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THE BUILDING STOCK IN MEMPHIS: RELATING STRUCTURAL TYPE AND USE

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ABSTRACT

The NCEER Loss Assessment of Memphis Buildings (LAMB) Project is a coordinated reasearch program that combines talents from structural engineering, seismology, risk/reliability and socioeconomic researchers. The effort provides a demonstration of how these various disciplines can be integrated to estimate economic losses for a scenario earthquake in the Memphis area. This study made direct estimates of the total number of buildings in the Memphis-Shelby County region to determine the distribution of buildings by number and square footage by structural type and cross classified buildings by structural type and the use to which they are put. The key to the relationship between urban vulnerability and structural engineering studies of the response, damage, repair and retrofit of individual buildings and building types in earthquakes derives from the uses and activities buildings accommodate and the impact their failure has on disruption of urban systems.

The study confirmed the general patterns of distribution by structural type and use found in the baseline study of Wichita. Residential buildings account for approximately 90% of the number and 60% of building area and are mostly wood frame. Engineered buildings accounted for approximately 2% of the number and 15% of the area but were extremely important to the operation of the social and economic system of the region.

KEYWORDS

Building stock inventory; building use and structural type; loss; assessment; Memphis; urban.

OBJECT

The key to the relationship between structural engineering studies of the response, damage, repair and retrofit of individual buildings and building types and the socio-economic impacts of building failure in earthquakes derives from the uses and activities buildings accommodate and the way in which their failure disrupts the operation of an urban system. The underlying assumption is that the distribution of structural types is not proportional or random over use categories but varies in some systematic way. The occupancy, activities, and uses to which various buildings are put differ in terms of their importance to the operation of the urban system. The failure of buildings of particular uses in earthquakes will have different consequences in terms of injuries and deaths, employment, economic disruption, and other effects, given the timing of the event and diurnal patterns of occupancy of buildings of different uses. The distribution of buildings by structural type

and use has a wide variety of implications for the impact of an earthquake on a social and economic system and for relief and recnstruction efforts.

Complete and comprehensive inventories of building stocks are difficult to obtain and usually involve substantial effort and expense. Information concerning characteristics of buildings such as area, structural type, age, etc. is even more scarce. In order to address the inventory problem, a series of projects have been carried out at Cornell University to develop methods for making indirect estimates of building stocks rapidly and inexpensively (Jones, 1994). The procedure consisted of making a baseline study of one medium-sized metropolitan area, Wichita-Sedgwick County, Kansas, for 1982, attempting to assemble as complete information as possible about all elements of the built physical environment and developing methods for making indirect estimates (Jones, Lewis, and Westendorff, 1991). These indirect estimates have been tested using direct counts in several cases. The study reported here was carried out in connection with one of these tests comparing indirect estimates with direct counts of buildings and their characteristics in a study of Memphis-Shelby County, Tennessee (Jones and Chang, 1994).

METHODS

For most regions in the United States, the most comprehensive, readily available, and easily accessible data on building inventories are the records of Property Tax Assessors who are County officials. Increasingly over the past ten years many assessors have filed their information on computer tapes. Since these are administrative records, assessors are primarily interested in parcels of land and improvements to them such as buildings that are subject to real property taxes. Many data may be missing such as properties of corporations that operate in a number of counties and are assessed by a state board of equalization, properties exempt from real estate tax because they belong to governments or tax-exempt organizations, properties that have been granted temporary real property tax waivers which is common with certain economic development incentives, and buildings which are legally classified as chattels rather than real property as is often the case with mobile homes. Since assessors are local officials and since laws differ from state to state, there is great variation from one locality to another in the information gathered and the data available on the tapes.

Nevertheless, the tax assessors' tapes provide substantial coverage which can be supplemented from other sources and direct survey to develop a basic inventory. The information included in the file on the buildings that are covered is primarily what assessors consider relevant to assigning an assessed value to the property. This often includes information on building area, number of stories, year built, structural type, wall surface material, and some indication of the use of the property. This information is frequently very general and not at a high level of detail. To develop a more precise inventory, it may be necessary to consult other sources and conduct field surveys.

Indirect methods for estimating building stocks and their characteristics developed in the baseline study of Wichita-Sedgwick County were used to estimate the building stock in the Memphis region. This was then compared to direct estimates of the Memphis stock made using the Shelby County Tax Assessor's computer tape supplemented with other information gathered from numerous other sources. The procedure is described in detail by Malik (1995). Structural type and use of building were compiled from this information and cross classified. Field work was necessary to verify the data, fill in gaps, and provide further detail. The Shelby County assessor's tape contained a highly aggregated classification of structural type. In some cases the study combined this with other information on the tape such as wall surface material to arrive at a structural type classification as reported here. For the substantial number of buildings not on the tape, other sources had to be used.

