# MULTIHAZARD DESIGN 3

## 3.1 INTRODUCTION

This chapter compares the effects of three natural hazards that are the subject of this publication, in terms of their geographical locations, relative warning times, frequency, risk, and potential for damage and loss. Comparative losses are discussed and fire and safety considerations are presented. The design methods used to protect against the hazards by looking at the ways in which these methods reinforce or are in conflict with one another are compared. This is a key aspect of multihazard design because the similarities and differences in the ways in which hazards affect buildings and how to guard against them demand an integrated approach to natural hazards design. This must be pursued as part of a larger integrated approach to the whole building design problem.

## 3.2 THE HAZARDS COMPARED

Natural hazards are not aberrations; they are part of the natural environment in which we live and in which our buildings should be designed to function. Therefore, it is necessary for designers to become knowledgeable about all natural hazards in order to gain an understanding of how they act and how they can be accommodated within the design process, rather than treating them as adversaries that the designer must reluctantly accommodate at the expense of more traditional design aspirations.

This section presents a comparative sketch of the three natural hazards covered in this publication together with some issues relating to the common hazard of fire. The threat of physical attack is covered in a companion publication, FEMA 428, *Primer to Design Safe School Projects in Case of Terrorist Attacks.* A general understanding of all hazards is necessary in order to develop an integrated multihazard approach to design. It has been a tenet of multihazard design that design for two or more hazards may reinforce one another, thus reducing cost and improving protection, but it has also been recognized that at times there may be conflicts between designs for different hazards. This section presents, for the first time, a systematic analysis of the reinforcements and conflicts between hazard protection methods. This takes the form of the matrices shown in Section 3.5. This section is presented to stimulate discussion and analysis at the outset of project design and to provide a format for further development and discussion of the issues involved.

### 3.2.1 Location: Where are They?

The public perception of natural hazards is that earthquakes occur in California, floods in many riverine and coastal locations, tornadoes in the Midwest, and hurricanes along the Atlantic and Gulf coasts. Although there is some truth to this perception as it relates to the highest probabilities for each hazard, hazard maps show that the entire United States is vulnerable to one or more of the three main natural hazards: earthquakes, floods, or high winds. Earthquakes are predominant in the West, but also threaten specific regions in the Midwest, Northeast, and Southeast. The great earthquakes centered on the little town of New Madrid, Missouri, in 1811 and 1812 caused little damage and only a few casualties; a recurrence of these earthquakes would impact some of the most populous cities of the Midwest. The worst earthquake in the eastern states occurred in Charleston, South Carolina, in 1886; 60 people were killed and the modest sized city suffered the equivalent of about $25 million damage in today’s dollars. Riverine floods occur along rivers, largely but not exclusively in the Midwest, and coastal flooding is associated with storm surges caused by high winds. Flash floods caused by sudden, intense rainstorms may occur anywhere. Some of the worst floods in U.S. history have been caused by dam failures, often when rivers are swollen by flood waters. Extreme winds are regional (e.g., hurricanes along the Atlantic and Gulf coasts, the Caribbean, and the South Pacific; tornadoes typically in the Midwest; and downslope winds adjoining mountain ranges), but high winds can also occur anywhere.

Floods are fairly specific and predictable in their location, and effective design against floods is less a matter of design concept than of siting. A building can be located in such a way that floods will never be a problem; however, flood-free locations are relatively rare and our floodplains are full of existing buildings. Other than use of elevation, which can be reasonably effective, design against floods consists of a number of detailed measures (e.g., dry and wet floodproofing, which is discussed in Chapter 5 of this publication), all of which can be overwhelmed by flooding that exceeds the design flood. In some regions of the country, the designer must consider two or three natural hazards. In parts of California (in certain coastal and river delta regions), buildings are vulnerable to both floods and earthquakes, although the probability of simultaneous occurrence is remote. The Hawaiian Islands, Guam, the Virgin Islands, Puerto Rico, and parts of the East coast may all be impacted by earthquakes, floods, and high winds; although all three are lateral forces, they have many different characteristics that must be taken into design consideration.

Figures 3-1, 3-2, 3-3, and 3-4 provide four maps that show an overview of the incidence of earthquakes, floods, hurricanes, and tornadoes in the United States. Figure 3-1 shows the earthquake hazard for the United States; the contour lines on the map indicate the 10 percent probability of exceedance of ground motion accelerations within each contour area (or the “odds” that there is a 10 percent chance that the accelerations will be exceeded in a 50-year period). Maps such as this are used for seismic design to estimate the forces for which structures must be designed. Figures 3-2, 3-3, and 3-4 show the Presidential Disaster Declarations between January 1965 and November 2000 for floods, hurricanes, and tornadoes, respectively. These maps show only major events, and do not show all the regions where there are hazards. Chapters 4, 5, and 6 provide information to enable the reader to establish the risk for each of these hazards (earthquakes, floods, and high winds) in a local region, respectively.

