for use by any interested people (so long as they are trained by a professional engineer experienced in seismic design), we chose to use only graduate students with undergraduate degrees in architecture or civil engineering. This would ensure a minimal level of skills in building design, and would also ensure that our inspectors have a level of expertise consistent with the participants in the CUSEC pilot test. Based on the CUSEC pilot tests cited above, we assumed that our training goal was to achieve approximately 80 to 90 percent accuracy.

At the University of Illinois, we trained two Urban Planning graduate students, both of whom had undergraduate architecture degrees. They began by reading the ATC-21 manual, and reviewing training materials from ATC. They then independently evaluated eight buildings on the University of Illinois campus. Following completion of the survey, Professor Mark Aschheim, a MAE Center structural engineer, reviewed each building in the field with them. We then assigned them an additional five buildings on campus, and instructed them to survey them together. Professor Aschheim reviewed their results, and we then assigned them an additional five buildings in downtown Champaign, which we believed to be more representative of buildings they would see in Carbondale. By the end of the training, we believed that the two students working together would get at least 80% percent accuracy in identifying buildings requiring additional study (**S**=?2).

At Georgia Tech we trained three City Planning graduate students to use the ATC-21 method. Two of these students were familiar with the ATC classification scheme from earlier work on the SE-1 inventory project. The students began by reviewing the ATC-21 training materials on 35mm slides. They then reviewed the ATC-21 manual. They pre-tested the method on a set of buildings in the Atlanta area. The results of this pretest were reviewed with the students before the field work was begun.

FIELD SURVEY METHODS

In Carbondale, we were fortunate to have the results of an ATC-21 survey performed by engineering students for the Illinois Emergency Management Agency (IEMA) in the summer of 1992**.** They inventoried 121 buildings, as part of a larger effort that covered 21 counties in southern Illinois.[3] We acquired their data for Carbondale, and designed our data collection method and database to be compatible with theirs. Our field manual, which consists of introductory instructions followed by IEMA's coding instructions, is included in Appendix A.

We surveyed buildings according to the following priority categories:

1. Essential facilities, residential buildings of 10 dwelling units or more, government offices, public utilities, places of public assembly.

2. Health care clinics, commercial structures larger than 5,000 square feet, transportation terminals, other public buildings, any other high-occupancy buildings.

3. Industrial buildings, warehouses, building supply stores.

The building inspector for the City of Carbondale was instrumental in helping to identify building locations, and also provided comments regarding building ages and structural types.

[3] The purpose of the IEMA inventory is to be able to evaluate buildings that would be needed following an earthquake, particularly those buildings that might be suitable for emergency shelters. IEMA's intent is to be able to use this list to be able to rapidly make informed decisions following a serious earthquake. IEMA conducted the survey over several summers, using engineering and architecture students, under direction of a structural engineer at IEMA.

The two surveyors spent approximately 12 days in the field over four visits to Carbondale late in the Fall Semester of 1998. They briefly confirmed the 121 buildings in the IEMA survey (116 still existed with usable information), and then surveyed an additional 179, for a total inventory of 295 buildings. The data collection includes a digital photo library, with two photographs showing all sides of each building. It also includes geographic coordinates of each building, obtained in the field with a GPS device. We also have a digital collection of the scanned images of the 179 new ATC-21 survey forms. All the databases image collections are available to other MAE Center researchers, as long as they do not release the survey results for individual buildings.

Three students made two data collection field trips to Sikeston, Missouri in the winter and spring of 1999. The team began by meeting with the City Manager and Building Inspector, who were quite helpful in providing insights on the local building stock. The team surveyed 124 buildings using the ATC-21 method. A follow-up trip in the spring of 2000 filled in missing data from the first trips.

We also added estimates of building replacement costs to our database. In order to have estimates that reflect local conditions in Carbondale and Sikeston, we asked the Carbondale Building Inspector to obtain cost estimates from a reliable local construction company. J&L Robinson Construction provided estimated building replacement costs per square foot, in 1999 dollars. These ranged from $46/sf to $95/sf.

ESSENTIAL FACILITIES

We surveyed 16 essential facility structures in Carbondale (10 of these were performed by IEMA in 1992, and six by us). These included one hospital, 12 public and private schools, one police station, and three fire stations.

Table 2-1
Essential Facilities, Carbondale

NAME	ADDRESS	AGE	STORIES
Carbondale Memorial Hospital	404 W. Main St.	1950's	4.0
Carbondale Central High School	200 N. Springer St.	1920's	3.0
Lakeland School	925 S. Giant City Rd.	1950's	1.0
Thomas School	1025 N. Wall St.	1950's	1.0
Lewis School	801 S. Lewis Lane	1960's	1.0
Lincoln Junior High School	501 S. Washington St.	1940's	2.0
Winkler School	1218 W. Freeman St.	1950's	2.0
Parrish Elementary School	121 N. Parrish Lane	1960's	1.0
Carbondale East High School	1301 E. Walnut St.	1960's	1.0
Carbondale New School	1302 Pleasanthill	1920's	1.0
Admiral Child Development Center	312 S. Wall	1980's	1.0
Brehm Preparatory School	1245 E. Grand Ave	1950's	2.0

Westown Center	2001, 2015, 2102 w.	1980's	1.0
Carbondale Police Dept.	610 E. College St.	1960's	3.0
Carbondale Fire Dept.	300 S. Oakland St.	1960's	1.0
Carbondale Fire Dept	600 E. College	1970's	1.0
Carbondale Township Fire Dept	1125 E. Park	1960's	1.0

Virtually all the buildings were constructed prior to the advent of seismic building codes in this part of the country. Of the 16 buildings, 10 of them scored less than 2.0, which means that they should be inspected by a qualified structural engineer[4]. The only buildings that received scores higher than 2.0 were four private wood-frame schools. The mean score of the 16 buildings was 1.6. Another way of looking at it is to compute the "risk floor area" (see p. 2-2). This totals 175,000 sf out of the approximate 615,000 sf in these 16 buildings. This means that, according to the ATC-21 survey, about 28% of the total floor area of these buildings is at risk of major earthquake damage, given Carbondale's location in a Moderate seismic hazard zone. In contrast, the Carbondale City Hall, a 26,000 square-foot, steel-frame structure built in the 1990s, was constructed to modern seismic standards, and received an ATC-21 rating of 5.0 ("risk floor area" equals 0.3 sf).

Many of these buildings were subsequently inspected in December, 2000 by several MAE Center structural engineering professors: Y.K. Wen, Don White, Joe Bracci, and Roberto Leon. Their observations were applied to for several projects under the MAE Center's Essential Facilities Program.

In Sikeston, we surveyed 31 structures at 21 essential facility sites. These included one medical center, one clinic, 14 schools, one police station, one public works facility, and three fire stations.

Table 2-2
Essential Facilities, Sikeston

NAME	ADDRESS	AGE	STORIES
Ferguson Medical Clinic	1012 US Hwy 61		2
Missouri Delta Medical Center (1 of 3	1008 US Hwy 61	1944	2
Missouri Delta Medical Center (2 of 3	1008 US Hwy 61	1968	3
Missouri Delta Medical Center (3 of 3	1008 US Hwy 61	1998	2
Lee Hunter Elementary School	300 Baker Ln		1
Matthews Elementary	Courtney & Elm	1955	1
New Dawn State School	710 Glen Dr		1

[4] We do not report individual ATC-21 scores for each building, because of the approximate nature of this survey method. Because the method is 80% accurate, up to 20% of the scores may be incorrect. Therefore, only aggregate scores and analyses are presented in this report.

Ralph T. Bailey School	534 Moore St	1936	2
SEMO Christian Academy	1440 Ables Rd	1981	1
Sikeston Area Higher Education Center	101 Kathleen St		1
Sikeston High School Field House	200 Pine St		1
Sikeston Junior High School	100 Twitty Dr		1
Sikeston Kindergarden Center (1 of 2)	1310 Salcedo Rd	1971	1
Sikeston Kindergarden Center (2 of 2)	1310 Salcedo Rd	1990	1
Sikeston Middle School	510 Lindenwood St		1
Sikeston Regional Center	112 Plaza Dr		1
Sikeston Senior High School (1 of 8)	200 Pine St		1
Sikeston Senior High School (2 of 8)	200 Pine St		1
Sikeston Senior High School (3 of 8)	200 Pine St		1
Sikeston Senior High School (4 of 8)	200 Pine St		1
Sikeston Senior High School (5 of 8)	200 Pine St		1
Sikeston Senior High School (6 of 8)	200 Pine St		1
Sikeston Senior High School (7 of 8)	200 Pine St		1
Sikeston Senior High School (8 of 8)	200 Pine St		1
Southeast Elementary	2300 Ables Rd		1
Southwest School	835 Murray Ln		1
Police Department(Sikeston)	215 New Madrid St	1931	2
Public Works Department Complex (1 of	316 West St	1960	1
Fire Station #1	405 Malone Ave	1950	1
Fire Station #2	506 US Hwy 61	1950	1
Fire Station #3	2003 Ables Rd	1998	1

Of the 31 buildings, 19 scored less than 2.0. The mean score was 1.4. In Sikeston we calculated 306,000 sf “risk floor area” out of a total of 868,000 sf. This means that 35% of the total floor area of these buildings is at risk of major earthquake damage, given Sikeston’s location in a High seismic hazard zone.

ANALYSIS OF CARBONDALE ATC-21 SURVEY

Summary results of the Carbondale ATC-21 survey are shown in Tables 2-3 and 2-4. Remember that, although these are not all the buildings in Carbondale, they are in our judgment the largest and most significant buildings in Carbondale. Figures 2-1and 2-2 summarize the buildings (and floor area) surveyed, by structure type and occupancy. Nearly 70% of the floor area is in residential and educational buildings, which reflects the dominance of Southern Illinois University (including dormitories) among the City’s larger buildings. SIU accounts for 61 of the buildings in the inventory, totaling 4.716 million square feet.

Table 2-3
Building Characteristics by Occupancy, Carbondale ATC-21 Survey

	No. Bldgs		Building Mean:							
Occupancy	**Number of Bldgs**	**Bldgs with score=2**	**Score**	**Struct cost ($1,000s)**	**Contents cost ($1,000s)**	**Floor area (1,000 sf)**	**Total floor area (1,000 sf)**	**Floor area in bldgs =2**	**% Floor area in bldgs =2**	**Full cost of bldgs =2 ($1,000s)**
Commercial	81	36	2.7	2,729	2,855	33	2,635	1,398	53.0%	238,065
Educational	58	45	1.6	3,860	5,586	70	4,061	3,222	79.3%	431,613
Government	19	11	2.3	1,229	1,080	20	380	276	72.6%	29,769
Industrial	1	1	0.0	1,650	2,475	30	30	30	100.0%	4,125
Religious	38	21	2.4	394	394	7	273	195	71.3%	21,420
Residential	98	37	3.1	1,422	710	30	2,948	1,839	62.4%	130,388
	295	**151**	**2.6**	**2,116**	**2,247**	**35**	**10,327**	**6,959**	**67.4%**	**855,378**

Note: Score of =2 means that the building requires further investigation by a structural engineer.

Table 2-4
Building Characteristics by Structure Type, Carbondale ATC-21 Survey

	No.Bldgs		Building Mean:							
Structure	**Number of Bldgs**	**Bldgs with score=2**	**Score**	**Struct cost ($1,000s)**	**Contents cost ($1,000s)**	**Floor area (1,000 sf)**	**Total floor area (1,000 sf)**	**Floor area in bldgs =2**	**% Floor area in bldgs =2**	**Full cost of bldgs=2 ($1,000s)**
C1	5	4	1.4	3,387	4,550	62	308	217	70.3%	27,129
C2	5	3	2.0	7,469	3,856	162	808	586	72.5%	40,406
C3	47	46	0.7	3,290	4,308	62	2,905	2,900	99.8%	356,595
PC2	1	1	0.4	12,962	19,443	236	236	236	100.0%	32,405
RM	43	15	3.0	4,072	4,002	43	1,839	953	51.8%	177,850
S	26	9	2.9	3,105	3,921	50	1,307	325	24.9%	43,378
URM	72	72	0.5	1,246	1,207	24	1,736	1,736	100.0%	176,579
W	96	1	4.8	592	395	12	1,189	8	0.6%	1,038
	295	**151**	**2.6**	**2,116**	**2,247**	**35**	**10,327**	**6,959**	**67.4%**	**855,378**

Note: Score of =2 means that the building requires further investigation by a structural engineer.

Of the 295 buildings surveyed, 151 of them (51%) have scores less than or equal to 2.0, and the mean score is 2.6. The buildings with scores less than or equal to 2.0 contain an estimated $855 million of building and contents value (66% out of a total of $1.287 billion in the inventory). By floor area, 67% of the floor area of buildings is in buildings with scores less than or equal to 2.0. An alternative way of looking at the vulnerability of the inventory is to compute the "risk floor area" (see p. 2-2), which totals 2.875 million sf, 28% of the total 10.327 million sf in the inventory.

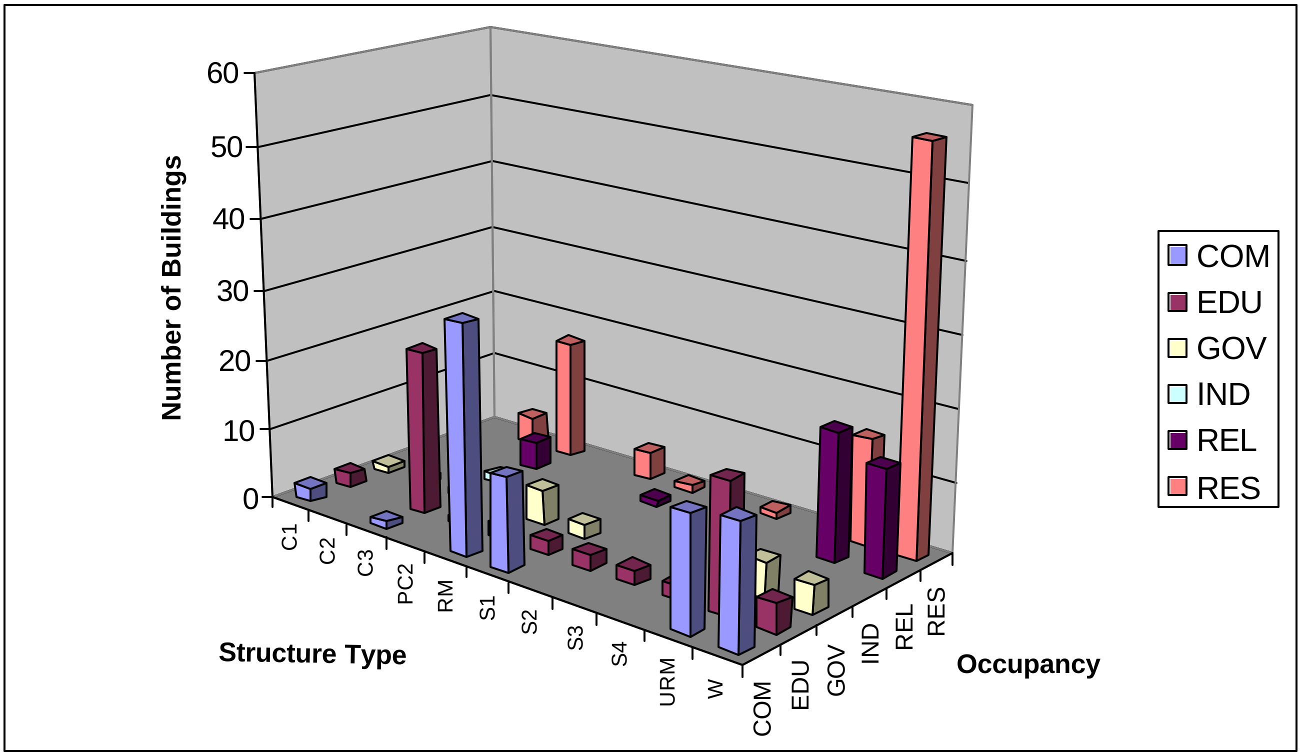


Figure 2-1
Number of Buildings by Structure Type and Occupancy, Carbondale ATC-21 Survey

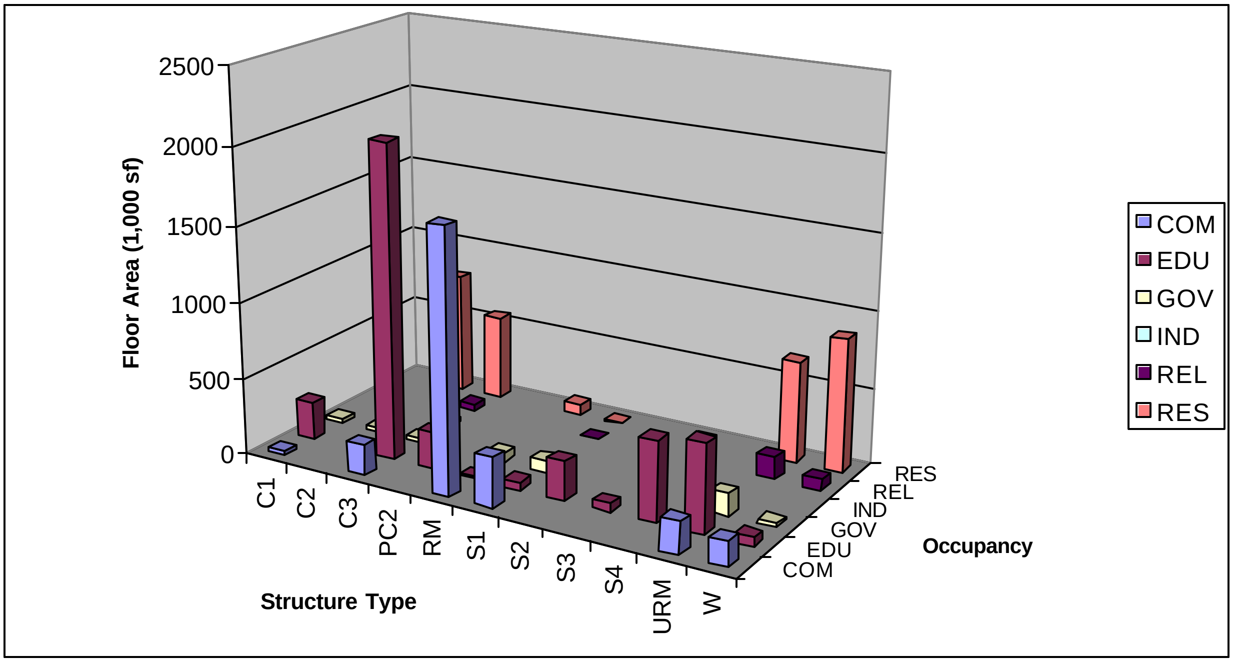


Figure 2-2
Building Floor Area by Structure Type and Occupancy, Carbondale ATC-21 Survey

Figures 2-3, 2-4, 2-5, and 2-6 illustrate the proportion of buildings with low ATC-21 scores, by occupancy and structure type. All occupancy categories contain significant amounts of low-scoring buildings, whether measured by number of buildings, floor area, total amounts, or percents. The educational category has the greatest amount of floor space in low-scoring buildings, and this accounts for 79% of educational floor area. This reflects both the high proportion of unreinforced masonry buildings in the public schools, as well as the high proportion of concrete-frame buildings at SIU. From Figures 2-5 and 2-6 it is clear that the most problematic structure types are unreinforced masonry and concrete frame. Almost all buildings constructed of these materials are suspect and require detailed inspections by a structural engineer to verify their quality.

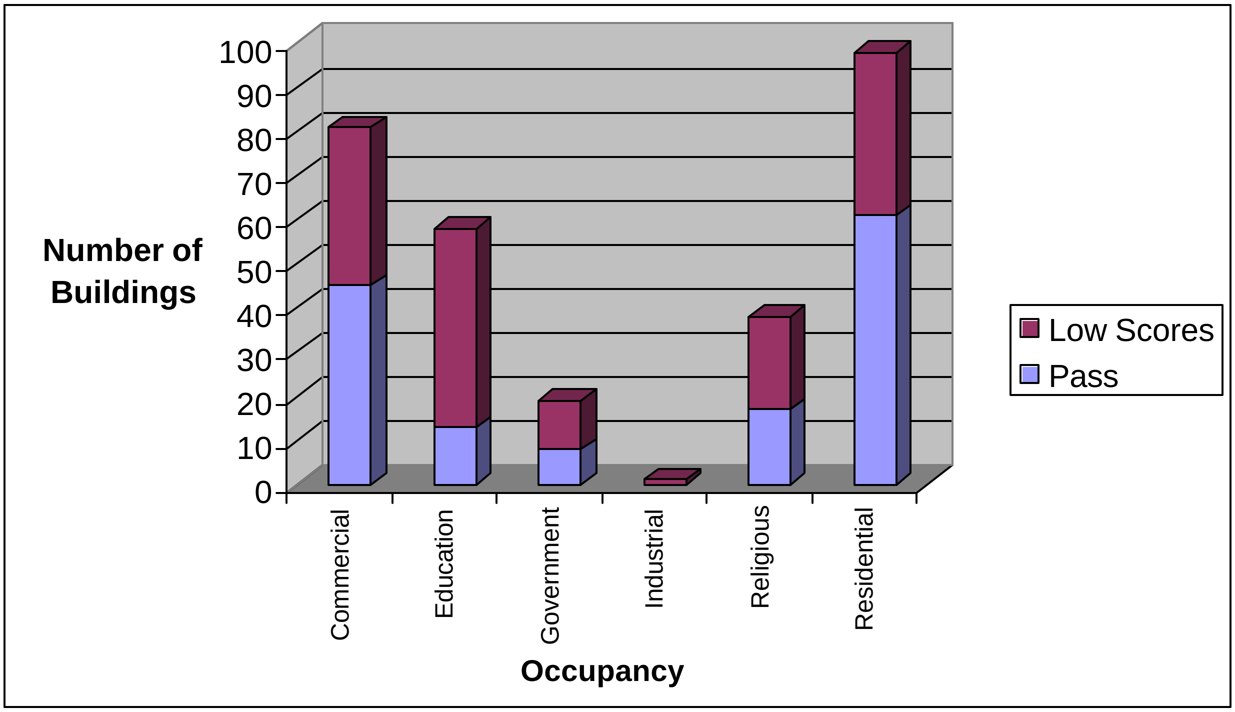


Figure 2-3
Number of Buildings by Occupancy Type, Carbondale ATC-21 Survey

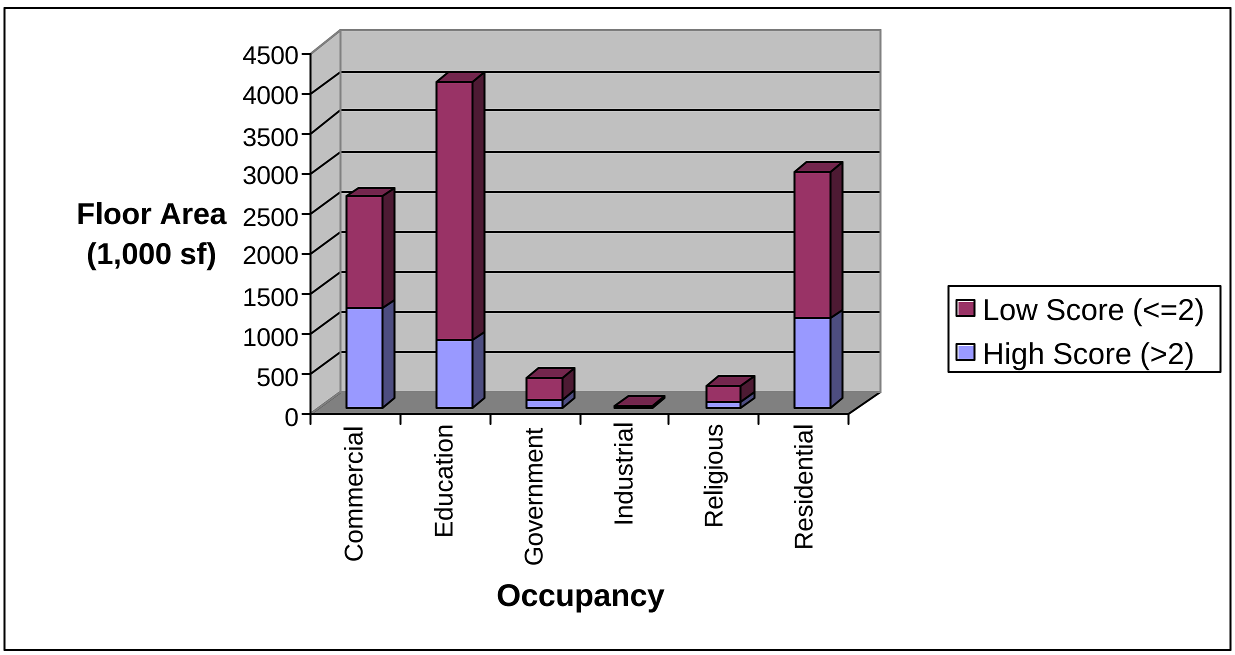


Figure 2-4
Floor Area by Occupancy Type, Carbondale ATC-21 Survey

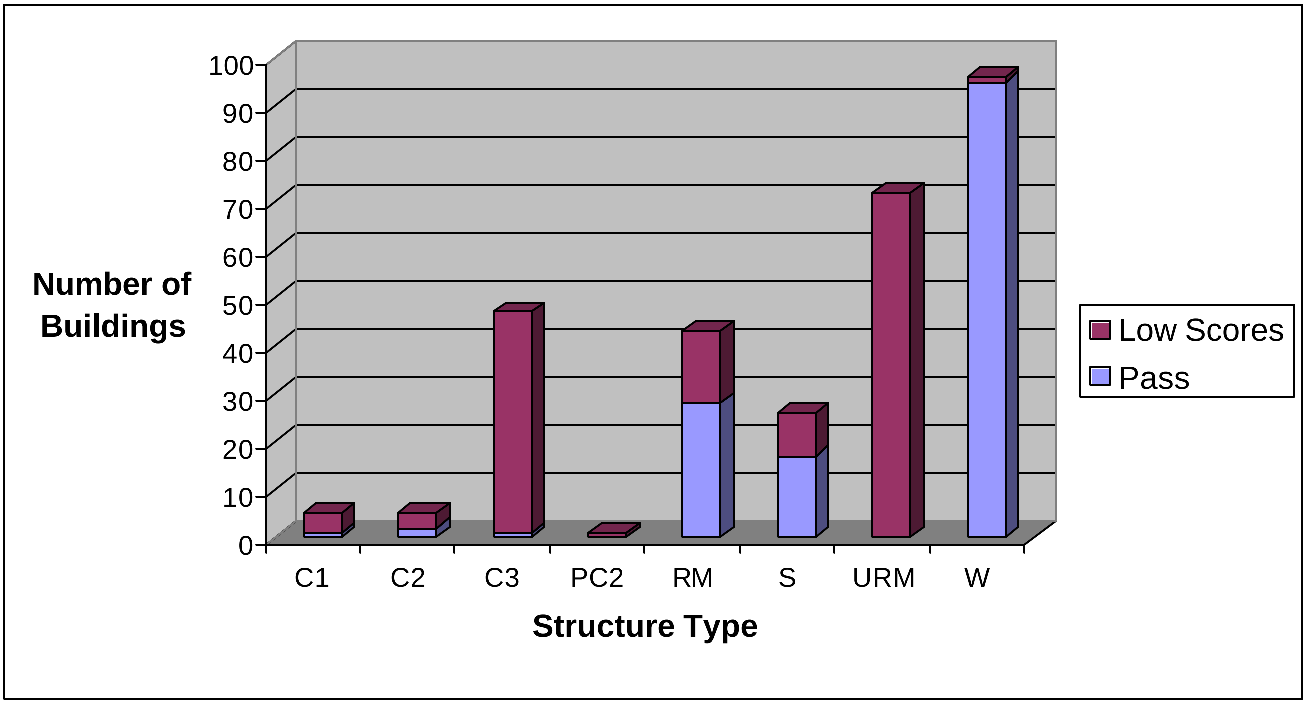


Figure 2-5
Number of Buildings by Structure Type, Carbondale ATC-21 Survey

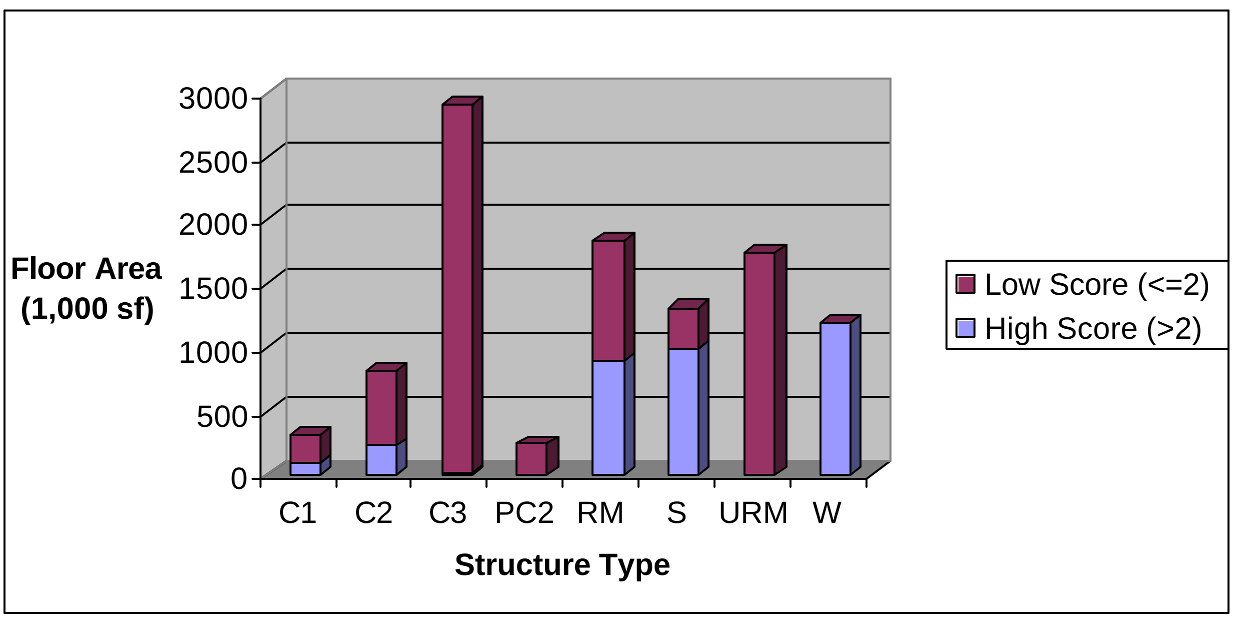


Figure 2-6
Floor Area by Structure Type, Carbondale ATC-21 Survey

Figures 2-7, 2-8, and 2-9 illustrate the calculations of “risk floor area” applied by occupancy and structure type to the Carbondale inventory. One advantage of this measure is that it considers the entire range of ATC-21 scores, rather than simply counting buildings with scores greater or less than 2.0. These figures underscore the primary seismic safety problem in Carbondale’s building stock: residential and and educational buildings constructed of unreinforced masonry and concrete frames. SIU’s 1.444 million sf of “risk floor area” accounts for nearly half of the total “risk floor area” in the Carbondale inventory. Carbondale’s schools contribute another 93,000 sf. In addition, there are a substantial amount of government, residential, and commercial unreinforced masonry buildings as well as concrete frame residential buildings.

