1.1 INTRODUCTION

Most Americans are accustomed to receiving sophisticated and prompt medical attention after an injury or a medical problem occurs, anytime and anywhere in the country, without traveling great distances. Such expectations are even greater during mass emergencies that require immediate care for a large number of casualties. In circumstances in which hospital operations are disrupted or completely disabled, the adverse effects of such disasters can be quickly compounded, frequently with catastrophic results. A recent report from the Congressional Research Service (CRS), *Hurricane Katrina: the Public Health and Medical Response*, examined the performance of the public health system during this devastating event. According to the CRS report, Hurricane Katrina pushed some of the most critical health care delivery systems to their limits, for the first time in recent memory (Lister, 2005). Therefore, the importance of uninterrupted hospital operations and ready access to, and availability of, immediate medical care cannot be exaggerated.

The intent of this publication is to provide guidelines for planning, design, and construction of new hospitals and rehabilitation of existing ones, for the purpose of improving their performance during, and in the immediate aftermath of, seismic, flooding, and high-wind events. It is important to acknowledge that there are no universal design guidelines to protect buildings from all such events. Different natural phenomena present different challenges, and each hazard requires a different approach and a different set of recommendations. When communities face more than one of these hazards, the design team must select the mitigation measures most appropriate for achieving the desired performance level, regardless of the immediate cause for the potential losses.

For instance, flooding is a more site-specific hazard than others. The preferred approach for new facilities is to select a site that is not subject to flooding. When that is not feasible, site modifications or other site-specific building design features that mitigate anticipated flood hazard will reduce the potential for damage. When it comes to seismic and high-wind events, however, in addition to carefully selecting the site, it is necessary to design the buildings to be resistant to the variety of forces associated with these phenomena. The protection against seismic forces requires that both structural and non-structural building components have sufficient resistance. For high winds, protection efforts focus mainly on the exposed building components and systems.

This chapter addresses the general issues that influence the operations and hospital building designs. Typically, the design of hospital facilities is driven by their function and the type of services they provide to the community. These services are constantly evolving in response to trends in the health care industry and changing expectations of health care customers. Some of these health care trends have been the logical result of advances in medical science and technology, while the others, driven by social and economic conditions, represent new approaches to management of medical care. Additionally, hospital design has been greatly influenced by the recognition that physical environment has a measurable influence on human well-being. A growing body of evidence has been accumulated that shows how appropriate hospital designs can create the healing environments that improve patient treatment outcomes and patient care in general. Increasingly, hospital designers are expected to use this new evidence-based design approach when designing new hospitals.

In order to design effective medical facilities for the future, designers must be familiar with the latest industry developments, building requirements stemming from these trends, and the latest research findings on the impact of building designs on hospital operations, staff and patient morale, and patient care. It is the purpose of this Design Guide to add to these general considerations the issues of buildings' resistance to natural hazards and recommended hazard mitigation measures for risk reduction.

1.2 HEALTH CARE INDUSTRY

1.2.1 AMBULATORY CARE

In the last 30 years or so, the health care industry has increasingly been moving toward greater emphasis on ambulatory care. The increasing availability of procedures that can be successfully completed without an overnight stay in the hospital has led to a proliferation of freestanding ambulatory care centers. Many of these centers are performing sophisticated surgeries and complicated diagnostic procedures. Frequently, these centers are not affiliated, or are only loosely affiliated with, other hospitals in the community.

The emphasis on the ambulatory care had a profound effect on the healthcare industry, leading to the reduction in the number of hospital beds and, in many cases, closing of hospitals because of the reduced demand for overnight stays. At the same time, hospitals had to increase their own role in ambulatory care to remain competitive. As the freestanding ambulatory facilities took an ever-increasing market share, many hospitals had to downsize, and in some cases, scale back even their surgical capacity. In many respects, this development has diminished the capacity of medical facilities to care for the casualties in the event of a disaster, because most of the freestanding ambulatory care centers are not suitable for post-disaster emergency care. There are several reasons for this:

- They do not have dedicated emergency departments or adequate facilities and equipment to deal with trauma patients.
- They are not available or staffed on a 24-hour, 7 days-a-week basis.
- They are not adequately equipped with emergency communications systems.
- The staff is not experienced or well trained to care for the types of patients and injuries expected in post-disaster emergencies.