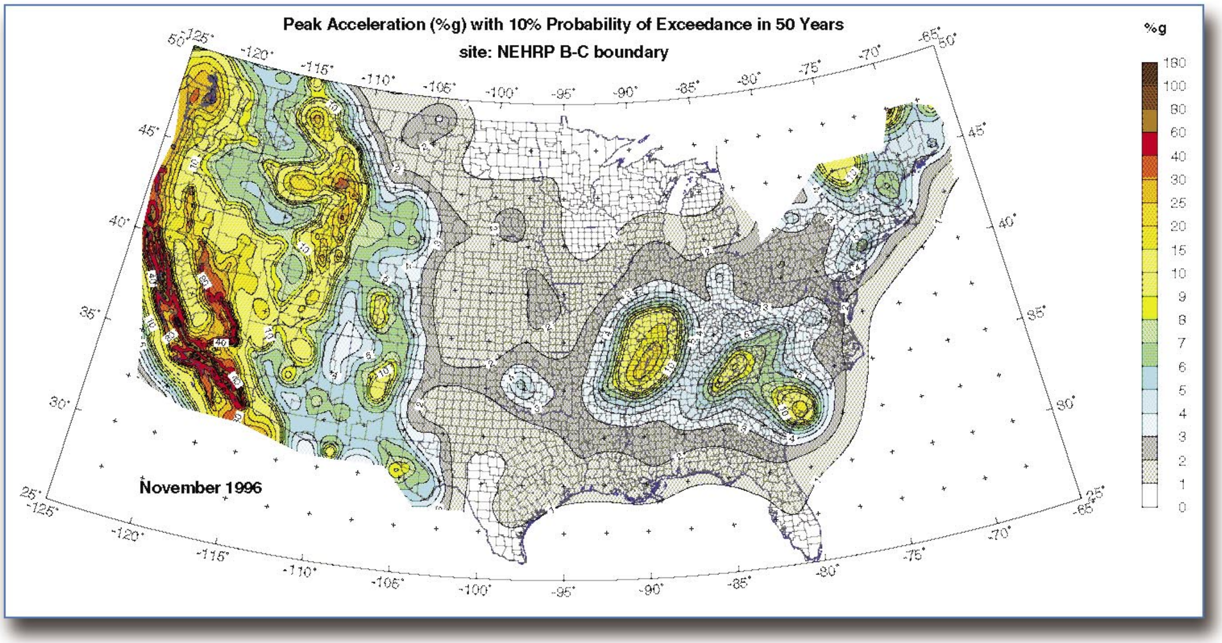

Figure 3-1
Peak accelerations (%g) with 10 percent probability of exceedance in 50 years. Color code shows %g for areas between contour lines. These values are used for seismic design.

SOURCE: USGS

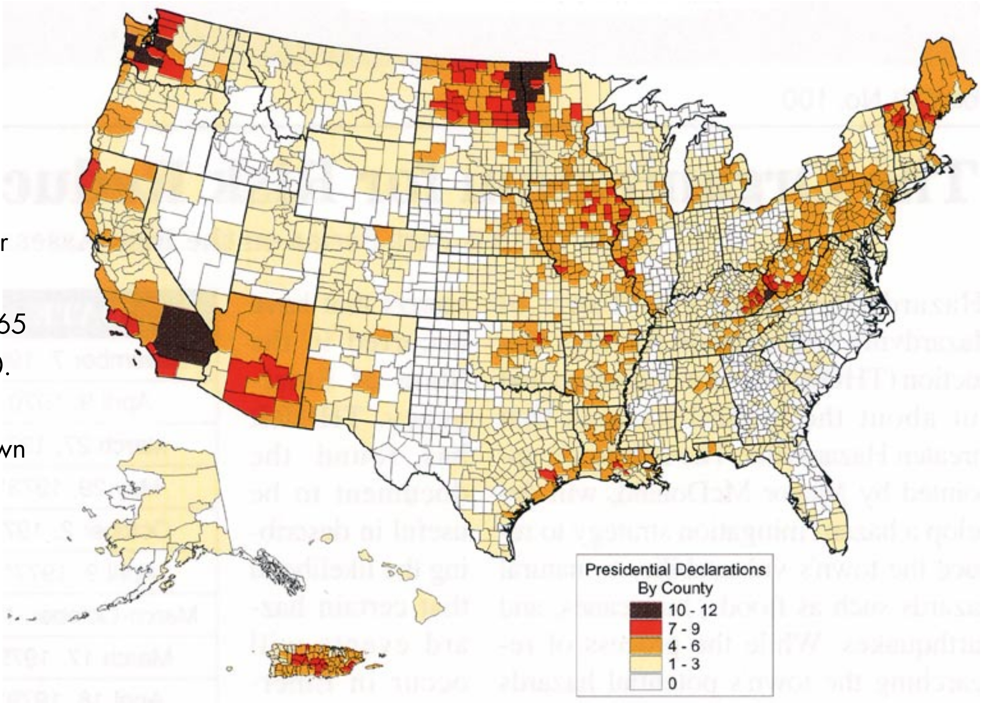

Figure 3-2
Presidential Disaster Declarations for floods, January 1965 to November 2000. The incidence of declarations is shown by counties.

SOURCE: FEMA 386-2

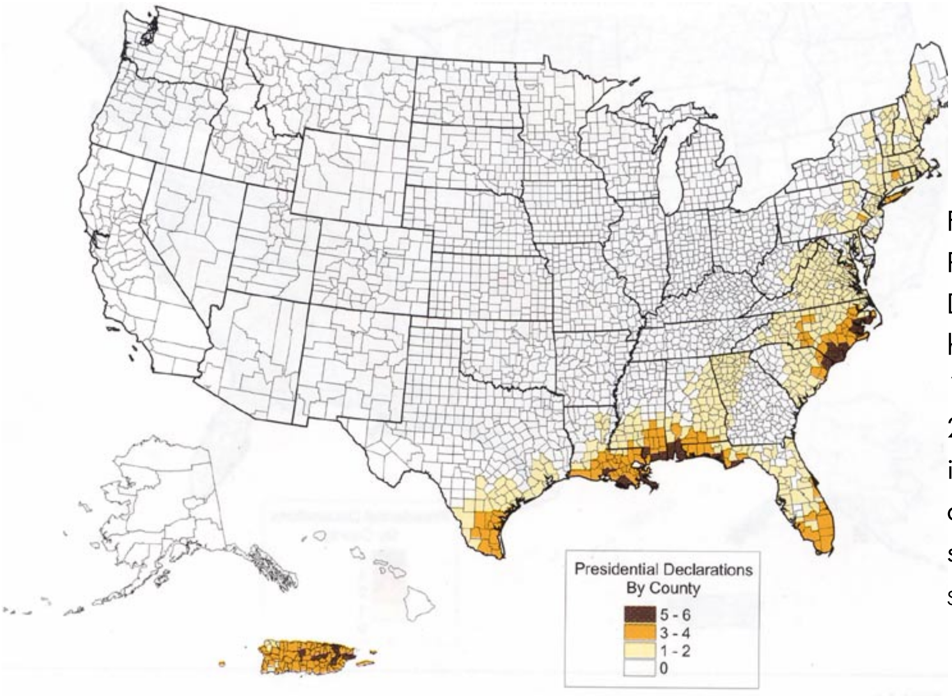

Figure 3-3
Presidential Disaster Declarations for hurricanes, January 1965 to November 2000. The incidence of declarations is shown by counties.