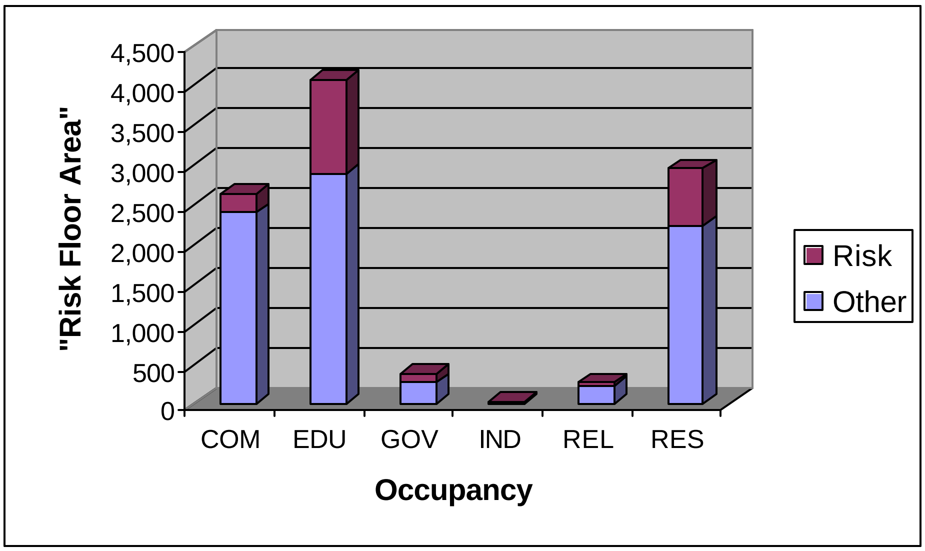


Figure 2-7
“Risk Floor Area” by Occupancy, Carbondale ATC-21 Survey
Note: This is the sum of risk floor area over all buildings. Risk floor area for a building = (building floor area) x 10^{-S}

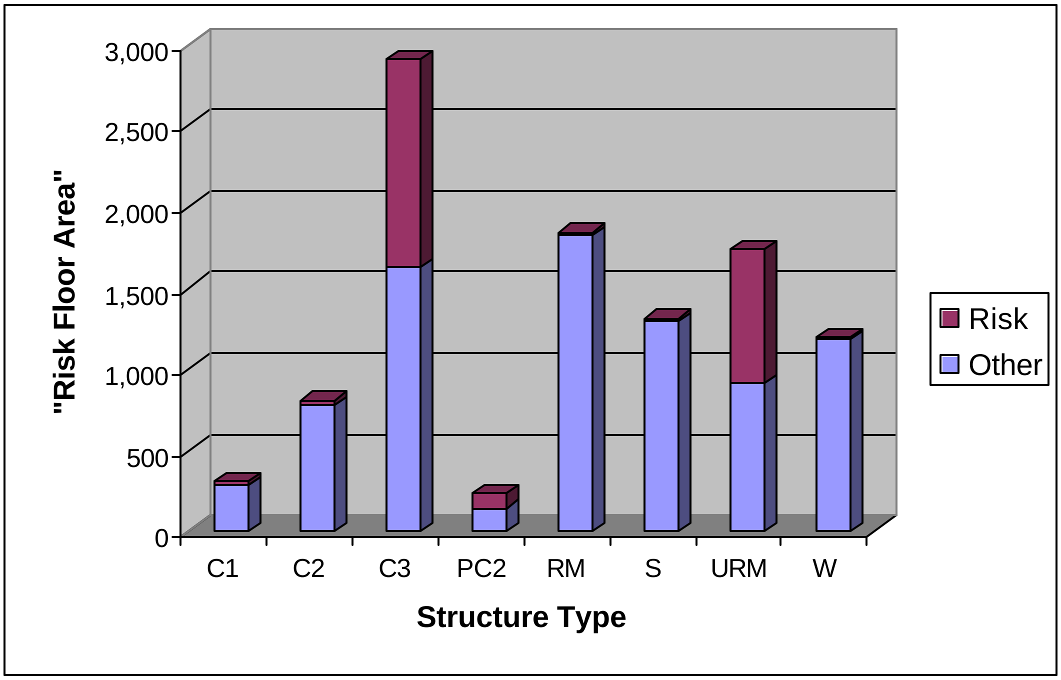


Figure 2-8
"Risk Floor Area" by Structure Type, Carbondale ATC-21 Survey

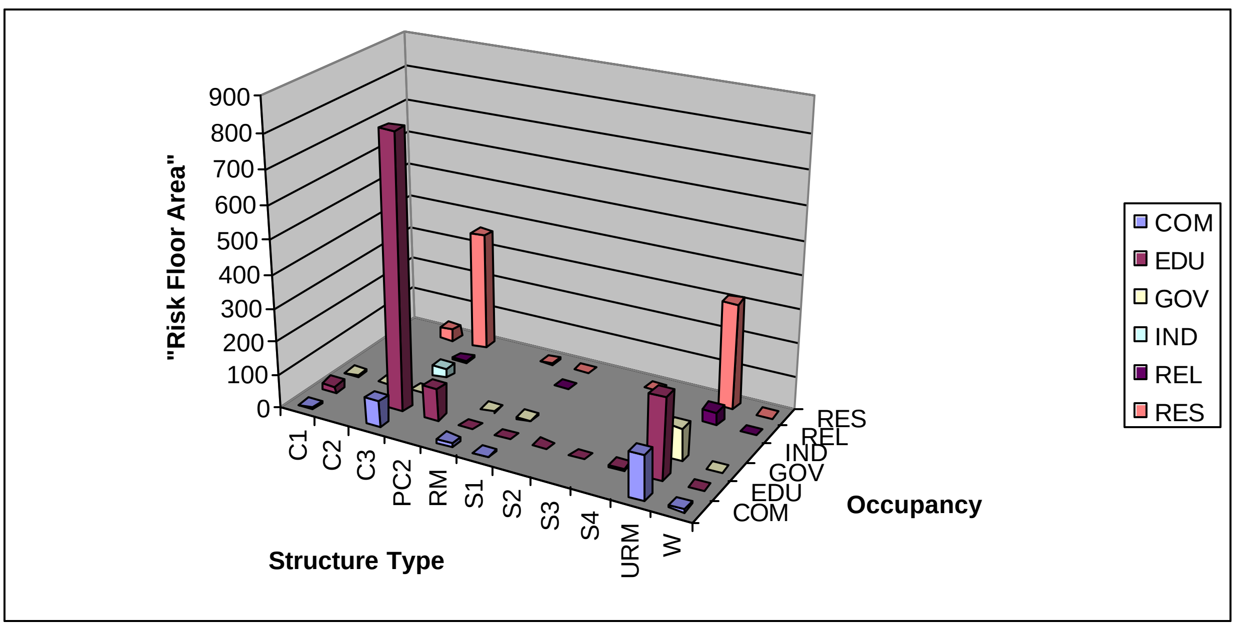


Figure 2-9
"Risk Floor Area" by Structure Type and Occupancy, Carbondale ATC-21 Survey

ANALYSIS OF SIKESTON ATC-21 SURVEY

Summary results of the Sikeston ATC-21 survey are shown in Tables 2-5 and 2-6. Figures 2-10 and 2-11 summarize the buildings (and floor area) surveyed, by structure type and occupancy. Nearly 60% of the inventory's floor area is in industrial and commercial buildings. This reflects the manufacturing base of Sikeston's economy, and contrasts with the building occupancies found in Carbondale. The ten largest buildings surveyed–those buildings larger than 80,000 sf–consist of five industrial, three commercial, one school, and one apartment building. Most (56%) of the surveyed buildings in Sikeston are constructed of reinforced masonry or steel

Table 2-5
Building Characteristics by Occupancy, Sikeston ATC-21 Survey

	No.	Bldgs.		Building Mean:						
Occupancy	**Number of Bldgs**	**Bldgs with score=2**	**Score**	**Struct cost ($1,000s)**	**Contents cost ($1,000s)**	**Floor area (1,000 sf)**	**Total floor area (1,000 sf)**	**Floor area in bldgs =2**	**% Floor area in bldgs =2**	**Full cost of bldgs =2 ($1,000s)**
COM	15	9	1.2	3,008	2,969	55	820	334	40.8%	40,752
EDU	21	12	1.6	1,387	1,387	25	529	363	68.6%	39,931
GOV	17	12	1.1	470	574	6	105	76	72.5%	13,439
IND	19	8	2.7	2,940	4,410	67	1,268	333	26.2%	55,368
REL	35	22	2.1	509	509	9	325	252	77.6%	27,751
RES	17	6	2.5	1,662	831	30	514	207	40.3%	17,098
	124	**69**	**1.9**	**1,485**	**1,606**	**29**	**3,561**	**1,566**	**44.0%**	**194,338**

Table 2-6
Building Characteristics by Structure Type, Sikeston ATC-21 Survey

	No.Bldgs			Building Mean:						
Structure	Number of Bldgs	Bldgs with score=2	Score	Struct cost ($1,000s)	Contents cost ($1,000s)	Floor area (1,000 sf)	Total floor area (1,000 sf)	Floor area in bldgs =2	% Floor area in bldgs =2	Full cost of bldgs =2 ($1,000s)
C1	2	2	0.9	1,045	1,045	19	38	38	100.0%	4,180
C3	4	2	1.0	809	809	13	52	36	69.7%	3,974
PC1	2	2	-0.1	620	899	11	23	23	100.0%	3,037
RM	46	27	2.1	1,639	1,854	29	1,343	571	42.5%	77,869
S1	18	6	2.3	1,225	1,158	22	401	115	28.8%	12,587
S2	1	1	0.9	4,856	4,856	88	88	88	100.0%	9,712
S3/5	21	9	2.4	1,760	2,334	45	953	169	17.7%	25,132
URM	17	14	1.0	1,026	1,103	17	284	268	94.3%	34,048
W	13	6	2.1	1,607	1,021	29	380	258	67.9%	23,800
	124	**69**	**1.9**	**1,485**	**1,606**	**29**	**3,561**	**1,566**	**44.0%**	**194,338**

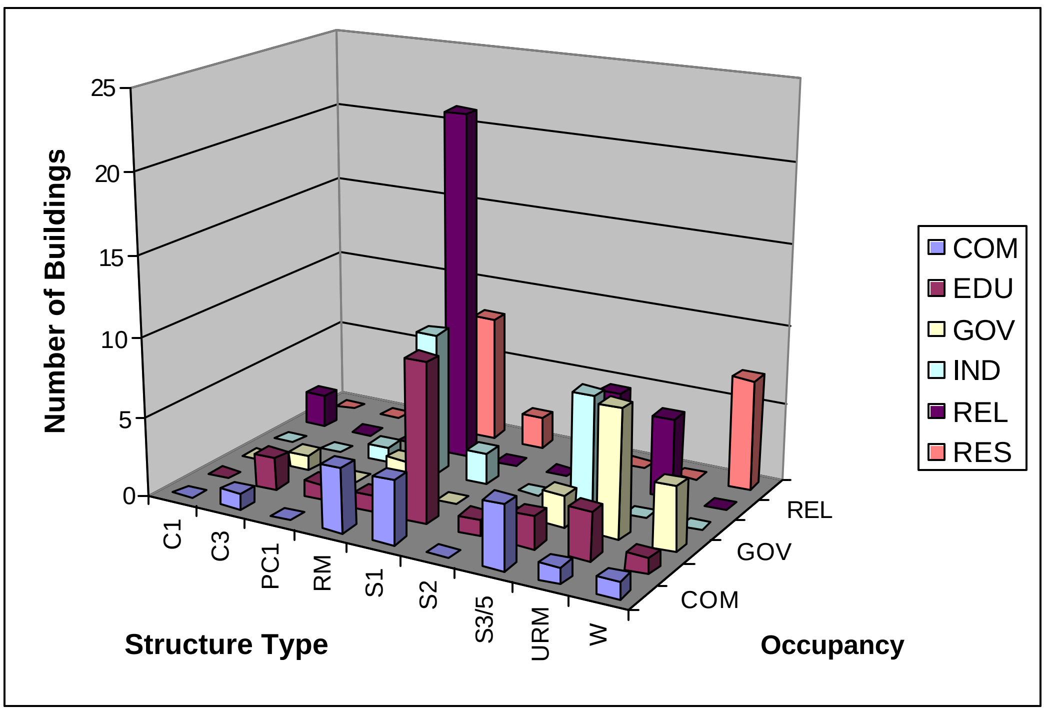


Figure 2-10
Number of Buildings by Structure Type and Occupancy, Sikeston ATC-21 Survey

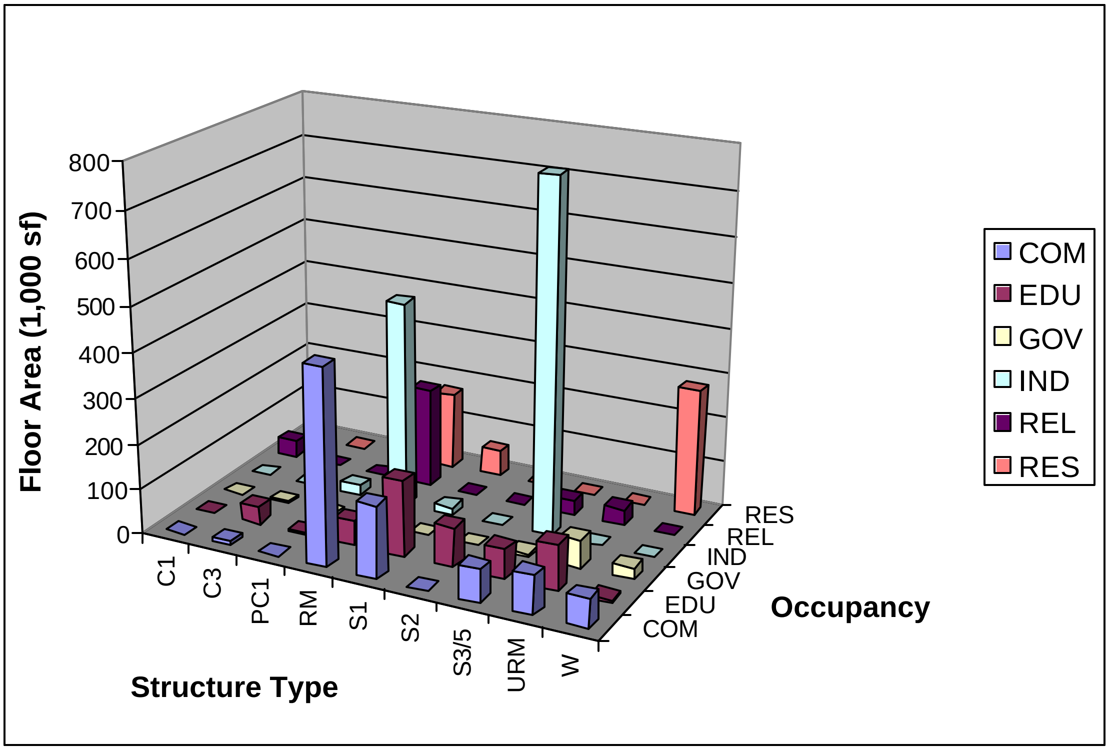


Figure 2-11
Floor Area by Structure Type and Occupancy, Sikeston ATC-21 Survey

Of the 124 buildings surveyed, 69 of them (56%) have scores less than or equal to 2.0, and the mean score is 1.9. The buildings with scores less than or equal to 2.0 contain an estimated $194 million of building and contents value (51% out of a total of $383 million in the inventory). By floor area, 44% of the floor area of buildings is in buildings with scores less than or equal to 2.0. An alternative way of looking at the vulnerability of the inventory is to compute the "risk floor area", which totals 573,000 sf, 16% of the total 3.561 million sf in the inventory.

Figures 2-12, 2-13, 2-14, and 2-15 illustrate the proportion of buildings with low ATC-21 scores, by occupancy and structure type. All occupancy categories contain significant amounts of low-scoring buildings, whether measured by number of buildings, floor area, total amounts, or percents. The industrial category has the smallest proportion of floor space in low-scoring buildings. In contrast, educational, religious, and government buildings all have greater than two-thirds of their floor space in low-scoring buildings. Figures 2-14 and 2-15 indicate that the most problematic structure types are unreinforced and reinforced masonry. Concrete buildings and braced steel frames are also rated poorly, but Sikeston has few such buildings. Several wood-frame buildings also receive low ratings–for their configurations–though most are not substantially lower than 2.0.

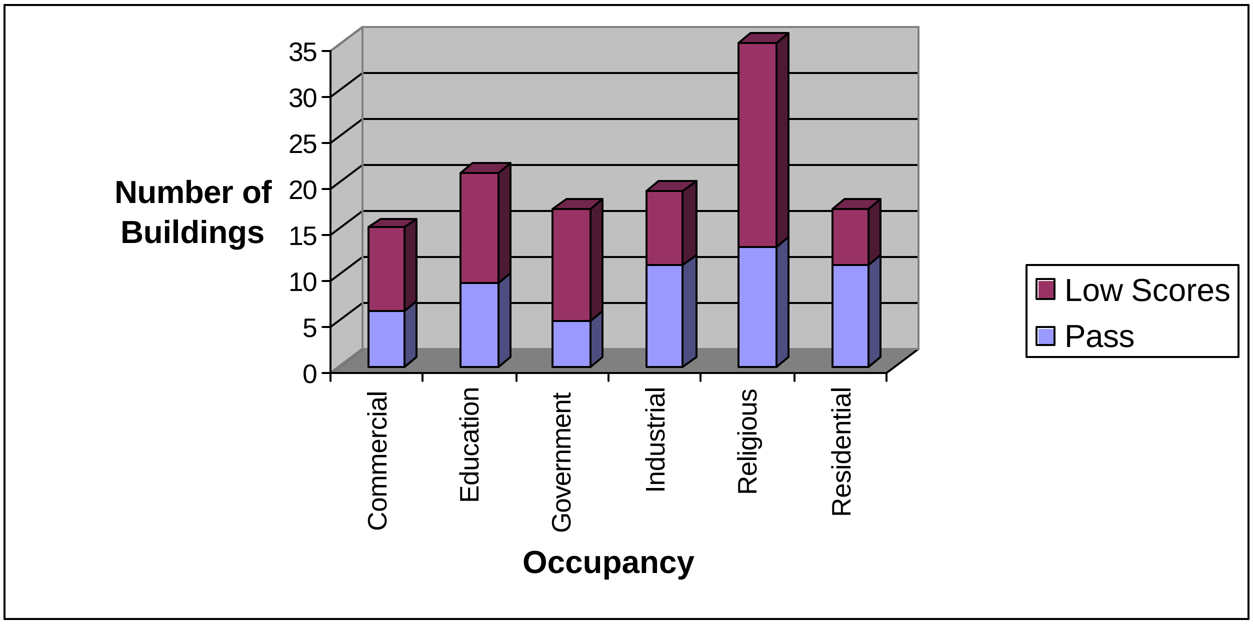


Figure 2-12
Number of Buildings by Occupancy, Sikeston ATC-21 Survey

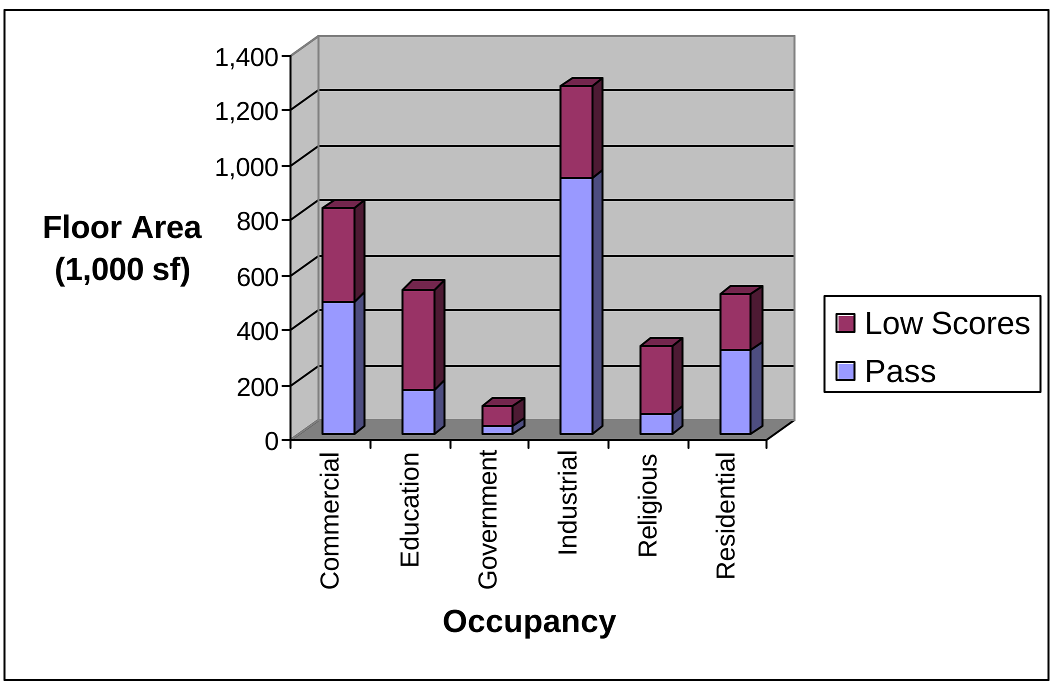


Figure 2-13
Floor Area by Occupancy, Sikeston ATC-21 Survey

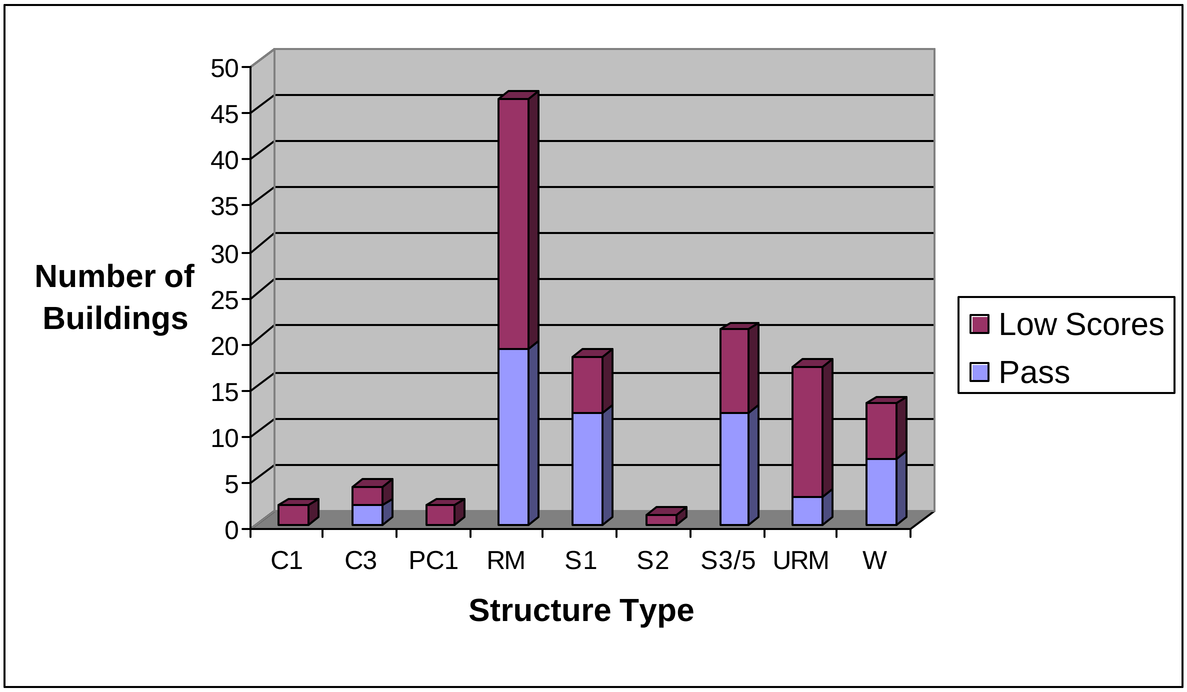


Figure 2-14
Number of Buildings by Structure Type, Sikeston ATC-21 Survey

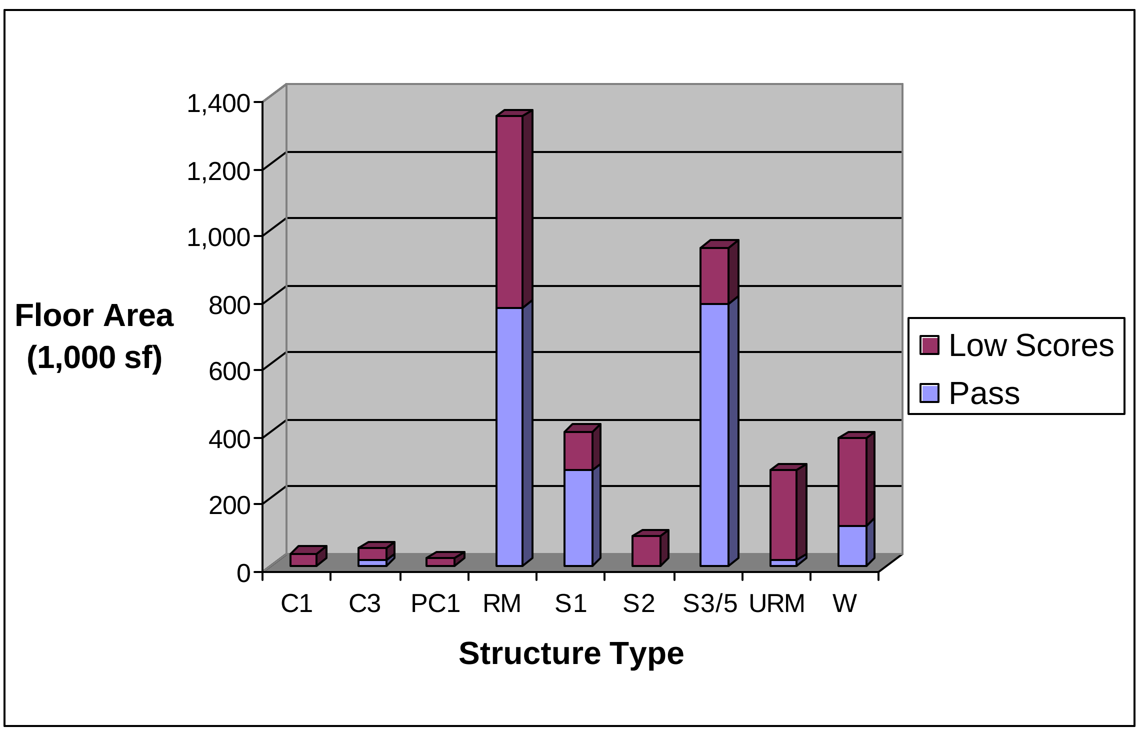


Figure 2-15
Floor Area by Structure Type, Sikeston ATC-21 Survey

Figures 2-16, 2-17, and 2-18 illustrate the calculations of "risk floor area" applied by occupancy and structure type to the Sikeston inventory. From these it appears that the primary seismic safety problem in Sikeston's building stock lies in unreinforced masonry commercial, government, and educational buildings, and secondarily reinforced masonry commercial and religious buildings. These five categories account for 46% of the total risk floor area in the inventory.

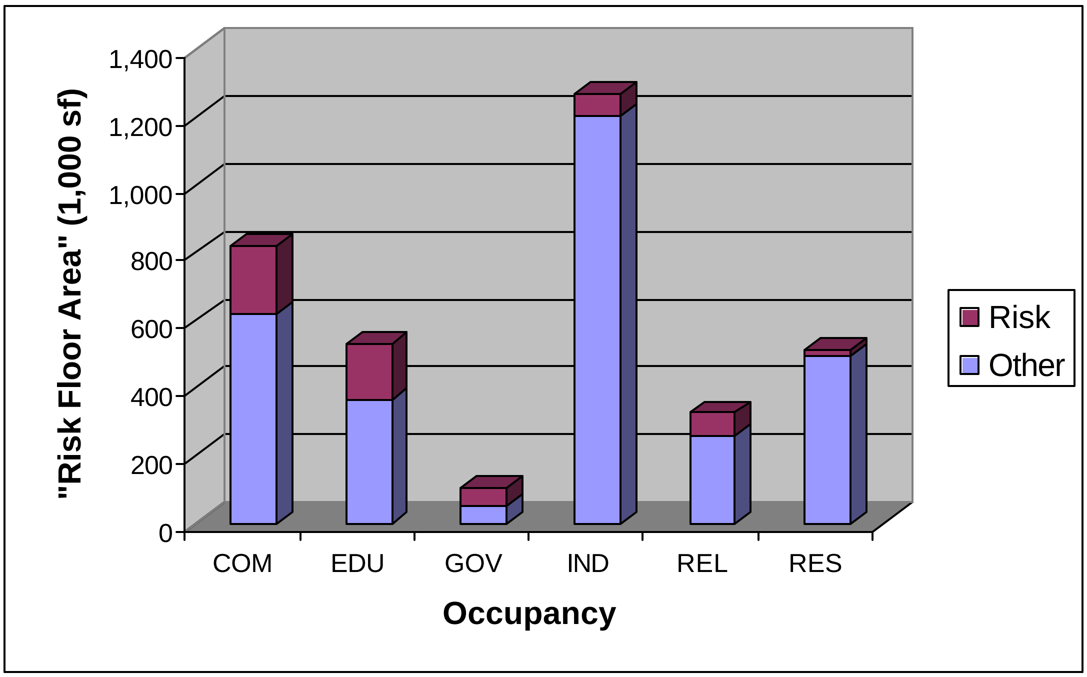


Figure 2-16
"Risk Floor Area" by Occupancy, Sikeston ATC-21 Survey

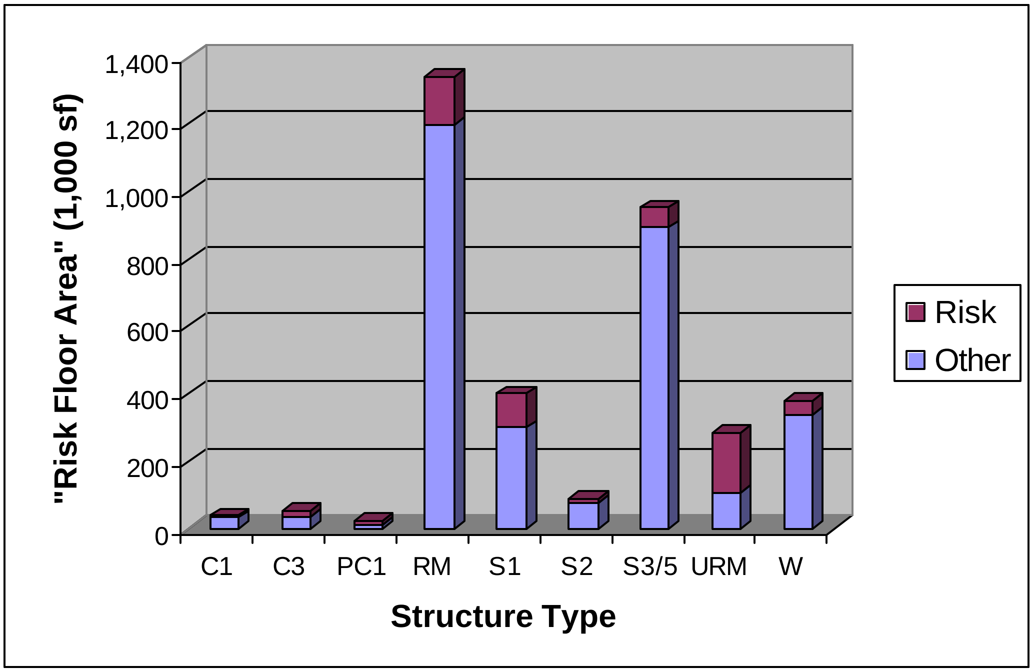


Figure 2-17
"Risk Floor Area" by Structure Type, Sikeston ATC-21 Survey

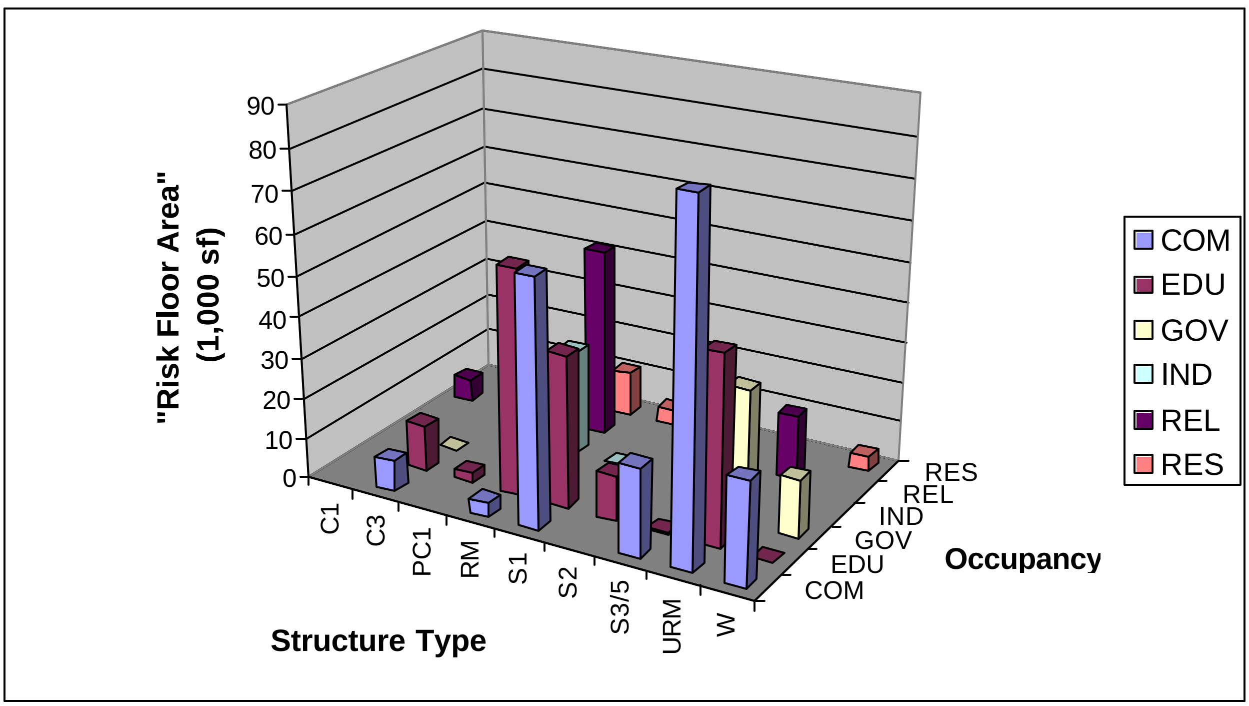


Figure 2-18
"Risk Floor Area" by Structure Type and Occupancy, Sikeston ATC-21 Survey

CHAPTER 3
HAZUS DEFAULT EARTHQUAKE LOSS ESTIMATES FOR CARBONDALE AND SIKESTON

We used the HAZUS earthquake loss estimation software (National Institute of Building Sciences, 1999a) to estimate the effects of a range of earthquakes that could plausibly affect Carbondale and Sikeston

This analysis used HAZUS 99 SR-1. Note that the various versions of HAZUS (HAZUS 97, HAZUS 99, HAZUS 99 SR-1) produce slightly different results, particularly in the casualty estimates.

