Design of Buildings Against Natural Hazards

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Credit: 1 PDH

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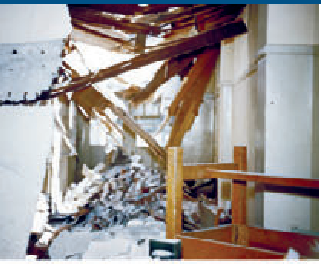




3 Multihazard Design

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, and how likely they are to occur. Fire and life safety considerations are discussed. The design methods used to resist the effects of each natural hazard are discussed in the context of the design methods for the other natural hazards. This integrated approach is a key aspect of multihazard design that must be reflected in a larger integrated approach to the whole building design.

3.2 The Hazards Compared

This section compares the three natural hazards together with issues relating to designing for fire protection, which is required for all school buildings. A general understanding of all hazards is necessary in order to develop an integrated approach which is important for locations subject to more than one hazard. Designs for two or more hazards may reinforce one another, thus reducing cost and improving protection. They may also conflict with each other. This section presents a systematic analysis of these multihazard protection methods. The analysis takes the form of the matrices shown in Section 3.5. Facility planners and designers faced with the challenge of multihazard design requirements may find this section beneficial to stimulate discussion and to prompt analysis at the outset of project design. The threat of physical attack is covered in a companion publication, FEMA 428, *Primer to Design Safe School Projects in Case of Terrorist Attacks.*

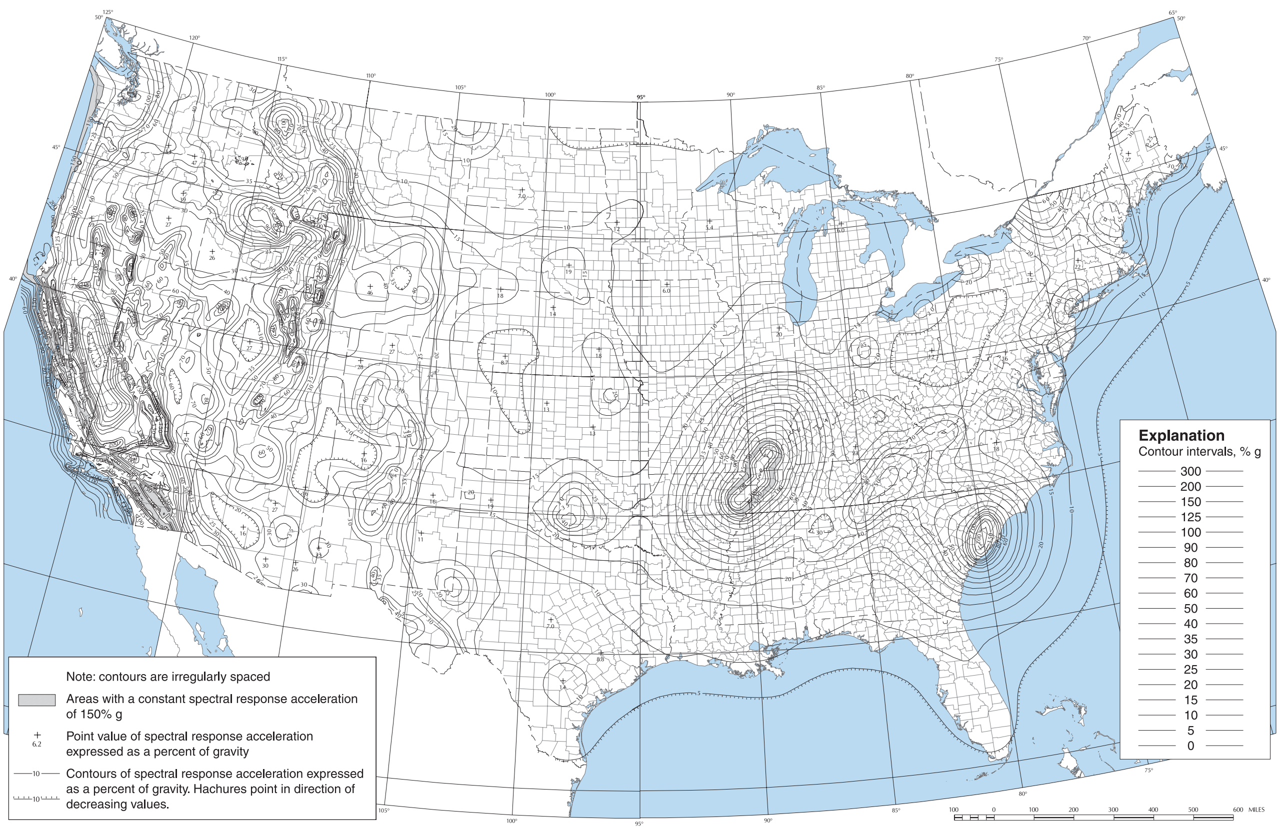
3.2.1 Location: Where do Hazards Occur?