- These facilities are not considered essential and are sometimes built to a lower building code standard than hospitals, which makes them more vulnerable to disruption resulting from building damage.

On the other hand, hospital-based ambulatory care (outpatient) departments can easily be converted for post-disaster care during an emergency, assuming the hospital itself remains operational. Hospital-based ambulatory surgeries are often contiguous to surgery for inpatients. Clinic space can be used for triage or emergency treatment rooms, and the ambulatory diagnostic equipment is suitable for use in an emergency. The key to having hospital-based ambulatory capacity available in the aftermath of major disasters is thoughtful planning, so that the emergency department can remain the command center, coordinating other areas of the hospital where post-disaster patients might be transferred and treated.

1.2.2 PATIENT VOLUME

Hospital emergency rooms have become the primary source of medical care for millions of people. Unlike other medical facilities, hospitals are required to treat anyone who walks in, or is brought in, irrespective of their insurance status or ability to pay. This trend puts an enormous pressure on emergency departments, not only because it increases the patient load, but also because it expands their functions beyond the treatment of emergency and trauma cases.

As a result, many hospitals have enlarged and better equipped their emergency departments to accommodate the ever-increasing patient load, which had a positive influence on their capacity to deal with disaster-related emergencies. Additionally, hospital emergency departments are well trained in triage that involves prioritization of cases according to the level of medical urgency. Patients who are most in need of immediate treatment are treated first, while the others who can wait without harm are treated later. Emergency department staff members also go through extensive disaster drills, and in most cases are well trained to respond to mass emergencies.

Despite current hospital construction boom, the trend towards reduced inpatient capacity in the past decades has adversely affected hospitals' readiness for emergencies. In 1990, the national average was 372 hospital beds per 100,000 people, whereas in 2004 there were only 275 beds. The number of hospitals in the country[1] dropped from 5,384 in 1990 to 4,919 in 2004. This has reduced the number of hospital beds in many commu-

1 Data from Trendwatch Chartbook 2006, by the American Hospital Association and the Lewin Group.

nities to the point where some rural communities were left without any acute inpatient capacity.

As a result of hospital closures and inpatient capacity reduction, occupancy rates in the remaining hospitals have increased. The increase means that most hospitals are operating at near-maximum inpatient capacity on a regular basis, making it difficult to accommodate a potential influx of casualties in a disaster emergency. Some reports, especially those that analyzed the response to Hurricane Katrina, singled out the limited surge capacity for health care emergencies as one of the most pressing problems of the Nation's health care system (see Lister, 2005).

1.2.3 AGING FACILITIES

Renovation and replacement of health facilities have been at record highs in recent years. Still, a majority of hospital buildings throughout the country are of considerable age. A great many of them were built in the 1950s and 1960s, particularly in rural areas, with Federal funding assistance provided by the Hill-Burton Act passed by Congress following World War II. In the 1960s and 1970s, this grant program was also used for replacement and renovation of urban hospitals. As a consequence, a large number of hospitals were built in a short period of time. Many of these hospitals are now nearing the end of their useful life. Even with periodic renovations, there are limits to the value of continued investment in older facilities to be used for acute care.

Hospitals are constantly renovating, whether they are just adding electrical outlets or communications cables, or engaging in more complex projects that involve moving functions and building additions to the existing structures. This kind of change is a result of many factors: changing personnel, new technologies, and competitive pressure. Some changes, however, may affect the use of spaces or facilities originally planned and built for emergency operations. For instance, renovation may inadvertently upset bracing for piping and communications conduits, making them more vulnerable to hazards like earthquakes or high winds. Similarly, functional reorganization of a hospital that makes some critical functions and services more accessible by placing them on the ground floor increases the risks from flooding to these facilities.

1.2.4 HEALING ENVIRONMENTS

Since the advent of the hospital "birthing unit" in the late 1970s, the health industry has shown an increasing interest in the ability of the physical environment to contribute to healing. The growing evidence indicates that a pleasant and comfortable environment reduces stress and provides a sense of well-being, both of which are important preconditions for successful recovery. Additionally, patient satisfaction with hospital services today extends beyond medical care and encompasses a whole hospital experience. To be able to compete successfully with the increasing number of outpatient and other alternative healthcare providers, hospitals have started to pay greater attention to providing a "hospitable" and "healing environment," in addition to medical expertise, new technology, and advanced procedures.