SOURCE: FEMA 386-2

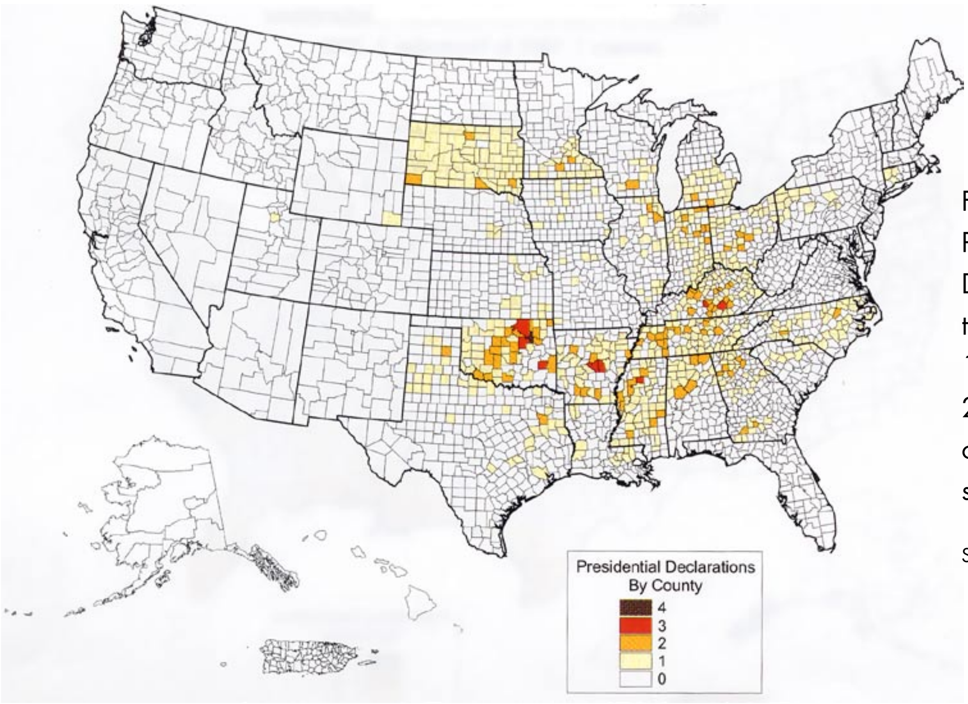

Figure 3-4
Presidential Disaster Declarations for tornadoes, January 1965 to November 2000. The incidence of declarations is shown by counties.

SOURCE: FEMA 386-2

### 3.2.2 Warning: How Much Time is There?

The warning times for these hazards vary. Earthquakes are unique among the natural hazards because there is no warning at all, although new sensing devices can now give a few seconds warning to locations far from the epicenter. Floods (except flash floods) can be predicted so as to give hours or days of warning; hurricanes can be tracked for days and give several hours of warning before hitting a specific location. Tornadoes are more localized and, though visible, may hit a specific location almost without notice.

Although the tornado gives warning and its approach is visible during daylight, its winds are often so strong that damage or destruction in its immediate vicinity is common. Hurricanes are tracked by the national hurricane tracking system and their movement is carefully and thoroughly reported. The hurricane's movement along its path is slower and its size is much larger than a tornado, yet even then its precise route and timing cannot be predicted until a few hours before making landfall.

In earthquake-prone areas that experience frequent events, such as California and Alaska, there is a continuous generalized prediction, but the earthquake always strikes totally without warning. Although much work has been done throughout the world to develop a scientific prediction methodology (based on characteristics such as changes in the dimensional or physical nature of the ground prior to an earthquake; detailed investigation of the geologic strata; or statistical data on the incidence of previous earthquakes), earthquakes must still be regarded as random events within a general envelope of probability.

### 3.2.3 Frequency: How Likely are They to Occur?

For all hazards, the regional probabilities are much higher than the local ones, and the extreme events are relatively rare for a given site. Inundation of floodplains in riverine areas and flooding of poorly protected or sited coastal locations may be relatively frequent; the general threat along rivers occurs each winter and spring, and a succession of hurricanes roam the Atlantic seaboard every year, bringing the risk of extreme winds and storm surge. Traditionally, residents in tornado-prone areas retreated to their basements, but engineered safe rooms are now being constructed in homes, schools, and other buildings. Earthquakes are perhaps the most difficult to deal with, because of their complete lack of warning, their rarity, and their possible extreme consequences. Although an earthquake of a given magnitude is still, in practical terms, unpredictable, its probability of occurrence can safely be predicted as far higher in California or Alaska than in, for example, Massachusetts or Tennessee. Even in California, the rarity of a large earthquake is such that many people will not experience one in their lifetime. In less seismic parts of the country, one must go back several generations, or to folklore, for earthquake stories, but even then there is a probability of an event.

Because natural hazards are only broadly predictable, the incidence of future events can only be expressed as probabilities. This presents a problem because what may be perfectly rational and useful to a mathematician may be confusing or even counterproductive to the public and their decision-makers. The probability of occurrence of earthquakes, floods, and high winds is commonly expressed by use of the term “return period” or “mean recurrence interval.” This is defined as the *average or mean time in years between the expected occurrence of an event of specified intensity.*

For example, until recently, earthquake codes used as a basis of severity a level of shaking (an acceleration value) that corresponded to a 10 percent probability of exceedance in 50 years (or a probability that it would be exceeded one time in approximately 500 years, a 500-year return period). More recently, it has become apparent that certain areas, such as the Mississippi embayment area, may, in fact, be vulnerable to much larger but more infrequent quakes. Therefore, a new set of hazard maps has been produced by the United States Geological Survey (USGS) that shows acceleration values for a 2 percent probability of exceedance in 50 years (approximately 2/3 of design value). Designing to this level would provide real protection against a large earthquake.

Values for high winds are commonly expressed in codes as a 50-year return period, much shorter than earthquakes because their incidence is much more frequent. Floods are expressed as a 100-year return period (i.e., the "100-year flood"). To the public, these return periods seem very long (i.e., why would a business owner confronting small crises every day and large ones every month be worried about an event that might not occur for 500 years - let alone 2,500 years? ). And if the return period for California is 500 years, would it not be another 400 years before something of the magnitude of the 1906 San Francisco earthquake occurs?

The problem is that these figures represent mean or average return periods over a very long period of time, with the result that the return period is often quite inaccurate in relation to the shorter time periods in which most of us are interested (i.e., the next year or the next 10 years). Because floods and high winds are relatively frequent, the discrepancy between the actual return period and the mean return period used in the codes is much more noticeable than the corresponding probabilities for earthquakes.

Currently, these statements of probability are the best we can do. Because they express mean values over long periods of time, they tell little about what will really happen this year or next year, but they may give a hint as to what will happen in our lifetime. Professional disaster planners must assume that disastrous hazards may occur at any time.