The seismicity of the New Madrid seismic zone (NMSZ) is poorly understood. This is because there have been few earthquakes in historic time, and because this mid-continent seismic zone has few analogs elsewhere in the world. Indeed, it does not seem to be large enough to generate a major earthquake, though it did just that in 1811-1812. At that time, it produced at least three large earthquakes generally believe to have moment magnitudes of about 8 (Atkinson, et al, 2000). In addition, two previous events–in approximately 1450 and 900 A.D.– caused widespread liquefaction. The seismic zone itself has been well-defined by studies of micro-seismicity since the early 1970s. It is troublesome, however, that moderate earthquakes–which in most seismic models occur much more frequently than great earthquakes-- are missing from the historical and prehistoric record. Damaging earthquakes also have occurred in the areas surrounding the New Madrid seismic zone, but this dispersed seismicity is not well understood (Hamilton and Johnston, 1990)

As the basis of this analysis, we have made the following assumptions regarding the seismicity of the NMSZ and surrounding areas. These assumptions are based upon current knowledge of the area (Atkinson, et al, 2000; Hamilton and Johnston, 1990, Johnston, 1996; Johnston and Schweig, 1996.), and have been discussed with Arch Johnston of the University of Memphis. We think they are reasonable assumptions, based on current understanding of Mid-America seismicity. We assume that the NMSZ is capable of generating earthquakes of **M**7 and **M**8, as well as smaller magnitude events. The surrounding area (which includes Carbondale) is capable of generating earthquakes as large as **M**5 and **M**6, which can occur anywhere within this region.

To capture the effects of this full range of possible seismic events, we performed HAZUS loss estimates for the following set of earthquakes affecting Carbondale and Sikeston: (1) moment magnitude **M**8.0 and **M**7.0 events evenly spaced along the axis of the New Madrid seismic zone, and (2) **M**6.0, 5.5, and 5.0 events occurring anyplace in the region. To represent the latter, we used a suite of events located at varying distances from each city: 0 km, 10 km, 25 km, 50 km, and 100 km (Wu 2002). These earthquake scenarios are listed in Tables 3-1 and 3-2 and are depicted in Figure 3-1. For Sikeston, we also thought it important to run a “worst case” event of a **M**7 and **M**8 emanating from the nearest portion of the axis of the NMSZ. Fortuitously, one of our **M**7/8 locations meets this criterion, located on the closest part of the axis of the NMSZ, only 34 km from

Sikeston. It is possible, of course, for a large earthquake to occur even closer to Sikeston, but the 34 km scenario seems to be the worst case that is most plausible.

Table 3-1 Carbondale Earthquake Scenarios

Scenario	Moment Magnitude	Longitude	Latitude	Distance	Depth
M5-1	5	-89.22	37.72	0 km	15 km
M5-2	5	-89.14	37.67	10	15
M5-3	5	-89.03	37.59	25	15
M5-4	5	-89.2	37.27	50	15
M5-5	5	-89.46	36.86	100	15
M5.5-1	5.5	-89.22	37.72	0	15
M5.5-2	5.5	-89.14	37.67	10	15
M5.5-3	5.5	-89.03	37.59	25	15
M5.5-4	5.5	-89.2	37.27	50	15
M5.5-5	5.5	-89.46	36.86	100	15
M6-1	6	-89.22	37.72	0	15
M6-2	6	-89.14	37.67	10	15
M6-3	6	-89.03	37.59	25	15
M6-4	6	-89.2	37.27	50	15
M6-5	6	-89.46	36.86	100	15
M7-1	7.0	-89.26	36.79	116	12
M7-2	7.0	-89.61	36.37	173	12
M7-3	7.0	-89.97	35.95	234	12
M7-4	7.0	-90.32	35.53	295	12
M8-1	7.0	-89.26	36.79	116	12
M8-2	7.0	-89.61	36.37	173	12
M8-3	7.0	-89.97	35.95	234	12
M8-4	7.0	-90.32	35.53	295	12
Attenuation function: Project97 East Coast					

Table 3-2 Sikeston Earthquake Scenarios

Scenario	Moment Magnitude	Longitude	Latitude	Distance	Depth
M5-1	5	-89.58	36.88	0 km	15 km
M5-2	5	-89.51	36.82	10	15
M5-3	5	-89.41	36.73	25	15
M5-4	5	-89.24	36.59	50	15
M5-5	5	-88.9	36.3	100	15
M5.5-1	5.5	-89.58	36.88	0	15
M5.5-2	5.5	-89.51	36.82	10	15
M5.5-3	5.5	-89.41	36.73	25	15
M5.5-4	5.5	-89.24	36.59	50	15
M5.5-5	5.5	-88.9	36.3	100	15
M6-1	6	-89.58	36.88	0	15
M6-2	6	-89.51	36.82	10	15
M6-3	6	-89.41	36.73	25	15
M6-4	6	-89.24	36.59	50	15
M6-5	6	-88.9	36.3	100	15
M7-2	7	-89.26	36.79	34	12
M7-3	7	-89.61	36.37	63	12
M7-4	7	-89.97	35.95	122	12
M7-5	7	-90.32	35.53	184	12
M8-2	8	-89.26	36.79	34	12
M8-3	8	-89.61	36.37	63	12
M8-4	8	-89.97	35.95	122	12
M8-5	8	-90.32	35.53	184	12

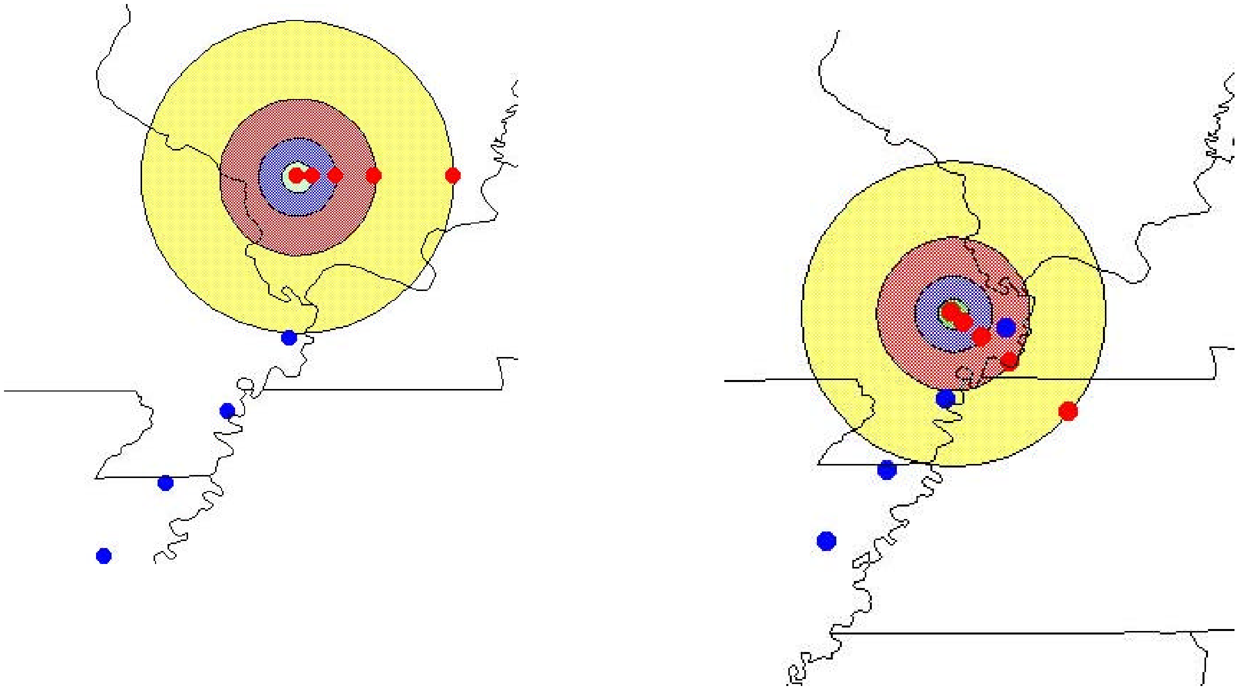


Figure 3-1. Carbondale (left) and Sikeston (right) earthquake scenarios.
The blue dots indicate locations of **M**7 and **M**8 scenarios, distributed along the New Madrid seismic zone (same locations used for both Carbondale and Sikeston). The red dots indicate locations of **M**5, **M**5.5, and **M**6 scenarios, located at distances of 0 km, 10 km, 25 km, 50 km, and 100 km from each community.

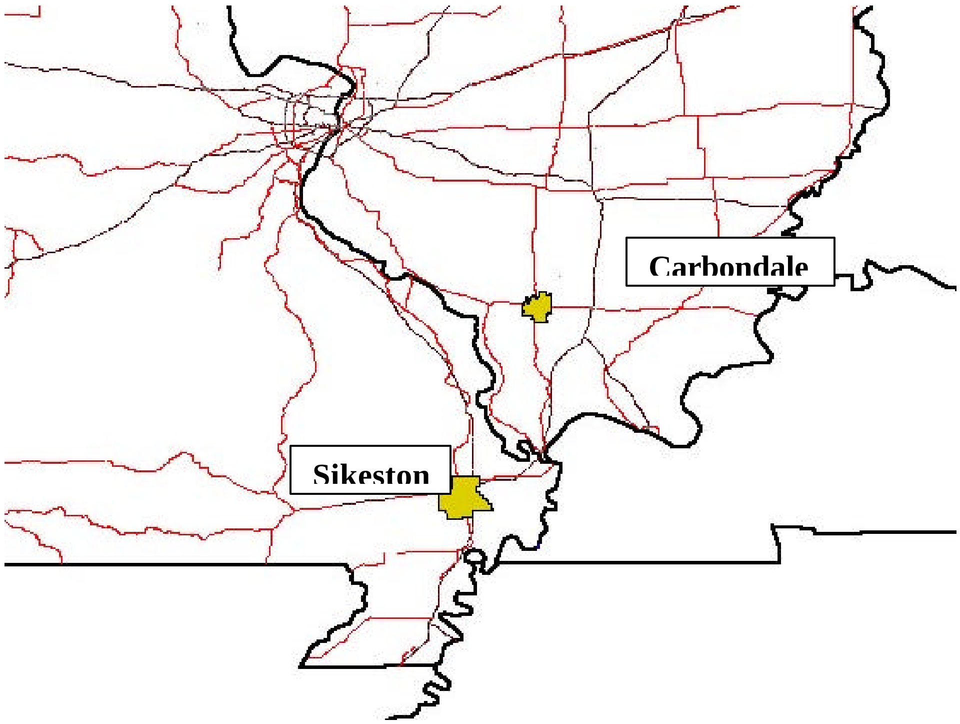


Figure 3-2. Carbondale and Sikeston Study Areas.

CARBONDALE

HAZUS study areas are composed of census tracts and counties. We constructed a census tract-based study area to approximate the City of Carbondale. It consists of eight census tracts that encompass and extend beyond the city limits. The 1990 census population of the study area is 33,066, and the population of Carbondale is 27,033. By population the city is 81.7% of the study area. Figure 3-2 shows both the Carbondale and Sikeston study areas, and Table 3-3 describes the Carbondale study area.

Table 3-3 Carbondale Study Area

Tract	Total Population of Tract (City + County)	City Residents in Tract	City Residents as % of Tract Population
108	4,108	2,889	70.3%
109	2,012	1,393	69.2%
110	5,618	4,256	75.8%
111	3,479	3,479	100.0%
112	5,580	5,123	91.8%
113	6,729	6,717	99.8%
114	3,204	2,099	65.5%
115	2,336	1,077	46.1%
TOTAL	**33,066**	**27,033**	**81.7%**

Default Community-wide Data

In order to estimate effects on the community as a whole, we ran the 23 HAZUS scenarios using the default data supplied with the HAZUS software. The default data contains inventories for key individual facilities, such as essential facilities and transportation, gathered from nationwide databases. These facilities have specific locations on the map. It also estimates the inventory of general building stock, by number of buildings and square footage, for 36 *structure types* and 28 *occupancy classes* (use types, such as residential, commercial, etc.). The general building stock data are derived from publicly available data and aggregated by census tract. For analytic purposes, we simplified these into 13 general structural classes and seven general occupancy classes. Table 3-4 summarizes the default general building stock for Carbondale, according to occupancy type.

Table 3-4
General Building Stock, by Occupancy (HAZUS Default)
Carbondale

Label	Occupancy Class	Floor Area (1,000 sq. ft.)	Dollar Exposure ($1,000	Number of Buildings
RES1	Single family	7,806	501,083	5,204
RES2	Mobile home	2,417	109,090	2,417
RES3	Multi Family	5,798	465,231	362
RES4	Temporary lodging	110	8,920	2
RES5	Dormitory	4,662	374,080	155
RES6	Nursing Home	90	6,861	2
COM1	Retail trade	1,225	62,672	86
COM2	Wholesale trade	303	10,336	8
COM3	Personal/repair svcs.	504	34,367	43
COM4	Financial/Professional	684	50,098	19
COM5	Banks	105	12,159	5
COM6	Hospital	42	5,098	0
COM7	Medical Office	246	22,179	20
COM8	Entertainment/Rec.	305	30,867	23
COM9	Theaters	11	803	0
COM10	Parking	0	0	0
IND1	Heavy Industry	265	13,576	5
IND2	Light	313	16,017	15
IND3	Food/Drugs/Chem.	5	271	0
IND4	Metals/Min Process.	0	0	0
IND5	High Technology	0	0	0
IND6	Construction	156	7,969	8
AGRI	Agriculture	65	842	4
REL1	Church	387	33,035	28
GOV1	General Services	66	4,404	1
GOV2	Emergency Response	0	0	0
EDU1	Schools	378	28,063	19
EDU2	Colleges	501	50,220	21
	TOTAL	**26,443**	**1,848,239**	**8,447**

Table 3-5 summarizes the default general building stock by structure type.

Table 3-5
General Building Stock, by Structure Type (HAZUS Default)
Carbondale

Label	**Structure Type**	**Floor Area (1,000 sq. ft.)**	**Dollar Exposure ($1,000)**	**Number of Buildings**
W	Wood	12,697	909,560	4,390
S1	Steel Moment Frame	150	10,688	7
S2	Steel Braced Frame	315	22,744	16
S3	Steel Light Frame	519	32,633	27
S4	Steel Frame, Concr. Shear Walls	282	17,799	16
S5	Steel Frame, URM infill	346	22,174	19
C1	Concrete Moment Frame	272	21,853	9
C2	Concrete Shear Walls	1,048	78,950	91
C3	Concrete Frame, URM infill	114	8,522	2
PC1	Precast Concrete Tilt-up	1,353	102,130	51
PC2	Precast Frames, Concrete Shear Walls	208	16,121	7
RM	Reinforced Masonry	406	32,030	20
URM	Unreinforced Masonry	6,315	463,943	1,374
MH	Mobile Homes	2,417	109,090	2,417
TOTAL		**26,443**	**1,848,239**	**8,446**

HAZUS categorizes damage into five damage states: None, Slight, Moderate, Extensive, and Complete. The precise definitions vary by structure type, but the HAZUS manual supplies the following graphic to illustrate the damage states:

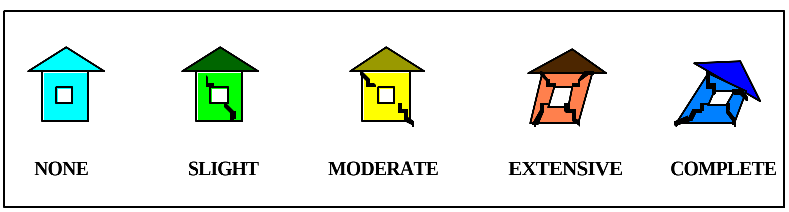


Figure 3-3. The Five Damage States in HAZUS (NIBS, 1999a)

For a given level of shaking for each structure type, HAZUS computes the probabilities of each damage state. In other words, for a given stock of buildings, HAZUS estimates the proportion that are likely to be in each damage state. Table 3-6 presents the damage state probabilities for the 23 Carbondale earthquake scenarios.

Table 3-6
Damage States by Floor Area (Total 26,443,000 sq. ft.), Carbondale

Scenario	None	Slight	Moderate	Extensive	Complete
M5, 0 km	75.18%	11.73%	6.34%	1.30%	0.00%
M5, 10 km	79.04%	9.89%	4.93%	0.89%	0.00%
M5, 25 km	88.29%	4.34%	1.61%	0.00%	0.00%
M5, 50 km	92.32%	1.79%	0.54%	0.00%	0.00%
M5, 100 km	94.64%	0.00%	0.00%	0.00%	0.00%
M5.5, 0 km	46.38%	21.88%	18.68%	6.41%	1.25%
M5.5, 10 km	54.13%	19.96%	15.14%	4.64%	0.84%
M5.5, 25 km	70.04%	14.02%	8.23%	1.95%	0.00%
M5.5, 50 km	85.88%	5.86%	2.32%	0.11%	0.00%
M5.5, 100 km	91.43%	2.46%	0.86%	0.00%	0.00%
M6, 0 km	22.52%	21.59%	29.39%	15.63%	5.59%
M6, 10 km	28.54%	22.41%	26.98%	12.84%	4.04%
M6, 25 km	46.04%	21.54%	19.07%	6.82%	1.46%
M6, 50 km	72.80%	12.93%	7.16%	1.54%	0.00%
M6, 100 km	86.00%	5.84%	2.32%	0.00%	0.00%
M7, 116 km	56.86%	18.50%	14.55%	4.27%	0.61%
M7, 173 km	72.45%	12.95%	7.55%	1.66%	0.00%
M7, 234 km	83.36%	7.52%	3.29%	0.46%	0.00%
M7, 295 km	87.70%	4.88%	1.80%	0.00%	0.00%
M8, 116 km	9.98%	13.32%	25.63%	25.14%	20.63%
M8, 173 km	20.21%	17.41%	26.61%	20.16%	10.27%
M8, 234 km	35.82%	18.36%	22.96%	13.18%	4.21%
M8, 295 km	53.14%	17.07%	16.11%	6.82%	1.52%

This analysis begins to indicate which scenarios are of greatest concern to Carbondale. Those scenarios with at least 5% of total floor area at least extensively damaged are summarized in Table 3-7.

Table 3-7
Scenarios with Greatest Damage to Building Stock, Carbondale

Scenario	Percent Floor Area With Extensive or Complete Damage
M 5.5, 0 km	7.66%
M 5.5, 10 km	5.48%
M 6, 0 km	21.22%
M 6, 10 km	16.88%
M 6, 25 km	8.28%
M 8, 116 km	45.79%
M 8, 173 km	30.43%
M 8, 234 km	17.39%
M 8, 295 km	8.34%

Table 3-8 shows the same damage summary, but by number of buildings.

Table 3-8
Damage States by Number of Buildings (Total 8,447), Carbondale

Scenario	None	Slight	Moderate	Extensive	Complete
M5, 0 km	6,836	1,053	488	56	13
M5, 10 km	7,210	839	360	36	1
M5, 25 km	7,918	387	135	6	0
M5, 50 km	8,272	134	40	0	0
M5, 100 km	8,446	0	0	0	0
M5.5, 0 km	4,067	2,332	1,613	383	51
M5.5, 10 km	4,882	2,026	1,250	258	30
M5.5, 25 km	6,358	1,345	654	74	15
M5.5, 50 km	7,735	523	172	16	0
M5.5, 100 km	8,147	221	78	0	0
M6, 0 km	2,011	2,427	2,641	1,081	286
M6, 10 km	2,708	2,442	2,285	827	184
M6, 25 km	4,295	2,031	1,417	366	64
M6, 50 km	6,661	1,152	565	58	10
M6, 100 km	7,776	510	145	15	0
M7, 116 km	5,557	1,520	1,094	236	39
M7, 173 km	6,617	1,117	631	78	3
M7, 234 km	7,507	665	258	16	0
M7, 295 km	7,902	408	121	15	0
M8, 116 km	2,047	1,935	1,897	1,519	1,048
M8, 173 km	3,202	1,819	1,674	1,222	529
M8, 234 km	4,549	1,491	1,355	813	238
M8, 295 km	5,429	1,251	1,134	520	112

HAZUS estimates many types of effects on the community. Several of the HAZUS outputs can be used to estimate demand on essential facilities: casualties, fire ignitions, and emergency shelter needs. Tables 3-9, 3-10, and 3-11 present the HAZUS casualty estimates for the 23 scenario earthquakes.

HAZUS classifies casualties into a four-tier scale. Severity 1 injuries require medical aid with no hospitalization. Severity 2 injuries require a greater degree of care and hospitalization, but are not life-threatening. Severity 3 injuries pose an immediate life threat if not treated adequately and expeditiously. Most of these injuries are due to structural collapse. Severity 4 casualties are deaths.

Table 3-9
Casualties by Location, by Time of Day (number of people), Carbondale

Scenario	2am			2pm			5pm		
	Home	Work	Commute	Home	Work	Commute	Home	Work	Commute
M5, 0 km	14	1	0	1	33	0	2	15	0
M5, 10 km	5	0	0	0	11	0	1	5	0
M5, 25 km	1	0	0	0	4	0	0	2	0
M5, 50 km	0	0	0	0	1	0	0	0	0
M5, 100 km	0	0	0	0	0	0	0	0	0
M5.5, 0 km	50	3	0	5	136	0	7	61	1
M5.5, 10 km	36	2	0	4	83	0	4	37	0
M5.5, 25 km	17	1	0	2	39	0	2	17	0
M5.5, 50 km	2	0	0	0	5	0	0	2	0
M5.5, 100 km	1	0	0	0	1	0	0	1	0
M6, 0 km	168	9	1	18	441	3	21	196	13
M6, 10 km	124	7	0	12	324	2	14	144	9
M6, 25 km	52	3	0	5	142	0	6	63	2
M6, 50 km	12	1	0	1	32	0	1	14	0
M6, 100 km	2	0	0	0	5	0	0	2	0
M7, 116 km	22	2	0	2	68	0	3	30	1
M7, 173 km	7	1	0	1	25	0	1	12	0
M7, 234 km	3	0	0	0	6	0	0	3	0
M7, 295 km	2	0	0	0	4	0	0	2	0
M8, 116 km	344	30	1	36	1326	3	43	587	14
M8, 173 km	144	15	0	14	665	2	17	295	7
M8, 234 km	59	7	0	6	307	1	7	137	3
M8, 295 km	31	3	0	3	123	0	3	55	2

Table 3-10
Casualties by Severity Classification, by Time of Day, Carbondale

	2:00 AM				2:00 PM				5:00 PM			
Scenario	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
M5, 0 km	12	2	0	0	29	5	0	0	14	2	0	0
M5, 10 km	5	1	0	0	11	1	0	0	5	1	0	0
M5, 25 km	1	0	0	0	3	0	0	0	2	0	0	0
M5, 50 km	0	0	0	0	1	0	0	0	0	0	0	0
M5, 100 km	0	0	0	0	0	0	0	0	0	0	0	0
M5.5, 0 km	45	7	1	1	118	19	2	2	57	9	1	1
M5.5, 10 km	32	5	0	0	74	11	1	1	35	5	1	1
M5.5, 25 km	15	2	0	0	35	5	0	0	17	2	0	0
M5.5, 50 km	2	0	0	0	5	1	0	0	2	0	0	0
M5.5, 100 km	1	0	0	0	1	0	0	0	1	0	0	0
M6, 0 km	147	25	3	3	378	68	9	8	181	35	9	5
M6, 10 km	109	18	2	2	278	49	6	5	132	25	6	3
M6, 25 km	46	7	1	1	123	20	2	2	58	10	2	1
M6, 50 km	11	2	0	0	28	4	0	0	13	2	0	0
M6, 100 km	2	0	0	0	5	0	0	0	2	0	0	0
M7, 116 km	21	3	0	0	59	9	1	1	28	4	1	0
M7, 173 km	6	1	0	0	22	3	0	0	11	1	0	0
M7, 234 km	3	0	0	0	6	1	0	0	3	0	0	0
M7, 295 km	2	0	0	0	4	0	0	0	2	0	0	0
M8, 116 km	306	57	6	6	1103	209	27	26	513	100	18	13
M8, 173 km	132	23	2	2	555	102	13	12	256	49	9	6
M8, 234 km	55	9	1	1	258	45	5	5	119	22	4	3
M8, 295 km	29	4	0	0	105	18	2	2	49	9	1	1

In all the Carbondale scenarios, daytime casualties exceed nighttime casualties, probably reflecting the fact that most residences are of wood-frame construction.

The scenarios that would place the greatest demand on medical services–those that would result in at least 30 total casualties– are summarized in Table 3-11.

Table 3-11
Scenarios with Largest Number of Casualties, Carbondale

Scenario	Total Casualties, 2 pm	Hospitalization (Severity 2+3)	Deaths, 2 pm
M 5, 0 km	34	5	0
M 5.5, 0 km	141	21	2
M 5.5, 10 km	87	12	1
M 5.5, 25 km	40	5	0
M 6, 0 km	463	77	8
M 6, 10 km	338	55	5
M 6, 25 km	147	22	2
M 6, 50 km	32	4	0
M 7, 116 km	70	10	1
M 8, 116 km	1,365	236	26
M 8, 173 km	682	115	12
M 8, 234 km	313	50	5
M 8, 295 km	127	20	2

HAZUS runs a simplified model of fire ignition and spread following earthquake shaking. This information can help to estimate the demand that would be placed on emergency responders. The number of ignitions in the model is based on peak ground acceleration and square footage of building inventory. The model also makes assumptions regarding fire station location, engine speed, and wind speed and direction. The user can modify these parameters, but we chose to use the default values. Because HAZUS models fire by means of simulation, users would obtain different results with each HAZUS run.

Table 3-12
Fire Following Earthquake, Carbondale

Scenario	# Of Ignitions	Population Exposed	Value Exposed (thous. 1994 $)
M5, 0 km	2	83	4,358
M5, 10 km	1	87	4508
M5, 25 km	1	2	94
M5, 50 km	0	0	0
M5, 100 km	0	0	0
M5.5, 0 km	3	77	4,019
M5.5, 10 km	2	84	4,393
M5.5, 25 km	2	9	356
M5.5, 50 km	0	0	0
M5.5, 100 km	0	0	0
M6, 0 km	5	220	13,409
M6, 10 km	3	90	4,639
M6, 25 km	2	88	4,606
M6, 50 km	1	2	94
M6, 100 km	0	0	0
M7, 116 km	1	2	94
M7, 173 km	0	0	0
M7, 234 km	0	0	0
M7, 295 km	0	0	0
M8, 116 km	2	9	356
M8, 173 km	2	9	356
M8, 234 km	0	0	0
M8, 295 km	0	0	0

Nine of the 23 scenarios predict multiple ignitions. Scenarios that would place the most demands on the fire department are those that would threaten more than 75 people and more than $3 million of property. Most of these represent more than one fire ignition. These scenarios are highlighted in the table.

HAZUS estimates displaced households based on actual damage, as well as on assumptions regarding resident perceptions of damage. All dwelling units in buildings that are completely damaged are assumed to be uninhabitable. In addition, HAZUS assumes that residents perceive some moderately damaged buildings and most extensively damaged buildings as being uninhabitable. This proportion varies by type of occupancy (single-family versus multifamily). The default data makes no assumptions regarding habitability with respect to power loss. In reality, power loss alone during the winter would force many residents to leave their homes.

Some of these displaced residents will require short-term shelter in public facilities. The default data in HAZUS makes assumptions for each census tract regarding proportion of displaced persons seeking shelter. These assumptions are based on income level, ethnicity, tenure, and age. Generally, HAZUS assumes that approximately 40% of displaced persons will require shelter, but this is highly sensitive to household income.

Table 3-13 summarizes estimates of displaced households and shelter needs for the 23 Carbondale earthquake scenarios.

Table 3-13
Emergency Shelter Demands, Carbondale

Scenario	Displaced Households	People Requiring Short-Term Shelter
M5, 0 km	59	69
M5, 10 km	30	27
M5, 25 km	0	0
M5, 50 km	0	0
M5, 100 km	0	0
M5.5, 0 km	354	400
M5.5, 10 km	245	296
M5.5, 25 km	59	69
M5.5, 50 km	0	0
M5.5, 100 km	0	0
M6, 0 km	1,023	1,152
M6, 10 km	757	851
M6, 25 km	355	405
M6, 50 km	59	69
M6, 100 km	0	0
M7, 116 km	59	69
M7, 173 km	59	69
M7, 234 km	0	0
M7, 295 km	0	0
M8, 116 km	1,288	1,403
M8, 173 km	540	597
M8, 234 km	115	139
M8, 295 km	59	69

Eight of the scenarios are expected to require shelter for over 100 people. These are highlighted above. If the earthquake occurs in the winter and disrupts power, these numbers could be substantially higher.

Finally, a useful way to summarize overall damage to the City of Carbondale for the 23 earthquake scenarios is by estimating total direct economic loss. By “direct” economic loss, we mean all structural and nonstructural loss, as well as all direct costs of economic disruption, such as lost wages, rent income, and relocation expenses. These are summarized in Table 3-14, and the total direct loss is depicted in Figure 3-3 according to magnitude and distance. “Indirect” losses, which we do not consider here, would include ripple effects through the economy.

Table 3-14
Direct Economic Losses for Buildings (Thousands of 1994 $)[5], Carbondale

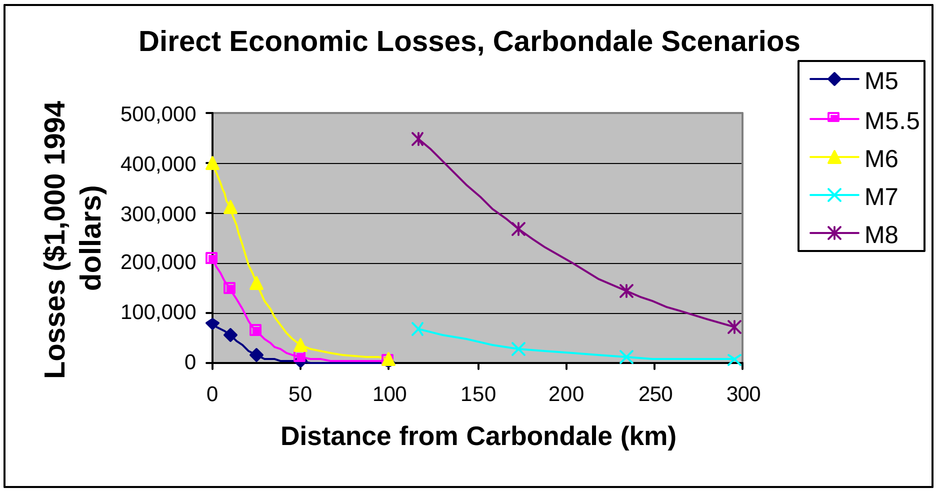
Scenario	Capital Stock Losses				Income Losses				Total Loss
	1*	**2***	**3***	**4***	**5***	**6***	**7***	**8***	
M5, 0 km	4,930	37,825	25,452	277	3,573	886	1,221	2,242	76,406
M5, 10 km	3,198	27,056	18,335	182	2,238	684	928	1,420	54,041
M5, 25 km	1,024	7,182	5,053	49	483	145	187	257	14,380
M5, 50 km	296	743	329	2	110	54	65	62	1,661
M5, 100 km	0	0	0	0	0	0	0	0	0
M5.5, 0 km	19,578	99,741	50,840	572	15,696	3,924	5,425	10,497	206,273
M5.5, 10 km	13,908	70,875	37,614	376	10,965	2,849	3,912	7,491	147,990
M5.5, 25 km	6,426	29,240	16,311	176	4,541	1,181	1,604	2,934	62,413
M5.5, 50 km	1,576	4,051	1,905	17	800	232	310	551	9,442
M5.5, 100 km	428	429	127	0	187	86	112	83	1,452
M6, 0 km	47,732	189,478	80,601	866	34,923	9,209	12,812	24,288	399,909
M6, 10 km	37,311	146,908	62,567	643	27,542	7,415	10,179	19,154	311,719
M6, 25 km	18,8040	72,426	33,139	332	14,671	3,978	5,408	9,964	158,722
M6, 50 km	5,255	15,014	6,952	80	3,819	1,038	1,400	2,352	35,910
M6, 100 km	1,401	3,013	1,050	15	714	191	252	370	7,006
M7, 116 km	10,883	25,932	10,995	142	7,470	2,779	3,690	4,403	66,244
M7, 173 km	4,702	10,692	3,440	42	3,888	1,140	1,539	2,282	27,725
M7, 234 km	1,989	3,700	1,294	15	1,198	431	569	764	9,960
M7, 295 km	1,167	1,410	400	3	640	178	239	321	4,358
M8, 116 km	84,223	196,541	38,977	388	50,847	18,590	25,382	34,964	449,912
M8, 173 km	51,361	110,460	22,428	257	31,636	12,520	16,969	21,231	266,862
M8, 234 km	28,242	56,605	12,478	158	17,334	7,737	10,378	10,511	143,447
M8, 295 km	14,418	25,264	6,093	80	9,549	3,970	5,305	5,238	69,917

* 1 = Structural Damage; 2 = Non-Structural Damage; 3 = Contents Damage; 4 = Inventory Loss; 5 = Relocation Loss; 6 = Capital Related Loss; 7 = Wage Losses; 8 = Rental Income Losses

Eight of the scenarios would result in total losses to the community exceeding $100 million (about $3,000 per person).