This trend manifests itself in building designs that introduce the spirit of nature into the hospital environment: more natural light, views of nature and direct access to the outdoors from many more areas of the hospital, and increased use of courtyards and gardens. Hospital gardens have been found to provide not only the restorative and calming nature views, but also help reduce stress by providing opportunities for escape from clinical settings, and by fostering greater social interaction among patients and staff. The social aspect is particularly important for patients who might feel isolated in a sterile hospital environment without the support of their families and friends. Considering the significance of social support for patients' successful recovery, hospitals are planning for greater involvement of the family in the care of their patients by requiring single-bed rooms for all newly built acute care hospitals. Additionally, hospitals are providing more public spaces that facilitate social interaction, such as lounges, atria, and interior streets with shops and restaurants that were not part of the traditional hospital environment.

The advent of new hospital architecture, especially the new physical arrangements designed to assist in healing have, in many respects, increased the exposure of hospital buildings to natural hazards. The emphasis on natural light, the use of single-patient rooms, and a greater variety of public spaces usually produces complex building designs with greater exterior perimeter and a greater number of doors and windows that frequently increase building's vulnerability to wind and windborne debris damage.

1.2.5 TECHNOLOGICAL ADVANCES

New and emerging technologies ranging from new electronic devices, such as nanoscale sensors, to new wireless communication networks are rapidly changing patient treatment practices as well as the organization of hospitals. These innovative medical technologies help empower the physicians, nurses, and patients with tools that enable faster diagnosis and better treatment of diseases. Most diagnostic practices and procedural functions in clinics and surgeries are dependent on modern instruments, tools, and laboratory equipment. Today's hospitals are in the process of replacing all analog-based instruments with digital ones. New hospital organization is now based on an IT architecture that maximizes the flow of diagnostic and monitoring data from these instruments through new communications networks and makes them available to hospital staff in making treatment decisions.

Digitized X-rays and other images are being transmitted electronically to all parts of the hospital and to doctors' offices. Clinical laboratory test results, prescriptions, and most forms of medical data are now instantly available to medical practitioners. There is a national movement to adopt a universal electronic medical record, which would make patient's medical history and other information almost instantly available to the treating physician.

These technological innovations substantially changed not only the medical practice, but also turned this new electronic and IT infrastructure into an essential and indispensable backbone of all hospital operations. Therein lays the grave vulnerability of hospitals in cases where this sensitive infrastructure can be disrupted, as was seen in many hospitals affected by Hurricane Katrina. When a disaster, such as Hurricane Katrina, disables or impairs the functioning of electronic equipment and data transmission systems, or even the hospital voice communications systems, the ability of the medical staff to care for their patients is significantly reduced.

Emergency power systems, therefore, become the critical component for maintaining hospital's functions. The dependence on electrical power generators is increasing as the hospitals rely more and more on energy-intensive equipment and procedures. Even if the hospital is designed to continue to care for patients after a disaster, its ability to function is limited by the emergency power supply capacity, the extent of coverage by emergency power systems, and the ability to remain operational for extended periods of time.

> A U.S. Department of Energy (DOE) 2002 report ranked healthcare facilities second only to food-service facilities in the intensity of energy use, defined as the amount of energy consumed per square foot of space.

1.3 HAZARD MITIGATION

Mitigation is defined as any sustained action taken to reduce or eliminate long-term risk to life and property from hazard events. The goal is to save lives and reduce property damage in ways that are cost-effective and environmentally sound. Hazard mitigation measures should be integrated into the process of planning and design because they reduce casualties and damage resulting from building failures during hazard events. The effects of a disaster on a hospital, however, are never restricted to the physical damage or the distress among the staff and patients as a result of such damage. Consequences frequently include partial or total loss of the ability to provide services and meet the demand for health care when it is most needed. Incorporating mitigation measures in the design of hospitals is therefore especially important because they minimize the disruption of hospital operations and protect the uninterrupted provision of critical health services.

Advances in building science and technology, and changes in design philosophy and quality assurance techniques for the construction and maintenance of medical infrastructure, now make it possible to limit the damage during seismic, flooding, and high-wind events. The advent of performance-based design allows the use of different levels of protection for different types of infrastructure and operations that frequently exceed the minimum requirements of currently applicable codes. However, it is not always possible to achieve the protection levels one might desire, owing to a variety of factors. Natural or technical barriers may exist, or the funding may be insufficient. Even though financial resources may be limited, and other circumstances may impose technical barriers to the fulfillment of performance objectives, a detailed assessment is still required in order to ensure the optimal utilization of available resources.