### 3.2.4 Risk: How Dangerous are They?

Deaths and injuries from natural hazards are serious, but are not statistically large on an annual basis (e.g., compared to deaths from automobile accidents); nor have we recently encountered the number of deaths caused by the Johnstown, Pennsylvania, dam failure and flood of 1889 (3,000 killed) or the Galveston, Texas, hurricane of 1900 (6,000 killed).

Deaths from earthquakes in the United States have been quite small (e.g., less than 200 people have been killed since 1971, including the San Fernando, California, earthquake that killed 65 people in that year and the later Loma Prieta and Northridge, California, earthquakes). However, the experience of Kobe, Japan, in 1995, when over 6,000 people were killed, shows that we cannot be complacent as to the ability of a modern city to withstand a direct hit.

A major concern for those working on reducing earthquake risks is that the United States has yet to experience a large earthquake in an urban location (such as the 1906 San Francisco earthquake or the New Madrid, Missouri, earthquakes of 1811 and 1812) that seismologists believe to be inevitable. The Northridge earthquake of 1994 caused approximately 60 deaths, with economic losses estimated to be over $30 billion. In January 1995, on the anniversary of the Northridge earthquake, an earthquake in Kobe, Japan, caused more than 6,000 deaths and economic losses estimated to be over $85 billion.

Since the Loma Prieta, Northridge, and Kobe earthquakes occurred, several analyses have been conducted on the potential effects of large earthquakes in California. It is estimated that a repeat of the 1906 earthquake on the San Andreas Fault near San Francisco would result in 3,000 to 8,000 deaths (depending on the time of day) with economic losses from $170 billion to $225 billion in today's dollars. It is also estimated that a magnitude 7 earthquake (a moderate to large shock) on the Newport-Inglewood Fault in Southern California would kill between 3,000 and 8,000 people and the economic losses would range from $175 billion to $220 billion.[1]

[1] Bendimerad, F., *Earthquake Scenarios in Three Cities: San Francisco, Los Angeles and Tokyo,* Proceedings, 11th World Conference on Earthquake Engineering, Acapulco, Mexico, 1996.

Earthquake-caused fires have historically been a major cause of casualties, most notably in the Tokyo earthquake of 1923. Approximately 30,000 people were killed in a single fire storm in a park along the Sunida River. Severe damage and casualties were caused by fires in the San Francisco earthquake of 1906 and the Kobe, Japan, earthquake of 1995.[2]

In the period between 1987 and 1997, floods caused 407 deaths: 187 were caused by the 1996 blizzard and flood in the Northeast. Hurricanes caused 599 deaths, 270 of which occurred in the 1993 blizzard and storm in the eastern United States. Although these numbers for hurricanes are substantial, relative to the size of the impacted area, the number of casualties is much less than in tornadoes. Between 1985 and 1997, the National Weather Service Storm Prediction Center reported 15 deaths in schools alone, of which 9 occurred in 1989.

Statistics for deaths from natural hazards over a recent 20-year period, on a mean annual basis, are as follows:[3]

| | |
|---|---|
| ❍ Earthquakes | 6 |
| ❍ Flash floods | 160 |
| ❍ Hurricanes | 30 |
| ❍ Tornadoes | 100 |

### 3.2.5 Cost: How Much Damage Will They Cause?

In the last two decades, losses from natural hazards have escalated. During the period from 1987 to 1997, floods caused $30 billion to $37 billion in damage, of which $15 billion was due to the Midwest floods of 1993. In the same 10-year period, hurricanes caused losses of between $60 billion to $66 billion, of which $27 billion was due to Hurricane Andrew in Florida and Louisiana.

---

[2] Arnold, C., *Reconstruction After Earthquakes:* Chapter Vb Toyko, Japan 1923 and 1945, Building Systems Development, Inc., Palo Alto, CA, 1990.

The three major California earthquakes that occurred in the period (Whittier Narrows, 1987, Loma Prieta, 1989, and Northridge 1994) caused some $36.5 billion in damages.

A statistical comparison of percentage of occurrence of property and economic losses between January 1986 and December 1992 is as follows:[4]

| | |
|---|---|
| Earthquakes | 3 |
| Hurricanes/Tropical storms | 48 |
| Tornadoes/Other winds | 40 |
| Fire/Explosion | 5 |
| Miscellaneous | 4 |

Although these statistics relate to events prior to the Northridge earthquake of 1994 and also predate a number of significant floods and hurricanes, the relative importance of each hazard has not changed significantly, even though the overall dollar values involved have increased sharply.

One cause of this serious increase in the social and economic impacts of natural hazards is the rapid pace and intensity of urban and suburban development since World War II, particularly in states such as California, the Carolinas, and Florida, all of which have their own high hazard probability. Another is the high cost of construction, now soaring to levels inconceivable only a few decades ago. A third problem is that our political, economic, and social mechanisms for decision-making are still ill equipped to deal with the multi-faceted problems of reducing the risks and consequences of natural disasters.

## 3.3 COMPARATIVE LOSSES

The HAZUS-MH (Hazards U.S.-Multihazards) program was developed by the Federal Emergency Management Agency (FEMA)

---

[4] Perry, D., *Buildings at Risk, Multi-Hazard Design for Earthquakes, Winds and Floods*, American Institute of Architects, Washington, DC, not dated.

to produce loss estimates for use by federal, state, regional, and local governments to plan for damage, prepare emergency response and recovery programs, and to help examine options to reduce future damage. HAZUS-MH is a Geographic Information System (GIS)-based program designed to help communities estimate future losses. The methodology covers nearly all aspects of the built environment and a wide range of losses. Originally developed to assess risks from earthquakes, the methodology has been expanded to address floods throughout the U.S. and hurricanes in the Atlantic and Gulf coast regions.

In order to obtain an indication of the magnitude of losses and their relative significance for the three hazards considered in this manual, a "Level 1" HAZUS-MH analysis was conducted for educational facilities in six areas of the United States. A Level 1 analysis uses the building inventory in the HAZUS-MH program and is intended to give a broad picture of damage and loss on a regional basis.

Due to the developmental status of HAZUS-MH Build 27E at the time of publication of this manual, it was not possible to use the program for the flood values. Instead the following procedure was used: Q3 flood data were used for each of the counties listed below in defining the extent of the 100-year and 500-year flood areas (this is similar to a Level 2 approach in HAZUS-MH). The Q3 flood data are developed by electronically scanning the current effective map panels of existing paper Flood Insurance Rate Maps (FIRMs). Q3 flood data capture certain key features from the existing paper FIRMs. 30-meter resolution USGS digital elevation data and the Q3 flood data were used to obtain flood elevation depths at different locations (using ArcGIS 3-D Analyst).