[5] Our version of HAZUS presented loss estimates in 1994 dollars, which is reflected in all the tables in this report. In some places we also present updated 2001 dollars.

Figure 3-3


Direct Economic Losses, Carbondale Scenarios
Losses ($1,000 1994 dollars)
500,000
400,000
300,000
200,000
100,000
0
0
50
100
150
200
250
300
Distance from Carbondale (km)
M5
M5.5
M6
M7
M8

SIKESTON

We used the following census tracts, as the closest approximation to the City of Sikeston:

Table 3-15
Sikeston Study Area

Tract	Total Population of Tract (City + County)	City Residents in Tract	City Residents as % of Tract Population
9805	4,107	4,078	99.3%
9806	4,930	2,858	58.0%
9807	3,911	3,911	100.0%
9808	3,335	3,287	98.6%
9809	2,775	2,775	100.0%
9601	4,044	732	18.1%
TOTALS	**23,102**	**17,641**	**76.4%**

All of the City population is within the HAZUS study area, as well as 5,461 additional inhabitants. City inhabitants represent 76.4% of the population of the HAZUS study area. Five of the census tracts are in Scott County, and tract 9601 is in New Madrid County.

The default general building stock for Sikeston is summarized in Table 3-16, according to occupancy type.

Table 3-16
General Building Stock, by Occupancy (HAZUS Default), Sikeston

Label	Occupancy Class	Floor Area (1,000 sq. ft.)	Dollar Exposure ($1,000	Number of Buildings
RES1	Single family	10,350	595,498	6900
RES2	Mobile home	845	34,184	845
RES3	Multi Family	1,734	124,709	109
RES4	Temporary lodging	137	9,948	2
RES5	Dormitory	402	28,947	13
RES6	Nursing Home	50	3,444	0
COM1	Retail trade	1,562	71,635	112
COM2	Wholesale trade	1,028	31,427	30
COM3	Personal/repair svcs.	553	33,799	47
COM4	Financial/Professional	1,021	67,031	29
COM5	Banks	89	9,270	4
COM6	Hospital	133	14,468	1
COM7	Medical Office	178	14,402	15
COM8	Entertainment/Rec.	241	21,909	18
COM9	Theaters	3	206	0

COM10	Parking	0	0	0
IND1	Heavy Industry	475	21,778	10
IND2	Light	156	7,149	8
IND3	Food/Drugs/Chem.	72	3,288	4
IND4	Metals/Min Process.	130	5,961	8
IND5	High Technology	0	0	0
IND6	Construction	244	11,186	14
AGRI	Agriculture	193	2,255	14
REL1	Church	244	18,663	16
GOV1	General Services	46	2,780	0
GOV2	Emergency Response	6	609	1
EDU1	Schools	611	40,627	30
EDU2	Colleges	6	494	0
	TOTAL	**20,510**	**1,175,671**	**8,230**

Table 3-17 summarizes the default general building stock by structure type.

Table 3-17
General Building Stock, by Structure Type (HAZUS Default), Sikeston

Label	**Structure Type**	**Floor Area (1,000 sq. ft.)**	**Dollar Exposure ($1,000)**	**Number of Buildings**
W	Wood	10,815	643,447	5,414
S1	Steel Moment Frame	175	9,352	7
S2	Steel Braced Frame	369	20,202	19
S3	Steel Light Frame	756	38,553	38
S4	Steel Frame, Concr. Shear Walls	409	20,879	20
S5	Steel Frame, URM infill	489	24,923	25
C1	Concrete Moment Frame	100	5,763	3
C2	Concrete Shear Walls	521	28,727	25
C3	Concrete Frame, URM infill	54	2,598	1
PC1	Precast Concrete Tilt-up	617	33,003	26
PC2	Precast Frames, Concrete Shear Walls	65	3,471	1
RM	Reinforced Masonry	40	14,806	13
URM	Unreinforced Masonry	5,053	295,760	1,793
MH	Mobile Homes	845	34,184	845
TOTAL L		**20,510**	**1,175,671**	**8,230**

As with Carbondale, we performed HAZUS loss estimates for the 23 earthquake scenarios. Table 3-18 summarizes the damage states resulting from each scenario.

Table 3-18
Damage States by Floor Area (Total = 20,510 Thous. sq. ft.), Sikeston

Scenario	None	Slight	Moderate	Extensive	Complete
M5, 0 km	82.48%	9.60%	4.45%	0.83%	0.00%
M5, 10 km	85.86%	7.81%	3.21%	0.64%	0.00%
M5, 25 km	93.40%	2.98%	1.02%	0.00%	0.00%
M5, 50 km	95.48%	1.57%	0.43%	0.00%	0.00%
M5, 100 km	97.62%	0.00%	0.00%	0.00%	0.00%
M5.5, 0 km	52.81%	23.12%	16.26%	4.55%	0.81%
M5.5, 10 km	60.88%	20.26%	12.71%	3.14%	0.33%
M5.5, 25 km	76.14%	13.17%	6.71%	1.29%	0.05%
M5.5, 50 km	89.14%	5.74%	2.31%	0.21%	0.00%
M5.5, 100 km	95.52%	1.69%	0.45%	0.00%	0.00%
M6, 0 km	30.69%	25.26%	26.64%	11.36%	3.33%
M6, 10 km	36.24%	25.33%	23.98%	9.36%	2.45%
M6, 25 km	52.88%	22.36%	16.43%	4.93%	1.02%
M6, 50 km	75.95%	13.24%	6.76%	1.33%	0.00%
M6, 100 km	91.14%	4.52%	1.62%	0.00%	0.00%
M7, 34 km	20.43%	22.95%	29.83%	16.88%	7.45%
M7, 63 km	44.45%	23.26%	20.50%	7.60%	1.88%
M7, 122 km	70.38%	15.52%	9.31%	2.19%	0.00%
M7, 184 km	83.24%	9.50%	4.29%	0.81%	0.00%
M8, 34 km	2.76%	9.52%	24.14%	24.31%	36.71%
M8, 63 km	9.62%	16.45%	27.95%	22.64%	21.00%
M8, 122 km	22.14%	20.64%	26.86%	17.50%	10.38%
M8, 184 km	41.60%	21.00%	20.79%	10.31%	3.88%

This analysis begins to indicate which scenarios are of greatest concern to Sikeston. Those scenarios with at least 5% of total floor area at least extensively damaged are summarized in Table 3-19.

Table 3-19
Scenarios with Greatest Damage to Building Stock, Sikeston

Scenario	Percent With Extensive or Complete Damage
M 5.5, 0 km	5.36%
M 6, 0 km	14.69%
M 6, 10 km	11.81%
M 6, 25 km	5.95%
M 7, 34 km	24.33%
M 7, 63 km	9.48%
M 8, 34 km	61.02%
M 8, 63 km	43.64%
M 8, 122 km	27.88%
M 8, 184 km	14.19%

Table 3-20 shows the same damage state summary for all the scenarios, but by number of buildings.

Table 3-20
Damage States by Number of Buildings (Total 8,231), Sikeston

Scenario	None	Slight	Moderate	Extensive	Complete
M5, 0 km	7,195	744	251	36	5
M5, 10 km	7,413	616	172	29	1
M5, 25 km	7,939	224	65	3	0
M5, 50 km	8,093	108	30	0	0
M5, 100 km	8,231	0	0	0	0
M5.5, 0 km	4,281	2,473	1,205	229	43
M5.5, 10 km	5,172	2,043	846	142	28
M5.5, 25 km	6,496	1,240	423	63	9
M5.5, 50 km	7,648	446	117	20	0
M5.5, 100 km	8,101	98	32	0	0
M6, 0 km	2,857	2,743	1,907	560	164
M6, 10 km	3,284	2,675	1,695	452	125
M6, 25 km	4,690	2,191	1,068	230	52
M6, 50 km	6,681	1,105	381	58	6
M6, 100 km	7,840	303	82	6	0
M7, 34 km	2,430	2,613	2,024	795	369
M7, 63 km	4,586	2,105	1,138	327	75
M7, 122 km	6,433	1,221	486	83	8
M7, 184 km	7,298	687	218	28	0
M8, 34 km	455	1,677	2,856	1,452	1,791
M8, 63 km	1,658	2,434	2,176	1,043	920
M8, 122 km	3,221	2,281	1,532	786	411
M8, 184 km	4,939	1,695	1,042	437	118

Table 3-21
Casualties by Location, by Time of Day(number of people), Sikeston

Scenario	2am			2pm			5pm		
	Home	Work	Commute	Home	Work	Commute	Home	Work	Commute
M5, 0 km	8	0	0	3	9	0	3	3	0
M5, 10 km	4	0	0	2	5	0	2	2	0
M5, 25 km	1	0	0	0	1	0	0	0	0
M5, 50 km	0	0	0	0	0	0	0	0	0
M5, 100 km	0	0	0	0	0	0	0	0	0
M5.5, 0 km	54	1	0	19	60	0	23	20	0
M5.5, 10 km	35	1	0	13	40	0	15	13	0
M5.5, 25 km	14	0	0	5	15	0	6	5	0
M5.5, 50 km	3	0	0	1	3	0	1	1	0
M5.5, 100 km	0	0	0	0	1	0	0	0	0
M6, 0 km	149	4	0	53	194	1	63	66	2
M6, 10 km	116	3	0	42	149	0	49	51	2
M6, 25 km	56	2	0	20	68	0	24	23	0
M6, 50 km	11	0	0	4	13	0	5	4	0
M6, 100 km	1	0	0	1	2	0	1	1	0
M7, 34 km	259	9	0	92	380	1	109	130	5
M7, 63 km	69	3	0	25	110	0	30	38	1
M7, 122 km	13	1	0	4	20	0	5	7	0
M7, 184 km	4	0	0	2	6	0	2	2	0
M8, 34 km	923	40	1	328	1557	5	390	538	17
M8, 63 km	528	24	0	189	940	2	224	325	8
M8, 122 km	272	13	0	97	499	1	115	173	3
M8, 184 km	79	6	0	28	202	0	34	71	1

Table 3-22
Casualties by Severity Classification, by Time of Day, Sikeston

	2:00 AM				2:00 PM				5:00 PM			
Scenario	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
M5, 0 km	7	1	0	0	10	1	0	0	6	1	0	0
M5, 10 km	4	0	0	0	6	1	0	0	3	0	0	0
M5, 25 km	1	0	0	0	1	0	0	0	1	0	0	0
M5, 50 km	0	0	0	0	1	0	0	0	0	0	0	0
M5, 100 km	0	0	0	0	0	0	0	0	0	0	0	0
M5.5, 0 km	47	7	1	1	67	10	1	1	38	6	1	1
M5.5, 10 km	31	5	0	0	44	7	1	1	24	4	0	0
M5.5, 25 km	12	2	0	0	17	2	0	0	10	1	0	0
M5.5, 50 km	3	0	0	0	4	0	0	0	2	0	0	0
M5.5, 100 km	0	0	0	0	1	0	0	0	0	0	0	0
M6, 0 km	128	22	2	2	205	35	4	4	107	19	3	2
M6, 10 km	100	17	2	2	159	27	3	3	84	15	2	2
M6, 25 km	49	8	1	1	74	12	1	1	39	6	1	1
M6, 50 km	10	1	0	0	15	2	0	0	8	1	0	0
M6, 100 km	1	0	0	0	2	0	0	0	1	0	0	0
M7, 34 km	221	39	4	4	387	70	8	8	197	37	6	4
M7, 63 km	61	10	1	1	113	19	2	2	57	10	1	1
M7, 122 km	12	1	0	0	21	3	0	0	11	1	0	0
M7, 184 km	4	0	0	0	7	1	0	0	3	0	0	0
M8, 34 km	780	150	17	17	1519	296	38	37	751	151	24	19
M8, 63 km	449	84	10	10	914	174	22	21	446	87	13	11
M8, 122 km	233	42	5	5	486	90	11	11	235	44	6	5
M8, 184 km	71	12	1	1	190	33	4	4	87	15	2	2

In all the Sikeston scenarios, daytime casualties exceed nighttime casualties, probably reflecting the fact that most residences are in wood-frame buildings.

The scenarios that would place the greatest demand on medical services–those that would result in at least 30 total casualties– are summarized in Table 3-23.

Table 3-23
Scenarios with Largest Number of Casualties, Sikeston

Scenario	Total Casualties, 2 pm	Hospitalization (Severity 2+3), 2 pm	Deaths, 2 pm
M 5.5, 0 km	79	11	1
M 5.5, 10 km	53	8	1
M 6, 0 km	248	39	4
M 6, 10 km	192	30	3
M 6, 25 km	88	13	1
M 7, 34 km	473	78	8
M 7, 63 km	136	21	2
M 8, 34 km	1,890	334	37
M 8, 63 km	1,131	196	21
M 8, 122 km	598	101	11
M 8, 184 km	231	37	4

Table 3-24
Fire Following Earthquake, Sikeston

Scenario	# Of Ignitions	Population Exposed	Value Exposed (thous. 1994 $)
M5, 0 km	2	10	574
M5, 10 km	2	10	574
M5, 25 km	1	0	0
M5, 50 km	0	0	0
M5, 100 km	0	0	0
M5.5, 0 km	2	10	574
M5.5, 10 km	2	10	574
M5.5, 25 km	1	0	0
M5.5, 50 km	0	0	0
M5.5, 100 km	0	0	0
M6, 0 km	2	20	1,003
M6, 10 km	2	7	349
M6, 25 km	2	10	574
M6, 50 km	1	0	0
M6, 100 km	0	0	0
M7, 34 km	1	14	614
M7, 63 km	2	10	574
M7, 122 km	0	0	0
M7, 184 km	0	0	0
M8, 34 km	5	21	1,100
M8, 63 km	2	10	574
M8, 122 km	2	10	574
M8, 184 km	1	0	0

Eleven of the 23 scenarios predict multiple ignitions. Fire following earthquake does not appear to be an unmanageable problem in Sikeston, according to these simulations; although, of course, every fire is important to its victims. Only two scenarios threaten more than 20 people and $1 million in property. These are highlighted in the table.

Table 3-25 summarizes estimates of displaced households and shelter needs for the 23 Sikeston earthquake scenarios.

Table 3-25
Emergency Shelter Demands, Sikeston

Scenario	Displaced Households	People Requiring Short-Term Shelter
M5, 0 km	5	6
M5, 10 km	0	0
M5, 25 km	0	0
M5, 50 km	0	0
M5, 100 km	0	0
M5.5, 0 km	114	100
M5.5, 10 km	18	16
M5.5, 25 km	14	14
M5.5, 50 km	0	0
M5.5, 100 km	0	0
M6, 0 km	250	215
M6, 10 km	203	174
M6, 25 km	106	93
M6, 50 km	14	14
M6, 100 km	0	0
M7, 34 km	458	390
M7, 63 km	122	104
M7, 122 km	14	14
M7, 184 km	0	0
M8, 34 km	1768	1505
M8, 63 km	908	776
M8, 122 km	455	390
M8, 184 km	133	115

Nine of the scenarios are expected to require shelter for at least 100 people. These are highlighted in the table. If the earthquake occurs in the winter and disrupts power, these numbers could be substantially higher.

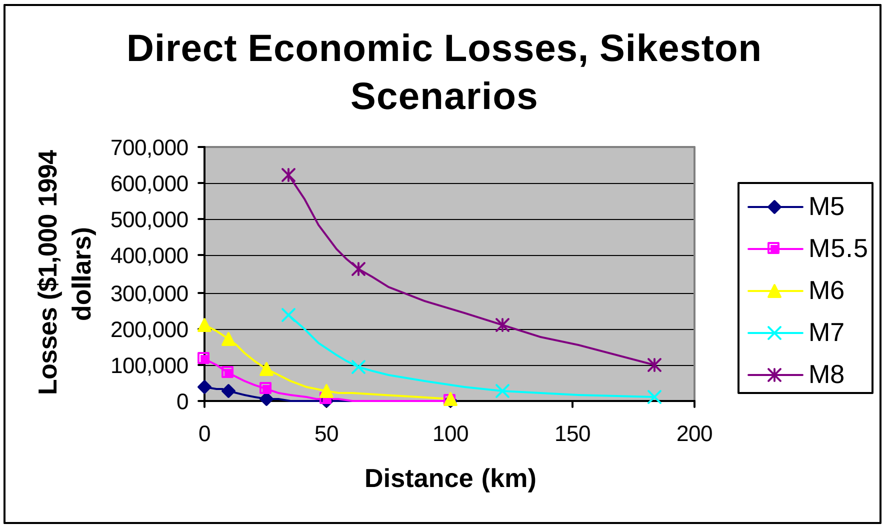
Table 3-26 summarizes direct economic losses for all the Sikeston earthquake scenarios. Figure 3-4 depicts the total losses according to magnitude and distance from Sikeston.

Table 3-26
Direct Economic Losses for Buildings (Thousands of 1994 $), Sikeston

Scenario	Capital Stock Losses				Income Losses				Total Loss
	1*	2*	3*	4*	5*	6*	7*	8*	
M5, 0 km	1,946	18,006	15,007	484	2,030	631	878	832	39,814
M5, 10 km	1,356	12,789	10,861	384	1,278	512	704	537	28,421
M5, 25 km	378	3,544	3,159	135	273	95	126	102	7,812
M5, 50 km	156	471	331	7	51	11	22	14	1,063
M5, 100 km	0	0	0	0	0	0	0	0	0
M5.5, 0 km	9,989	50,899	30,707	940	11,518	2,843	4,051	4,819	115,766
M5.5, 10 km	6,883	34,203	22,671	727	7,066	1,999	2,779	2,901	79,229
M5.5, 25 km	3,232	15,011	10,624	352	3,445	854	1,160	1,388	35,706
M5.5, 50 km	924	3,078	1,709	65	741	204	304	267	7,292
M5.5, 100 km	160	230	104	1	59	15	27	17	613
M6, 0 km	21,729	89,183	48,492	1,446	22,969	6,745	9,516	9,977	210,057
M6, 10 km	17,920	71,163	38,402	1,227	19,148	5,477	7,596	8,277	169,210
M6, 25 km	9,800	35,785	20,091	679	11,019	3,160	4,298	4,697	89,529
M6, 50 km	2,988	10,154	6,107	245	3,265	907	1,248	1,338	26,252
M6, 100 km	541	1,569	657	26	523	119	161	181	3,777
M7, 34 km	33,094	95,044	38,495	1,217	31,988	10,316	14,245	14,346	238,745
M7, 63 km	12,816	35,156	16,481	563	13,501	4,650	6,288	5,840	95,295
M7, 122 km	3,984	10,906	5,490	231	4,217	1,366	1,872	1,734	29,800
M7, 184 km	1,636	3,807	1,614	64	1,481	605	833	618	10,658
M8, 34 km	95,526	268,260	80,366	2,497	77,891	25,997	35,457	36,316	622,310
M8, 63 km	58,806	142,736	41,385	1,280	50,725	18,294	24,834	23,519	361,579
M8, 122 km	34,505	77,061	22,559	700	32,011	11,874	16,179	16,649	209,538
M8, 184 km	16,387	32,934	10,990	411	16,004	6,351	8,623	7,109	98,809

* 1=Structural Damage, 2= Non-structural Damage, 3=Contents Damage, 4=Inventory Loss, 5=Relocation Loss, 6=Capital Related Loss, 7=Wage Losses, 8=Rental Income LossesSeven of the scenarios would result in over $100 million in costs to the community (over $4,000 per person).

Figure 3-4


Direct Economic Losses, Sikeston Scenarios
Losses ($1,000 1994 dollars)
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
0
50
100
150
200
Distance (km)
M5
M5.5
M6
M7
M8

CHAPTER 4
HAZUS ANALYSIS OF INVENTORY DATA

HAZUS has the capability to estimate direct structural, nonstructural, and contents losses to specific user-defined structures. We applied this analysis to the buildings in our ATC-21 inventories for Carbondale and Sikeston.

INPUT DATA

To run the user-defined structure module of HAZUS required that we add several fields to our ATC-21 inventory. For all structures this included:

Structural Building Classification. This is the same as the ATC-21 classification, but with the addition of categories for low-rise (1-3 stories), mid-rise (4-7) and high-rise (8+).

Design Level. This describes the estimated seismic design characteristics of the building, based on a combination of the building's age and its seismic hazard zone. This combination reflects the assumed seismic design practices, based on the location and date of construction. This rating defines the building damage function in HAZUS. Carbondale is in NEHRP Map Area 4, which means that the seismic design level is Low for all buildings built since 1941, and Pre-code for older buildings (HAZUS Technical Manual, Table 5.20; though note that HAZUS treats Low and Pre-code buildings the same). Sikeston is in Map Area 5, which means that the seismic design level is Moderate for post-1975 buildings, Low for 1941-1975, and Pre-code for older buildings..

Bias. This refers to construction quality: "Poor," "Typical," or "Superior." It allows the user to add this bias if they have particular knowledge of the construction quality. We assumed "Typical" quality for all the buildings in the two inventories.

Foundation. Foundations can be classified as deep or shallow. We assumed shallow foundations for all buildings.

Year. This required a specific year of construction. For each building, we used our best estimate of the year of construction, in consultation with local building officials.

Building and Contents Value. Building replacement value was estimated as a product of floor area and construction cost per square foot. We used the construction cost estimates provided by J&L Robinson Construction to the Carbondale Building Inspector (see Chapter 2). Contents value is estimated according to the method used by HAZUS: as a percentage of building value, according to occupancy type (HAZUS Technical Manual, Table 15.5). Generally, contents values are 50% of building value for residential uses; 150% for industrial, medical facilities, emergency response facilities, and universities; and 100% for all other uses.

For hospitals, it also included:

Number of beds. We obtained this information directly from the hospitals.

For hospitals and emergency response facilities, it also included:

Power. This describes whether there is a backup power system. We assume no backup power, unless we have specific information otherwise.

Number of trucks. We obtained the number of fire trucks directly from the fire departments.

Daytime Capacity. This is the maximum number of occupants in the daytime. We estimated this according to Table 3.2 in ATC-13 (Applied Technology Council, 1985), based on floor area of the building.

Nighttime Capacity. Estimated same as Daytime.

Kitchen. This identifies whether there is a kitchen on the premises. We obtained this information directly from the facilities.

For schools, it also included:

Number of students. We obtained this directly from the school districts.

Shelter capacity. Carbondale staff provided estimates of the shelter capacity of schools (this does not count additional shelter space that would be available in churches and other facilities). We did not obtain any shelter estimates for Sikeston.

Kitchen. This identifies whether there is a kitchen on the premises. We obtained this directly from the facilities.

ECONOMIC LOSSES FOR SURVEYED BUILDINGS

The following tables summarize direct economic losses for the two sets of inventories. It is important to note that these represent only direct structural, nonstructural and contents losses, and do not reflect the other categories of direct losses used in the community-wide loss estimates (inventory, relocation, capital-related, wages, rental income).

Table 4-1
Expected annual direct economic losses for 295 Carbondale buildings
($1,000s, 2001 dollars)

Scenario	Construction Cost	Contents Cost	Total Cost
M5, 0 km	10,867	10,044	20,911
M5, 10 km	8,420	7,687	16,107
M5, 25 km	2,491	2,392	4,883
M5, 50 km	209	182	391
M5, 100 km	0	0	0
M5.5, 0 km	34,925	20,081	55,006
M5.5, 10 km	23,130	14,509	37,639
M5.5, 25 km	9,600	7,195	16,795
M5.5, 50 km	1,326	914	2,240
M5.5, 100 km	137	76	213
M6, 0 km	88,674	30,321	118,995
M6, 10 km	64,109	23,102	87,211
M6, 25 km	29,570	13,310	42,880
M6, 50 km	5,889	3,526	9,415
M6, 100 km	1,060	816	2,419
M7, 116 km	10,183	5,074	15,257
M7, 173 km	4,319	2,023	6,342
M7, 234 km	1,603	816	2,419
M7, 295 km	702	260	962
M8, 116 km	67,716	12,641	80,357
M8, 173 km	43,609	8,785	52,394
M8, 234 km	21,978	5,978	27,956
M8, 295 km	10,507	3,326	13,833

Table 4-2
Expected annual direct economic losses for 124 Sikeston buildings
($1,000s, 2001 dollars)

Scenario	Construction Cost	Contents Cost	Total Cost
M5, 0 km	3,505	3,288	6,793
M5, 10 km	2,510	2,390	4,900
M5, 25 km	684	692	1,376
M5, 50 km	96	71	167
M5, 100 km	0	0	0
M5.5, 0 km	8,592	6,185	14,776
M5.5, 10 km	5,959	4,421	10,380
M5.5, 25 km	2,767	2,084	4,851
M5.5, 50 km	605	393	998
M5.5, 100 km	62	26	88
M6, 0 km	15,988	9,393	25,381
M6, 10 km	12,328	7,200	19,528
M6, 25 km	6,302	3,789	10,090
M6, 50 km	2,175	1,395	3,570
M6, 100 km	357	183	541
M7, 34 km	17,919	7126	25044
M7, 63 km	7,558	3258	10815
M7, 122 km	2,612	1222	3835
M7, 184 km	910	386	1297
M8, 34 km	54,127	14269	68396
M8, 63 km	30,319	7468	37787
M8, 122 km	16,333	4084	20417
M8, 184 km	8,948	2475	11423

CASUALTY ESTIMATES

HAZUS does not have a method of estimating casualties for user-defined facilities. A tedious, manual method exists, but would involve separate estimates for each of the 419 buildings for each of the scenarios in the two cities. Nevertheless, we applied the method to two dormitories on the SIU campus in Carbondale, because these buildings are among the most significant concerns with respect to potential casualties.

Both buildings were surveyed by IEMA in 1992, and so our estimates are based on their field data. Dormitory 1 is a concrete frame (C3), 4-story building constructed in 1956, with an estimated floor area of 28,300 sf. Dormitory 2 is a URM, 4-story building constructed in 1965, with an estimated floor area of 85,600 sf. For occupancy, we estimated 2.0 occupants per 1,000 sf in the daytime and 3.0 occupants per 1,000 sf in the nighttime, as per Table 3-8 in FEMA-227 (VSP Associates, 1991, adapted from ATC-13). This results in daytime and nighttime occupancy estimates of 57 and 85 for Dormitory 1 and 171 and 257 for Dormitory 2.

Table 4-3 summarizes nighttime casualties for the two buildings. Highlighted are those scenarios for which total casualties for either building add up to greater than 0.7; these are all scenarios for which at least one casualty is considered likely.

Table 4-3
Estimated Nighttime Casualties for Two Dormitories, Carbondale

	Dormitory 1 (C3)				Dormitory 2 (URM)			
Scenario	**Severity 1**	**Severity 2**	**Severity 3**	**Severity 4**	**Severity 1**	**Severity 2**	**Severity 3**	**Severity 4**
M5, 0 km	0.020	0.002	0.000	0.000	0.069	0.007	0.000	0.000
M5, 10 km	0.020	0.002	0.000	0.000	0.058	0.006	0.000	0.000
M5, 25 km	0.004	0.000	0.000	0.000	0.014	0.001	0.000	0.000
M5, 50 km	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000
M5, 100 km	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
M5.5, 0 km	0.094	0.009	0.000	0.000	0.983	0.150	0.013	0.013
M5.5, 10 km	0.067	0.007	0.000	0.000	0.323	0.032	0.000	0.000
M5.5, 25 km	0.027	0.003	0.000	0.000	0.157	0.016	0.000	0.000
M5.5, 50 km	0.006	0.001	0.000	0.000	0.018	0.002	0.000	0.000
M5.5, 100 km	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000
M6, 0 km	0.629	0.104	0.013	0.013	2.675	0.422	0.040	0.040
M6, 10 km	0.453	0.073	0.009	0.009	1.979	0.301	0.027	0.027
M6, 25 km	0.094	0.009	0.000	0.000	0.993	0.151	0.013	0.013
M6, 50 km	0.025	0.002	0.000	0.000	0.157	0.016	0.000	0.000
M6, 100 km	0.004	0.000	0.000	0.000	0.031	0.003	0.000	0.000
M7, 116 km	0.057	0.006	0.000	0.000	0.406	0.041	0.000	0.000
M7, 173 km	0.023	0.002	0.000	0.000	0.180	0.018	0.000	0.000
M7, 234 km	0.006	0.001	0.000	0.000	0.055	0.006	0.000	0.000
M7, 295 km	0.003	0.000	0.000	0.000	0.030	0.003	0.000	0.000
M8, 116 km	2.258	0.419	0.061	0.061	8.018	1.419	0.160	0.160
M8, 173 km	1.252	0.222	0.030	0.030	4.541	0.763	0.080	0.080
M8, 234 km	0.297	0.043	0.004	0.004	2.615	0.416	0.040	0.040
M8, 295 km	0.057	0.006	0.000	0.000	0.396	0.040	0.000	0.000

Because Dormitory 2 is a URM building, its probability of sustaining earthquake-related casualties is much greater than Dormitory 1. In addition, it is approximately three times larger than Dormitory 1. Therefore, seven of the 23 scenarios are expected to result in at least one casualty in Dormitory 2, compared to three of the scenarios for Dormitory 1. Even so, the chances of serious injury are quite low for all the scenarios. Only two of the scenarios (the two nearest **M**8 earthquakes) are likely to have one injury requiring hospitalization. Furthermore, most of these scenarios have relatively low probabilities of occurring (see Chapter 5). For example, using the probabilities developed in Chapter 5, the highlighted scenarios in Table 4-3 have a 0.08% chance of occurring in any given year, and a 3.9% chance of occurring in the next 50 years; that is, there is approximately a 4% chance of having an earthquake in the next 50 years that would be large enough to cause one casualty (most likely a minor one) in either dormitory.

We also estimated the annualized casualty probabilities (see Chapter 5), which are shown in Table 4-4.

Table 4-4
Annualized Casualties for Two Dormitories, Carbondale

	Severity 1	Severity 2	Severity 3	Severity 4
Dormitory 1 (Concrete, 85 occupants)				
One year	0.001	0.000	0.000	0.000
30 years	0.026	0.004	0.001	0.001
50 years	0.043	0.007	0.001	0.001
Dormitory 2 (URM, 257 occupants)				
One year	0.004	0.001	0.000	0.000
30 years	0.117	0.018	0.002	0.002
50 years	0.194	0.030	0.003	0.003

According to this analysis, it is unlikely that these dormitories will have any earthquake-related casualties during their lifetime. Assuming that these are representative of approximately 20 dormitory buildings on the campus, this analysis suggests that approximately two minor injuries could occur due to earthquakes in the next 50 years. It further suggests only about 0.45 hospitalization injury or death in the next 50 years; in probabilistic terms, this is a 45% chance of one hospitalization (including a slight possibility of one death) due to earthquake in the 20 dormitories over the next 50 years. Even so, the ATC-21 survey suggests that they warrant further inspection by a structural engineer to verify. Furthermore, economic loss is still a concern; our analysis shows, for example, that Dormitory 2 could experience direct economic losses of $200,000 to over $400,000 in a **M**8 event within 234 km.

ESSENTIAL FACILITIES

Although HAZUS estimates post-earthquake functionality of essential facilities using its default inventories, we chose to perform the analysis using only our augmented ATC-21 survey as inputs. For each essential facility, HAZUS estimates restoration curves, describing the proportion of facilities in each damage state that would restore their functions over time. This admittedly abstract concept can also be expressed in terms of hospital beds, available trucks, or shelter capacity.

Carbondale

Table 4-5 describes the functionality of the Carbondale hospital for each scenario, at various times after the earthquake. The Day 1 and Day 3 functionalities describe its ability to treat earthquake victims. The longer time periods indicate its ability to quickly return to normal operations. We multiply the percent functionality times the number of beds to provide a more tangible measure of the hospital's ability to serve patients.