The common public perception of natural hazards is that earthquakes occur in California, floods involve major rivers, tornadoes strike the Midwest, and hurricanes affect the shorelines of the southern Atlantic and Gulf of Mexico. Although there is some truth to this perception as it relates to the highest probabilities, maps that show past disasters reveal that the entire United States is vulnerable to one or more of the three primary natural hazards: earthquakes, floods, or high winds.

- Earthquakes are predominant in the West, but also threaten specific regions in the Midwest, Northeast, and Southeast, and the U.S. territories.[1] The great earthquakes centered on the little town of New Madrid, MO, 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, SC, 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 and streams of all sizes, and coastal flooding is associated with storm surges caused by high winds along the entire U.S. shoreline and Great Lakes. 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 already 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.
- Alaska, Hawaii, parts of the East Coast, and the U.S. territories may all be affected by earthquakes, floods, and high winds.

1 The U.S. territories include American Samoa, Guam, Northern Mariana Islands, Puerto Rico, and the U.S. Virgin Islands.

Figure 3-1 illustrates the areas where earthquakes are likely to occur on the U.S. mainland. The contour lines indicate the 2-percent probability of exceedance of ground motion accelerations within each contour area (or the "odds" [2 percent] that the accelerations will be exceeded in a 50-year period). Figure 3-2 is the basic wind speed map from ASCE 7 that is cited in the model building codes and used to select design wind speeds. In addition to high wind regions around the Gulf and Atlantic Coasts, it identifies "special wind regions" in mountainous areas where high winds are likely. Locations where flooding is likely cannot be illustrated in a similar manner because flooding occurs along virtually every body of water, whether large or small. Flood hazard maps are available at the county and municipality level. Chapters 4, 5, and 6 provide information that will help establish the risk for each of these hazards (earthquakes, floods, and high winds) in a local region, respectively.



Source: *Minimum Design Loads for Buildings and Other Structures*, ASCE/SEI 7-05. Used with permission of ASCE.

Figure 3-1:
Areas where earthquakes are likely to occur on the U.S. mainland. The contour lines indicate the 2-percent probability of exceedance of ground motion accelerations within each contour area (or the "odds" [2-percent] that the accelerations will be exceeded in a 50-year period).