The analysis was a regional loss analysis and was based on the building information for the EDU 1 occupancy class in the general building stock module from the upcoming release of HAZUS-MH. (This occupancy class is the HAZUS-MH designation for the school building inventory.) The regions chosen were those prone to two or more of the hazards addressed in HAZUS-MH, and deemed to provide a useful range geographic range. For each region and applicable hazard, probabilistic losses for a 100-and 500-year return period event (earthquake, flood, or high wind) were computed. The column "EDU 1 Exposure" in Table 3-1 refers to the total school inventory in each region.

The following regions were evaluated:

- Charleston County, South Carolina (Charleston) (earthquake, flood, and hurricane)
- Shelby County, Tennessee (Memphis) (earthquake and flood)
- Bexar County, Texas (San Antonio) (hurricane and flood)
- Salt Lake County, Utah (Salt Lake) (earthquake and flood)
- Suffolk County, Massachusetts (Boston) (earthquake, flood, and hurricane)
- Hillsborough County, Florida (Tampa) (hurricane and flood)

Table 3-1 is a summary of the results for the earthquake, wind, and flood scenarios as outlined above.

Table 3-2 shows another comparison of these losses in the form of the percentage loss of school inventory for each event. It is instructive to note, in some cases, the wide disparity in losses between the 100-year and 500-year events.

Table 3-1: HAZUS-MH Earthquake, Hurricane, and Flood Losses (All values are in $1,000s (2002 valuation))

| **Charleston, SC** | **Earthquake** | | **Hurricane** | | **Flood** | | **EDU 1 Exposure** |
|---|---|---|---|---|---|---|---|
| | **100-yr** | **500-yr** | **100-yr** | **500-yr** | **100-yr** | **500-yr** | |
| Building Damage | 31 | 3,449 | 5,802 | 22,290 | 1,378 | 1,554 | 63,787 Building |
| Contents and Inventory | 4 | 1,365 | 3,690 | 16,897 | 392 | 557 | 63,787 Contents |
| Business Interruption | 5 | 320 | 2,052 | 6,558 | NE | NE | |
| **TOTAL** | **40** | **5,134** | **11,544** | **45,745** | **1,770** | **2,111** | |

| **Shelby, TN** | **Earthquake** | | **Hurricane** | | **Flood** | | **EDU 1 Exposure** |
|---|---|---|---|---|---|---|---|
| | **100-yr** | **500-yr** | **100-yr** | **500-yr** | **100-yr** | **500-yr** | |
| Building Damage | 243 | 10,464 | | | 4,184 | 6,784 | 137,927 Building |
| Contents and Inventory | 53 | 3,723 | | | 1,203 | 2,002 | 137,927 Contents |
| Business Interruption | 29 | 916 | | | NE | NE | |
| **TOTAL** | **325** | **15,103** | | | **5,387** | **8,786** | |

Table 3-1: HAZUS-MH Earthquake, Hurricane, and Flood Losses (All values are in $1,000s (2002 valuation)) (continued)

| **Bexar, TX** | **Earthquake** | | **Hurricane** | | **Flood** | | **EDU 1 Exposure** |
|---|---|---|---|---|---|---|---|
| | **100-yr** | **500-yr** | **100-yr** | **500-yr** | **100-yr** | **500-yr** | |
| Building Damage | | | 94 | 2,753 | 1,502 | 2,384 | 238,608 Building |
| Contents and Inventory | | | 5 | 1,259 | 487 | 727 | 238,608 Contents |
| Business Interruption | | | 7 | 2,078 | NE | NE | |
| **TOTAL** | | | **106** | **6,090** | **1,989** | **3,111** | |

| Salt Lake, UT | **Earthquake** | | **Hurricane** | | **Flood** | | **EDU 1 Exposure** |
|---|---|---|---|---|---|---|---|
| | **100-yr** | **500-yr** | **100-yr** | **500-yr** | **100-yr** | **500-yr** | |
| Building Damage | 2,175 | 30,313 | | | 15 | 204 | 177,728 Building |
| Contents and Inventory | 881 | 9,016 | | | 4 | 57 | 177,728 Contents |
| Business Interruption | 259 | 2,488 | | | NE | NE | |
| **TOTAL** | **3,315** | **41,817** | | | **19** | **261** | |

| **Suffolk, MA** | **Earthquake** | | **Hurricane** | | **Flood** | | **EDU 1 Exposure** |
|---|---|---|---|---|---|---|---|
| | **100-yr** | **500-yr** | **100-yr** | **500-yr** | **100-yr** | **500-yr** | |
| Building Damage | 0 | 1,544 | 4,837 | 58,640 | 254 | 907 | 268,311 Building |
| Contents and Inventory | 0 | 484 | 2,258 | 40,665 | 70 | 305 | 268,311 Contents |
| Business Interruption | 0 | 172 | 2,871 | 18,316 | NE | NE | |
| **TOTAL** | **0** | **2,200** | **9,966** | **117,621** | **324** | **1,212** | |

| **Hillsborough, FL** | **Earthquake** | | **Hurricane** | | **Flood** | | **EDU 1 Exposure** |
|---|---|---|---|---|---|---|---|
| | **100-yr** | **500-yr** | **100-yr** | **500-yr** | **100-yr** | **500-yr** | |
| Building Damage | | | 10,257 | 47,213 | 10,727 | 11,776 | 175,981 Building |
| Contents and Inventory | | | 6,045 | 39,016 | 4,329 | 4,624 | 175,981 Contents |
| Business Interruption | | | 4,291 | 13,004 | NE | NE | |
| **TOTAL** | | | **20,593** | **99,233** | **15,056** | **16,400** | |

Notes:

EDU 1 Exposure: total school and contents inventory in each region (2003).

NE: HAZUS did not estimate these losses.

0: Evaluated, but no losses.

Boxes left blank have little or no activity for the referenced hazard.