The starting point for such an assessment should be a general review of the existing hospital network in the area—its operational characteristics, geographical distribution, the degree to which it is able to meet health care needs and expectations, the epidemiological and demographic profile of the population served, and the natural hazards that threaten the provision of medical services. The effective functional capacity of all existing hospitals should be taken into account, considering as fully as possible all factual information on the natural hazards they face and their current level of vulnerability. Once the actual characteristics of this network and the potential hazards have been identified, and the need to build a new hospital in a specific location has been established, it is still necessary to define the role that the new facility will play, both in normal times and during emergencies of various kinds and intensities. Based on all this information, the level of overall functional performance should be set for the new facility. The process of determination of the performance level must address the questions of the importance of continued and uninterrupted operation of the facility, as well as the feasibility and cost-effectiveness of such a performance objective.

All this will be influenced by the characteristics of the site, the specifics of the infrastructure to be built, and the basic services it can realistically be expected to provide based on different disaster scenarios. In considering disaster mitigation, the goal should be to provide the community with access to health care in a reasonable period of time, within reasonable travel distances, and to have essential services available to treat patients who sustained injuries as a result of the disaster. At the same time, a hospital needs to continue to care for their pre-disaster patients and ensure that no harm comes to them.

Much of the procedure for a new building described above can apply to hazard mitigation in an existing building as well, with obvious limitations.

1.3.1 ASSESSING RISK

Beyond the building codes in existence at the time a hospital is designed or slated for renovation, the leadership of the facility and the design consultants must address key questions to establish the adequacy of the building's performance in the event of a disaster. Hospitals are under enormous financial pressure. Any funds invested in making a hospital facility safer for patients and staff, more resistant to damage, or capable of continued operations in a post-disaster situation must consider the following questions:

- What types and magnitudes of hazard events are anticipated at the site?
- What are the vulnerabilities of the site or existing building to natural hazards?

- What are the anticipated frequencies of hazard events?
- What level of loss/damage/injury/death, if any, is acceptable?
- What might be the financial impact of extended downtime on the institution?
- What is the impact to the community if the hospital cannot maintain operations in the aftermath of a disaster?

It is not possible to protect against every conceivable event, or to be 100 percent safe and free of damage in a major disaster. The level of acceptable risk must be decided on an individual facility basis by those responsible for the institution and its mission.

1.3.2 EVACUATION CONSIDERATIONS

In anticipation of high winds or flooding, timely evacuation of some or all of the hospital patients to facilities out of the disaster area may sometimes be a prudent choice for patient welfare. The risks of transferring acutely ill patients must be taken into consideration, as pointed out by the General Accounting Office (GAO) report to Congress dated February 16, 2006, titled, *Disaster Preparedness: Preliminary Observations on the Evacuation of Hospitals and Nursing Homes Due to Hurricanes.* It stated: "Administrators consider several issues when deciding to evacuate or to shelter in place, including the availability of adequate resources to shelter in place, the risks to patients in deciding when to evacuate, the availability of transportation to move patients and of receiving facilities to accept patients, and the destruction of the facility's or community's infrastructure."

Many patients have limited mobility and some are on critical life support, oxygen or other medical gasses, ventilators, or IV pumps. Moving these patients to evacuate the hospital is difficult and requires highly trained staff.

In each geographical area, acute care facility managers must evaluate the likely time that they would need to hold patients, how many additional patients might arrive seeking care, and what services would be needed and for what period of time. In the case of Hurricane Katrina, some hospitals evacuated their Neonatal Intensive Care Unit, bariatric patients, and dialysis patients before the storm landfall, which proved both prudent and beneficial. For hospitals planning to retain their dialysis patients, it is essential to assure a constant supply of electricity to power the equipment needed for these patients.

Most hospitals plan to "shelter in place" and weather the storms, rather than evacuate. In order to do this, they must take care of their existing patients, many of whom are critically ill, and in addition, be prepared to accommodate the casualties as well as the increased number of outpatients. In order to accomplish this, there are a wide variety of services that must remain functional. Often municipal utility services will be cut off during a disaster, so alternative power, water, and waste disposal services need to be provided onsite whenever possible. Communication systems are often cut off, so redundancy is a key factor in maintaining links to the outside world as well as internal communications within the hospital. FEMA publications 361 and 543 both address the specific needs of structures to be used as disaster shelters. Sheltering in place can be challenging, but in most cases it is the preferred option for most acutely ill patients.