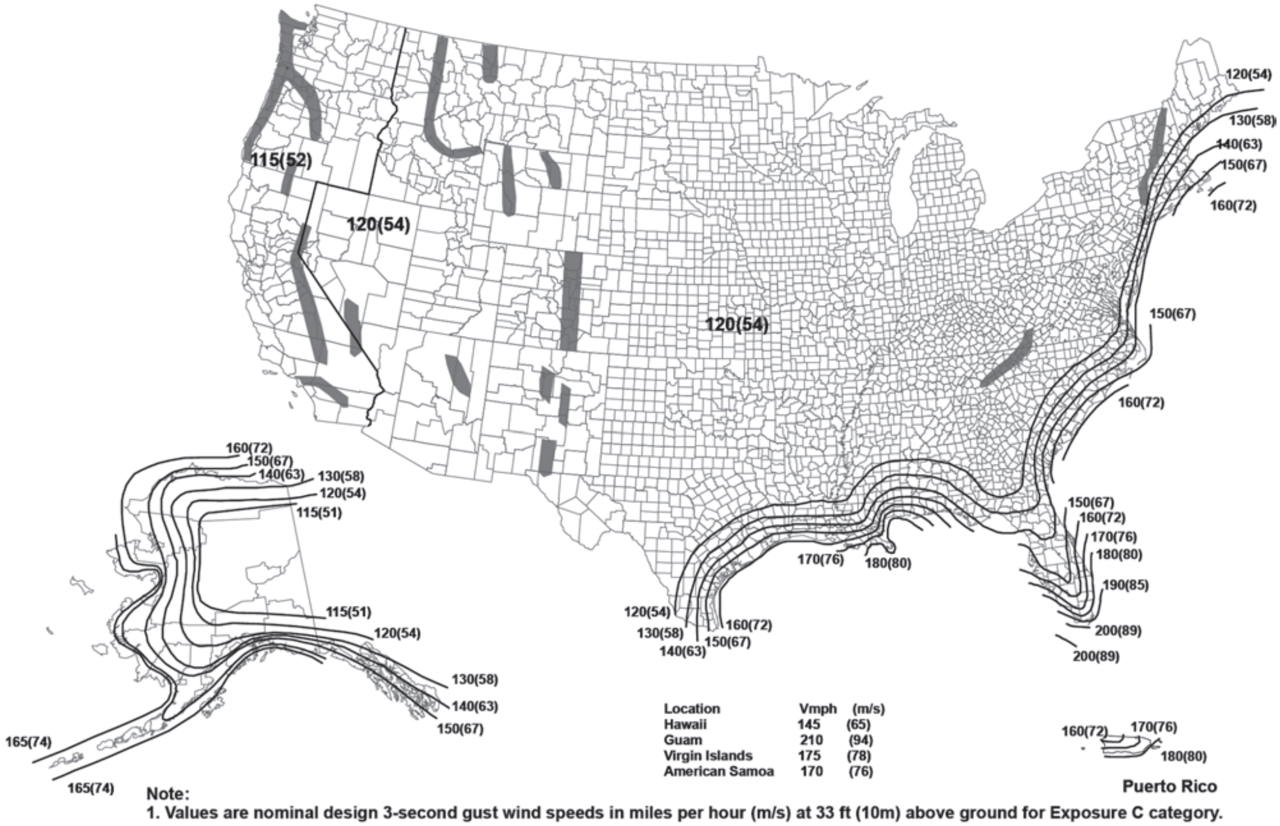


Figure 3-2:
Basic wind speed map from ASCE 7 for Risk Category III and IV buildings and other structures. ASCE 7 is cited in the model building codes and used to select design wind speeds.

SOURCE: ASCE 7-10

3.2.2 Warning: How Much Warning is There?

The warning times for the three primary natural hazards vary as a function of many variables:

- Earthquakes are unique among the natural hazards because there is no warning at all, although new sensing devices can give a few seconds warning to locations far from the epicenter. 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.
- Riverine floods (except flash floods) can usually be predicted to give hours or days of warning. National and regional river monitoring

systems and numerous local weather and flood warning systems provide improved warning along many waterways.

- Coastal flooding associated with hurricanes can be anticipated because tropical systems can be tracked for days before making landfall. Hurricanes are tracked by the National Hurricane Center and their movements are carefully and thoroughly reported although there are many variables that limit the precision of predictions. Other coastal storms, such as nor'easters and those that affect the Pacific and Great Lakes shorelines are less predictable.
- Tornadoes are localized, though sometimes visible from a distance. However, modern technology allows the National Weather Surface to identify conditions that are conducive to the formation of tornadoes. Typically, they hit a specific location with only a few minutes notice.

3.2.3 Frequency: How Likely are They to Occur?

For all hazards, the probability that an event will occur within a region is much higher than the probability that an event will occur at a specific location. Extreme events are relatively rare for a given site. Some level of inundation in riverine floodplains and coastal shorelines occurs relatively frequently. Storms that produce sufficient rainfall-runoff to cause river and stream flooding can occur throughout the year, although are more prevalent during specific seasons in some areas of the country. Coastal nor'easter storms generally occur in the winter and early spring months, while hurricanes roam the Gulf Coast and Atlantic seaboard between June 1st and the end of November, bringing both high winds and storm surge flooding.