Table 3-2: HAZUS-MH Estimated Losses by Percentage of School Building and Contents Inventory

| | Earthquake | | Hurricane | | Flood | |
|---|---|---|---|---|---|---|
| **County** | **100-year** | **500-year** | **100-year** | **500-year** | **100-year** | **500-year** |
| **Charleston, SC** | 0.2 | 17.3 | 4.54 | 17.50 | 1.38 | 1.65 |
| **Shelby, TN** | 0.12 | 5.47 | | | 1.95 | 2.46 |
| **Bexar, TX** | | | 0.02 | 1.27 | 0.40 | 0.65 |
| **Salt Lake, UT** | 1.1 | 11.76 | | | 0.01 | 0.07 |
| **Suffolk, MA** | 0 | 0.8 | | | | |
| **Hillsborough, FL** | | | 5.85 | 28.20 | 4.27 | 4.65 |

Notes:
Boxes left blank have little or no activity for the referenced hazard.

This HAZUS-MH study, though limited in scope and relying on built inventory information, reveals some useful information:

- Generally, the 100-year earthquake causes insignificant damage, except in Salt Lake City, UT ($3 million).
- The 500-year earthquake causes the most damage in Salt Lake City, UT ($42 million), followed by Shelby, TX ($15 million) and Charleston, SC ($5 million).
- The 100-year flood causes by far the most damage in Hillsborough, FL ($15 million; however, the 500-year flood causes only another $1 million in damage). In Shelby, TN, the 100-year flood causes $5 million in damage and the 500-year flood causes $9 million. Elsewhere, flood damage is insignificant.
- The 100-year hurricane causes the most damage in Hillsborough, FL ($20.5 million), followed by Charleston, SC ($11.5 million) and Suffolk, MA ($10 million).
- The 500-year flood causes $118 million in damage in Suffolk, MA, $99 million in damage in Hillsborough, FL, and $46 million in damage in Charleston, SC.

Charleston, SC, has the greatest combined threat from earthquakes and hurricanes; Hillsborough, FL, has the greatest combined threat from hurricanes and floods.

The relatively modest damage figures shown in this study could be changed dramatically by a single large event, whether an earthquake, flood, or hurricane. It should also be noted that none of these locations were on the west coast and, thus, the damage figures for earthquakes are low.

## 3.4 FIRE AND LIFE SAFETY

Of the many hazards that can endanger a school facility and its service to the community, the most prevalent is fire. This is more pervasive than any of the hazards noted above. However, design against fire has long been built into our building codes, in the form of approved materials, fire-resistant assemblies, exiting requirements, the width and design of stairs, the dimensions of corridors, fire suppression systems, and many other issues. In fact, fire considerations are now so embedded in our design culture and regulation that there is a real danger that some designers may not fully realize that fire hazard is a specific design issue that must be considered.

According to the *Special Report on Educational Property Structure Fires in the United States* published by the NFPA in 1989, an average of 11,100 structural fires occur annually in educational properties. These fires resulted in a direct property loss of nearly $100 million, with 236 injuries and 3 fatalities. According to both NFPA and the United States Fire Administration (USFA), a substantial number of fires in schools are the result of arson.

Fires in older school buildings often result in a total loss of the building. This is due to a variety of factors, which include: delay of discovery and alarm, remote locations, lack of fire walls and/or compartmentation, lack of draft stopping in combustible attics, lack of automatic fire sprinkler systems, and inadequate water supplies for manual fire suppression activities. Losses in buildings without automatic fire alarm and detection systems are twice those in buildings with such systems. Additionally, fire losses in buildings without automatic fire sprinkler protection are five times higher than those in buildings protected by sprinklers.

Often there appears to be a concern that there is not enough water for automatic fire sprinklers. The reality is that the water supply necessary for the proper operation of an automatic fire sprinkler system is far less than the amount of water necessary for manual fire suppression by the fire department. As an example, the water supply for a fire sprinkler system protecting a typical school building would be in the 350 gallons per minute (gpm) range, although 2,500 gpm or more would be required by a typical school building without sprinklers.

Since the 1970s, the provisions of the various building codes have continued to improve the level of fire and life safety of new school facilities. The level of fire and life safety in existing buildings is, however, another matter because the provisions of the various building codes are generally not applied to existing facilities except when renovations or additions are made and then only to the new work. Given that the average age of a school facility in the United States is currently 42 years, it is highly likely that older buildings do not provide the same level of protection as newer buildings. In order to protect these older facilities, their levels of fire and life safety must be evaluated. After an evaluation has been conducted, solutions using prescriptive and/or performance approaches can be developed and undertaken.

One system of evaluation is that contained in the existing structures chapter of the *International Building Code*. The "compliance alternatives" section provides a way of evaluating the overall level of fire and life safety in an existing building. Although the provisions of this section are generally intended to be applied to an existing building during changes in occupancy or renovation, it can provide the basis for the evaluation of any existing building.

The evaluation comprises three categories: fire safety, means of egress, and general safety. The fire safety evaluation includes structural fire resistance, automatic fire detection, and fire alarm and fire suppression systems. Included within the means of egress portion are the configuration, characteristics, and support features for the means of egress. The general safety section evaluates various fire safety and means of egress parameters. The evaluation method generates a numerical score in the various areas, which can then be compared to mandatory safety scores. Deficiencies in one area may be offset by other safety features.

Another method of evaluating and upgrading an existing facility is the application of the provisions of the NFPA 101 *Life Safety Code*. Unlike the provisions of the various building codes, this document is intended to be applied retroactively to existing facilities and has a chapter specifically for existing educational occupancies. Even if this code is not adopted by the local jurisdiction, it can be used as the basis for an evaluation of any existing facility.

There is no question that upgrading an existing school facility can be costly. However, the cost of upgrades is far less than the direct and indirect losses of the facility to fire. The most effective method of providing fire protection is through automatic fire sprinklers, but other lower cost methods can be utilized, including:

- Automatic fire alarm and detection
- Draft stopping in combustible attic spaces
- Smoke and fire compartmentation walls in occupied spaces

Upgrades in fire and life safety can often be coordinated with other building renovations or upgrades to help reduce costs. For instance, draft stopping could be installed in a wood framed attic during roof deck replacement. Fire sprinklers could be installed during asbestos abatement or ceiling replacement/upgrades for seismic concerns.

## 3.5 HAZARD PROTECTION METHODS COMPARISONS: REINFORCEMENTS AND CONFLICTS

An important aspect of designing against all hazards in an integrated approach is that the methods used for design may reinforce one another or may conflict with one another; in the former case, the costs of multihazard design can be reduced, but, in the latter, they may be increased. Table 3-3 summarizes the effects that design for more than one hazard may have on the performance and cost of the building, addition, or repair.