If there is a plan to evacuate patients, or a probability that patients will need to be evacuated, regional planning with other hospitals in the area and coordination of resources is essential. Agreements and appropriate provisions need to be put in place so that space and staff are available to accommodate evacuated patients. The State of Florida has put in place an evacuation tracking system for all evacuated patients. This might be a useful model for other States to follow.

1.3.3 POTENTIAL VULNERABILITIES

Hospitals provide services that are essential for protecting and safeguarding the health and well-being of a community. The continued provision of these services is even more critical during and in the immediate aftermath of disasters. Considering the complexity of hospital operations, even the smallest breakdown in one of its building or equipment systems can cause serious disruption of hospital functions. This makes the hospitals extremely vulnerable to a variety of natural hazards.

Hospitals usually have high levels of occupancy, with patients, staff, and many visitors present 24 hours a day. Many patients require constant attention, and in many cases continuous specialized care and the use of sophisticated medical instruments or other equipment. Hospital operations also depend on a steady supply of medical and other types of material, as well as public services or lifelines. In addition, hospital vulnerability is aggravated by the presence of hazardous substances that may be spilled or released in a hazard event.

Given the importance of hospital services for response and recovery following emergencies, and the need for uninterrupted operation of these facilities, hospital administrators and designers must consider all aspects of their vulnerability. Three main aspects of hospital vulnerability must be taken into account:

- Structural
- Nonstructural
- Organizational

1.3.3.1 Structural Vulnerability

Structural vulnerability is related to potential damage to structural components of a building. They include foundations, bearing walls, columns and beams, staircases, floors and roof decks, or other types of structural components that help support the building. The level of vulnerability of these components depends on the following factors:

- The level to which the design of the structural system has addressed the hazard forces
- The quality of building materials, construction, and maintenance
- The architectural and structural form or configuration of a building

The aspects of adequate design and construction in most hazard-prone areas are regulated by building codes and other regulations. The main purpose of these regulations is to protect the safety of occupants. They are usually prescriptive in nature, i.e. they establish minimum requirements that are occasionally updated based on newly acquired knowledge. The building regulations alone, however, cannot guarantee uninterrupted operation of a hospital, because a great many other factors affect hospital functions.

1.3.3.2 Nonstructural Vulnerability

The experience of hospital evacuations and other types of disruption during recent hazard events (many of which are described in greater detail in later chapters) has heightened the awareness that hospital functions could be seriously impaired or interrupted, even when the facilities did not sustain significant structural damage. The effects of damage to nonstructural building components and equipment, as well as the effects of breakdowns in public services (lifelines), transportation, re-supply, or other organizational aspects of hospital operations, can be as disruptive, and as dangerous for the safety of patients, as any structural damage.

Architectural Components

Nonstructural vulnerabilities that can affect hospital functions and the safety of occupants include the potential failures of architectural components, both on the exterior and the interior of buildings.

Damage to roof coverings, facades, or windows can make way for water penetration that can damage sensitive equipment and shut down many hospital functions. When roofing material is disturbed by wind, the roof may start to leak and the moisture can knock out vital equipment, disrupt patient care, and penetrate walls and other concealed spaces, allowing mold to build up over time. Window breakage resulting from high winds, earthquakes, and even flooding frequently requires patient evacuation from affected areas. Patients in critical care and acute care units are particularly vulnerable because the move separates them from medical gas outlets, monitors, lighting, and other essential support services.

Non-load bearing and partition walls and ceilings, for instance, are rarely designed and constructed to the same standards of hazard resistance as the structural elements. Collapse of these components has caused a number of evacuations and closures of hospitals following a hazard event.