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 reasonably 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 seismically active parts of the country, the probability of an event is even smaller.

Because the occurrence of natural hazards is only broadly predictable, the frequency of occurrence of future events can only be expressed as probabilities. The probability of occurrence of earthquakes, floods, and high winds is commonly expressed by the term "return period" or "mean recurrence interval," which is defined as the average or mean time in years between the expected occurrence of events of specified intensity.

Prior to the 2000 *International Building Code* (IBC), the seismic maps in the model buildings codes used a level of shaking (an acceleration value) that corresponds to a 10-percent probability of exceedance in 50 years (or a probability that it would be exceeded one time in approximately 475 years, a 475-year recurrence interval). More recently, research suggests that certain areas, such as the central and eastern United States and in particular the New Madrid Seismic Zone, may be vulnerable to much larger but less frequent quakes. More recent seismic hazard maps produced by the U.S. Geological Survey (USGS) and appearing in the 2000 IBC and later editions show acceleration values for a 2-percent probability of exceedance in 50 years (e.g., a recurrence interval of 2,475 years). Designs based on this level are expected to provide significant protection in areas subject to large but less frequent earthquakes. Additional information about seismic maps appearing in the IBC can be found in FEMA 450, *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures* (2003a).

Beginning with the 2010 edition of ASCE 7, for Risk Category III and IV buildings, the basic wind speed is associated with a return period of 1,700 years, or an annual exceedance probability of 0.000588. The magnitude of flood event used as the minimum design value is the 1-percent-annual-chance flood, which has a 100-year return period (often call the "100-year flood"). These return periods may seem very long (i.e., a business owner confronting small crises every day and large ones every month may not be worried about an event that might not occur for 500 years). And if the return period for an earthquake event in California is 500 years, the public may erroneously believe that it will be another 400 years before an event of the magnitude of the 1906 San Francisco earthquake occurs.

These expressions of frequency represent mean or average return periods over a very long period of time, but may be perceived as not pertinent in relation to the shorter time periods that most people are interested in (i.e., the next year or the next 10 years). Because floods and high winds occur relatively more frequently, the discrepancy between the actual occurrence experienced at a given location and the mean return period used to establish design loads is much more noticeable than the corresponding probabilities for earthquakes.

3.3 A Comparison of Potential Losses

The HAZUS-MH (Hazards U.S. Multi-Hazards) program is a Geographic Information System (GIS)-based program developed by FEMA to estimate future losses for use by Federal, State, regional, and local governments to plan for damage, to prepare emergency response and recovery programs, and to help examine options to reduce future damage. The methodology covers nearly all aspects of the built environment and estimates a wide range of losses. Originally developed to assess risks from earthquakes, the methodology has been expanded to address floods throughout the United States 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 design guide, a "Level 1" HAZUS-MH analysis was conducted in 2003 for educational facilities in six areas of the United States. The Level 1 analysis uses the building inventory data that are packaged with the HAZUS-MH program and is intended to give a broad picture of damage and loss on a regional basis. Although prepared several years ago, the results remain useful to compare potential losses between different parts of the country.

The analyses were based on the building information for the EDU 1 occupancy class (the HAZUS-MH designation for the school building inventory) in the general building stock module of HAZUS-MH. The regions chosen for this comparative example are each prone to two or more of the hazards addressed in HAZUS-MH, and are deemed to provide a useful 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 results are summarized in Table 3-1, in which the column "EDU 1 Exposure" refers to the total school inventory in each region.

The following regions were evaluated:

- Charleston County, SC (Charleston) (earthquake, flood, and hurricane)
- Shelby County, TN (Memphis) (earthquake and flood)
- Bexar County, TX (San Antonio) (hurricane and flood)
- Salt Lake County, UT (Salt Lake City) (earthquake and flood)
- Suffolk County, MA (Boston) (earthquake, flood, and hurricane)
- Hillsborough County, FL (Tampa) (hurricane and flood)

Table 3-2 shows the estimated losses expressed as a percentage of the total school inventory. It is instructive to note, in some cases, the wide disparity in losses between the 100-year and 500-year events, which supports the idea that school facilities should be designed to resist the impacts of events that have a lower probability of occurrence.

