DESIGN FOR EXTREME HAZARDS 10

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10.1 INTRODUCTION

Earthquakes are only one of several hazards to which buildings are vulnerable. The two other significant natural hazards are floods and high winds, including tornadoes. These hazards are extreme variants of benign natural processes. Earthquakes represent a highly accelerated instance of the slow adjustment that the earth makes as it cools. High winds and tornadoes are an exaggerated form of the pleasant winds and breezes that freshen our everyday existence. Devastating floods are the result of excessive localized rainfall that, when normal, is necessary for the provision of water supply and the nurturing of plant life. These natural hazards are not aberrations, are not malicious, and are part of nature's order.

The traditional hazard to which buildings are vulnerable is fire, and history abounds with urban fire disasters right up to the present day. Fire disasters are usually due to human errors and carelessness, but are sometimes originated by earthquakes and made more lethal by winds (Figure10-1). Fire, however, when properly controlled, is an important

Figure 10-1

Earthquake and Fire, Marina District, Loma Prieta, 1989.

SOURCE: EERI. JOHN EGAN/ GEOMATRIX CONSULTANTS contributor to human comfort. Sometimes, of course, a fire disaster is the result of malicious intent. The newest hazard - that of a terrorist attack on a building - is malicious, but is also an extreme form of everyday circumstance that we have come to accept: criminality. Building design has long recognized the need for locks and, more recently, remote cameras and sensing devices are also designed to prevent criminal - and now terrorists - from gaining entry to our buildings[1]

10.2 MULTIHAZARD DESIGN SYSTEM INTERACTIONS

This publication focuses on design against earthquakes, but the other hazards must also be assessed. Each of them has differing levels of risk—i.e., the probabilities and consequences of an event. Some, such as earthquakes, floods, and high winds, are specific to certain regions. The risks of terrorism are still uncertain compared to those of natural hazards that have a long history of statistical and scientific observation and analysis. Fires are more pervasive than any of the natural hazards. 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, and many other issues.

An important aspect of designing against a single hazard such as earthquakes is the extent to which the design methods may reinforce or conflict with those necessary for protection against other hazards. Multihazard design involves a risk assessment of all hazards at a programmatic stage to ensure that protection measures are not in conflict. Ideally, the measures used would focus on reinforcement rather than conflict, so that the overall risk management plan enables the cost of construction to be reduced.

To assist the reader in evaluating the interactions between protective design methods, Table 10-1 summarizes the effects that seismic design measures may have on performance of the building in relation to other hazards.

[1] More buildings have been destroyed by war in the 20th century than by all natural disasters; modern terrorism is the latest variation on traditional wartime urban destruction by shells or bombs.

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 based on commonly accepted methods of risk reduction for the three main natural hazards, together with fire protection methods, and the methods for security/blast protection presented in FEMA 426, *Reference Manual to Mitigate Potential Terrorist Attacks against Buildings*, and FEMA 430, *Site Design Guidance to Mitigate Potential Terrorist Attacks*.

The comments in this matrix are not absolute restrictions or recommendations, but rather are intended to provoke thought and further design integration. 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.

Table 10-1 provides information to help the reader 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 multi-hazard design on the building performance and cost that, in turn, guide an integrated design strategy for 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.

The following Table, Multi-hazard Design System Interactions, refers to the typical structures illustrated in Chapter 8. An explanation of the symbols used is below:

+ Indicates desirable condition or method for designated component/system (cell color green)

- Indicates undesirable condition for designated component/system (cell color red)