Installations

Hospitals are extremely complex building systems that depend on an extensive network of mechanical, electrical, and piping installations. The air and ventilation system is one of the most important ones because it is responsible for maintaining an appropriate environment in different parts of the hospital. Isolation rooms usually have negative pressure so that harmful airborne organisms do not migrate outside the patient's room and infect others. Likewise, wards housing patients with immune system deficiencies require a positive pressure differential, so that harmful organisms do not enter the patient room and needlessly infect them. The malfunction in any one part of this ventilation system could create a risk of infection to patients and staff. This system is extremely vulnerable to disruption as a result of indirect building damage. Winds habitually overturn improperly attached roof-mounted ventilation and air-conditioning equipment, while the ductwork is very susceptible to collapse in earthquakes. Additionally, strong winds may change the airflow from ventilation exhaust outlets, potentially causing harmful discharges from patient care areas and the clinical laboratory to be sucked back into the fresh air intakes. Airborne debris from windstorms could quickly clog the air filtration systems, making them inoperable or impaired.

Hospitals depend on several essential piping systems. Medical gasses are among the most important, along with water, steam, and fire sprinkler systems. Physicians and nurses depend on oxygen and other gasses required for patient care. Unless properly secured and braced, these installations can be easily dislodged or broken, causing dangerous leakage and potential additional damage.

In floods and earthquakes particularly, sewers are apt to overflow, back up, or break down. Waste disposal is essential for any hospital, because when the toilets back up, or sterilizers, dishwashers, and other automated cleaning equipment cannot be discharged, patient care is immediately affected. Retention ponds or holding tanks coupled with backflow and diversion valves can be employed to solve this problem; however, in many hospitals, this issue has not been adequately addressed.

Elevator service is vulnerable not only to power outage, but also to direct damage to elevator installations. Wind and windborne debris can damage elevator penthouses, opening a path for water penetration that can disable elevator motors and controls, as has happened in numerous hurricanes in recent years. In the event of an earthquake, elevator shafts and other equipment can be damaged or dislodged, effectively shutting down the building. Flooding of elevator pits was a common problem during Hurricane Katrina, and responsible for the loss of elevator service.

The emergency power supply system is probably the most critical element in this group. Together with fuel supply and storage facilities, this system enables all the other hospital installations and equipment that have not sustained direct physical damage to function normally in any disaster. However, uninterrupted operation of a hospital during a power outage is possible only if adequate electrical wiring is installed in all the areas that require uninterrupted power supply. Since extra wiring and additional circuits for emergency power increase the initial construction costs of the building, the decision on the emergency power coverage requires a thorough evaluation of the relative vulnerability of various functions to power outage. As patients become more critically ill and the nature of diagnosis and treatment becomes more dependent on computers, monitors, and other electrical equipment, the need for emergency power will continue to grow.

The experience of Hurricane Katrina has demonstrated the need for emergency power coverage even for services that typically have not been regarded as critical, such as climate control and air-conditioning systems. Extreme heat caused a number of hospitals to evacuate their patients and staff when the conditions became unbearable.

Equipment and Furnishings

There are many types of internal hazards that might occur as the result of a disaster. In the past, bottles in clinical laboratories have fallen and started fires. Earthquakes have catapulted filing cabinet drawers and ventilators across rooms at high speed, with the potential of causing considerable injury to personnel. Any wheeled equipment is vulnerable to displacement and has the potential to cause injury.

Electronic communication systems

Hospitals use and depend on many types of communication systems. For communications with emergency vehicles or first response agencies, hospitals depend on radio equipment that is frequently mounted on roofs and exposed to high winds and windborne debris impact. Satellite dishes, communication masts, antennae, and other equipment can be blown off the roof or be severely damaged, leaving the hospital without this vital service at a critical time.

1.3.3.3 Spatial and Other Organizational Vulnerabilities

Most hospitals have disaster mitigation or emergency operation plans, but not all of them provide organizational alternatives in the event of disruption of the normal movement of staff, patients, equipment, and supplies that characterizes everyday hospital operations. The critical nature and interdependence of these processes represent a separate category of vulnerabilities that need careful attention. Spatial distribution of hospital functions and their inter-relationship determines the extent hospital operations are affected when normal movement and communication of people, materials, and waste are disrupted. The disruption by natural hazard events of administrative services such as contracting, procurement, maintenance, as well as allocation of resources, can impair hospital functions almost as much as any physical damage.

Just-in-time delivery: Many hospitals have currently eliminated, or greatly reduced, onsite storage for linen, supplies, food, and other materials essential to normal operations. Any prolonged isolation or blockage of streets serving the hospital could lead to a need to ration supplies and triage patients for treatment, due to the limited supplies stored on site. During Hurricane Katrina, many hospitals were isolated by floodwaters for 5 or more days and, in many cases, could not replenish critical supplies, which in some instances contributed to the decision to evacuate the facility.