RESULTS

The results of the study of Memphis are presented and compared with the results of the baseline study of Wichita in Tables 1 and 2 for number of buildings and in Tables 3 and 4 for area in square feet cross-classified by structural type and use. Tables 1 and 3 show the numerical results obtained, and Tables 2 and

Table 1. Number of Buildings by Use and Structural Type: Memphis and Wichita.

	Residential	Comm./Ind.	Agriculture	Instit.	Education	Hospital	Government	Total
Wood	222,004	3,029	1,667	243	26	52	78	227,099
	112,127	*1,125*	*1,232*	*596*	*68*	*1*	*75*	*115,224*
Light Metal	3,406	5,858	39	44	14	14	52	9,427
	7,589	*1,649*	*811*	*27*	*21*	*3*	*130*	*10,230*
Masonry	898	12,010	18	386	215	217	230	13,974
	322	*5,228*	*100*	*58*	*161*	*37*	*82*	*5,988*
Rein. Conc.	1,016	534	0	0	526	51	607	2,734
	21	*269*	*5*	*1*	*98*	*10*	*19*	*423*
Prot. Steel	53	269	0	7	40	30	64	463
	52	*78*	*5*	*0*	*42*	*13*	*1*	*191*
Other/Unc	2,098	136	0	0	0	16	127	2,377
	17	*384*	*20*	*18*	*7*	*3*	*109*	*558*
Total	229,475	21,836	1,724	680	821	380	1,158	256,074
	120,128	*8,733*	*2,173*	*700*	*397*	*67*	*416*	*132,614*

Memphis-Shelby County
Wichita-Sedgwick County

Table 2. Distribution of Number of Buildings by Use and Structural Type: Memphis and Wichita.

	Residential	Comm./Ind.	Agriculture	Instit.	Education	Hospital	Government	Total
Wood	86.70%	1.18%	0.65%	0.09%	0.01%	0.02%	0.03%	88.68%
	84.55%	*0.85%*	*0.93%*	*0.45%*	*0.05%*	*0.00%*	*0.06%*	*86.89%*
Light Metal	1.33%	2.29%	0.02%	0.02%	0.01%	0.01%	0.02%	3.68%
	5.72%	*1.24%*	*0.61%*	*0.02%*	*0.02%*	*0.00%*	*0.10%*	*7.71%*
Masonry	0.35%	4.69%	0.01%	0.15%	0.08%	0.08%	0.09%	5.46%
	0.24%	*3.94%*	*0.08%*	*0.04%*	*0.12%*	*0.03%*	*0.06%*	*4.52%*
Rein. Conc.	0.40%	0.21%	0.00%	0.00%	0.21%	0.02%	0.24%	1.07%
	0.02%	*0.20%*	*0.00%*	*0.00%*	*0.07%*	*0.01%*	*0.01%*	*0.32%*
Prot. Steel	0.02%	0.11%	0.00%	0.00%	0.02%	0.01%	0.02%	0.18%
	0.04%	*0.06%*	*0.00%*	*0.00%*	*0.03%*	*0.01%*	*0.00%*	*0.14%*
Other/Unc	0.82%	0.05%	0.00%	0.00%	0.00%	0.01%	0.05%	0.93%
	0.01%	*0.29%*	*0.02%*	*0.01%*	*0.01%*	*0.00%*	*0.08%*	*0.42%*
Total	89.61%	8.53%	0.67%	0.27%	0.32%	0.15%	0.45%	100.00%
	90.58%	*6.59%*	*1.64%*	*0.53%*	*0.30%*	*0.05%*	*0.31%*	*100.00%*

Memphis-Shelby County
Wichita-Sedgwick County

Table 3. Building Area in Square Feet by Use and Structural Type: Memphis and Wichita.

	Residential	Comm./Ind.	Agriculture	Instit.	Education	Hospital	Government	Total
Wood	380,223,571	9,727,919	1,764,386	886,701	295,803	351,081	369,193	393,618,654
	151,738,458	*3,733,603*	*1,368,017*	*4,655,721*	*1,266,939*	*720*	*508,930*	*163,272,388*
Light Metal	2,892,207	81,442,289	29,174	442,684	166,124	74,610	649,531	85,696,619
	6,681,339	*19,084,365*	*1,918,357*	*256,732*	*357,909*	*8,880*	*1,366,894*	*29,674,476*
Masonry	3,855,342	116,357,185	11,003	2,594,668	4,407,139	1,785,615	2,583,958	131,594,910
	3,794,783	*37,529,150*	*212,524*	*384,256*	*2,604,350*	*487,718*	*1,140,686*	*46,153,467*
Rein. Conc.	8,339,346	31,766,451	0	0	17,456,725	7,753,497	12,564,670	77,880,689
	868,457	*9,417,223*	*9,604*	*1,800*	*4,612,938*	*1,539,359*	*325,936*	*16,775,317*
Prot. Steel	1,037,781	16,532,423	0	58,420	1,674,095	4,114,896	3,153,292	26,570,907
	148,721	*454,750*	*21,330*	*0*	*1,594,650*	*1,439,678*	*21,475*	*3,680,604*
Other/Unc	2,483,723	302,282	0	0	0	4,762,042	484,606	8,032,653
	197,869	*7,069,293*	*40,471*	*248,041*	*201,379*	*157,590*	*1,610,611*	*9,525,254*
Total	398,831,970	256,128,549	1,804,563	3,982,473	23,999,886	18,841,741	19,805,250	723,394,432
	163,429,627	*77,288,384*	*3,570,303*	*5,546,550*	*10,638,165*	*3,633,945*	*4,974,532*	*269,081,506*