0 Indicates little or no significance for designated component/system (cell color yellow)

+/- Indicates significance may vary, see discussion column

Table 10-1 Multihazard Design System Interactions

Building System Protection Methods: Reinforcements and Conflicts							
		The Hazards					
System ID	Existing Conditions or Proposed Protection Methods	Earthquakes	Flood	Wind	Security/Blast (FEMA 426)	Fire	Discussion Issues
1	**Site**						
	1-1 Site-specific hazard analysis	+	+	+	+	+	Beneficial for all hazards
	1-2 Two or more means of site access	+	+	+	+	+	Beneficial for all hazards
2	**Architectural**						
2A	**Configuration**						
	2A-1 Reentrant-corner plan forms	-	o	-	-	o	May cause stress concentrations and torsion in earthquakes, and concentrate wind and blast forces.
	2A-2 Enclosed-courtyard building forms	-	o	+	+/-	o	May cause stress concentrations and torsion in earthquakes; 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 reentrant corners create blast vulnerability. If enclosed on all sides, they might experience significant blast pressures, depending on roof and building design. Since most courtyards have significant glazed areas, they could be problematic
	2A-3 Very complex building forms	-	-	-	-	-	May cause stress concentrations, torsion, and indirect load paths in highly stressed structures, and confusing evacuation paths and access for firefighting. Complicates flood resistance by means other than fill.
	2-A4 Large roof overhangs	-	o	-	-	o	Possibly vulnerable to vertical earthquake forces. Wall-to-roof intersection will tend to contain and concentrate blast forces, if the point of detonation is below the eaves.
2B	**Planning and Function**						
	not applicable						

Table 10-1 Multihazard Design System Interactions (continued)

Building System Protection Methods: Reinforcements and Conflicts							
		The Hazards					
System ID	Existing Conditions or Proposed Protection Methods	Earthquakes	Flood	Wind	Security/Blast (FEMA 426)	Fire	Discussion Issues
2C	**Ceilings**						
	2C-1 Hung ceiling diagonally braced to structure	+	o	+	+	+	Reduced damage from earthquake, wind forces, blast. If part of fire protection system, increases possibility of retaining integrity.
2D	**Partitions**						
	2D-1 Concrete block, hollow clay tile partitions	-	+	-	-	+	Earthquake and wind force reactions similar to heavy unreinforced wall sections, with risk of overturning. Tile may become flying debris in 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 nonrigid (ductile) connections for attachment of interior non load-bearing walls to structure	+	o	+	+	-	Non rigid connections necessary to avoid partitions that influence structural response. However, gaps provided for this threaten the fire resistance integrity, and special detailing is necessary to close gaps and retain ability for independent movement.
	2D-3 Gypsum wall board partitions	+	-	-	-	-	Light weight reduces effect of structural response in earthquakes. Although gypsum wallboard partitions can be constructed to have a fire rating, they can be easily damaged during fire events. Such partitions can be more easily damaged or penetrated during normal building use.
	2D-4 Concrete block, hollow clay tile around exit ways and stairs	-	o	o	+/-	+	May create torsional response and/or stress concentrations in earthquakes, unless separated from structure, and if unreinforced, are prone to damage. Properly reinforced walls preserve evacuation routes in case of fire and blast.

Table 10-1 Multihazard Design System Interactions (continued)

Building System Protection Methods: Reinforcements and Conflicts							
		The Hazards					
System ID	Existing Conditions or Proposed Protection Methods	Earthquakes	Flood	Wind	Security/Blast (FEMA 426)	Fire	Discussion Issues
2E	**Other Elements**						
	2E-1 Heavy ceramic/concrete tile roof	-	o	-	-	+/-	Heavy roofs undesirable in earthquakes; tiles may detach and fall. Provide good protection from fire spread, but can also cause collapse of fire-weakened structure. Dangerous in high winds unless very carefully attached. If a blast wave hits them they may become flying debris and dangerous to people outside the building.
	2E-2 Parapets	+/-	o	+	-	+	Properly engineered parapet OK for seismic, but unbraced URM is very dangerous. May assist in reducing fire spread.
3	**Structural System**						
	3-1 Heavy Structure, RC masonry. Steel structure with masonry or concrete fireproofing	-	+	+	+	+	Increases seismic forces, requires sophisticated design. Generally beneficial against other hazards.
	3-2 Light structure: steel/ wood	+	-	-	-	-	Decreases seismic forces but generally less effective against other hazards
	3-3 URM load bearing walls	-	-	-	-	-	Poor performance against all hazards
	3-4 RC or reinforced concrete block structural walls	+	+	+	+	+	Generally good performance against all hazards, provided correctly reinforced
	3-5 Soft /weak first story (architectural/ structural design)	-	+/-	-	-	-	Very poor earthquake performance and vulnerable to blast. Generally undesirable for flood and wind. Elevated first floor is beneficial for flood, if well constructed and not in seismic zone.
	3-6 Indirect load path	-	o	-	-	-	Undesirable for highly stressed structures, and fire-weakened structure is more prone to collapse. Not critical for floods.