Evacuation: Evacuation of patients is a measure of last resort, but occasionally necessary, especially in extreme situations. Many different conditions or vulnerabilities mentioned above can cause the evacuation of a hospital, but the process of evacuation itself can also be vulnerable to disruption that can seriously aggravate the health and safety of patients. Frequently, a flood, earthquake, or a windstorm can cause blockage of access roads, cut ting off a hospital from normal evacuation routes, as happened during Hurricane Katrina. Surface escape routes were under water and unusable, and even air evacuation was impaired because many ground level helicopter landing pads were under water. Elevated helipads located on roof tops or elevated parking structures proved invaluable features in this type of an emergency. The spatial relationship to the hospital building was another aspect that greatly influenced the evacuation and reduced the risk of aggravating patients' condition. Helipads physically connected to the hospital were most useful, because patients could be transported directly and very rapidly from the upper levels of the hospital to the helipad without interference from other hospital functions.

1.4 HOSPITAL DESIGN AND CONSTRUCTION

Permanent high occupancy and the need for uninterrupted operation are the most important characteristics of hospital facilities. They determine most of the building design requirements and pose the greatest challenge in the design of mitigation measures. Contemporary hospitals must accommodate both critically ill patients and a high volume of ambulatory patients. Length of stay for inpatients may be as short as one day, but usually averages around 5 to 6 days in most hospitals. Acute care patients often have visitors on a daily basis, while emergency departments are routinely crowded with patients and their families, particularly at peak times during the day.

It is not uncommon that some building designs that are otherwise suitable for the complex requirements of hospital operations can impair these operations in emergency conditions. This is particularly true of many older hospitals that were not designed to maintain their performance level in all conditions. Older emergency departments are generally not large enough and are often overcrowded. Many of the older hospitals would not have been designed to adjust their operations and their physical space to the conditions of mass post-disaster care.

Similarly, larger hospitals typically have greater flexibility to cope with the emergencies and large numbers of casualties than smaller hospitals. This, however, can be a liability, especially in dense urban areas where hospitals buildings are frequently 10 or more stories high. Large, tall hospital buildings, with greater than usual floor-to-floor height, are almost completely dependent on elevators for vertical communication, which exposes them to serious disruption in case of electrical or mechanical failures common during hazard events. Such difficulties are further compounded if an evacuation is necessary. When the elevators are rendered inoperable, the patients must be carried up or down long stairwells, which can be an overwhelming task for the staff of any large hospital.

Since the development of effective ventilation systems, most hospitals were designed as "thick" buildings, where many areas do not have natural light and depend on mechanical ventilation to be usable. Generally, the larger the hospital, the more functions and areas depend on mechanical ventilation and artificial light. This is another important aspect of hospital vulnerability in situations where normal power supply is disrupted. Hospital closures and evacuations caused by nonfunctioning air-conditioning systems in the wake of Hurricane Katrina stand as stark examples of the need to protect these systems much more effectively.

Hospitals usually do not occupy just one building. In most cases a hospital is located on campus that comprises a number of different buildings, each housing a separate function. In addition to an acute care hospital, which might be composed of several wings of varying ages, there might also be a separate power plant, medical office building, ambulatory surgery and procedures building, behavioral health building, fitness center, dialysis center, or cancer center. Since all of these buildings have a different type and level of occupancy, from the perspective of patient safety and that of uninterrupted hospital operations, they do not need the same level of disaster-resistant construction.

1.4.1 BUILDING CODES

Most States have adopted one of the model building codes, frequently with modifications and local additions. Building codes address minimum requirements for building resistance to major hazards based on historical experience. Recent disaster experience, however, indicates that current code requirements are not always adequate, especially not for essential facilities such as hospitals. To make things worse, many existing hospitals were built to older codes that frequently did not have any provisions for protection against natural hazards.

Most essential facilities require special attention, in addition to compliance with building code requirements, in order to be able to sustain their operations after a major disaster. Some States, like Florida or California, for example, have amended their codes to address the need for adequate protection of hospitals and other critical facilities from prevailing local hazards. California has adopted legislation for seismic design based on the principle that hospitals should be able to function at least at a basic level after an earthquake of moderate to large magnitude. This new standard has resulted in the closure of many hospitals that could not comply with the new requirements in a cost-effective manner. The implementation of this standard was significant because it established the new criterion for post-disaster functionality that should serve as a model for hazard-prone regions. This and similar standards have expanded the narrow, prescriptive nature of most building codes, by defining the performance goals that hospitals must achieve. This Design Guide fully supports the trend toward performance-based codes for design and construction of hospitals.