Memphis-Shelby County
Wichita-Sedgwick County

Table 4. Distribution of Building Area by Use and Structural Type: Memphis and Wichita.

	Residential	Comm./Ind.	Agriculture	Instit.	Education	Hospital	Government	Total
Wood	52.56%	1.34%	0.24%	0.12%	0.04%	0.05%	0.05%	54.41%
	56.39%	*1.39%*	*0.51%*	*1.73%*	*0.47%*	*0.00%*	*0.19%*	*60.68%*
Light Metal	0.40%	11.26%	0.00%	0.06%	0.02%	0.01%	0.09%	11.85%
	2.48%	*7.09%*	*0.71%*	*0.10%*	*0.13%*	*0.00%*	*0.51%*	*11.03%*
Masonry	0.53%	16.08%	0.00%	0.36%	0.61%	0.25%	0.36%	18.19%
	1.41%	*13.95%*	*0.08%*	*0.14%*	*0.97%*	*0.18%*	*0.42%*	*17.15%*
Rein. Conc.	1.15%	4.39%	0.00%	0.00%	2.41%	1.07%	1.74%	10.77%
	0.32%	*3.50%*	*0.00%*	*0.00%*	*1.71%*	*0.57%*	*0.12%*	*6.23%*
Prot. Steel	0.14%	2.29%	0.00%	0.01%	0.23%	0.57%	0.44%	3.67%
	0.06%	*0.17%*	*0.01%*	*0.00%*	*0.59%*	*0.54%*	*0.01%*	*1.37%*
Other/Unc	0.34%	0.04%	0.00%	0.00%	0.00%	0.66%	0.07%	1.11%
	0.07%	*2.63%*	*0.02%*	*0.09%*	*0.07%*	*0.06%*	*0.60%*	*3.54%*
Total	55.13%	35.41%	0.25%	0.55%	3.32%	2.60%	2.74%	100.00%
	60.74%	*28.72%*	*1.33%*	*2.06%*	*3.95%*	*1.35%*	*1.85%*	*100.00%*

Memphis-Shelby County
Wichita-Sedgwick County

4 show the percentage distributions. The most striking finding is the similarities in the distributions for both number and area in Tables 2 and 4 despite the major differences in the two metropolitan areas in population size, location, primary functions and other characteristics. Memphis is a much older city than Wichita. The periods of greatest growth of the cities differ. The region served by Memphis is much larger than that for Wichita and has a more dense population.

In both regions, residential buildings account for 90% of the structures and the distributions across other uses are quite similar. The area in residential buildings is somewhat larger in Wichita than in Memphis, and commercial and industrial buildings account for a greater percentage of building area in Memphis. However, in both regions, the distributions for non-residential buildings are reasonably close.

Wood frame construction predominates in both regions accounting for more than 85% of the buildings and 55% to 60% of the area. The distribution across other structural types is quite close for both number and area. The predominance of wood frame construction derives from the prevalence of its use for residential buildings. For both the number and area of residential buildings 90% to 95% are of wood.

While engineered buildings accounted for perhaps 2% of the total number and 15% of the area, however, these structures were extremely important to the operation of the social and economic system of the region. Many of the other buildings were of quite vulnerable structural types and contained important uses.

There are certain differences in the distributions and they are continuing to be investigated. Shelby County has far fewer mobile homes than expected which is reflected in the light metal-residential category. This may be attributable to differences in consumer preferences, legal restrictions, or information not yet obtained. There is obviously a serious under-count of religious buildings and steps are being taken to fill this gap. Differences in commercial, industrial, and agricultural structures derive from differences in the sectoral mix of the economies in the two metropolitan areas. When these three categories are combined, the results are very close.