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	N/A	N/A	4,184	6,784	137,927 Building
Contents and Inventory	53	3,723	N/A	N/A	1,203	2,001	137,927 Contents
Business Interruption	29	916	N/A	N/A	NE	NE	
TOTAL	325	15,103	–	–	5,387	8,786	
Bexar, TX	**Earthquake**		**Hurricane**		**Flood**		**EDU 1 Exposure**
	100-yr	500-yr	100-yr	500-yr	100-yr	500-yr	
Building Damage	N/A	N/A	94	2,753	1,502	2,384	238,608 Building
Contents and Inventory	N/A	N/A	5	1,259	487	727	238,608 Contents
Business Interruption	N/A	N/A	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	N/A	N/A	15	204	177,728 Building
Contents and Inventory	881	9,016	N/A	N/A	4	57	177,728 Contents
Business Interruption	259	2,488	N/A	N/A	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	N/A	N/A	10,257	47,213	10,727	11,776	175,981 Building
Contents and Inventory	N/A	N/A	6,045	39,016	4,329	4,624	175,981 Contents
Business Interruption	N/A	N/A	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.
N/A = hazard not present in the area.

Table 3-2: HAZUS-MH estimated losses by percentage of school building and contents inventory

County	Earthquake		Hurricane		Flood	
	100-yr	500-yr	100-yr	500-yr	100-yr	500-yr
Charleston, SC	0.20	17.30	4.54	17.50	1.38	1.65
Shelby, TN	0.12	5.47	N/A	N/A	1.95	2.46
Bexar, TX	N/A	N/A	0.02	1.27	0.40	0.65
Salt Lake, UT	1.10	11.76	N/A	N/A	0.01	0.07
Suffolk, MA	0	0.80	N/A	N/A	N/A	N/A
Hillsborough, FL	N/A	N/A	5.85	28.20	4.27	4.65

NOTES: N/A = hazard not present in the area.

These HAZUS-MH results, though prepared in 2003, limited in scope, and based on limited school building inventory information, provide some interesting comparisons:

- Generally, the 100-year earthquake causes insignificant damage, except in Salt Lake City, UT ($3.3 million).
- The 500-year earthquake causes the most damage in Salt Lake City, UT ($41.8 million), followed by Shelby, TN ($15.1 million), and Charleston, SC ($5.1 million).
- The 100-year hurricane causes the most damage in Hillsborough, FL ($20.6 million), followed by Charleston, SC ($11.5 million), and Suffolk, MA ($10 million).
- The 500-year hurricane causes $117.6 million in damage in Suffolk, MA, $99.2 million in damage in Hillsborough, FL, and $45.7 million in damage in Charleston, SC.
- The 100-year flood causes by far the most damage in Hillsborough, FL ($15.1 million; however, the 500-year flood causes only another $1.3 million in damage). In Shelby, TN, the 100-year flood causes $5.4 million in damage and the 500-year flood causes another $3.3 million.
- Charleston, SC, has the greatest combined threat from earthquakes and hurricanes; Hillsborough, FL, has the greatest combined threat from hurricanes and floods.

3.4 Fire and Life Safety

Of the many hazards that can endanger a school, its occupants, and its service to the community, the most prevalent is fire. Structure fires occur more frequently than any of the hazards noted above. However, requirements to account for fire protection and safety have long been included in building codes in the form of requirements for approved materials, fire-resistant assemblies, exiting, 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 the design culture and regulation that some designers may not fully consider the fire hazard as a specific design issue.

Of the many hazards that can endanger a school, its occupants, and its service to the community, the most prevalent is fire. Structure fires occur more frequently than any of the hazards noted above.

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.