The horizontal rows show the five primary hazards. The vertical rows show methods of protection for the building systems and components that have significant interaction, either reinforcement or conflict. These methods are taken from the extended descriptions of risk reduction methods for the three main natural hazards discussed herein, together with the methods for security/blast protection presented in FEMA 428, *Primer to Design Safe School Projects in Case of Terrorist Attacks*. In addition, the interactions of these four categories of risk protection with fire safety, where they occur, are also shown.

The designations are intended to provoke thought and design integration; they are not absolute restrictions or recommendations. In general, reinforcement between hazards may be gained and undesirable conditions and conflicts can be resolved by coordinated design between the consultants, starting at the inception of design. The reader is encouraged to use the list as a basis for discussion relative to specific projects and to structure the benefits and conflicts of multihazard design depending on local hazards.

Table 3-3 also provides information to help the reader to develop a list of reinforcements and conflicts for the particular combination of hazards that may be faced. Development of lists such as these can be used to structure initial discussions on the impact of multihazard design on the building performance and cost that, in turn, guide an integrated design strategy for multihazard protection. The system and component heading list is similar to that used for the building security assessment checklist in FEMA 426, *Reference Manual to Mitigate Potential Terrorist Attacks Against Buildings.*

Table 3-3: Multihazard Design System Interactions

| **Key** | | |
|---|---|---|
| ✔ | | Indicates desirable condition or method for designatedcomponent/system |
| ✘ | | Indicates undesirable condition or method for designated component/system |
| ❑ | | Indicates little or no significance for designated component/system |
| | | Split box indicates significance may vary, see discussion issues |

**Building System Protection Methods: Reinforcements and Conflicts**

| **System ID** | **Existing Conditions or Proposed Protection Methods** | **The Hazards** | | | | | |
|---|---|---|---|---|---|---|---|
| | | Earth-quake | Flood | Wind | Security/Blast (FEMA 428) | Fire | Discussion Issues |
| **1** | **Site** | | | | | | |
| | 1-1 Building elevated on fill | ❑ | ✔ | ❑ | ❑ | ❑ | Excellent solution for flood. |
| | 1-2 Two means of site access | ✔ | ✔ | ✔ | ✔ | ✔ | |
| | 1-3 In close proximity to other facilities that are high risk targets for attack | ❑ | ❑ | ❑ | ✘ | ❑ | |

Table 3-3: Multihazard Design System Interactions (continued)

| Building System Protection Methods: Reinforcements and Conflicts | | | | | | | |
|---|---|---|---|---|---|---|---|
| **System ID** | **Existing Conditions or Proposed Protection Methods** | **The Hazards** | | | | | |
| | | Earthquake | Flood | Wind | Security/Blast (FEMA 428) | Fire | Discussion Issues |
| **2** | **Architectural** | | | | | | |
| 2A | Configuration | | | | | | |
| | 2A-1 Large roof overhangs | ✘ | ❑ | ✘ | ✘ | ❑ | Possibly vulnerable to vertical forces in earthquake, uplift wind forces. The wall to roof intersection will tend to contain and concentrate blast forces if the point of detonation is below the eaves. |
| | 2A-2 Re-entrant corner (L-, U-shape, etc.) building forms | ✘ | ❑ | ✘ | ✘ | ❑ | May concentrate wind or blast forces; may cause stress concentrations and torsion in earthquakes. |
| | 2A-3 Enclosed courtyard building forms | ✘ | ❑ | ✔ | ✔ ✘ | ❑ | May cause stress concentrations and torsion in earthquake; courtyard provides protected area against high winds. Depending on individual design, they may offer protection or be undesirable during a blast event. If they are not enclosed on all four sides, the "U" shape or re-entrant corners create blast vulnerability. If enclosed on all sides, they might experience significant blast pressures, depending on building and roof design. Because most courtyards have significant glazed areas, this could be problematic. |
| | 2A-4 Very complex building forms | ✘ | ✘ | ✘ | ✘ | ✘ | May cause stress concentrations and torsion in highly stressed structures, and confusing evacuation paths and access for firefighting. Complicates flood resistance by means other than fill. |
| 2B | Planning and Function (No significant impact) | | | | | | |

Table 3-3: Multihazard Design System Interactions (continued)

**Building System Protection Methods: Reinforcements and Conflicts**

| **System ID** | **Existing Conditions or Proposed Protection Methods** | **The Hazards** | | | | | |
|---|---|---|---|---|---|---|---|
| | | Earth-quake | Flood | Wind | Security/Blast (FEMA 428) | Fire | Discussion Issues |
| 2C | Ceilings (No significant impact) | | | | | | |
| 2D | Partitions | | | | | | |
| | 2D-1 Block, hollow clay tile partitions | ✘ | ✔ | ✘ | ✘ | ✔ | Wind and seismic force reactions would be similar for heavy unreinforced wall sections, with risk of overturning. Tile may become flying debris during a blast. It is possible, but difficult, to protect structures with blast walls, but a weak nonstructural wall has more chance of hurting people as debris. Desirable against fire and not seriously damaged by flood. |
| | 2D-2 Use of non-rigid connections for attaching interior non-load bearing walls to structure | ✔ | ❑ | ✔ | ✔ | ✘ | Non-rigid connections are necessary to avoid partitions influencing structural response. However, gaps provided for this threaten the fire resistance integrity and special detailing is necessary to close gaps, but retain ability for independent movement. |
| | 2D-3 Gypsum wallboard partitions | ✔ | ✘ | ❑ | ✘ | ✘ | Although gypsum wallboard partitions can be constructed to have a fire resistance rating, they can be easily damaged during fire operations. Such partitions can be more easily damaged or penetrated during normal building use. |
| | 2D-4 Concrete block, hollow clay tile around exit ways and exit stairs | ✘ | ❑ | ❑ | ✘ ✔ | ✔ | May create torsional structural response and/or stress concentration in earthquakes in frame structures unless separated and, if unreinforced, wall is prone to damage. Properly reinforced walls preserve evacuation routes in case of fire or blast. |