Table 4-5 Carbondale Hospital Functionality (Total # of Beds = 151)

Scenario	At Day 1		At Day 3		At Day 7		At Day 30		At Day 90	
	Beds	%	Beds	%	Beds	%	Beds	%	Beds	%
M5, 0 km	138	91.4	141	93.4	146	96.7	150	99.3	151	100.0
M5, 10 km	150	99.3	150	99.3	151	100.0	151	100.0	151	100.0
M5, 25 km	151	100.0	151	100.0	151	100.0	151	100.0	151	100.0
M5, 50 km	151	100.0	151	100.0	151	100.0	151	100.0	151	100.0
M5, 100 km	85	56.3	97	64.2	113	74.8	140	92.7	149	98.7
M5.5, 0 km	103	68.2	113	74.8	125	82.8	145	98.0	149	98.7
M5.5, 10 km	128	84.8	133	88.1	140	92.7	149	98.7	151	100.0
M5.5, 25 km	147	97.4	147	97.4	149	98.7	149	98.7	149	98.7
M5.5, 50 km	151	100.0	151	100.0	151	100.0	151	100.0	151	100.0
M5.5, 100 km	40	26.5	53	35.1	71	47.0	121	80.1	143	94.7
M6, 0 km	52	34.4	66	43.7	84	55.6	128	84.8	145	96.0
M6, 10 km	85	56.3	97	64.2	113	74.8	140	92.7	149	98.7
M6, 25 km	125	82.8	131	88.8	139	92.1	149	98.7	151	100.0
M6, 50 km	145	96.0	147	97.4	149	98.7	151	100.0	151	100.0
M6, 100 km	85	56.29	97	64.24	113	74.83	140	92.72	149	98.68
M7, 116 km	112	74.17	120	79.47	131	86.75	147	97.35	151	100.0
M7, 173 km	135	89.40	139	92.05	144	95.36	150	99.34	151	100.0
M7, 234 km	142	94.04	144	95.36	147	97.35	150	99.34	151	100.0
M7, 295 km	13	8.61	21	13.91	34	22.52	87	57.62	124	82.12
M8, 116 km	26	17.22	37	24.50	54	35.76	108	71.52	137	90.73
M8, 173 km	41	27.15	55	36.42	73	48.34	121	80.13	143	94.70
M8, 234 km	67	44.37	80	52.98	98	64.90	135	89.40	148	98.01

In nine of the 23 scenarios the hospital is expected to be operating at less than 70% of capacity three days after the earthquake (highlighted).

Not only would an earthquake constrain the ability of essential facilities to provide services, but it would also place demands on them. Based on the analysis of casualties in Chapter 3, Table 4-6 compares Day 1 and Day 3 capacities with the number of expected injuries requiring hospitalization (Severity 2 and 3), for those scenarios that result in significant numbers of casualties.

Table 4-6
Hospital Capacity for High-Casualty Scenarios, Carbondale

Scenario	Total Casualties, 2 pm	Hospitalization (Severity 2+3)	Beds, Day 1	Beds, Day 3
M 5, 0 km	34	5	134	138
M 5.5, 0 km	141	21	85	97
M 5.5, 10 km	87	12	103	113
M 5.5, 25 km	40	5	128	133
M 6, 0 km	463	77	40	53
M 6, 10 km	338	55	52	66
M 6, 25 km	147	22	85	97
M 6, 50 km	32	4	125	131
M 7, 116 km	70	10	85	97
M 8, 116 km	1,365	236	13	21
M 8, 173 km	682	115	26	37
M 8, 234 km	313	50	41	55
M 8, 295 km	127	20	67	80

In five of the scenarios (the two closest **M** 6 events and the three closest **M** 8 events), highlighted above, hospitalizations exceed the number of beds available. In addition, several other events would strain the capability of the hospital. For example, according to the default HAZUS analysis, four of the scenarios would result in at least 10 injuries requiring medical attention when the hospital would be less than 60% functional on the day of the earthquake.

Similar to the method used for hospital functionality, HAZUS also estimates the functionality of emergency response facilities and schools. In particular, we measure the ability of the schools to be used as post-earthquake emergency shelters. Table 4-7 summarizes the functionality of these facilities on Day 1, for the 23 Carbondale scenarios.

Table 4-7
Emergency Response Facilities and School Functionality at Day 1, Carbondale

Scenario	Emergency Response Facilities		School	
	Functionality (%)	Fire Trucks Available (12 total)	Functionality (%)	Shelter Capacity Available (people)
M5, 0 km	13.31	2	13.66	666
M5, 10 km	19.47	2	20.34	992
M5, 25 km	48.05	6	49.06	2393
M5, 50 km	89.14	11	89.21	4352
M5, 100 km	99.91	12	99.92	4874
M5.5, 0 km	6.93	1	6.99	341
M5.5, 10 km	10.30	1	10.48	511
M5.5, 25 km	26.23	3	26.78	1306
M5.5, 50 km	77.72	9	77.93	3801
M5.5, 100 km	96.77	12	96.73	4718
M6, 0 km	3.62	0	3.47	169
M6, 10 km	5.32	1	5.25	256
M6, 25 km	14.40	2	14.33	699
M6, 50 km	54.02	6	54.23	2645
M6, 100 km	87.35	10	87.11	4249
M7, 116 km	51.36	6	51.38	2506
M7, 173 km	77.58	9	77.28	3770
M7, 234 km	91.62	11	91.47	4462
M7, 295 km	95.65	11	95.95	4680
M8, 116 km	14.29	2	13.87	677
M8, 173 km	30.21	4	31.72	1547
M8, 234 km	52.90	6	52.57	2564
M8, 295 km	70.91	9	70.80	3454

Note: Total school shelter capacity is 4,878 people

It is instructive to compare estimates of emergency service functionality to the fire ignition estimates, in Chapter 3. HAZUS predicts less than 50% functionality for 11 of the 23 scenarios, and less than 60% functionality for 14 of the 23. This raises concerns about the emergency response facilities. In particular, the seven scenarios that would place the greatest demands on fire services (highlighted in Table 3-12) are precisely those that would most severely reduce the capacity of emergency services to respond. Combining the estimates from Table 3-12 and Table 4-7 produces the following:

Table 4-8
Scenarios with Greatest Fire Threat, Carbondale

Scenario	Population exposed to fire ignitions	Value exposed (thousands 1994 $)	Emergency services functionality, Day 1
M 5, 0 km	83	4,358	13.31%
M 5, 10 km	87	4,508	19.47%
M 5.5, 0 km	77	4,019	6.93%
M 5.5, 10 km	84	4,393	10.30%
M 6, 0 km	220	13,409	3.62%
M 6, 10 km	90	4,639	5.32%
M 6, 25 km	88	4,606	14.40%

Sikeston

Table 4-9 summarizes the analysis of hospital functionality in Sikeston.

Table 4-9
Hospital functionality (Total # of beds = 188), Sikeston

Scenario	At Day 1		At Day 3		At Day 7		At Day 30		At Day 90	
	Beds	%	Beds	%	Beds	%	Beds	%	Beds	%
M5, 0 km	142	75.53	150	79.79	161	85.64	179	95.21	186	98.94
M5, 10 km	159	84.57	164	87.23	171	90.96	183	97.34	187	99.47
M5, 25 km	179	95.21	180	95.74	183	97.34	185	98.40	186	98.94
M5, 50 km	183	97.34	184	97.87	186	98.94	188	100.00	188	100.00
M5, 100 km	188	100.00	188	100.00	188	100.00	188	100.00	188	100.00
M5.5, 0 km	81	43.09	95	50.53	114	60.64	156	82.98	178	94.68
M5.5, 10 km	104	55.32	116	61.70	132	70.21	167	88.83	182	96.81
M5.5, 25 km	135	71.81	144	76.60	156	82.98	177	94.15	184	97.87
M5.5, 50 km	166	88.30	170	90.43	176	93.62	184	97.87	187	99.47
M5.5, 100 km	183	97.34	184	97.87	186	98.94	188	100.00	188	100.00
M6, 0 km	38	20.21	50	26.60	67	35.64	122	64.89	159	84.57
M6, 10 km	53	28.19	67	35.64	86	45.74	138	73.40	170	90.43
M6, 25 km	85	45.21	98	52.13	116	61.70	157	83.51	177	94.15
M6, 50 km	139	73.94	147	78.19	158	84.04	179	95.21	186	98.94
M6, 100 km	172	91.49	175	93.09	179	95.21	185	98.40	186	98.94
M7, 34 km	24	12.77	35	18.62	50	26.60	105	55.85	148	78.72
M7, 63 km	79	42.02	93	49.47	112	59.57	156	82.98	178	94.68
M7, 122 km	133	70.74	143	76.06	155	82.45	178	94.68	186	98.94
M7, 184 km	155	82.45	162	86.17	170	90.43	183	97.34	187	99.47
M8, 34 km	2	1.06	4	2.13	8	4.26	32	17.02	75	39.89
M8, 63 km	9	4.79	14	7.45	23	12.23	68	36.17	118	62.77
M8, 122 km	24	12.77	35	18.62	50	26.60	105	55.85	148	78.72
M8, 184 km	76	40.43	89	47.34	108	57.45	154	81.91	177	94.15

In 11 of the 23 scenarios the hospital is expected to be operating at less than 70% of capacity three days after the earthquake (highlighted). In particular, Table 4-10 compares Day 1 and Day 3 capacities with the number of expected injuries requiring hospitalization (Severity 2 and 3), for those scenarios that result in significant numbers of casualties.

Table 4-10
Hospital Capacity for High-Casualty Scenarios, Sikeston

Scenario	Total Casualties, 2 pm	Hospitalization (Severity 2+3)	Beds, Day 1	Beds, Day 3
M 5.5, 0 km	79	11	81	95
M 5.5, 10 km	53	8	104	116
M 6, 0 km	248	39	38	50
M 6, 10 km	192	30	53	67
M 6, 25 km	88	13	85	98
M 7, 34 km	473	78	24	35
M 7, 63 km	136	21	79	93
M 8, 34 km	1,890	334	2	4
M 8, 63 km	1,131	196	9	14
M 8, 122 km	598	101	24	35
M 8, 184 km	231	37	76	89

Five of the scenarios would result in casualties that would exceed the reduced hospital capacity on the day of the earthquake. The **M**8 scenarios would be particularly problematic. Even without any damage to the hospital, casualties from such an earthquake would exceed or severely strain the hospital capacity.

Table 4-11
Emergency response facilities and school functionality at day 1, Sikeston

Scenario	Emergency Response Facilities		School	
	Functionality (%)	Fire Trucks Available (7 total)	Functionality (%)	Shelter Capacity Available
M5, 0 km	13.23	1	13.50	NA
M5, 10 km	20.22	1	20.64	NA
M5, 25 km	49.71	3	50.10	NA
M5, 50 km	84.96	6	84.82	NA
M5, 100 km	98.62	7	98.66	NA
M5.5, 0 km	6.64	0	7.13	NA
M5.5, 10 km	10.35	1	10.94	NA
M5.5, 25 km	27.00	2	27.90	NA
M5.5, 50 km	69.02	5	69.31	NA
M5.5, 100 km	96.54	7	96.28	NA
M6, 0 km	3.19	0	3.70	NA
M6, 10 km	5.05	0	5.75	NA
M6, 25 km	14.14	1	15.38	NA
M6, 50 km	44.75	3	45.87	NA
M6, 100 km	83.29	6	83.92	NA
M7, 34 km	5.14	0	5.80	NA
M7, 63 km	21.08	1	21.74	NA
M7, 122 km	53.68	4	54.33	NA
M7, 184 km	80.18	6	80.86	NA
M8, 34 km	0.73	0	0.69	NA
M8, 63 km	3.73	0	3.76	NA
M8, 122 km	14.00	1	14.09	NA
M8, 184 km	35.62	2	32.01	NA

HAZUS predicts less than 50% functionality for emergency response facilities for 16 of the 23 scenarios. This raises particular concerns for the emergency response facilities, particularly for scenarios with extensive injuries or fires. In particular, the two scenarios that would place the greatest demands on fire services (highlighted in Table 3-24) are precisely those that would most severely reduce the capacity of emergency services to respond. Combining the estimates from Table 3-24 and Table 4-11 produces the following:

Table 4-12
Scenarios with Greatest Fire Threat, Sikeston

Scenario	Population exposed to fire ignitions	Value exposed (thousands 1994 $)	Emergency services functionality, Day 1
M 6, 0 km	20	1003	3.19%
M 8, 34 km	21	1100	0.73%

As shown in Table 4-12, the two scenarios that pose the greatest fire threat to Sikeston are also those that would most severely reduce the ability of emergency services to respond. The M 8 earthquake, because of its widespread effect, would create more serious demands on local response, because other communities in the area would not be likely to provide assistance.

CHAPTER 5
ANALYSIS

The Introduction identified three groups of research questions, regarding: use of HAZUS, integration of ATC-21 inventories into HAZUS, and characteristics of seismic risk in Mid-America. This chapter addresses these questions in reverse order.

CHARACTERISTICS OF SEISMIC RISK IN MID-AMERICA

Questions regarding the characteristics of seismic risk in Mid-America:

a. ***What are the expected earthquake effects in each community? What is the estimated direct damage to essential facilities? What are the expected community demands on essential facilities?***

b. ***How are the damages and casualties distributed across the community? What is the effect of structure type? Functions? Occupancies? What are the priority candidates for retrofit or replacement?***

Earthquake Probabilities in Mid-America

To truly understand seismic risk requires consideration of earthquake probabilities. For example, a **M**8 earthquake 34 km from Sikeston would be devastating for that community, but it may be too unlikely for serious consideration.

Seismic probabilities for Mid-America are difficult to estimate, however, because so few events have occurred in historic time. Even the best estimates, therefore, have very high uncertainties. We have selected one set of probability estimates to use as the basis for our risk calculations, but our method is such that other probability estimates could be substituted for ours.

We base our probability estimates on Johnston and Nava (1985) and related work. This assumes two seismic source zones in Mid-America: a small zone, which represents seismicity of the New Madrid seismic zone; and a large zone, which represents diffuse seismicity in surrounding areas (Figure 5-1).

Johnston and Nava define Gutenberg-Richter relationships for the two zones, as follows:

Large zone $Log(N_c) = 3.43 - 0.88m_b$ $\sigma_a \approx 0.060$ $\sigma_b \approx 0.030$ (5-1)

Small zone $Log(N_c) = 3.32 - 0.91m_b$ $\sigma_a \approx 0.090$ $\sigma_b \approx 0.045$ (5-2)

N_c is the rate of earthquakes of body magnitude m_b or greater per year; and σ_a and σ_b are standard errors of the first and second constants in each equation. Note that $1/N_c$ is the average recurrence interval of an earthquake of magnitude m_b. Body-wave magnitude can be converted into moment magnitude, **M**, by using an empirical relation of Johnston (1996):

$$\boldsymbol{M} = 3.45 - 0.473m_b + 0.145m_b^2 \qquad (5\text{-}3)$$

Alternatively,

$$m_b = 1.631 + (0.58\,\boldsymbol{M} - 1.777)^{0.5}/0.29 \qquad (5\text{-}4)$$

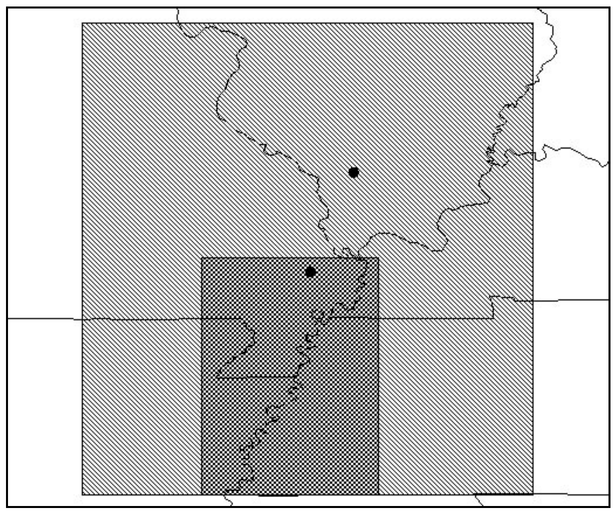


Figure 5-1
Seismic Source Zones in Mid-America (Johnston and Nava, 1985)

Uncertainty in equations 5-1 and 5-2 is low at low and moderate magnitudes, but high at high magnitudes because of limited historical earthquakes. Even though earthquakes of **M** =7.0 could only occur near the New Madrid seismic zone, the required crustal area for strain energy accumulation far exceeds the size of the small zone. For this reason, equation 5-1 is used for recurrence estimation (Johnston and Nava, 1985).

One can then use Poisson probability functions derived by Johnston and Nava to estimate conditional probability:

$$P(?t) = 1 - e^{-?t/Tr}$$

or cumulative probability:

$$P(T{=}t) = 1 - e^{-t/Tr}$$

Where T is a time interval, ?t is the time interval from current time until some time under consideration, t is the elapsed time since the last damaging event, and Tr is the average recurrence time of an earthquake event of magnitude **M** or greater. Table 5-1 illustrates the conditional and cumulative probability estimates for the next 15 years and 50 years.[6]

Table 5-1 Time-dependent earthquake probability estimates for the NMSZ

m_b	**M**	Recurrence Time (years)	Probability of recurrence (%) Cumulative		Conditional	
			Next 15 years	Next 50 years	Next 15 years	Next 50 years
=5.3	=5.0	17	87.83	98.52	59.45	95.06
=5.7	=5.5	41	69.05	86.83	30.68	70.52
=6.1	=6.0	92	73.06	81.57	15.01	41.84
=6.8	=7.0	389	40.96	46.04	3.78	12.06
=7.4	=8.0	1379	13.75	15.91	1.08	3.56

To standardize the risk analysis, we use annualized probability, which is just the inverse of the average recurrence interval.[7] The annual probabilities of our scenario magnitudes occurring anywhere within the large seismic source zone are listed in Table 5-2.

These earthquake probabilities are highly uncertain, and it is very difficult to even know how uncertain they are. Statistically, there are not enough data to determine the appropriate probability distribution to apply. For this reason, Johnston and Nava observe that standard deviation must be assumed. For their final probability estimates--based on trials assuming four different probability distributions and a range of standard deviations--they assume standard deviations of 21% to 24% of average recurrence intervals.[8] In Table 5-2 we assume standard deviations of 25%. Table 5-2 lists the estimates, and standard deviations, for recurrence interval and annual probability for each of our scenario magnitudes.

Table 5-2. Probabilities and Uncertainties for Scenario Earthquake Magnitudes

M	m_b	Recurrence (years)	Annual probability	Low estimate	High estimate
=5.0	=5.28	17 ± 4	.06018	.04814	.08024
=5.5	=5.73	41 ± 10	.02444	.01955	.03258
=6.0	=6.13	92 ± 24	.01084	.008673	.01446
=7.0	=6.84	389 ± 97	.002571	.002056	.003428
=8.0	=7.46	1379 ± 345	.0007253	.0005802	.0009671

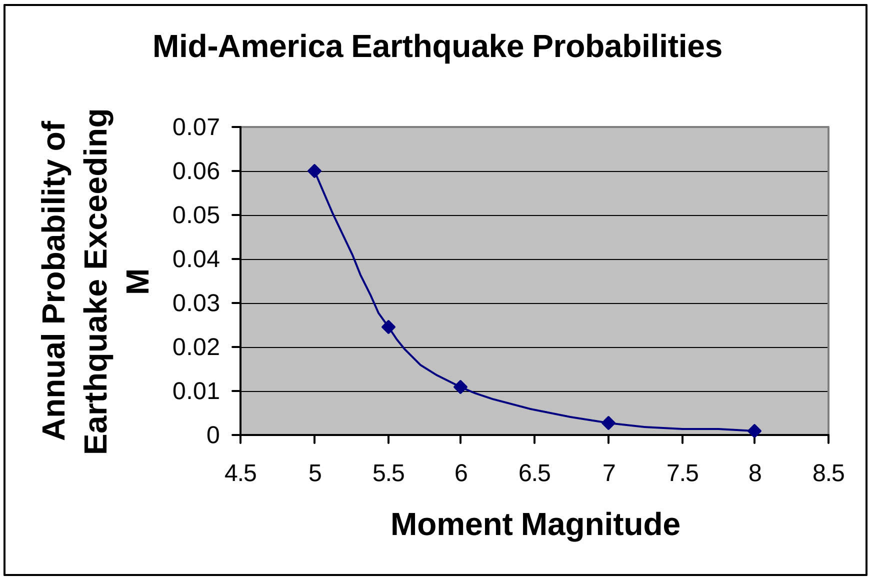
[6] More recent paleoseismic studies suggest that large (**M** =7.6) events have, in the recent past, occurred closer to once every 500 years, which is substantially more frequent than the 1379 years shown in Table 5-1 (Tuttle, et al, 2002).

[7] It is also virtually identical to an annualized conditional probability, where *?t =1*. For $T_r > 50$, annualized conditional probability and annualized probability differ by less than 0.1%.

[8] Seismologists are now less confident regarding the regularity of events on faults, and so the standard deviation may well be closer to 50% (see Cramer et al, 2000).

These probabilities represent a continuous cumulative probability curve (Figure 5-1).

Figure 5-1



By subtracting probabilities for successive magnitudes, we can estimate the annual probability for each range of magnitudes:

Table 5-3 Probabilities for Scenario Earthquake Magnitude Ranges

M	**Annual probability**	**Low estimate**	**High estimate**
5.0 =**M**<5.5	.03574	.02860	.04766
5.5 =**M**<6.0	.01359	.01088	.01812
6.0 =**M**<7.0	.008271	.006617	.01103
7.0 =**M**<8.0	.001845	.001476	.002460
8.0 =**M**	.0007253	.0005802	.0009671

Probabilities of the Earthquake Scenarios

Estimating the probabilities of each scenario has three aspects. First is the probability that the specified range of magnitudes (e.g., 5.0 =**M** < 5.5) will occur within the seismic source zone. This probability, which is shown in Table 5-3 for each magnitude range, describes the likelihood of an earthquake of such magnitude occurring *anywhere* in the seismic zone, and it may or may not be close enough to cause damage in Carbondale or

Sikeston. As discussed in Chapter 3, we assume that all earthquakes of **M** =7.0 will occur only within the small seismic source zone, along the general alignment of the New Madrid seismic zone. And we assume that all earthquakes of **M** <7.0 can occur anywhere within the large seismic source zone, with equal probability at every location within that zone.

Second, we designate each HAZUS scenario to represent the effects of all earthquakes that would occur within the specified range of magnitudes. Thus, for example, we assume that each **M**5.0 scenario represent the effects of all earthquake that would occur at that location in the 5.0 = **M** < 5.5 range. This is an important simplifying assumption that allows us to use our 23 discrete scenarios to represent a continuum of earthquake probabilities.

Third, for each magnitude range, we distribute the Table 5-3 probability over all the earthquake scenarios of that magnitude. In other words, we assign a probability to each 6.0 = **M**<7.0 scenario so that the sum of the scenario probabilities adds to .008271. This distribution of probabilities over the scenarios requires another set of simplifying assumptions, described as follows.

For the large magnitude (**M** 7.0 or 8.0) earthquakes, we assume that the total probability of scenarios is equally distributed along the New Madrid seismic fault within the small source zone. Because we selected the epicenter of each scenario as the center point of one-fourth of the New Madrid seismic fault, each scenario has a one-fourth share of the total probability.

For the moderate magnitude scenarios (**M** 5.0, 5.5, and 6.0), we partition the probability over the scenario distances from each case community: 1 km, 10 km, 25 km, 50 km, and 100 km. The share of each scenario is estimated to be proportional to the area of a ring centered on each distance. This is illustrated in Figure 5-2 and Table 5-4. For example, the **M**6.0 scenario at 25 km away is assumed to represent all **M**6.0 events that would occur between 17.5 and 37.5 km away from the case community, where 17.5 km is an average of 10 km and 25 km, and 37.5 km an average of 25 km and 50 km. The probability of an **M** 6.0 event occurring in this ring is proportionate to the ring's area as a fraction of the large seismic source zone's area. Similarly, the **M**6.0 scenario at 10 km away represents all **M**6.0 events that could occur in a ring between 5.5 and 17.5 km. The share of the innermost scenario is proportional to the area of a circle centered at the case community with a radius of 5.5 km. And the outermost scenario represents the area beyond the 75-km circle around the case community; its probability is the difference between the total source zone probability and the sum of probabilities of the other scenarios in each magnitude group.

Table 5-4 Allocation of Probabilities to Moderate (M 5.50, 5.5, 6.0) Earthquake Scenarios

Scenario Distance(km)	Ring inner radius(km)	Ring outer radius(km)	Ring Area (km^2)	Share of source zone probability[a]
1		5.5	95	0.000603
10	5.5	17.5	867	0.005498
25	17.5	37.5	3,455	0.021913
50	37.5	75	13,253	0.084043
100	75	source zone boundary	140,028	0.887943

a. Area of large seismic source zone is 157,700 km^2

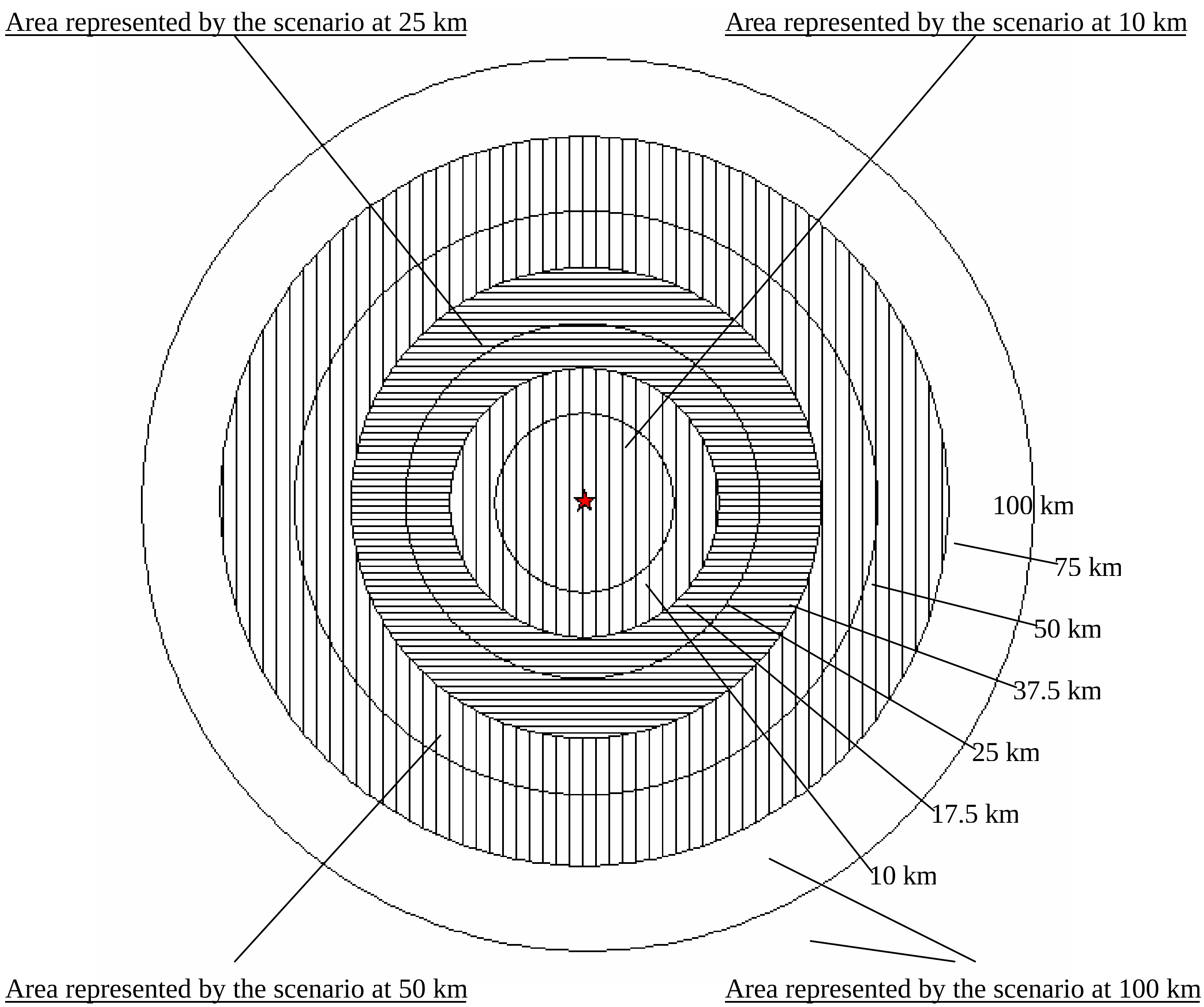
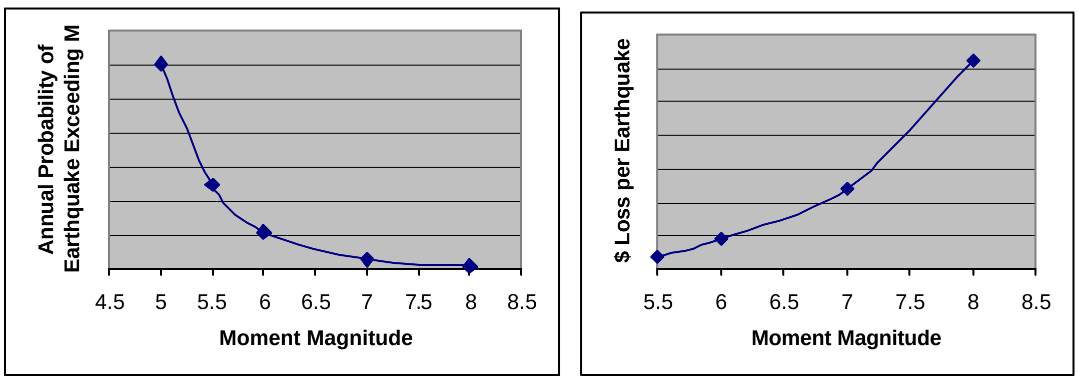


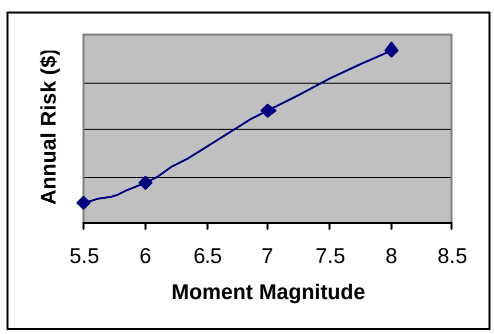
Figure 5-2. Distribution of probability for a set of moderate earthquake scenarios. The center star represents the case community.

Risk Analysis

Risk analyses for Carbondale and Sikeston require multiplying the loss estimate for each HAZUS scenario by its probability of occurring g. In general, the seismic risk for each community can be seen as a hazard probability function multiplied by a loss function, as illustrated in Figure 5-3.



Earthquake Probability (hazard) X Economic loss per event (vulnerability) =



Annual risk

Figure 5-3. Calculation of Earthquake Risk

Figure 5-3 depicts a risk that increases with earthquake magnitude, but this may not be so. It may decrease, or it may have some other relationship to magnitude. The difficult problem in risk analysis is that the most damaging events are the least likely to occur. We seek to determine which poses the greatest threat to Mid-American communities: the infrequent large events, or the more frequent moderate events? Infrequent events close to the community, or less frequent events at a greater distance away?

Based on our assumptions that cast the 23 scenarios as representing the total earthquake hazard to each community, we can calculate the risk for each scenario, and can then sum them to represent the total earthquake risk for each community.