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 code requirements do not apply to existing buildings until renovations or additions are made, and then the requirements may apply only to the new work. Given that the average age of school facilities in the United States is more than 40 years, older buildings likely do not provide the same level of protection as newer buildings. In order to provide the level of protection achieved in newer buildings, the levels of fire and life safety of older facilities should be evaluated. After an evaluation has been conducted, solutions using prescriptive and/or performance approaches can be developed and undertaken.

The existing structures chapter of the IBC provides a method to evaluate the overall level of fire and life safety in an existing building. Although the method is 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 method 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.

The provisions of NFPA 101 provide another method of evaluating and upgrading existing facilities. 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.

Upgrading an existing school facility can be costly. However, the cost of upgrades generally is less than the direct and indirect losses if a facility sustains major damage caused by 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 Multihazard Design Interactions

An integrated approach to designing for all hazards can help to identify potentially conflicting effects of certain mitigation measures and help to avoid aggravating the vulnerability of school systems and components. Table 3-3 summarizes the effects that design for more than one hazard may have on the performance of the building, addition, or repair. The columns show the five primary hazards. The rows show examples of methods of protection that have significant interaction (either beneficial, undesirable, or little to no significance). These methods are taken from the extended descriptions of risk reduction methods for the three primary natural hazards (see Chapters 4, 5, and 6), together with the methods for security/blast protection presented in FEMA 428. In addition, the interactions of these four categories of risk protection with fire safety, where they occur, are also suggested.

The suggested interactions are intended to provoke thought and design integration; they are not absolute restrictions nor are they recommendations. In general, beneficial conditions can be identified and undesirable conditions and conflicts can be avoided through coordinated design between the consultants, starting at the inception of design. The table can be used as a starting point for discussion relative to specific projects and to structure the benefits and conflicts of multihazard design depending on local hazards.

Table 3-3: Multihazard design system interactions

Key	
✔	Indicates desirable condition or method for designated component/system
✘	Indicates undesirable condition or method for designated component/system
❍	Indicates little or no significance for designated component/system
(split box)	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					
		Earthquake	Flood	Wind	Security/ Blast	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

Building System Protection Methods: Reinforcements and Conflicts							
System ID	Existing Conditions or Proposed Protection Methods	The Hazards					
		Earthquake	Flood	Wind	Security/ Blast	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)**						
2C	**Ceilings (No significant impact)**						

Table 3-3: Multihazard design system interactions

Building System Protection Methods: Reinforcements and Conflicts							
System ID	Existing Conditions or Proposed Protection Methods	The Hazards					
		Earthquake	Flood	Wind	Security/ Blast	Fire	Discussion Issues
2	Architectural (continued)						
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 board partitions	✔	✘	❍	✘	✘	Although gypsum board 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 masonry units (CMUs), 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

Building System Protection Methods: Reinforcements and Conflicts							
System ID	Existing Conditions or Proposed Protection Methods	The Hazards					
		Earthquake	Flood	Wind	Security/ Blast	Fire	Discussion Issues
2	Architectural (continued)						
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 acceptable for seismic; unbraced unreinforced masonry (URM) is dangerous. May assist in reducing the spread of fire.
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

Building System Protection Methods: Reinforcements and Conflicts								
System ID	Existing Conditions or Proposed Protection Methods	The Hazards						
		Earthquake	Flood	Wind	Security/ Blast	Fire	Discussion Issues
3	Structural Systems (continued)						
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 masonry units, 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.
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.

Table 3-3: Multihazard design system interactions

Building System Protection Methods: Reinforcements and Conflicts							
System ID	Existing Conditions or Proposed Protection Methods	The Hazards					
		Earthquake	Flood	Wind	Security/ Blast	Fire	Discussion Issues
5	Utilities (No significant impact)						
6	Mechanical						
6-1	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 flood level.
7	Plumbing and Gas (No significant impact)						
8	Electrical (No significant impact)						
9	Fire Alarm (No significant impact)						
10	Communications and Information Technology (IT) (No significant impact)						
11	Equipment Operations and Maintenance (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)						

SOURCE: FEMA 426, *REFERENCE MANUAL TO MITIGATE POTENTIAL TERRORIST ATTACKS AGAINST BUILDINGS,* 2003

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.

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