Table 3-3: Multihazard Design System Interactions (continued)

| Building System Protection Methods: Reinforcements and Conflicts | | | | | | | |
|---|---|---|---|---|---|---|---|
| **System ID** | **Existing Conditions or Proposed Protection Methods** | **The Hazards** | | | | | |
| | | Earth-quake | Flood | Wind | Security/Blast (FEMA 428) | Fire | Discussion Issues |
| 2E | Other Elements | | | | | | |
| | 2E-1 Heavy roof (e.g. slate, tile) | ✘ | ❑ | ✘ | ✘ | ✘ ✔ | Heavy roofs are undesirable in earthquakes; slates and tiles may detach. Heavy roofs provide good protection from fire spread, but can also cause collapse of a fire-weakened structure. Almost always used on steep-sloped roofs; if wind-blown debris or a blast wave hits them, they become flying debris and dangerous to people outside the building. |
| | 2E-2 Parapet | ✘ ✔ | ❑ | ✔ | ✘ | ✔ | Properly engineered parapet is OK for seismic; unbraced unreinforced masonry (URM) is dangerous. May assist in reducing the fire spread. |
| **3** | **Structural Systems** | | | | | | |
| | 3-1 Heavy structure: reinforced concrete (RC) masonry, RC or masonry fireproofing of steel | ✘ | ✔ | ✔ | ✔ | ✔ | Increases seismic forces, but generally beneficial against other hazards. |
| | 3-2 Light structure: steel/wood | ✔ | ✘ | ✘ | ✘ | ✘ | Decreases seismic forces, but generally less effective against other hazards. |
| | 3-3 URM exterior load bearing walls | ✘ | ✘ | ✘ | ✘ | ✘ | |
| | 3-4 Concrete or reinforced CMU exterior structural walls | ✔ | ✔ | ✔ | ✔ | ✔ | |
| | 3-5 Soft/weak first story | ✘ | ✘ ✔ | ✘ | ✘ | ✘ | Very poor earthquake performance, and vulnerable to blast. Generally undesirable for flood and wind. Elevated first floor is beneficial for flood if well constructed, but should not be achieved by a weak structure that is vulnerable to wind or flood loads. |

Table 3-3: Multihazard Design System Interactions (continued)

**Building System Protection Methods: Reinforcements and Conflicts**

| **System ID** | **Existing Conditions or Proposed Protection Methods** | **The Hazards** | | | | | |
|---|---|---|---|---|---|---|---|
| | | Earth-quake | Flood | Wind | Security/Blast (FEMA 428) | Fire | Discussion Issues |
| | 3-6 Indirect load path | ✘ | ❑ | ✘ | ✘ | ✘ | Undesirable for highly stressed structures, and fire weakened structure is more prone to collapse. Not critical for floods. |
| | 3-7 Discontinuities in vertical structure | ✘ | ❑ | ✘ | ✘ | ✘ | Undesirable for highly stressed structures causes stress concentrations, and fire-weakened structure is more prone to collapse. Not critical for floods. |
| | 3-8 Seismic separation joints | ✔ | ❑ | ❑ | ❑ | ✘ | Possible path for toxic gases to migrate to other floors. |
| | 3-9 Ductile detailing and connections/steel | ✔ | ❑ | ✔ | ✔ | ❑ | Provides a tougher structure that is more resistant to collapse. |
| | 3-10 Ductile detailing/RC | ✔ | ❑ | ✔ | ✔ | ❑ | Provides a tougher structure that is more resistant to collapse. |
| | 3-11 Design for uplift (wind) | ✔ | ❑ | ✔ | ✔ | ❑ | Necessary for wind; may assist in resisting seismic or blast forces. |
| | 3-12 Concrete block, hollow clay tile around exit ways and exit stairs | ✘ | ❑ | ❑ | ✘ | ✔ | May create torsional structural response and/or stress concentration in earthquakes in frame structures unless separated, and if unreinforced wall is prone to damage. Properly reinforced walls preserve evacuation routes in the event of fire or blast. |
| **4** | **Building Envelope** | | | | | | |
| 4A | Wall Cladding | | | | | | |
| | 4A-1 Masonry veneer on exterior walls | ✘ | ✘ | ✘ | ✘ | ❑ | In earthquakes, material may detach and cause injury. In winds and attacks, may detach and become flying debris hazard. Flood forces can separate veneer from walls. |

Table 3-3: Multihazard Design System Interactions (continued)

| Building System Protection Methods: Reinforcements and Conflicts | | | | | | | |
|---|---|---|---|---|---|---|---|
| **System ID** | **Existing Conditions or Proposed Protection Methods** | **The Hazards** | | | | | |
| | | Earth-quake | Flood | Wind | Security/Blast (FEMA 428) | Fire | Discussion Issues |
| 4B | Glazing | | | | | | |
| | 4B-1 Metal/glass curtain wall | ✓ | ☐ | ✗ | ✗ | ✗ | Fire can spread upward behind the curtain wall if not properly fire-stopped. Not blast-resistant without special glass and detailing. Light weight reduces earthquake forces. |
| | 4B-2 Impact-resistant glazing | ☐ | ☐ | ✓ | ✓ | ✗ | Can cause problems during fire suppression operations, limiting access and smoke ventilation. |
| **5** | **Utilities** (No significant impact) | | | | | | |
| **6** | **Mechanical** | | | | | | |
| | 6-1 Heating, ventilation, and air conditioning (HVAC) system designed for purging in the event of fire | ☐ | ☐ | ☐ | ✓ | ✓ | Can be effective in reducing chemical, biological, or radiological (CBR) threat if it has rapid shut-down and efficient dampers, and is located in an airtight building. |
| | 6-2 Large rooftop-mounted equipment | ✗ | ✓ | ✗ | ✗ | ☐ | Vulnerable to earthquake and wind forces. Raises equipment above floor level. |
| **7** | **Plumbing and Gas** (No significant impact) | | | | | | |
| **8** | **Electrical** (No significant impact) | | | | | | |
| **9** | **Fire Alarm** (No significant impact) | | | | | | |
| **10** | **Communications and IT** (No significant impact) | | | | | | |
| **11** | **Equipment O&M** (No significant impact) | | | | | | |
| **12** | **Security** (No significant impact) | | | | | | |
| 12A | Perimeter Systems (No significant impact) | | | | | | |
| 12B | Interior Security (No significant impact) | | | | | | |
| 12C | Security System Documents (No significant impact) | | | | | | |
| **13** | **Security Master Plan** (No significant impact) | | | | | | |

Notes:

The table refers to typical school structures: steel frame, concrete block or RC walls, wood frame, 1-2 stories suburban, 2-4 stories urban.