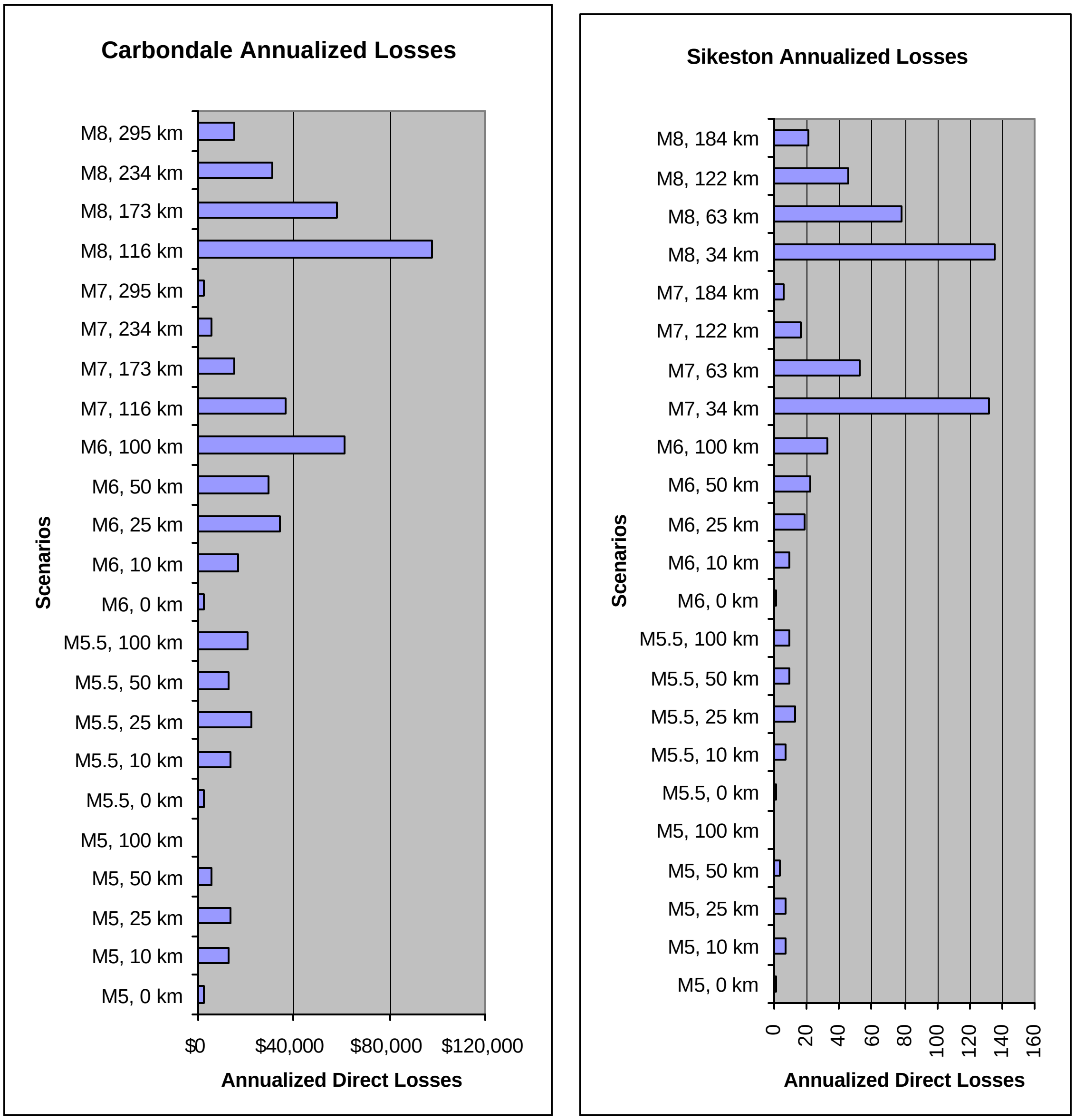
Table 5-5 Annualized Losses, Carbondale Scenarios

Scenario	Hospital-izations (severity 2&3)	Deaths	Direct loss, $thousands (1994$)	Direct loss, $thousands (2001$)	Annual probability	Annual hospital-ization	Annual deaths	Annual loss (2001$)
M5, 0 km	5	0	76,406	91,510	0.00002	0.0001	0.0000	1,967
M5, 10 km	1	0	54,041	64,724	0.00020	0.0002	0.0000	12,718
M5, 25 km	0	0	14,380	17,223	0.00078	0.0000	0.0000	13,490
M5, 50 km	0	0	1,661	1,989	0.00300	0.0000	0.0000	5,976
M5, 100 km	0	0	0	0	0.03174	0.0000	0.0000	0
M5.5, 0 km	21	2	206,273	247,048	0.00001	0.0002	0.0000	2,026
M5.5, 10 km	12	1	147,990	177,244	0.00007	0.0009	0.0001	13,240
M5.5, 25 km	5	0	62,413	74,750	0.00030	0.0015	0.0000	22,268
M5.5, 50 km	1	0	9,442	11,308	0.00114	0.0011	0.0000	12,920
M5.5, 100 km	0	0	1,452	1,739	0.01207	0.0000	0.0000	20,991
M6, 0 km	77	8	399,909	478,961	0.00001	0.0004	0.0000	2,395
M6, 10 km	55	5	311,719	373,338	0.00005	0.0025	0.0002	16,987
M6, 25 km	22	2	158,722	190,097	0.00018	0.0040	0.0004	34,446
M6, 50 km	4	0	35,910	43,008	0.00070	0.0028	0.0000	29,895
M6, 100 km	0	0	7,006	8,391	0.00734	0.0000	0.0000	61,624
M7, 116 km	10	1	66,244	79,339	0.00046	0.0046	0.0005	36,599
M7, 173 km	3	0	27,725	33,206	0.00046	0.0014	0.0000	15,318
M7, 234 km	1	0	9,960	11,929	0.00046	0.0005	0.0000	5,503
M7, 295 km	0	0	4,358	5,219	0.00046	0.0000	0.0000	2,408
M8, 116 km	236	26	449,912	538,848	0.00018	0.0428	0.0047	97,693
M8, 173 km	115	12	266,862	319,614	0.00018	0.0208	0.0022	57,946
M8, 234 km	50	5	143,447	171,803	0.00018	0.0091	0.0009	31,148
M8, 295 km	20	2	69,917	83,738	0.00018	0.0036	0.0004	15,182
				TOTAL		**0.0964**	**0.0093**	**512,740**

Table 5-6 Annualized Losses, Sikeston Scenarios

Scenario	Hospital-izations (severity 2&3)	Deaths	Direct loss, $thousands (1994$)	Direct loss, $thousands (2001$)	Annual probability	Annual hospital-ization	Annual deaths	Annual loss (2001$)
M5, 0 km	1	0	39,814	47,684	0.00002	0.0000	0.0000	1,025
M5, 10 km	1	0	28,421	34,039	0.00020	0.0002	0.0000	6,689
M5, 25 km	0	0	7,812	9,356	0.00078	0.0000	0.0000	7,329
M5, 50 km	0	0	1,063	1,273	0.00300	0.0000	0.0000	3,825
M5, 100 km	0	0	0	0	0.03174	0.0000	0.0000	0
M5.5, 0 km	11	1	115,766	138,650	0.00001	0.0001	0.0000	1,137
M5.5, 10 km	8	1	79,229	94,891	0.00007	0.0006	0.0001	7,088
M5.5, 25 km	2	0	35,706	42,764	0.00030	0.0006	0.0000	12,739
M5.5, 50 km	0	0	7,292	8,733	0.00114	0.0000	0.0000	9,978
M5.5, 100 km	0	0	613	734	0.01207	0.0000	0.0000	8,862
M6, 0 km	39	4	210,057	251,580	0.00001	0.0002	0.0000	1,258
M6, 10 km	30	3	169,210	202,658	0.00005	0.0014	0.0001	9,221
M6, 25 km	13	1	89,529	107,227	0.00018	0.0024	0.0002	19,429
M6, 50 km	2	0	26,252	31,441	0.00070	0.0014	0.0000	21,855
M6, 100 km	0	0	3,777	4,524	0.00734	0.0000	0.0000	33,222
M7, 34 km	78	8	238,745	285,939	0.00046	0.0360	0.0037	131,904
M7, 63 km	21	2	95,295	114,132	0.00046	0.0097	0.0009	52,649
M7, 122 km	3	0	29,800	35,691	0.00046	0.0014	0.0000	16,464
M7, 184 km	1	0	10,658	12,765	0.00046	0.0005	0.0000	5,888
M8, 34 km	334	37	622,310	745,325	0.00018	0.0606	0.0067	135,127
M8, 63 km	196	21	361,579	433,054	0.00018	0.0355	0.0038	78,513
M8, 122 km	101	11	209,538	250,958	0.00018	0.0183	0.0020	45,499
M8, 184 km	37	4	98,809	118,341	0.00018	0.0067	0.0007	21,455
				TOTAL		**0.1754**	**0.0183**	**631,157**

Figure 5-4. Annualized Losses, Carbondale and Sikeston Scenarios



Another way to look at these numbers is to summarize by magnitudes, as shown in Tables 5-7 and 5-8.. These tables allow one to compare the relative effects of various magnitude earthquakes occurring anywhere in the region, and they can show which magnitude events pose the greatest overall risks to each community.

Table 5-7 Annualized Losses by Magnitude, Carbondale

Magnitude	Annual hospital-ization	Annual deaths	Annual loss (2001$)
5.0-5.5	0.0003	0.0000	34,152
5.5-6.0	0.0037	0.0001	71,445
6.0-7.0	0.0097	0.0006	145,347
7.0-8.0	0.0065	0.0005	59,827
8.0+	0.0763	0.0082	201,969
TOTAL	**0.0964**	**0.0093**	**512,740**

Table 5-8 Annualized Losses by Magnitude, Sikeston

Magnitude	Annual hospital-ization	Annual deaths	Annual loss (2001$)
5.0-5.5	0.0002	0.0000	18,867
5.5-6.0	0.0013	0.0001	39,805
6.0-7.0	0.0053	0.0003	84,986
7.0-8.0	0.0475	0.0046	206,905
8.0+	0.1211	0.0132	280,594
TOTAL	**0.1754**	**0.0183**	**631,157**

Interpretation of Risk Analysis Results

So, what do all these numbers mean for residents, officials, and property owners in these communities? We identify several key conclusions, and then discuss their implications:

1. Neither community can expect earthquakes to cause many deaths or injuries requiring hospitalization (assuming that the HAZUS casualty models are reasonably accurate). Although the annual numbers seem quite small, a more cautious way to express this would be over a person's 70-year lifetime. Over such a time span, Carbondale would expect to have 7 injuries needing hospitalization and 0.6 deaths, and Sikeston would have 12 injuries requiring hospitalization and 1.3 deaths.

2. In both communities, the M 8.0+ earthquakes represent the greatest risk to human life. These earthquakes account for over 69% of the annualized expected injuries and deaths in each community.

3. For both communities, annualized direct losses are relatively low, at about $500,000 to $600,000 per year. Although low, these amounts are still significant, for at least two reasons.

First, direct losses represent only part of the economic effects of earthquakes. The actual economic effects on the communities would be much greater.

Second, the losses are more significant if one takes a medium-term view. Most plans and policies address time periods of several years, reflecting the long-term interests of the community. This is because current residents can be expected to continue to live and work in the community for many years, and because any new structures or land uses can be expected to exist as permanent parts of the community for at least 30 years. Viewed in these terms, the expected losses amount to $5 to $6 million per decade, or $15 to $18 million per 30 years.

4. In Carbondale, annualized losses for **M** $>$ 7.0 are nearly equal to those for **M** $<$ 7.0. This is because of the large annualized losses for **M** 6.0-7.0 and for **M** 8.0+. Moderate earthquakes, of **M** $<$ 6.0, pose a relatively small threat, amounting to only about 20% of total annualized risk. Thus the greatest risk to Carbondale comes from moderate **M** 6.0-7.0 events and large **M** 8.0+ events.

5. In Sikeston, earthquakes of **M** $>$ 7.0 represent over 75% of total annualized losses.

6. What is the chance of having a damaging earthquake each year, or over the next 30 years? From Tables 5-5 and 5-6, we can sum the probabilities for all the damaging scenarios (all except the most distant **M** 5 scenarios). This shows that each community has a 2.844% chance per year of a damaging earthquake, or a 57.4% chance of having a damaging earthquake in a 30-year period.

Most importantly, the difficult issue in Mid-America is how to respond to different types of earthquake risk: how to value small, frequent losses versus large, infrequent losses. We illustrate with two examples.

On the one hand, it is clear that **M** $>$ 7.0 earthquakes represent the greatest annualized risk to Sikeston. On the other hand, this risk is computed by multiplying enormous losses by an annual probability of only 0.0026. An earthquake of **M** $>$ 7.0 is expected to occur, on average, once every 389 years. Looked at another way, however, over the 50-year life of a built environment, such an earthquake has a 12% chance of occurring. These are small, but finite, odds of a highly destructive event. At best, a **M** 7.0 event occurring far southwest of Sikeston would cause over $10 million in direct damage, and 8 injuries (7 minor, and one requiring hospitalization). If it occurs closer to Sikeston, or if it exceeds **M** 7.0, its effects would be dramatically greater.

For Carbondale, **M** < 6.0 earthquakes represent only 20% of earthquake risk. But the annual probability is 0.0493, which means such an earthquake is expected to occur, on average, once every 20 years. With an annualized risk of about $100,000, these earthquakes are expected to cause $1 million in damage every decade. On average, such an earthquake is expected to affect Carbondale every 20 years, and, on average, it would cause $2 million in direct damage.

These two examples suggest that each community should be concerned enough about the threat to take prudent, cost-effective actions. Economic damage is likely to occur, and life-endangering events have a finite chance of occurring during the life of the community.

Another way to view the earthquake threat to Carbondale and Sikeston is to identify all the scenarios that would overwhelm or severely strain the capacity of essential facilities, and to evaluate the likelihood of each[9]. These scenarios are summarized in Tables 5-9 and 5-10. To evaluate the likelihood, it is useful to think in terms longer than just one year. A viable plan for emergency preparedness should reflect a typical urban planning timeframe of 20-30 years. Tables 5-9 and 5-10 show 30-year probabilities for each scenario.

Table 5-9 Scenarios Exceeding Capacity of Essential Facilities, Carbondale

Scenario	Hospitalization (Severity 2+3), 2 pm	Beds, Day 1	Population exposed to fire ignitions	Value exposed (thousands 1994 $)	Emergency services functionality, Day 1	Annual Probability (%)	30-year Probability (%)
M 5, 0 km			83	4,358	13.31%	0.002%	0.065%
M 5, 10 km			87	4,508	19.47%	0.020%	0.588%
M 5.5, 0 km			77	4,019	6.93%	0.001%	0.025%
M 5.5, 10 km			84	4,393	10.30%	0.007%	0.224%
M 6, 0 km	77	40	220	13,409	3.62%	0.000%	0.015%
M 6, 10 km	55	52	90	4,639	5.32%	0.005%	0.136%
M 6, 25 km			88	4,606	14.40%	0.018%	0.542%
M 8, 116 km	236	13				0.018%	0.543%
M 8, 173 km	115	26				0.018%	0.543%
M 8, 234 km	50	41				0.018%	0.543%
M 8, 295 km	20	67				0.018%	0.543%
					TOTAL	**0.125%**	**3.767%**

[9] In the case of Carbondale, Tables 4-6 and 4-8 identify the scenarios that would exceed or strain the capacity of essential facilities. For Sikeston, Tables 4-10 and 4-12 identify the scenarios. One difference between them is that HAZUS predicts more fire ignitions in Carbondale.

Note: data entries are only for those scenarios and services where capacities will be exceeded or severely strained.

Table 5-10 Scenarios Exceeding Capacity of Essential Facilities, Sikeston

Scenario	**Hospitalization (Severity 2+3), 2 pm**	**Beds, Day 1**	**Population exposed to fire ignitions**	**Value exposed (thousands 1994 $)**	**Emergency services functionality, Day 1**	**Annual Probability (%)**	**30-year Probability (%)**
M 6, 0 km	39	38	20	1003	3.19%	0.000%	0.015%
M 6, 10 km	30	53				0.005%	0.136%
M 7, 34 km	78	24				0.046%	1.374%
M 8, 34 km	334	2	21	1100	0.73%	0.018%	0.543%
M 8, 63 km	196	9				0.018%	0.543%
M 8, 122 km	101	24				0.018%	0.543%
M 8, 184 km	37	76				0.018%	0.543%
					TOTAL	**0.123%**	**3.697%**

Note: data entries are only for those scenarios and services where capacities will be exceeded or severely strained.

From the point of view of emergency services, these scenarios are the most problematic for each community. Fortunately, these scenarios have low individual probabilities; only one of them exceeds a 1% probability over 30 years. However, it is also useful to sum the probabilities. This tells us that Carbondale and Sikeston each have approximately a 3.7% chance over the next 30 years of experiencing an earthquake that would strain or exceed the capacity of some of their essential facilities.

It is clear that each community has a finite chance of experiencing a damaging earthquake, although the most severe ones are least likely. It is clear that some level of preparedness is appropriate. The continuing question is this: which types and magnitudes of earthquake consequences should local officials plan for, and what types of actions are most appropriate?[10]

[10] Another important source of information is the USGS maps themselves. The USGS website allows users to "deaggregate" the shaking map at any location to reveal all the earthquake sources (magnitudes and distances) that compose a given probabilistic shaking value.

For example, for Carbondale, the 224-year (20% chance of being exceeded in 50 years) peak ground acceleration is 0.083g. This is due to a variety of earthquake sources. Approximately 20% is due to earthquakes of about M_w 4.8 within 100 km, 18% is due to earthquakes of about M_w 5.2 within 100 km, 12% is due to earthquakes of about M_w 5.7 at 50-100 km, 11% is due to earthquakes of about M_w 6.2 within 115 km, and 21% is due to earthquakes of M_w 8 at about 50-90 km. So, relatively frequent shaking that would be slightly damaging (roughly equal to MMI VI) is due primarily to earthquakes of M_w 5.0-6.0.

The 2475-year (2% chance of being exceeded in 50 years) peak ground acceleration is 0.551g. Approximately 64% of this is due to earthquakes of M_w 8.0 at about 50-90 km, and 26% is due to

Summary: Characteristics of Seismic Risk

What are the expected earthquake effects in each community?

For both communities, annualized direct economic losses are relatively low, at about \$500,000 to \$600,000 per year, but they are significant over the lifetime of the community. Neither community can expect earthquake to cause many deaths or injuries requiring hospitalization (assuming that the HAZUS casualty models are reasonably accurate). The greatest risk to Carbondale comes from **M** 6.0-7.0 events and large **M** 8.0+ events. The greatest risk to Sikeston comes from earthquakes of **M** > 7.0. Each community has a 2.8% chance per year of a damaging earthquake, or a 57% chance of having a damaging earthquake in a 30-year period. Each community has a 3.7% chance over the next 30 years of experiencing an earthquake that would strain or exceed the capacity of some of their essential facilities.

How are the damages and casualties distributed across the community?

This question is answered best in Chapters 2, 3, and 4. The primary seismic safety problem in Carbondale's building stock consists of residential and educational buildings constructed of unreinforced masonry and concrete frames. SIU buildings account for a significant part of this. The primary seismic safety problem in Sikeston's building stock lies in unreinforced masonry commercial, government, and educational buildings, and secondarily reinforced masonry commercial and religious buildings. In both communities, an earthquake during the day would have the greatest number of casualties, because workplaces and schools are generally less seismically safe than homes.

INTEGRATION OF ATC-21 INVENTORIES WITH HAZUS INVENTORY

Questions regarding integration of ATC-21 inventories with HAZUS:

a. How feasible is it to integrate ATC-21 inventories into HAZUS? How can HAZUS best reflect the intelligence gained by doing local ATC-21 surveys?

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earthquakes of about M_w 5.2 to M_w 6.2 at 12 to 37 km. Thus, relatively infrequent shaking that would be highly damaging (roughly equal to MMI IX) is due primarily to earthquakes of M_w 8.0 from the New Madrid seismic zone.

Sikeston's hazard is more clearly dominated by the New Madrid seismic zone, particularly for the higher return periods. The 224-year peak ground acceleration is 0.092g, only slightly higher than for Carbondale. Approximately 19% is due to earthquakes of about M_w 4.8 within 50 km, 16% due to earthquakes of about M_w 5.2 within 65 km, 11% due to earthquakes of about M_w 5.7 within 75 km, 9% due to earthquakes of M_w 6.2 at 25 to 100 km, and 22% due to earthquakes of M_w 8.0 at 13 to 32 km. The 2475-year peak ground acceleration is 1.581g, of which 95% is due to earthquakes of M_w 8.0 at 13 to 32 km.

b. How does the ATC-21 information change the output of HAZUS, as compared to using default data only? What is the value added by augmenting HAZUS with ATC-21?

HAZUS General Building Stock Inventory

According to the HAZUS manuals, the results are more accurate if an actual building inventory is substituted for the default general building stock inventory. This is easier said than done.

The General Building Stock (GBS) module estimates floor area and number of buildings for each combination of the 36 structure types and 28 occupancy classes (Technical Manual, Chapter 3). It creates these by combining two sets of inputs. First, it uses a variety of available data sources to estimate, for each census tract, the floor area for each occupancy class. Second, in what is called the "occupancy mapping," it estimates the percentage of floor area for structure types within each occupancy class (separate tables for low-rise, mid-rise, and high-rise). HAZUS uses three default occupancy mappings: for the West, Midwest, and East. For single-family dwellings, it has separate mappings for each state.[11] It combines the default mapping with the occupancy data for the census tract to estimate square footage for each of the 1,008 structure-occupancy categories. Finally, it applies default parameters for floor area per building, to estimate number of buildings in each category.

For damage estimates, HAZUS applies default parameters for: structural repair cost per square foot for each of the 1,008 structure-occupancy categories, contents value as percentage of replacement value, business sales per square foot, repair time, and income per day, rental costs, and several other economic assumptions for each occupancy class. The tables of "total dollar exposure" by occupancy and building type appear to have been calculated as the total structural and nonstructural replacement costs for each category.

In light of this detailed database structure, there are two ways to apply local knowledge to the GBS inventory. The first is to conduct a complete survey of all community buildings, in order to fill out the floor areas for the 1,008 categories. The second is to change some of the parameters, chiefly the occupancy mapping and the repair costs. But, because of the specificity of the categories, this demands comprehensive knowledge of the building stock, which is not very different from needing a complete survey. Alternatively, it might be possible to do a random survey in order to develop an appropriate occupancy apping scheme.

[11] For Illinois, it assumes 77% of single-family residences are wood-frame, 1% are concrete shear wall, and 22% are unreinforced masonry. For Missouri, it assumes 76% wood-frame and 24% unreinforced masonry.

Use of ATC-21 Survey to Augment HAZUS GBS Inventory

Because of the labor required, we decided not to modify the GBS default inventory. Instead, we chose to use the ATC-21 method to inventory the most significant buildings in the two communities. This seemed like a cost-effective way to obtain the most critical building information for each community. Thus, rather than integrate the ATC-21 inventory into the default analysis, we performed the two analyses in parallel.

The important question is this: *What is the value added to the HAZUS analysis by performing an ATC-21 survey?* It seems to us that there must be a middle ground between relying completely on the default GBS inventory and doing a comprehensive inventory of one's own. There ought to be some value in augmenting the HAZUS defaults with field-collected data on the most important buildings in town. To answer this question, we consider three issues: (1) comparison of the ATC-21 and GBS inventories themselves, (2) comparison of the resulting damage estimates, and (3) evaluation of value of each method.

Comparison of ATC-21 and GBS inventories

This section compares the GBS and ATC-21 inventories, by occupancy and by structure type. It can show whether the two inventories are consistent with one another, confirm whether the GBS default inventory for each community is plausible, and estimate what proportion of the building stock is covered by the ATC-21 survey.

Tables 5-11 and 5-12 summarize both inventories for Carbondale, by building occupancy type. The ATC-21 survey represents 3.5% of the number of buildings in the GBS, but 39.0% of the floor area. This is consistent with our assumption that the ATC-21 survey includes the largest buildings in Carbondale.

Given that we know something about Carbondale, as represented by the ATC-21 survey, does the default GBS inventory seem plausible? Put another way: *Does the ATC-21 survey tell us enough to say whether or not the default GBS inventory reasonably represents buildings in Carbondale?* For the vast majority of the building stock, residential and commercial buildings, the GBS inventory appears to be reasonable. But for the specialized categories for which we tried to survey all buildings in Carbondale–education, government, and religious–the default inventory appears to underestimate the actual amount. The greatest discrepancies are for general government and for colleges, both reflecting the unique nature of Carbondale as a university town, with many associated governmental services. In addition, Carbondale has a large new city hall, which is not typical of most towns of this size.

Therefore, the GBS default inventory totals appear to represent the community reasonably well, but the ATC-21 inventory is useful in allowing us to focus attention on some of the more important buildings in the community, especially those at SIU.

Table 5-11
GBS and ATC-21 Inventories, by Specific Occupancy
Carbondale

		GBS (HAZUS Default)			ATC-21 Inventory		
Label	**Occupancy Class**	**Floor Area (1,000 sq. ft.)**	**Dollar Exposure ($1,000**	**No. of Bldgs.**	**Floor Area (1,000 sq. ft.)**	**Dollar Exposure ($1,000**	**No. of Bldgs.**
RES1	Single family	7,806	501,083	5,204			
RES2	Mobile home	2,417	109,090	2,417			
RES3	Multi Family	5,798	465,231	362	964	46,892	54
RES4	Temporary lodging	110	8,920	2	209	9,600	8
RES5	Dormitory	4,662	374,080	155	1,504	70,170	30
RES6	Nursing Home	90	6,861	2	271	12,646	6
COM1	Retail trade	1,225	62,672	86	1,806	166,074	26
COM2	Wholesale trade	303	10,336	8			
COM3	Personal/repair svcs.	504	34,367	43	303	19,430	21
COM4	Financial/Professional	684	50,098	19	74	6,199	9
COM5	Banks	105	12,159	5	38	3,639	4
COM6	Hospital	42	5,098	0	200	11,000	1
COM7	Medical Office	246	22,179	20	87	6,095	5
COM8	Entertainment/Rec.	305	30,867	23	105	7,458	13
COM9	Theaters	11	803	0	21	1,155	2
COM10	Parking	0	0	0			
IND1	Heavy Industry	265	13,576	5			
IND2	Light	313	16,017	15	30	1,650	1
IND3	Food/Drugs/Chem.	5	271	0			
IND4	Metals/Min Process.	0	0	0			
IND5	High Technology	0	0	0			
IND6	Construction	156	7,969	8			
AGRI	Agriculture	65	842	4			
REL1	Church	387	33,035	28	273	14,971	38
GOV1	General Services	66	4,404	1	342	19,665	13
GOV2	Emergency Response	0	0	0	38	3,965	6
EDU1	Schools	378	28,063	19	352	19,346	11
EDU2	Colleges	501	50,220	21	3,709	204,560	47
	TOTAL	**26,443**	**1,848,239**	**8,447**	**10,327**	**624,258**	**295**

Table 5-12
GBS and ATC-21 Inventories, by General Occupancy
Carbondale

	GBS (HAZUS Default)			**ATC-21 Inventory**			**ATC-21/GBS**	
Occupancy	**Floor Area (1,000 sq. ft.)**	**Dollar Exposure ($1,000**	**No. of Bldgs.**	**Floor Area (1,000 sq. ft.)**	**Dollar Exposure ($1,000**	**No. of Bldg**	**% Floor Area**	**% Bldgs**
Commercial	3,425	228,579	204	2,635	221,049	81	76.9	39.7
Educational	879	78,283	40	4,061	223,880	58	462.0	145.0
Government	66	4,404	1	380	23,351	19	575.8	1900.0
Industrial	739	37,833	28	30	1,650	1	4.0	3.6
Religious	387	33,035	28	273	14,972	38	70.5	135.7
Residential	20,883	1,465,265	8,142	2,948	139,356	98	14.1	1.2
TOTAL	**26,443**	**1,848,239**	**8,447**	**10,327**	**624,258**	**295**	**39.0**	**3.5**

We can also compare the two inventories by structure type, as shown in Table 5-13. The ATC-21 inventory exceeds the GBS inventory for the following structure types: Steel moment frame (S1), steel frame with concrete (S4), concrete moment frame (C1), concrete frame with URM infill (C3), pre-cast frames (PC2), and reinforced masonry (RM).

Table 5-13
GBS and ATC-21 Inventories by Structure Type
Carbondale

		GBS (HAZUS Default)			ATC-21 Inventory		
Label	**Structure Type**	**Floor Area (1,000 sq. ft.)**	**Dollar Exposure ($1,000)**	**No. of Bldgs.**	**Floor Area (1,000 sq. ft.)**	**Dollar Exposure ($1,000)**	**No. of Bldgs.**
W	Wood	12,697	909,560	4,390	1,189	56,837	96
S1	Steel Moment Frame	150	10,688	7	464	34,401	19
S2	Steel Braced Frame	315	22,744	16	257	14,135	2
S3	Steel Light Frame	519	32,633	27	61	3,330	3
S4	Steel Frame, Concr. Shear Walls	282	17,799	16	525	28,868	2
S5	Steel Frame, URM infill	346	22,174	19			
C1	Concrete Moment Frame	272	21,853	9	308	16,936	5
C2	Concrete Shear Walls	1,048	78,950	91	808	37,347	5
C3	Concrete Frame, URM infill	114	8,522	2	2,905	154,623	47
PC1	Precast Concrete Tilt-up	1,353	102,130	51			
PC2	Precast Frames, Concrete Shear Walls	208	16,121	7	236	12,962	1
RM	Reinforced Masonry	406	32,030	20	1,839	175,109	43
URM	Unreinforced Masonry	6,315	463,943	1,374	1,736	89,697	72
MH	Mobile Homes	2,417	109,090	2,417			
TOTAL		**26,443**	**1,848,239**	**8,446**	**10,327**	**624,258**	**295**

We can ask the same questions regarding the Sikeston inventories. Tables 5-14 and 5-15 summarize both inventories for Sikeston, by building occupancy type. The ATC-21 survey represents 1.5% of the number of buildings in the GBS, but 17.4% of the floor area. As with Carbondale, this is consistent with our assumption that the ATC-21 survey includes the largest buildings in Sikeston.

As was true in Carbondale, for the vast majority of the building stock, residential and commercial buildings, the GBS inventory appears to be reasonable. We tried to inventory all educational, governmental, and religious buildings, and, for the most part, the two inventories appear to be relatively consistent. As with Carbondale, the GBS inventory seems to underestimate floor area in government buildings. And it appears that the GBS inventory underestimates the amount of industrial space in Sikeston. As Carbondale is a university town, Sikeston is an industrial center, which is not completely captured by the default inventory.

Table 5-14
GBS and ATC-21 Inventories, by Specific Occupancy
Sikeston

		GBS (HAZUS Default)			ATC-21 Inventory		
Label	**Occupancy Class**	**Floor Area (1,000 sq. ft.)**	**Dollar Exposure ($1,000**	**No. of Bldgs**	**Floor Area (1,000 sq. ft.)**	**Dollar Exposure ($1,000)**	**No. of Bldgs**
RES1	Single family	10,350	595,498	6900			
RES2	Mobile home	845	34,184	845			
RES3	Multi Family	1,734	124,709	109	331	18,222	9
RES4	Temporary lodging	137	9,948	2	72	3,974	4
RES5	Dormitory	402	28,947	13			
RES6	Nursing Home	50	3,444	0	110	6,056	4
COM1	Retail trade	1,562	71,635	112	339	18,645	4
COM2	Wholesale trade	1,028	31,427	30	133	7,322	5
COM3	Personal/repair svcs.	553	33,799	47			
COM4	Financial/Professional	1,021	67,031	29			
COM5	Banks	89	9,270	4	48	2,640	1
COM6	Hospital	133	14,468	1	292	16,088	4
COM7	Medical Office	178	14,402	15			
COM8	Entertainment/Rec.	241	21,909	18			
COM9	Theaters	3	206	0			
COM10	Parking	0	0	0			
IND1	Heavy Industry	475	21,778	10			
IND2	Light	156	7,149	8	924	36,982	11
IND3	Food/Drugs/Chem.	72	3,288	4	343	18,876	8
IND4	Metals/Min Process.	130	5,961	8			
IND5	High Technology	0	0	0			
IND6	Construction	244	11,186	14			
AGRI	Agriculture	193	2,255	14			
REL1	Church	244	18,663	16	324	17,824	35
GOV1	General Services	46	2,780	0	41	4,477	7
GOV2	Emergency Response	6	609	1	64	3,520	10
EDU1	Schools	611	40,627	30	537	29,543	22
EDU2	Colleges	6	494	0			
	TOTAL	**20,510**	**1,175,671**	**8,230**	**3,561**	**184,140**	**124**

Table 5-15
GBS and ATC-21 Inventories, by General Occupancy
Sikeston

	GBS (HAZUS Default)			ATC-21 Inventory			ATC-21/GBS	
Occupancy	**Floor Area (1,000 sq. ft.)**	**Dollar Exposure ($1,000**	**No. of Bldgs.**	**Floor Area (1,000 sq. ft.)**	**Dollar Exposure ($1,000**	**No. of Bld g**	**% Floor Area**	**% Bldgs**
Commercial	4,808	264,147	256	812	44,695	14	16.9	5.5
Educational	617	41,121	30	537	29,543	22	87.0	73.3
Government	52	3,389	1	105	7,997	17	201.9	1700.0
Industrial	1,077	49,362	44	1,267	55,858	19	117.6	43.2
Agriculture	193	2,255	14	0	0	0	0.0	0.0
Religious	244	18,663	16	324	17,824	35	132.8	218.8
Residential	13,518	796,730	7,869	513	28,252	17	3.8	0.2
TOTAL	**20,510**	**1,175,671**	**8,230**	**3,561**	**184,140**	**124**	**17.4**	**1.5**

We can also compare the two Sikeston inventories by structure type, as shown in Table 5-16. The ATC-21 inventory exceeds the GBS inventory for the following structure types: steel moment frame (S1), steel light frame (S3), and reinforced masonry (RM). For both Carbondale and Sikeston, the ATC-21 inventories report significantly more RM than the GBS default inventory. This may reflect a consistent underestimation in the HAZUS default. But it is also true that it is often difficult to distinguish RM from URM by visible inspection, as was done in the ATC-21 surveys.