Table 10-1 Multihazard Design System Interactions (continued)

Building System Protection Methods: Reinforcements and Conflicts								
		The Hazards						
System ID	Existing Conditions or Proposed Protection Methods	Earthquakes	Flood	Wind	Security/Blast (FEMA 426)	Fire	Discussion Issues
	3-7 Discontinuities in horizontal and vertical structure	-	o	-	-	-	Undesirable for highly stressed structures, causes stress concentrations, and fire-weakened structure is more prone to collapse. Not critical for floods.
	3-8 Seismic separations in structure	+	o	o	o	-	Simplifies seismic response, possible paths for toxic gases in fires.
	3-9 Ductile detailing of steel and RC structure and connections	+	o	+	+	o	Provides tougher structure that is more resistant to collapse. Not significant for fire.
	3-10 Design certain elements for uplift forces	+	o	+	+	o	Necessary for wind, may assist in resisting blast or seismic forces.
	3-11 RC, reinforced concrete blocks around exit ways and stairs.	-	o	o	-/+	+	May create torsional structural response and/or stress concentration in earthquakes or blast. May preserve evacuation routes in the event of fires or blast.
4	**Building Envelope**						
4A	**Wall cladding**						
	4A-1 Masonry veneer on exterior walls	-	-	-	-	o	In earthquakes, material may detach and cause injury. In winds and blast, may detach and become flying debris hazards. Flood forces can separate veneer from walls.
	4A-2 Lightweight insulated cladding	+	o	o	-	o	Lightweight reduces structural response modification, may be less resistant to blast.
	4A-3 Precast cladding panels	-	o	+	+	o	Require special detailing for earthquake.
4B	**Glazing**						
	4B-1 Metal/glass curtain wall	+	o	-	-	-	Light weight reduces earthquake forces, and if properly detailed and installed, performance is good. Fire can spread upward behind curtain wall if not properly fire-stopped. Not blast resistant without special glass and detailing. Vulnerable to high winds.

Table 10-1 Multihazard Design System Interactions (continued)

Building System Protection Methods: Reinforcements and Conflicts							
		The Hazards					
System ID	Existing Conditions or Proposed Protection Methods	Earthquakes	Flood	Wind	Security/Blast (FEMA 426)	Fire	Discussion Issues
	4B-2 Impact resistant glazing	o	o	o	+	-	Can cause problems during fire suppression operations, limiting smoke ventilation and access. Not significant for earthquake, flood or wind.
5	**Utilities**						
	5-1 Braced and well supported	+	o	+	+	+	Essential for earthquake, beneficial for wind, blast and fire.
6	**Mechanical**						
	6-1 System components braced and well supported	+	o	+	+	+	Essential for earthquake, beneficial for wind, blast and fire
7	**Plumbing and gas piping**						
	7-1 System components braced and well supported	+	o	+	+	+	Essential for earthquake, beneficial for wind, blast and fire
8	**Electrical and communications equipment**						
	8-1 System components braced and well supported	+	o	+	+	+	Essential for earthquake, beneficial for wind, blast and fire
9	**Fire suppression system and alarm**						
	9-1 System components braced and well supported	+	o	+	+	+	Essential for earthquake, beneficial for wind, blast and fire