The studies of Wichita and Memphis provide data on building stocks for two metropolitan areas carefully enumerated and cross-classified by use and structural type. These represent almost 400,000 buildings or slightly less than .5 percent of the buildings in the United States and 1.4 billion square feet of building area. The two enumerations have been pooled into a single count which represents a weighted average of the two regions. As additional data can be included, confidence in our knowledge of the ways in which structural type varies with use will increase.

The results of the studies are not satisfactory for a number of uses for which such information is needed. The levels of aggregation are too great for both structural type and use. The structural type categories are too general to permit accurate prediction of performance under various seismic conditions. The categories need to be disaggregated to a much greater degree of specificity to be really useful in predicting destruction and levels of damage. For the most part, the use categories are also too aggregated. Single family and mobile home residential structures are quite specific. However, the commercial and industrial category is much too aggregated to be useful in predicting economic impact. Disaggregation to at least the three digit Standard Industrial Classification level would be necessary for use in economic models to assess potential primary and secondary losses. Greater specificity of uses might be possible through laborious manipulation of some assessors' tapes by matching names of occupants with buildings. Some tapes do not contain the necessary information. Structural type categories are even more troublesome. The assignment has usually been made by individuals with little or no background in engineering or construction, and the accuracy of even the aggregated categorization may be questionable. It is unlikely that further disaggregation could be obtained from the tapes with any kind of manipulation. Inspection of individual buildings by qualified experts would be required. Since the numbers of buildings for which such investigations would matter are relatively small and a minor percent of the total, this might not be such an overwhelming task as it may appear. There remains the problem of the variation in tapes from one county to another in terms of the information contained, the architecture of the data system, the format, the completeness of the coverage, and the conscientiousness with which data were collected and entered. To obtain any more disaggregated results than resulted from this study would require substantially greater effort and resources than were available.

The results obtained for Wichita and Memphis can be compared with two other recent studies: one of Salt Lake County, Utah by Anne Kiremidjian and others (King and Kiremidjian, 1994), which will appear in ATC-36 (ATC), and the other of Los Angeles, carried out by Stephanie Chang and colleagues at EQE International (EQE, 1995). A summary of comparisons is presented in Table 5. The extent to which these two studies represent enumerations as complete as for those for Memphis and Wichita is not known. Both of the other studies have almost 16 percent of their structures unclassified by structural type. Nevertheless, the results from the Los Angeles study are relatively close to those for Wichita and Memphis. The results for the Salt Lake County study show a substantially different distribution by structural type. A possible explanation for this may be differences in the availability of various structural materials in Salt Lake City. It is possible Salt Lake City represents an outlier among the metropolitan areas in the United States in the distribution of structural types of buildings. Studies of other characteristics of building stocks indicate strong general patterns with substantial deviation on the part of specific metropolitan areas some of which seem attributable to the nature of the individuals who settled in them, others to special economic functions, and others to regional differences. In other words, outlying observations are not uncommon.

Table 5. Summary Comparison of Estimates of Four Studies of Building Use and Structural Type

	Memphis-Shelby County		Wichita-Sedgwick County		Salt Lake County		Los Angeles County	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
TOTAL	256,074		132,614		195,785		2,066,488	
USE								
Residential	229,475	89.61%	120,128	90.58%	176,657	90.23%	1,627,221	78.74%
Non-Residential	26,599	10.39%	12,486	9.42%	19,128	9.77%	114,520	5.54%
Unc							324,747	15.71%
STRUCTURE TYPE								
Wood	227,099	88.68%	115,224	86.89%	111,732	57.07%	1,677,951	81.20%
Masonry	13,974	5.46%	5,988	4.52%	52,519	26.82%	60,335	2.92%
Concrete	2,734	1.07%	423	0.32%	156	0.08%	2,000	0.10%
Steel	463	0.18%	191	0.14%	555	0.28%	1,455	0.07%
Other	11,804	4.61%	10,788	8.13%	30,823	15.74%	324,747	15.71%

CONCLUSIONS

The study of the Memphis-Shelby County building stock confirmed the general patterns of distribution by structural type and use found in the baseline study. While considerable differences can be expected in construction methods in specific metropolitan areas, a general pattern should represent most regions in the United States. The conformity of the patterns for Wichita, Shelby County, and Los Angeles would appear to indicate the general pattern that would emerge from the collection of vastly more data. However, this can only be confirmed by further studies.

The accretion over many decades of stocks of buildings in metropolitan areas of the United States has resulted in inventories that are less vulnerable than those in other parts of the world. However, they are subject to substantial damage which will result in social disruption and economic loss. Reducing urban vulnerability to earthquakes in the United States will require more than the adoption of more stringent building codes: it will involve systematic inspection and retrofit of existing building stocks. Cross-classifications of buildings by structural type and use will be helpful in assigning priorities and also assist in estimating damage and losses from possible events.

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