Table 5-16
GBS and ATC-21 Inventories by Structure Type
Sikeston

		GBS (HAZUS Default)			ATC-21 Inventory		
Label	**Structure Type**	**Floor Area (1,000 sq. ft.)**	**Dollar Exposure ($1,000)**	**No. of Bldgs.**	**Floor Area (1,000 sq. ft.)**	**Dollar Exposure ($1,000)**	**No. of Bldgs.**
W	Wood	10,815	643,447	5,414	380	20,896	13
S1	Steel Moment Frame	175	9,352	7	401	22,048	18
S2	Steel Braced Frame	369	20,202	19	88	4,856	1
S3	Steel Light Frame	756	38,553	38	883	33,112	18
S4	Steel Frame, Concr. Shear Walls	409	20,879	20	0	0	0
S5	Steel Frame, URM infill	489	24,923	25	70	3,844	3
C1	Concrete Moment Frame	100	5,763	3	38	2,090	2
C2	Concrete Shear Walls	521	28,727	25	0	0	0
C3	Concrete Frame, URM infill	54	2,598	1	52	3,237	4
PC1	Precast Concrete Tilt-up	617	33,003	26	22	1,240	2
PC2	Precast Frames, Concrete Shear Walls	65	3,471	1	0	0	0
RM	Reinforced Masonry	40	14,806	13	1,344	75,401	46
URM	Unreinforced Masonry	5,053	295,760	1,793	284	17,442	17
MH	Mobile Homes	845	34,184	845	0	0	0
TOTAL		**20,510**	**1,175,671**	**8,230**	**3,561**	**184,140**	**124**

Comparison of HAZUS Loss Estimates From the Two Methods

How do the HAZUS loss estimates differ for the two inventories? We applied HAZUS to estimate losses to both inventories, but it was necessary to apply two different HAZUS modules to the task. HAZUS uses one method to estimate losses to General Building Stock, applying the GBS module to the GBS inventory. For user-defined structures, one must use the User-defined Facilities Module, as described in Chapter 4.

These two modules operate in slightly different ways and report their results differently. Tables 5-17 and 5-18 summarize the loss estimates using the two methods for both Carbondale and Sikeston. To make them as comparable as possible, this table reports the loss estimates for the GBS inventory for the sum of structural and nonstructural direct losses only, and the loss estimates for the ATC-21 inventory (using the user-defined facilities module) are for building reconstruction costs.

Table 5-17
Structural and Nonstructural Loss Estimates, GBS and ATC-21 Inventories, Carbondale (thousands of 1994 $)

Scenario	Loss Estimate, GBS inventory	Loss Estimate, ATC-21 Inventory	ATC-21 Loss as Proportion of GBS Loss
M5, 0 km	42,755	10,867	25.4%
M5, 10 km	30,254	8,420	27.8%
M5, 25 km	8,206	2,491	30.4%
M5, 50 km	1,039	209	20.1%
M5, 100 km	0	0	NA
M5.5, 0 km	119,319	34,925	29.3%
M5.5, 10 km	84,783	23,130	27.3%
M5.5, 25 km	35,666	9,600	26.9%
M5.5, 50 km	5,627	1,326	23.6%
M5.5, 100 km	857	137	16.0%
M6, 0 km	237,210	88,674	37.4%
M6, 10 km	184,219	64,109	34.8%
M6, 25 km	260,466	29,570	11.4%
M6, 50 km	20,269	5,889	29.1%
M6, 100 km	4,414	1,060	24.0%
M7, 116 km	36,815	10,183	27.7%
M7, 173 km	15,394	4,319	28.1%
M7, 234 km	5,689	1,603	28.2%
M7, 295 km	2,577	702	27.2%
M8, 116 km	280,764	67,716	24.1%
M8, 173 km	161,821	43,609	26.9%
M8, 234 km	84,847	21,978	25.9%
M8, 295 km	39,682	10,507	26.5%

Table 5-18
Structural and Nonstructural Loss Estimates, GBS and ATC-21 Inventories
Sikeston (thousands of 1994 $)

Scenario	Loss Estimate, GBS inventory	Loss Estimate, ATC-21 Inventory	ATC-21 Loss as Proportion of GBS Loss
M5, 0 km	19,952	3,505	17.6%
M5, 10 km	14,145	2,510	17.7%
M5, 25 km	3,922	684	17.4%
M5, 50 km	627	96	15.3%
M5, 100 km	0	0	NA
M5.5, 0 km	60,888	8,592	14.1%
M5.5, 10 km	41,086	5,959	14.5%
M5.5, 25 km	18,243	2,767	15.2%
M5.5, 50 km	4,002	605	15.1%
M5.5, 100 km	390	62	15.9%
M6, 0 km	110,912	15,988	14.4%
M6, 10 km	89,083	12,328	13.8%
M6, 25 km	45,585	6,302	13.8%
M6, 50 km	13,142	2,175	16.5%
M6, 100 km	2,110	357	16.9%
M7, 34 km	128,138	17,919	14.0%
M7, 63 km	47,972	7,558	15.8%
M7, 122 km	14,890	2,612	17.5%
M7, 184 km	5,443	910	16.7%
M8, 34 km	363,786	54,127	14.9%
M8, 63 km	201,542	30,319	15.0%
M8, 122 km	111,566	16,333	14.6%
M8, 184 km	49,321	8,948	18.1%

For both cities, the ratios of ATC-21 loss estimates to GBS loss estimates are relatively consistent among the scenarios. For Carbondale, the proportions range from 11.4% to 37.4%, but 18 of the 23 scenarios have proportions in the range of 20% to 30%. For Sikeston, all the scenarios have proportions in the range of 13.8% to 18.1%. For Sikeston, this proportion is relatively consistent with the ATC-21 inventory's 17.4% proportion, by floor area, of the GBS inventory. For Carbondale, this proportion is less than the corresponding floor area proportion of 39.0%.

These tables illustrate a few points. First, they are not inconsistent with our assumption that the ATC-21 inventory represents a subset of the overall building inventory in each community. Second, they are consistent with our assumption that, although the ATC-21 inventory represents a small sample of the number of buildings in each community, it represents the largest buildings and therefore a significant proportion of the overall building floor area in the community. Third, they show that by accomplishing an ATC-21 inventory according to the criteria we used, we are able to evaluate buildings that represent about 15% to 30% of the community's direct economic losses in an earthquake.

Value of Conducting an ATC-21 Survey

Conducting an ATC-21 survey of significant buildings complements the default HAZUS analysis in several ways:

- The act of performing the survey allows one to become more familiar with the potential vulnerability of key buildings.

- As shown in Chapter 2, there are many ways to use an ATC-21 survey to analyze the vulnerability of building stock, even without performing HAZUS loss estimates.

- The ATC-21 inventory provides a useful, albeit imperfect, calibration check on the structural and occupancy categories in the default General Building Stock inventory in HAZUS.

- By selecting appropriate buildings, it is feasible to conduct an ATC-21 survey of the most significant buildings in a community, about 2% to 4% of the total number of buildings. In doing so, it is possible to account for approximately 15% to 30% or more of the total floor area and total potential direct economic damage in the community.

- One can use the user-defined module of HAZUS to perform loss estimates of the ATC-21 inventory. Such estimates provide a complement to the default analyses of the GBS module. Because of the inherent uncertainties in loss estimation, additional forms of estimation can add depth to the overall analysis.

- Such loss estimates provide the opportunity to perform more detailed assessments of specific classes of significant buildings.

- The key buildings in the ATC-21 inventory have more importance than can be measured by direct economic damages. Some are essential facilities, needed to respond to disasters. Some are important symbols. All are critical to the functioning of the community.

Summary of ATC-21/HAZUS Integration

How feasible is it to integrate ATC-21 inventories into HAZUS?

It is quite easy to apply HAZUS loss estimation to an ATC-21 inventory of buildings, using the User-defined Facilities module. This allows the user to focus the loss estimate on an actual set of buildings of interest in the community. In this case, we were able to obtain loss estimates for the most significant buildings in each community. If we chose, we also could have calculated subtotals by occupancy and structure types.

What is the value added by augmenting HAZUS with ATC-21?

This question assumes that it is normally difficult to perform an ATC-21 survey of all the buildings in a community. We found that the default inventories appear to represent the community reasonably well, in the aggregate. Thus, HAZUS loss estimates of default data can give community-wide loss estimates, whereas the ATC-21 survey allows one to focus on key buildings. Both approaches are useful. We found that it is feasible to conduct an ATC-21 survey of the most significant buildings in a community, representing about 2% to 4% of the total number of buildings. By picking the largest buildings, this method accounts for approximately 15% to 30% of the total floor area and of the potential direct economic damage in the community.

USE OF HAZUS IN MID-AMERICAN COMMUNITIES

Questions regarding use of HAZUS:

- ***a.*** ***How easy is HAZUS to use? What are the hardware, software, and operator requirements? How appropriate is it for use by communities in Mid-America?***
- ***b.*** ***Does HAZUS give plausible results? (It has not yet been tested in this part of the country).***
- ***c.*** ***How sensitive is HAZUS to the inputs of vulnerability and hazard?***

Feasibility of Using HAZUS

HAZUS is designed for desktop computers with typical hardware characteristics. For example, the newest version (released in early 2002), HAZUS 99 SR-2, is recommended for a Pentium 800MHz or better, with at least 128 MB of RAM. Although HAZUS is free, it requires the user to purchase MapInfo or ArcView. Both of these are relatively common geographic information system software in many municipal and county offices. On the other hand, smaller offices are less likely to have the software or the capability to acquire and learn it.

As a test of transferability, we set up HAZUS in the Community Development Department in the City of Urbana, Illinois, and we trained one of the planning staff members in its use. Although quite feasible, this required some effort and expense. Because HAZUS has very specific requirements regarding which versions of Windows and ArcView it operates on, Urbana had to purchase a computer solely dedicated to running HAZUS. Secondly, because a comprehensive HAZUS study is time-consuming, Urbana needed to hire one of our students (previously trained on HAZUS on another MAE Center project) to perform the analysis.

Based on this experience, we believe that it is feasible for medium-sized communities in Mid-America to acquire, learn, and use HAZUS to analyze their earthquake risk. But such an effort should not be taken lightly. It could require several thousand dollars of hardware and software, as well as a time commitment for training and for performing the analysis. Although a few trial HAZUS runs can be performed in a matter of a few hours, a comprehensive effort would require approximately 100 to 200 hours of staff time.

We also note that we encountered some difficulties with using HAZUS, which added significantly to the labor time. We hope many of these issues will be resolved in future versions of the software.

FEMA and states could facilitate the use of HAZUS by providing more opportunities for local training sessions and more reliable technical support. Future versions of HAZUS would be more usable if designed to run on a variety of Windows operating systems as well as previous versions of ArcView and MapInfo. It would also be helpful to issue updates to allow previous HAZUS versions to run on new releases of ArcView and MapInfo. Finally, states should consider ways to provide assistance for consortia of smaller communities to perform loss estimates and risk analyses using HAZUS.

Plausibility of Results

Limitations of HAZUS

The "Message to Users" preceding the *HAZUS User's Manual* (NIBS, 1999, gives several warnings relevant to this study:

(1) "...the losses from small magnitude (less than M 6.0) earthquakes appear to be overestimated."

(2) "Uncertainty related to the characteristics of ground motion in the Eastern U.S. is high. Conservative treatment of this uncertainty may lead to overestimation of losses in this area, particularly for buildings and infrastructure located close to the projected earthquake source."

Communication with one of the developers of HAZUS confirmed that for earthquake events smaller than M 5.5, the default HAZUS results tend to overestimate damages (Jawhar Bouabid, personal communication, April 10, 2001). This was confirmed by the

M5.0 June 18, 2002 earthquake, which occurred approximately 10 miles from Evansville, Indiana, but caused only some cracked chimneys and broken glass in that city.

Thus, we know that the results reported herein are uncertain, and that they probably overestimate damage from small earthquakes and from nearby earthquakes. The difficulty, of course, is that we do not know the extent of the overestimation, and we cannot truly know how well HAZUS estimates losses for the Central and Eastern U.S. until we have a moderate or large earthquake in this region in modern times.

According to a recent study on uncertainty in HAZUS conducted for Oakland, California (Grossi, 2000), the ranking of factors that HAZUS outputs (direct economic loss estimates) are sensitive to is "(1) ground attenuation function, (2) earthquake recurrence, (3) residential inventory exposure, (4) soils mapping scheme/structural fragility before mitigation, and (5) structural fragility after mitigation (p. 203). This is instructive, although the work by Grossi is not fully comparable to our study because of the seismological difference in the West Coast and Mid-America.

In addition, according to the HAZUS user manual (NIBS, 1999a), certain outputs by HAZUS are not quite reliable. Specifically, these outputs include:

1. Consequences of M = 6 or M = 7.5 earthquakes, because the implications of very short and very long durations of ground motions upon damage are poorly understood.

2. Results for non-structural damage because coefficients for non-structural damage are based upon less complete data than that of structures.

3. Casualty results, because coefficients for casualty estimates are based primarily upon damage from earthquake events that occurred in suburban areas at times of the day when people were generally not occupying commercial structures.

Consequently, as mentioned in the HAZUS user manual (NIBS, 1999a), HAZUS outputs should not be regarded as a precise prediction but rather as an indication of what the future may hold. This is particularly true in Mid-America where seismicity is poorly understood.

Sources of Uncertainty

Risk analysis is a highly uncertain enterprise, particularly when it concerns unfamiliar phenomena such as earthquakes in Mid-America. Use of HAZUS has considerable uncertainty even in California, which has much more complete seismic risk models, based on more substantial earthquake experience than in Mid-America (Grossi, 2000).

Our analysis contains several sources of uncertainty: in knowledge of earthquake hazard in Mid-America, in the building inventories, in the structure damage functions, in the models within HAZUS, and in our application of HAZUS. The chief sources of uncertainty are detailed below.

First, the hazard itself is poorly understood, as discussed in Chapter 3 and earlier in Chapter 5. Johnston and Nava (1985) assume standard deviations of 21% to 24% of their estimates of average earthquake recurrence intervals. For smaller earthquakes farther away from the New Madrid seismic zone, such as near Carbondale, the standard deviations could be much greater.

Second, knowledge of ground-shaking attenuation (the decay of ground-shaking by its distance from the epicenter) in Mid-America is very poor. Attenuation models in this part of the country are based on a few small earthquakes and on qualitative reports of shaking from the 1811-1812 events. In HAZUS, we used the "Project 97 East Coast" attenuation function, which is a USGS-derived average of the two other attenuation functions offered by HAZUS (Frankel, 1996; and Toro, Abrahamson, and Schneider, 1997). These three HAZUS attenuation functions predict ground motions quite differently. Table 5-19 presents an example illustrating the effect of attenuation function on **M**8 HAZUS loss estimates, and Figure 5-5 illustratively compares these results. As both show, assuming other conditions unchanged and using default inputs in HAZUS, the Frankel (1996) attenuation function predicts the highest direct economic losses in Carbondale while the Toro et al (1997) attenuation function predicts the lowest. Compared to our estimates using Project 97 East Coast, the Frankel attenuation function would produce loss estimates 28% higher for closer events up to 230% higher for more distant **M**8 events. Conversely, the Toro et al attenuation function would produce loss estimates lower than ours by 37% for closer **M**8 events and 78% for the more distant ones. This example demonstrates that HAZUS outputs are very sensitive to the choice of a HAZUS attenuation function. Furthermore, it is not possible to judge which attenuation function best simulates the actual characteristics of potential ground motions because little historical seismic evidence exists in Mid-America.

Table 5-19 Direct economic losses for default GBS inventory by attenuation function (thousands 1994 $), Carbondale

Scenario	Frankel (1996)	Project 97 East Coast	Toro, Abrahamson & Schneider (1997)	Range
M8, 116 km	576,964	449,912	284,609	292,355
M8, 173 km	452,035	266,862	122,796	329,239
M8, 234 km	270,405	143,447	44,130	226,275
M8, 295 km	162,771	69,917	15,229	147,542

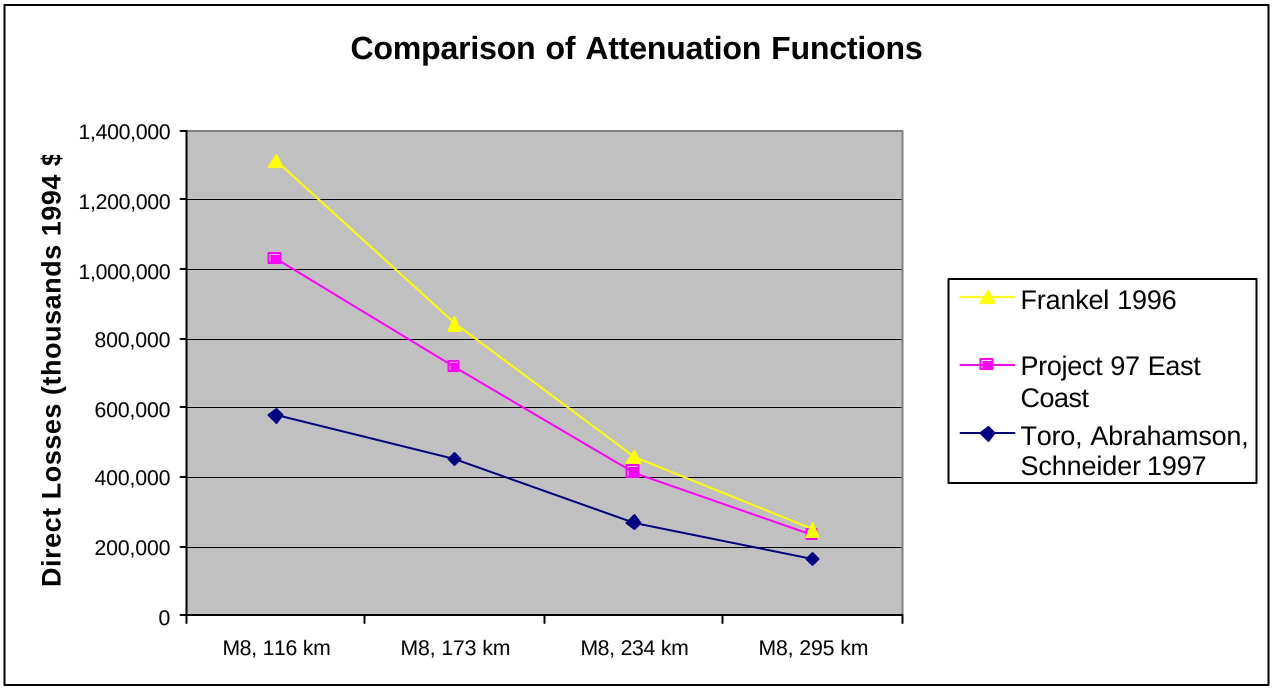


Figure 5-5. Comparison of the three attenuation functions in HAZUS (Carbondale M8 scenarios)

Third, the default inventory is an imperfect representation of each community. Default inventories in HAZUS are from publicly available databases and aggregated on a county or census tract scale. Many of these databases are either out of date, overly generalized, or inaccurate. In addition, such databases do not capture data characteristics of a specific community that may have a wide variety of ages, sizes, shapes, and structural systems of buildings constructed under diverse seismic design codes. To address these issues, HAZUS has to make some general assumptions (NIBS, 1999a). For example, the default general building stock inventory in HAZUS in the Carbondale case was created based upon an assumption that Carbondale is a typical Midwest community, even though it is atypical because it is a university town. As a result, Carbondale has considerably more educational and governmental buildings than assumed by the HAZUS default.

Fourth, the models within HAZUS of building response to shaking are based on a limited number of earthquakes, most of which occurred in California. Thus, the building vulnerability estimates contain significant uncertainty. Limited data and available theories are used to estimate default parameters in order to establish relationships between a few key features of ground shaking and average damage and associated losses for each category. These default parameters are calibrated by using historical seismic evidence collected in the Western U.S. Because historical records of seismic damage in Mid-America are insufficient, however, the default parameters are not calibrated for Mid-America.

Fifth, casualty estimates are particularly uncertain (National Institute of Building Sciences, 1999a), because data are not available across all building types, and injury data are not of high quality. Even less certain, because of insufficient data from, are the models of functionality of essential facilities and the models of fire following earthquake.

Sixth, we accepted the HAZUS default for soil conditions. Variations in site soils can affect the amplitude of ground motions significantly. As an example, Table 5-20 presents the sensitivity of HAZUS outputs to the choice of on-site soil type, and Figure 5-6 illustratively compares five soil types defined by HAZUS (NIBS, 1999a). As both show, assuming other conditions unchanged and using default inputs in HAZUS and the attenuation function "Project 97 East Coast", HAZUS outputs are very sensitive to soil type, and softer soils tend to amplify certain frequencies within the ground shaking, resulting in greater damage. Specifically, if parts of our study areas have firmer Type C soils, they would have about 36% to 61% less economic loss than calculated for Type D soil. Conversely if parts of our study areas have softer Type E soils, they would have about 70% to 200% more economic loss than calculated for Type D soil.

Table 5-20. Direct economic losses for default GBS inventory by soil type (thousands 1994 $), Carbondale

Scenario	**Type A** Hard Rock	**Type B** Rock	**Type C** Very Dense Soil	**Type D** Stiff Soil	**Type E** Soft Soil	Range
M8, 116 km	83,966	143,316	286,275	449,912	759,558	675,592
M8, 173 km	41,690	71,096	145,815	266,862	579,301	537,611
M8, 234 km	17,737	33,394	63,106	143,447	369,804	352,067
M8, 295 km	7,062	15,516	27,031	69,917	213,412	206,350

Note: Attenuation function is "Project 97 East Coast", and other inputs are default. Soil types from NIBS (1999a).

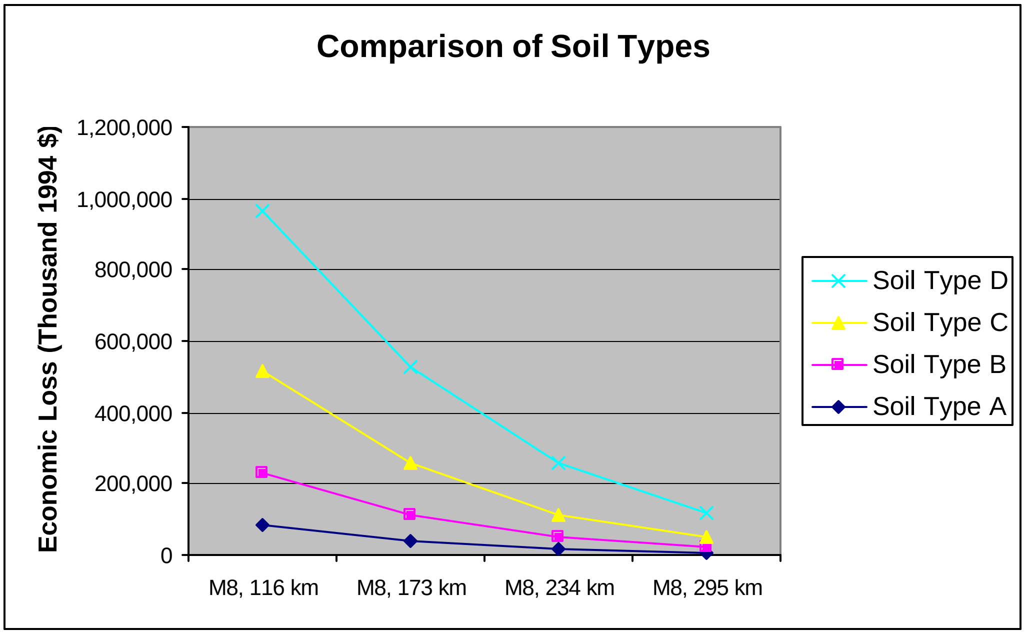


Figure 5-6. Comparison of five soil types in HAZUS (Carbondale M8 scenarios).

Since our analysis was completed, the CUSEC State Geologists completed soil amplification mapping of the area around the New Madrid seismic zone, including Carbondale and Sikeston (Bauer et al, 2001). According to their map, Sikeston is underlain by very soft, potentially liquefiable Type F soils. This means that Sikeston probably would have on the order of twice or more economic loss than we estimated, using the HAZUS default of Type D soil.

Similarly, the CUSEC State Geologists' map shows Carbondale as likely underlain by Type C or Type B soils. This means that Carbondale probably would have on the order of one-third to one-half the economic loss that we estimated, using the HAZUS default of Type D soil.

Limitations of the Annualized Loss Model

In addition to the uncertainties detailed above, our annualized loss model makes several simplifying assumptions in order to use 23 earthquakes to represent a continuum of all possible earthquakes to strike Carbondale and Sikeston. It is difficult to say whether this simplified hazard model systematically overestimates or underestimates the true risk.

With regard to using one scenario to represent a broad magnitude range, each scenario represents a set of earthquakes that are larger–but less probable–than itself. Given that risk equals the product of damage times probability, the question is which effect is greater: the decrease in probability with magnitude or the increase in damage cost with magnitude? Our risk estimates indicate that the latter is the greater effect, and thus this aspect of our model probably *underestimates* the true risk. For example, using the damage from a **M** 5.5 event to represent all earthquakes between **M** 5.5 and **M** 6.0

probably underestimates the true risk of this range of earthquakes. This is because for earthquakes larger than **M** 5.5 (e.g. 5.8) the product of probability times damage is greater than for **M** 5.5.

With regard to the simplification of earthquake locations into a discrete set of five distances, systematic bias is less apparent. Because each scenario is at the distance midpoint (though, admittedly, not the area midpoint) of the range of earthquakes it represents, it will underestimate risk for some while overestimating for others. We have not had the opportunity to analyze any systematic effects of this aspect of our model, but we assume it is small.

Given all the assumptions in our risk model, it seems likely that, if there is any systematic bias, the earthquake hazard part of our model probably leads to underestimation of the true risk. Based on this aspect alone, we estimate that the true risks may be 10% to 60% greater than our model's estimates. But this must be considered in the context of other uncertainties, such as soil variations, higher frequencies of large events (based on recent paleoseismic work), and HAZUS' substantial overestimation of damage from moderate earthquakes in Mid-America.

Alternative Risk Analysis Method: HAZUS Probabilistic Loss Option

HAZUS also has the capability to estimate probabilistic losses, based on USGS probabilistic shaking maps. Using the USGS maps, it estimates losses that would occur from groundshaking intensities with return periods of 100, 250, 500, 750, 1000, 1500, 2000, and 2500 years.

We chose not to use this approach because it is less accessible to lay users and less useful for scenario planning. Still, it is an equally valid approach, and its results provide another piece of information to help Carbondale and Sikeston in understanding their earthquake risk.

We used HAZUS to compute probabilistic losses for Carbondale and Sikeston (Table 5-21). HAZUS also uses these values to estimate annualized losses. These totals for Sikeston and Carbondale are approximately double our estimates. This reflects at least two reasons. First, as discussed above, our method probably underestimates total risk, such that true risk may be about 10% to 60% greater. Second, the USGS maps use a different hazard probability model, based on a variety of sources. The annualized results from these two methods help to further illustrate some of the range of uncertainty in estimating long-term earthquake losses in Mid-America.

Table 5-21 Probabilistic and Annualized Losses from HAZUS

Return Period	Direct Losses to Buildings (1994 $1,000)	
	Carbondale	Sikeston
100 years	$14,582	$3,920
250 years	$63,612	$29,940
500 years	$187,599	$108,369
750 years	$321,108	$227,491
1000 years	$416,143	$363,558
1500 years	$558,406	$675,485
2000 years	$681,239	$955,745
2500 years	$790,599	$1,110,617
ANNUALIZED	**$1,288**	**$1,163**

Summary of Use of HAZUS

How easy is HAZUS to use by communities in Mid-America?

As a test of transferability, we set up HAZUS in the Community Development Department in the City of Urbana, Illinois. Based on this experience, we believe that it is feasible for medium-sized communities in Mid-America to acquire, learn, and use HAZUS to analyze their earthquake risk. But such an effort should not be taken lightly. It could require several thousand dollars of hardware and software, and a comprehensive effort would require approximately 100 to 200 hours of staff time, following initial training. We also recommend that FEMA offer more opportunities for local training, more reliable technical support, and the capability to run HAZUS on a variety of Windows operating systems and several releases of ArcView and MapInfo software.

Does HAZUS give plausible results?

We believe that the HAZUS results are plausible, in the sense that they are a reasonable indication of what the future may hold (to use the words of the HAZUS User Manual). But some aspects are less reliable than others, because of limited data from previous earthquakes. For Mid-America, the User Manual warns that HAZUS overestimates losses from **M** < 6.0 earthquakes, and probably also overestimates losses from earthquakes close to the study area. In addition, HAZUS is limited by the lack of data for **M** > 7.5 earthquakes, nonstructural losses, and casualties.

How sensitive is HAZUS to the inputs of vulnerability and hazard?

HAZUS is highly sensitive to all of the vulnerability and hazard inputs. Regarding vulnerability, we were not able to test the sensitivity of HAZUS to this, although it is obvious that the results directly follow from the input inventories. If an inventory overestimates the total floor area of buildings, or the proportion of poor quality buildings, then the HAZUS loss estimates would reflect this.

With respect to hazard, we looked at the sensitivity of our results by attenuation function, soil type, and earthquake probabilities. HAZUS outputs are highly sensitive to the choice of attenuation function; for example, compared to our estimates using Project 97 East Coast, the Frankel attenuation function would produce loss estimates 28% higher for closer events up to 230% higher for more distant **M**8 events. Furthermore, based on existing data, there is no way to know which attenuation function is most appropriate. Regarding soils, if parts of our study areas have firmer or softer soils than the mean Type D we selected, they could have as little as 39% or as much as 300% of the economic loss that we estimated. Regarding earthquake probabilities, our own assessment suggests that our method underestimates risk such that true risk may be about 10% to 60% greater. The USGS probabilistic model suggests risk about 100% greater than our estimate.

CHAPTER 6
CONCLUSIONS

What have we learned about earthquake risk in Mid-America communities, and what are the implications for local mitigation and preparedness actions? How might earthquakes affect cities in Mid-America, and how likely are such earthquakes to occur in our lifetimes and the lifetimes of the communities? In addressing these questions, we performed a variety of different types of analyses, all aimed at understanding the potential effects of earthquakes on people, structures, and essential services. This report presents an often-dizzying array of tables, diagrams, and calculations to provide different ways of looking at the problem. Here we try to summarize the major factual findings and their implications.

ANALYTICAL CONCLUSIONS

1. **The earthquake threat is real, with a finite chance of a damaging earthquake within the next 20 to 50 years.** Economic damage is likely to occur, and life-endangering events have a finite chance of occurring during the life of the community.

   The expected annual direct loss is approximately $500,000 for Carbondale, and $600,000 for Sikeston. This translates into $10 to $30 million for each community over the next 20 to 50 years. The full economic effects on the communities would be much greater.

   Each community has a 2.8% chance per year of experiencing a damaging earthquake. This translates to a 44% to 76% chance of a damaging earthquake over the next 20 to 50 years.

2. **Significant risk is represented by both low frequency/high consequence events (e.g., M8+ and M7) and higher frequency/lower consequence events (e.g., M5.5 and M6).** It is difficult to make definitive conclusions regarding which type of risk is most important.

   The greatest economic risk to Carbondale comes from **M** 6.0-7.0 and **M**8.0+ events. In Sikeston, it is the largest earthquakes (**M** > 7.0) that represent most of the annualized losses.

   Smaller earthquakes pose a threat, because they are relatively more likely to occur. For example, M < 6.0 earthquakes are expected to affect Carbondale every 20 years, and would cause, on average, $2 to $5 million in damage over the next 20 to 50 years.

   Even large earthquakes, though rare, have a finite chance of occurring over the next 20 to 50 years. For example, although a **M** > 7.0 earthquake is expected to occur, on average, every 389 years, it has a 12% chance of occurring over the next 50 years. Such an event could cause significant damage and injuries in Sikeston in particular.

3. **Life safety does not appear to be a major concern, except in the largest, rarest earthquakes.** This statement, however, needs to be tempered with the understanding that the casualty estimation model in HAZUS is currently based on limited data.

   Even over a 70-year life span, Carbondale would expect to have seven injuries needing hospitalization and 0.6 deaths (this could be read as "60% chance of one death"), and Sikeston would have 12 injuries requiring hospitalization and 1.3 deaths. In both communities, the **M** 8.0+ earthquakes represent the greatest risk to human life.

   Our analysis of two typical SIU dormitories suggests that it is unlikely that they will have any earthquake-related casualties during their lifetime, assuming that they are of typical construction quality.

4. **There is a small, but finite, chance that vital services will be overwhelmed.**

   In both Carbondale and Sikeston, several of the scenarios predict straining or exceeding the capacity of hospitals or emergency services to respond. For each community, there is approximately a 2.5% to 6.0% chance that such an event could occur in the next 20 to 50 years.

   Although the chances are relatively small, the probability is much greater than zero, and the consequences of such an event would be unacceptable.

5. **According to the ATC-21 building surveys, a number of buildings in each community warrant further inspection.**

   Of the 295 buildings surveyed in Carbondale, 151 of them (51%) have ATC-21 scores less than or equal to 2.0, which means they require further inspection. Education is the occupancy category with the greatest amount of floor space in low-scoring buildings. This reflects both the high proportion of unreinforced masonry in the public schools as well as the high proportion of concrete-frame buildings at Southern Illinois University

   Of the 124 buildings surveyed in Sikeston, 69 of them (56%) have scores less than or equal to 2.0. These represent 44% of the floor area in the inventory. All occupancy categories contain significant amounts of low-scoring buildings. Educational, religious, and government buildings all have greater than two-thirds of their floor space in low-scoring buildings.

Vulnerable structure types in the two study areas include unreinforced masonry, reinforced masonry, and concrete frame; which are common among important educational, governmental, residential, and commercial buildings in the two communities studied.

Although HAZUS analysis indicates that these buildings probably do not pose life safety risks, this assumes that they are of at least average construction quality. Given the level of earthquake hazard in Mid-America, it would seem prudent to inspect these buildings, especially high occupancy buildings and those that provide essential services.

6. **Most medium-sized communities should be able to acquire, learn, and use HAZUS to analyze their earthquake risk.**

   Such an effort, however, should not be taken lightly. Earthquake-prone communities would benefit from having in-house capability to run HAZUS on desktop computers. This may require an investment of several thousand dollars in hardware and software, if appropriate hardware and GIS software are not already in the office. It would also require some initial training, and a comprehensive risk analysis would require approximately 100 to 200 hours of staff time.

7. **Most medium-sized communities have the capability to perform an ATC-21 survey of the most important buildings in town.**

   The survey requires 30 minutes or less per building, and can easily be performed by appropriate city staff. The method is easy to learn for those in building-related fields. By selecting appropriate buildings, it is feasible to survey the most significant buildings in town, about 2% to 4% of the total number of buildings. This can account for approximately 15% to 30% of the total floor area and potential direct economic damage in the community.

   Performing the survey provides many benefits, such as: gaining familiarity with vulnerability of key buildings, identifying buildings and building types most in need of further attention, and supplementing HAZUS with structure-specific analyses of key buildings.

POLICY IMPLICATIONS

In deciding how to best use this information, local officials, property owners, and facility managers need to consider several key points. First, they need to think in an appropriate time frame. Although many of us generally think in terms of one budget year (or month) at a time, it is important to consider the risk that earthquakes pose to the longer-term lifetime of the community. Prudent decisions would consider expected consequences over the next 20 to 50 years. Second, they need to consider the potential consequences of earthquakes. Are the threats to property or lives? What types of property? What about special needs populations, such as the elderly and children? Would damage to infrastructure and essential facilities have potential far-reaching consequences? Third, they need to consider what they can feasibly accomplish. It is easier, for example, to construct new buildings according to seismic design principles than it is to retrofit existing buildings.

Communities need to balance the costs of achieving seismic safety—including monetary costs, time, and labor—against the benefits to be achieved, in full recognition of the characteristics of seismic risk in their location. The following list, appropriate to the level of seismic risk in Mid-America, identifies feasible actions that all communities in this area should take, in priority order.

1. **At a minimum, communities in Mid-America must be prepared to respond to future earthquakes.**

   Because risks are posed by earthquakes of all magnitudes, communities should prepare to respond to the largest (M 8.0+) events. Although it may seem odd to prepare for an event of low likelihood, this is the best way to ensure preparedness for the broad range of earthquakes that could occur.

2. **Adoption and enforcement of current seismic building codes is the best way to ensure the safety of all buildings constructed from today into the future.**

   In the long run, constructing new buildings to be earthquake resistant will lead to communities that are earthquake resistant. It is far easier to ensure the quality of new buildings than to discover a need to retrofit them later on. All the national model building codes, now integrated into the International Building Code, have seismic provisions developed through national consensus processes of engineers and building officials. They are also based on the latest USGS seismic hazard maps. These codes are widely used, inexpensive, and widely accepted as the standard of practice for new buildings. Even so, not all communities have adopted them, and not all communities implement them effectively. Adopting and enforcing these codes will ensure that all new buildings are as earthquake-resistant as possible.

3. **Communities should inspect all potential high-risk, high-occupancy, high-importance buildings to verify their worthiness to withstand seismic shaking.**

   An important first step to minimizing risk is to identify existing high-risk structures. Our study has shown the feasibility and efficacy of performing an ATC-21 rapid visual survey of important structures. Based on these results, communities can arrange for structural inspections of potential high-risk structures. This information can then become the basis for establishing priorities for strengthening or replacement.

4. **Strengthening efforts should focus on essential facilities and other key uses.**

   Although life safety appears to be a minimal risk, our analysis estimates a 6% chance of an earthquake straining or exceeding the capacity of hospitals or emergency services to respond in each community sometime during the next 50 years. The consequences of such an event would be unacceptable.

   For other uses, where economic damage is the only risk, owners may be more willing to wait until the end of the economic life of older buildings before replacing them. As long as their replacements follow modern seismic design requirements, this is another—albeit incremental--way of ensuring that seismic safety improves over the next 20 to 50 years.

In conclusion, this research illustrates the characteristics and magnitude of seismic risk to communities in Mid-America. It also demonstrates methods appropriate for accomplishing such an analysis.

This study takes an important step in describing the earthquake risk characteristics of two typical Mid-American communities. It describes the types of buildings at risk and estimates the probabilities of damaging events. Although earthquakes are relatively infrequent, they have a finite chance of inflicting significant harm.

The study underscores the need for a prudent level of mitigation and preparedness in Mid-America. It also demonstrates how local officials can use HAZUS and ATC-21 to assess the vulnerabilities and risks in their own communities.

REFERENCES

Applied Technology Council (1988a). *Rapid visual screening of buildings for potential seismic hazards: A handbook*, prepared for Federal Emergency Management Agency, FEMA 154, July 1988.

Applied Technology Council (1988b). *Rapid visual screening of buildings for potential seismic hazards: Supporting documentation,* prepared for Federal Emergency Management Agency, FEMA 155, September 1988.

Applied Technology Council (1985). *Earthquake damage evaluation data for California.* ATC-13, Redwood City, California.

Atkinson, G., et al. (2000). "Reassessing the New Madrid Seismic Zone," *EOS, American Geophysical Union* 81(35), 397, 402-403.

Bauer, R.A., Kiefer, J., and Hester, N. (2001). "Soil amplification maps for estimating earthquake ground motions in the Central U.S.," *Engineering Geology* 62 (1-3), 7-17.

Building Seismic Safety Council (1998). *NEHRP recommended provisions for seismic regulations for new buildings and other structures, 1997 edition, Part 1 – Provisions*, Federal Emergency Management Agency (FEMA-302), February 1998.

Building Seismic Safety Council (1985). *NEHRP recommended provisions for the development of seismic regulations for new buildings, 1985 edition,* Federal Emergency Management Agency (FEMA-95), December 1985.

Central U.S. Earthquake Preparedness Project (1990). *Estimated future earthquake losses for St. Louis City and County, Missouri,* prepared for the Federal Emergency Management Agency (FEMA-192), Washington, D.C.

Central U.S. Earthquake Preparedness Project (1985). *An assessment of damage and casualties for six cities in the Central United States resulting from earthquakes in the New Madrid seismic zone*, FEMA, October 1985.

Cramer, C.H., Petersen, M.D., Cao, T., Toppozada, T.R., and Reichle, M. (2000). "A time-dependant probabilistic seismic hazard model for California," *Bulletin of the Seismological Society of America*, 90, 1-21.

EQE Engineering and Design (1992). *Training local officials in rapid visual screening of seismically hazardous buildings*. Prepared for Central U.S. Earthquake Consortium, Memphis, September 1992.

Frankel, A.D., Mueller, C.S., Barnhard, T.P., Leyendecker, E.V., Wesson, R.L., Harmsen, S.C., Klein, F.W., Perkins, D.M., Dickman, N.C., Hanson, S.L., and Hopper, M.G. (2000). "USGS national seismic hazard maps," *Earthquake Spectra* 16(1), 1-19.

Frankel, A., et al. (1996). *National Seismic-Hazard Maps: Documentation*, USGS Open-File Report 96-532.

Grossi, P. (2001). Quantifying the uncertainty in seismic risk and loss estimation, *Ph.D. dissertation*, University of Pennsylvania.

Hamilton, R.M., and Johnston, A.C., editors (1990). *Tecumseh's prophecy: Preparing for the next New Madrid earthquake*, U.S. Geological Survey Circular 1066, U.S. Government Printing Office, Washington, D.C.

Johnston, A.C. (1996). "Moment magnitude assessment of stable continental earthquakes, Part I: instrumental seismicity," *Geophysical Journal International* 124, 381-414.

Johnston, A.C. and S.J. Nava (1985). "Recurrence rates and probability estimates for the New Madrid seismic zone," *Journal of Geophysical Research* 90(B8), 6737-86753.

Johnston, A.C., and Schweig, E.S., III (1996). "The enigma of the New Madrid earthquakes of 1811-1812," *Annual Review of Earth and Planetary Sciences* 24, 339-384.

National Institute of Building Sciences (1999a). *HAZUS User's Manual*, prepared for Federal Emergency Management Agency, Washington, D.C.

National Institute of Building Sciences (1999b). *HAZUS Technical Manual* (3 volumes), prepared for Federal Emergency Management Agency, Washington, D.C.

Olshansky, R.B., and Wu, Y. (2001). "Earthquake risk analysis for Los Angeles County under present and planned land uses," *Environment and Planning B: Planning and Design*, 28, 419-432.

Porter, K.; Scott, A., Johnson, M.; Scawthorn, C.; and Ryland, H. (1993). "Training local officials in rapid visual screening of seismically hazardous buildings." Pages 675-684 in *Proceedings, 1993 National Earthquake Conference*, Memphis, Tennessee, Volume I.

Stauder, W. (1982). *Present-day seismicity and identification of active faults in the New Madrid seismic zone*, U.S. Geological Survey Professional Paper 1236-C, U.S. Government Printing Office, Washington, D.C.

Stover, C.W. and Coffman, J.L. (1993). *Seismicity of the United States, 1568-1989*, U.S. Geological Survey Professional Paper 1527, U.S. Government Printing Office, Washington, D.C.

Toro, et al (1992). "Probabilistic seismic hazard mapping of the Mississippi embayment," *Seismological Research Letters* 63(3), 449-475.

Toro, G., Abrahamson, N., and Schneider, J. (1997). "Model of strong ground motions from earthquakes in the central and eastern North America: best estimates and uncertainties," *Seismological Research Letters* 68, 41-57.

Tuttle, M.P., Schweig, E.S., Sims, J.D., Lafferty, R.H., Wolf, L.W., and Haynes, M.L. (2002). "The earthquake potential of the New Madrid seismic zone," *Bulletin of the Seismological Society of America* 92(6), 2080-2089.

U.S. Geological Survey (1996). *National Seismic Hazard Maps, Central and Eastern U.S. Maps*, available at http://geohazards.cr.usgs.gov/eq/html/ceusmap.html, site updated June 4, 2001.

VSP Associates, Inc. (1991). *A benefit-cost model for the seismic rehabilitation of hazardous buildings. Volume 1: A user's manual.* Prepared for the Federal Emergency Management Agency, FEMA-227, April 1992.

Whitman, R.V., Anagnos, T., Kircher, C.A., Lagorio, H.J., Lawson, R.S., and Schneider, P. (1997). "Development of a national earthquake loss estimation methodology," *Earthquake Spectra* 13(4), 643-661.

Wu,Y. (2002). Seismic risk assessment for typical communities in Mid-America, *Ph.D. dissertation*, University of Illinois at Urbana-Champaign.

APPENDIX A
FIELD MANUAL

Rapid Visual Screening (ATC-21) of Buildings in Carbondale, Illinois
Mid-America Earthquake Center Project SE-5

University of Illinois at Urbana-Champaign
Department of Urban and Regional Planning
October 1998

We will be adding to work previously performed by engineering students under contract to the Illinois Emergency Management Agency (IEMA). In 1992 they surveyed government, health care, educational, religious, and fraternal organization buildings in Carbondale. They were particularly interested in buildings that could be used for emergency shelters after an earthquake. For consistency, we will use their coding system and their field methods. This Manual is based on theirs, which was developed after several years of experience with ATC-21.

Structures to be Surveyed

Based on IEMA=s experience, each person can expect to survey 15-20 buildings per day. This will vary, depending on the types and sizes of buildings, but the average should be 15-20 buildings per day.

Our priorities are as follows (codes are from IEMA=s Building Use Codes, attached):

PRIORITY 1

41 Hospitals
4B Police/sheriff station
48 Fire station
21 Elementary school
22 Junior/senior high or preparatory school
23 College/university building

11 Apartment/hotel (of 10 dwelling units or more)
12 Dormitory (of 10 dwelling units or more)
14 Motel (of 10 dwelling units or more)
16 Nursing/convalescent home

43 Public utility
44 Communications facility
45 Government office
46 Jail/prison
49 Other government/public service

31 Church/synagogue
71 Theater/auditorium
72 Community center
76 Senior Citizens center

PRIORITY 2

42 Health care clinic
52 Food store (larger than 5,000 square feet)
53 Other stores (larger than 5,000 square feet)
51 Office (larger than 5,000 square feet)
55 Bank/financial institution (larger than 5,000 square feet)
56 Restaurant/snack bar/cafeteria (larger than 5,000 square feet)
26 Library or museum
27 Gymnasium

81 Railroad terminal/station
82 Bus terminal/station
83 Airport terminal/station

Plus any other high-occupancy buildings

PRIORITY 3

54 Warehouse
57 Building supply/hardware store
61 Factory/plant/manufacturing center
62 Food processing plant
69 Other industrial

Plus any other buildings of significant size, function, or occupancy (see Building Use Codes to see if they have a classification).

For all buildings previously surveyed by IEMA, you must verify their location and condition, and should take photographs for our records. Verification of these buildings should take less than five minutes each.

Over 12 field days, two people should be able to survey 360 to 480 buildings. This should cover all of the Priority 1 and Priority 2 buildings, as well as many, if not most, of the Priority 3 buildings.

Contacting Building Representatives

When you arrive at a facility, you should attempt to talk to someone about the building. If there is no one available to talk with, you must make a judgment. If you can easily determine the necessary data from the exterior of the building and/or if the building is relatively small, then you can gather the data based only on exterior visual inspection. If the building is large or is an essential facility, then you should make further attempts to talk to someone. If someone in a building asks you to return and talk with another person, you should return to talk with this other person, unless it will be excessively inconvenient or you can gather the necessary data based on your visual inspection. *We do not want to create any problems between the building owner and the University or City of Carbondale.*

SAMPLE INTRODUCTION

AHello, my name is ______________, and I=m from the University of Illinois in Urbana-Champaign. We=re gathering information on significant buildings in Carbondale that could be affected by an earthquake in southern Illinois. I would like to ask you a few general questions about the building and spend a few minutes looking at the interior and exterior.@

BE PROFESSIONAL

Look presentable. Use a clipboard. Wear a badge, showing the name of the University and Department, with your name typed on it. You will also carry several copies of a letter, explaining the project, and inviting them to call us or the City for further information.

IF THEY WANT TO KNOW MORE

Give them a copy of the letter. Be cooperative in answering their questions. Tell them that this is being done by the University to assist the City of Carbondale. Tell them that, although the City is not performing the work, they endorse our efforts and will use the results to help in earthquake preparedness planning. Tell them that we will use the information gathered from several hundred buildings in order to estimate damages and casualties from a future earthquake near Carbondale. Refer them to our Department for further information.

IF THEY DENY YOU ACCESS TO THE BUILDING

Thank them for their time, and leave. At minimum, you should be able to do an exterior inspection. It is, of course, perfectly legal to stand on a public sidewalk, public street, or other public space and inspect a building. Still, if their objection is strong, it is best to walk away. The bottom line is this: *we cannot afford to antagonize anyone to the extent that they will complain to the City or to the University.*

IF THEY WANT TO KNOW THE CHANCES OF AN EARTHQUAKE HERE

Tell them that southern Illinois has had earthquakes in the past and can expect them in the future. Southern Illinois, and nearby parts of Kentucky, Missouri, Tennessee, and Arkansas, are all near the New Madrid seismic zone, an active earthquake region. It is highly likely (more likely than not) that a Magnitude 6 earthquake could occur somewhere in this region within the next 20 to 50 years. Such an earthquake could cause severe damage to towns near where it occurs, and lesser damage over a wide area.

General Guidelines

At least one photograph of the front must be taken of all buildings surveyed. Preferably, you should take two photographs, each one showing portions of two sides of the building (take the two photos from opposite corners of the building).

Take time to check the forms for accuracy and completeness. The information on the form must appear to be in agreement with the building in the photo.

If a structure has two or more significant parts with a different construction type for each part, divide the structure into separate facilities using the construction type as the guide.

Provide a plan-view sketch of the floor level of each building. This will be located in the grid portion of the Data Collection Form, if there is sufficient space; or on another sheet of paper if necessary. Each sketch should include accurate dimensions of the floor shown, a north arrow, side A (front address side) labeled, and other adjacent buildings if they affect the surveyed building. If a large building is broken into parts, a key plan must be included to show how the parts fit together; this key plan should be included with the Data Collection Form for each part. The sketch can be done freehand, as long as it is readable and to scale.

Numerical street addresses must be provided for all facilities. In addition, provide the nearest cross street. We will also use the GPS to provide latitude and longitude, to the nearest second. You might want to take three or four measurements at each site, and then average them, to improve measurement accuracy.

Data Entry

Enter all data into an Excel spreadsheet, using the same columns and format as the spreadsheet from IEMA, of which you have a copy.

Attached is a detailed description of all the data categories, copied directly from IEMA=s field guide (last revised 7/98).

entries are to be left justified. The computer does not properly justify all fields. The surveyor must make sure all fields are properly justified.

GENERAL COMPUTER USE BY THE FST CONTRACTOR

The computer system used for the CFS is to be used for business purposes only. All persons in the field office will be responsible for the security and cooperative use of this equipment. The CFS data will be backed up daily on a diskette.

DATA COLLECTION FORM/DATA ENTRY FORM

When using Data Collection Form, data can be entered by directly writing it in the space provided or circling the appropriate entry. When using the Data Entry Form on the computer, the FST Contractor must enter the appropriate data.

Name Enter the building name using up to 30 spaces. Vowels may be dropped, when necessary to shorten the name, beginning with the rightmost vowel in the rightmost word. Do not drop vowels which start a word. Use descriptive names such as, CARBONDALE CITY HALL, COBDEN FIRE DEPT., etc.

Address Enter the street address using up to 30 spaces. Vowels may be dropped in the street name, when necessary to shorten the name, beginning with the rightmost vowel in the rightmost word. Do not drop vowels which start a word. Do not use Post Office Box or Rural Route numbers in the address. Numbers will be used where appropriate in the street name, such as 4TH ST., 8TH ST., etc. Street, road, boulevard, route, etc. designations will be abbreviated using standard abbreviations. For example:

ST.	Street	RD.	Road
AVE.	Avenue	BLVD.	Boulevard
LN.	Lane	HWY.	Highway
PKWY.	Parkway		

US RT. 51	INTERSTATE 57
CO. RD. 10	ST. RT. 148

City Enter the city name or if appropriate, the township or precinct name, where the building is located. This is not for mailing purposes, but to help locate the building. Be sure to include "TWP." or "PCT." in the name if appropriate.

Zip Enter the five-digit zip code for the building.

Other Identifiers Enter other items which will help to locate the building. Usually this will be a cross street.

Latitude	Enter the degrees, minutes and seconds of the latitude of the building measured using the GPS unit.
Longitude	Enter the degrees, minutes and seconds of the longitude of the building measured using the GPS unit.
County Name	Enter the name of the county in which the building is located.
FIPS Code	Enter the state and county Census FIPS Code for the county in which the building is located. Refer to the code sheet for a list of all FIPS codes.
No. of Stories	Enter the total of above-ground stories for the building. Do not include the basement. If there are no above-ground stories, enter a "0".
Year Built	Enter the year the building was built. If the year built is unknown, estimate the year and enter a "0" as the first digit (e.g. 0950).
Total Floor Area	Enter the total floor area of the building in square feet, including all aboveground stories.
Comments	**Enter any miscellaneous comments that are appropriate.**
Floor Plan Sketch	**Draw the floor plan sketch of the building in this area.**
Instant Photo	**Attach the instant photo of the front side of the building here.**
Building Type	Enter the appropriate building type code from the following:

Type	Code	Definition
W	1	Wood Frame
S1	2	Steel MRF
S2	3	Braced Steel Frame
S3	4	Light Metal
S4	5	Steel Frame with Concrete Shear walls
C1	6	Concrete Moment Resisting Frame
C2	7	Concrete Shear wall
C3/S5	8	Steel/Concrete Frame with URM Infill
PC1	9	Tilt-up Concrete
PC2	10	Pre-cast Concrete Frame
RM	11	Reinforced Masonry
URM	12	Unreinforced Masonry

Basic Score	Enter the basic score from the data collection form for the building type.
High Rise	Enter the structural modifier if the building is considered to have a high rise condition. High rise condition exists if the building is eight (8) stories

or tall for building types 1-11, and five (5) stories or above for building type 12 (URM). Enter zero (0) if the building is not considered a high rise.

Poor Condition Enter the structural modifier if the building is considered to be in poor condition. The building must be showing cracks or damage to the structural system or excessive settlement to be considered in poor condition. Enter zero (0) if the building is not in poor condition.

Vert. Irregularity Enter the structural modifier if the building is considered to have a vertical irregularity. The building must have steps in the elevation, inclined walls, discontinuities in load paths or be built on a hill. Enter zero (0) if the building has no vertical irregularity.

Soft Story Enter the structural modifier if the building is considered to have a soft story condition. The building is considered to have a soft story condition if it has openings on all sides of the building, a tall ground floor or discontinuous shear walls. Enter zero (0) if the building has no soft story condition.

Torsion Enter the structural modifier if the building is considered to have torsion problems. Torsion problems are mainly created by an eccentric stiffness in plan. Enter zero (0) if the building has no torsion problems.

Plan Irregularity Enter the structural modifier if the building is considered to have an irregular plan shape. The building plan is considered irregular if it has an "L", "U', "E", "T' or other non-symmetrical plan shape. Enter zero (0) if the building doesn't have irregular plan shape.

Pounding Enter the structural modifier if the building will be affected by pounding from adjacent structures. Enter zero (0) if the building cannot be damaged by pounding.

Large Heavy Cladding Enter the structural modifier if the building has large heavy stone or concrete cladding panels (ignore glass and masonry veneer). Enter zero (0) if the building doesn't have large heavy cladding.

Short Columns Enter the structural modifier if the building has a short column condition. A short column condition exists when some columns are restrained by half walls or spandrel beams. Enter zero (0) if no short column condition exists.

Post Benchmark Year Enter the structural modifier if the building was constructed after benchmark building code year for the building type and jurisdiction. Enter zero (0) if the building was constructed prior to the benchmark year.

Soil Conditions Enter the structural modifier for the soil conditions at the building location.

In most cases use a soil profile of SL3 unless the building has greater than eight (8) stories. Sufficient geological data is not available for us to make a soil determination for a specific site.

Final Score Write the final score on the Data Collection Form and enter in on the computer.

Occupancy Circle the appropriate occupancy type on the Data Collection Form. On the computer, enter the appropriate code for the occupancy type of the building from the following:

Code	Occupancy Type
1	Residential
2	Commercial
3	Office
4	Industrial
5	Public Assembly
6	School
7	Government Building
8	Emergency Services Building
9	Historic Building

Use Code(s) Enter a primary and if necessary, as secondary use code for the Enter the primary use code first. Refer to the code sheet for a list of all use codes.

No. of Persons Enter the numeric code for the number of persons range from the following:

Code	Range
0	0
1	1-10
2	11-100
3	100+

Data Confidence Enter the appropriate code for the data confidence level from the following:

Level	Code	Definition
Good	3	Talked with person at the building and was able to perform a full inspection.
Fair	2	Talked with person at the building, but was not able to perform full inspection. Performed Interior/exterior visual inspection only.

	Poor	1	Did not talk to person at the building and performed only an exterior visual inspection.

Non-structural Falling Hazard Enter a "Y" if a non-structural falling hazard exists for the building. Enter a "N" if no hazard exists. Non-structural falling hazards can include: chimneys, parapets, cornices, veneers and overhangs.

Non-structural Falling Hazard Description Enter a description of the non-structural falling hazard which exists at the building. If no hazard exists, leave this field blank.

Inspector Enter the Inspector's initials.

Inspection Date Enter the date of the inspection.

Detailed Evaluation Required Enter a "Y" if a detailed evaluation is required for the building. If a building has a final score of 2.0 or less, it should be given a detailed evaluation by a professional engineer experienced in seismic design. If the building has a score of greater than 2.0, enter an "N" indicating it doesn't require any further evaluation.

Illinois Critical Facility Survey (CFS)
Building Use Codes

Residential

11 Apartment/hotel
12 Dormitory/barracks
13 Row house and duplex
14 Motel/tourist court
15 Condominium
16 Nursing/convalescent home
19 Other residential

Educational

21 Elementary school
22 Junior/senior high or preparatory school
23 College/university
24 Business/professional
25 Correctional school
26 Library or museum
27 Gymnasium
29 Other educational

Religious

31 Church/synagogue
32 Retreat/monastery/convent
33 Church hall/recreation center
39 Other religious

Government/Public Service

41 Hospital
42 Health care clinic
43 Public utility
44 Communications facility
45 Office facility
46 Jail/prison/correctional center
47 Armory/monument/memorial
48 Fire station
49 Other government/public service
4A Post office
4B Police/sheriff station

Commercial

51 Office facility
52 Food store
53 Stores other than food stores
54 Warehouse
55 Bank/financial institution
56 Restaurant/snack bar/cafeteria
57 Building supply/hardware store
59 Other commercial

Industrial

61 Factory/plant/manufacturing center
62 Food processing plant
69 Other industrial

Amusement/Assembly

71 Theater/auditorium
72 Community center
73 Bowling facility
74 Fraternal hall
75 Health club/fitness center
76 Senior citizens center
79 Other amusement/assembly

Transportation

81 Railroad terminal/station
82 Bus terminal/station
83 Airport terminal
84 Airport hanger
85 Marine terminal
86 Automotive repair and storage
87 Automotive sales facility
88 Gasoline service station
89 Other transportation
8A Trucking terminal/warehouse

Miscellaneous

99 Categories not covered above

Illinois Critical Facility Survey (CFS)
Miscellaneous Codes

Occupancy Type

Code	Type
1	Residential
2	Commercial
3	Office
4	Industrial
5	Public Assembly
6	School
7	Government Building
8	Emergency Services
9	Historic Building

No. of Persons

Code	Range
1	0
2	1-10
3	11-100
4	100+

Data Confidence

Code	Level
3	Good
2	Fair
1	Poor

Structure Type

Code	Type	Definition
1	W	Wood Frame
2	S1	Steel Moment Resistant Frame (MRF)
3	S2	Steel Braced Frame
4	S3	Light Metal Steel Frame
5	S4	Steel Frame w/Concrete Shear Walls
6	C1	Concrete Moment Resistant Frame (MRF)
7	C2	Concrete Shear Walls
8	C3	Concrete Frame with Unreinforced Masonry (URM) Infill
9	PC1	Tilt-Up Concrete
10	PC2	Pre-cast Concrete Frame
11	RM	Reinforced Masonry
12	URM	Unreinforced Masonry

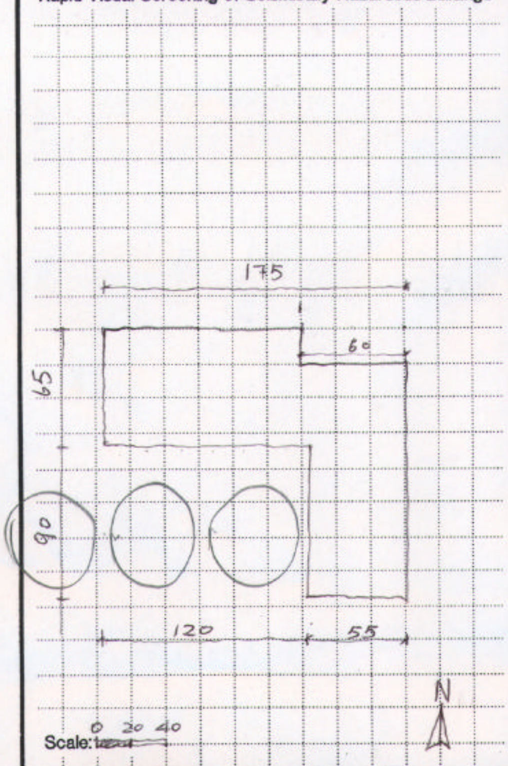
County FIPS Codes

County	Code	County	Code	County	Code
Alexander	17003	Jersey	17083	Randolph	17157
Calhoun	17013	Johnson	17087	Richland	17159
Crawford	17033	Lawrence	17101	St. Clair	17163
Edwards	17047	Madison	17119	Saline	17165
Franklin	17055	Massac	17127	Union	17181
Gallatin	17059	Monroe	17133	Wabash	17185
Hamilton	17065	Perry	17145	Washington	17189
Hardin	17069	Pike	17149	Wayne	17191
Jackson	17077	Pope	17151	White	17193
Jefferson	17081	Pulaski	17153	Williamson	17199

APPENDIX B
SAMPLE ATC-21 FIELD DATA FORM

ATC-21/ (NEHRP Map Areas 3,4, Moderate)
Rapid Visual Screening of Seismically Hazardous Buildings

Address 2401 S. Mclapherty
Zip
Other Identifiers Pleasanthill & Mcla.
No. Stories 3 Year Built 1970'
Inspector GW Date Nov 13
Total Floor Area (sq. ft) 40000
Building Name City Treatment Plant
Use Water treatment plant



OCCUPANCY

Occupancy	No. Persons
Residential	
Commercial	0–10
Office	11–100 (circled)
Industrial	100+
Pub. Assem.	
School	
Govt. Bldg (circled)	122
Emer. Serv.	
Historic Bldg.	

Non Structural Falling Hazard ☑ o

DATA CONFIDENCE
* = Estimated, Subjective, or Unreliable Data
DNK = Do Not Know

STRUCTURAL SCORES AND MODIFIERS

BUILDING TYPE	W	S1 (MRF)	S2 (BR)	S3 (LM)	S4 (RC SW)	C1 (MRF)	C2 (SW)	C3/S5 (URM INF)	PC1 (TU)	PC2	RM	URM
Basic Score	6.0	4.0 (circled)	3.0	6.0	4.0	3.0	3.5	2.0	3.5	2.0	3.5	2.0
High Rise	N/A	−1.0	−0.5	N/A	−1.0	−0.5	−1.0	−1.0	N/A	0	−0.5	−0.5
Poor Condition	−0.5	−0.5	−0.5	−0.5	−0.5	−0.5	−0.5	−0.5	−0.5	−0.5	−0.5	−0.5
Vert. Irregularity	−0.5	−0.5 (circled)	−0.5	−0.5	−1.0	−1.0	−0.5	−1.0	−1.0	−1.0	−0.5	−1.0
Soft Story	−1.0	−2.0	−2.0	−1.0	−2.0	−2.0	−2.0	−1.0	−1.0	−1.0	−2.0	−1.0
Torsion	−1.0	−2.0	−1.0	−1.0	−1.0	−1.0	−1.0	−1.0	−1.0	−1.0	−1.0	−1.0
Plan Irregularity	−1.0	−0.5 (circled)	−0.5	−0.5	−0.5	−0.5	−0.5	−0.5	−1.0	−1.0	−1.0	−1.0
Pounding	N/A	−0.5	−0.5	N/A	−0.5	−0.5	N/A	N/A	N/A	−0.5	N/A	N/A
Large Heavy Cladding	N/A	−2.0	N/A	N/A	N/A	−1.0	N/A	N/A	N/A	−1.0	N/A	N/A
Short Columns	N/A	N/A	N/A	N/A	N/A	−1.0	−1.0	−1.0	N/A	−1.0	N/A	N/A
Post Benchmark Year	+2.0	+2.0	+2.0	+2.0	+2.0	+2.0	+2.0	N/A	+2.0	+2.0	+2.0	N/A
SL2	−0.3	−0.3	−0.3	−0.3	−0.3	−0.3	−0.3	−0.3	−0.3	−0.3	−0.3	−0.3
SL3	−0.6	−0.6 (circled)	−0.6	−0.6	−0.6	−0.6	−0.6	−0.6	−0.6	−0.6	−0.6	−0.6
SL3 & 8 to 20 stories	N/A	−0.8	−0.8	N/A	−0.8	−0.8	−0.8	−0.8	N/A	−0.8	−0.8	−0.8
FINAL SCORE		2.4										

COMMENTS

N 37°41'.65 W 89° 14.17 002

Detailed Evaluation Required? YES NO (circled)

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APPENDIX C
EXCERPT FROM 1985 NEHRP Aa MAP (BSSC, 1985)
(Basis of three seismicity hazard areas in ATC-21)