In addition to local building codes, various organizations and agencies, like the U.S. Department of Veterans Affairs (VA), have developed their internal building design and construction regulations to address the three major hazards: flood, wind and earthquake. The VA standard "*Natural Disasters Non-Structural Resistive Design (formerly CD-54)*" together with this publication, is a valuable resource for information on new hospital construction and renovation of existing hospitals.

1.5 MULTI-HAZARD DESIGN CONSIDERATIONS

A comprehensive hazard risk reduction design strategy that considers all the risks to which a facility may be subject is an evolving concept that is still in its infancy. Multi-hazard design is an approach that aims to integrate risk reduction with the building design process, rather than pursuing a traditional tendency towards fragmented risk reduction efforts.

Chapters 2, 3, and 4 outline the characteristics of the three natural hazards that are the subject of this publication, in terms of their geographical locations, intensity, and frequency. In addition, methods used to mitigate the risks and issues relating to building codes and regulations are also discussed. However, each hazard is discussed separately, without reference to the others. Many building locations are vulnerable to more than one hazard, requiring the application of appropriate design solutions that would mitigate each relevant hazard.

This section looks at the interaction between various building design features and mitigation measures used to protect buildings against specific hazards, by comparing their effects for each individual hazard. The similarities and differences in the ways that hazards affect buildings, and how to guard against them, demand an integrated approach to building design that would be resistant to natural hazards. This, in turn, must be pursued as part of a larger, integrated approach to the whole building design process.

Of the many hazards that can endanger a hospital and impair the services it provides to a community, fire is the most prevalent. Every hospital is at risk from fire, which makes this hazard much more pervasive than any of the natural hazards noted above. However, fire protection measures have been present in building codes for a long time, in the form of approved materials, fire-resistant assemblies, exiting requirements, the minimum number and capacity of emergency exit routes, and many other specifications. For that reason, fire hazards are not addressed in this publication as a stand-alone hazard. However, the mitigation measures used to protect the buildings against high winds, floods, and earthquakes may interact favorably or unfavorably with the need for fire protection. For this reason, fire is included as a hazard in the table of system interactions at the end of this chapter.

1.5.1 THE NEED FOR A MULTI-HAZARD APPROACH

The need to embrace a multi-hazard approach when designing or retrofitting a hospital is essential for their protection, especially when they are located in areas that are exposed to a variety of natural and man-made hazards. A multi-hazard approach can help identify potentially conflicting effects of certain mitigation measures and help to avoid aggravating the vulnerability of many hospital building components and systems. A comprehensive evaluation and application of hazard mitigation in building design serves to improve the overall effectiveness of mitigation measures that protect the continuity of hospital functions and operations. The importance of this practice has become increasingly evident following the catastrophic disasters that have occurred in the recent past.

The aim should be to anticipate and coordinate how the building and its systems interact, how mitigation of the risk from one hazard can influence the building's vulnerability to others, and how undesirable conditions and conflicts may be avoided or resolved. Through the application of a multi-hazard and multi-disciplinary approach, cost savings, efficiency, and better performance can be achieved in programming and planning new buildings and retrofitting existing ones.

> A multi-hazard risk reduction approach requires a multidisciplinary design team. This ensures that the project design benefits from an appropriate professional expertise and a thorough discussion of project issues from start to finish.

The design team should be able to take an all-hazard viewpoint, and understand how the structure and systems interact under extreme conditions imposed by natural hazards. Thus, an important aspect of multi-hazard design should be to investigate the extent to which the methods used for mitigation of one hazard may reinforce or conflict with design elements necessary for protection against other possible hazards. When the design methods reinforce one another, the costs of multi-hazard design may be reduced and the performance improved, but where they conflict, costs may be increased in order to satisfy the requirements for resistance to all relevant hazards.

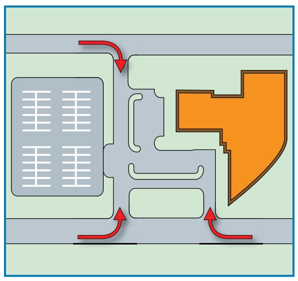
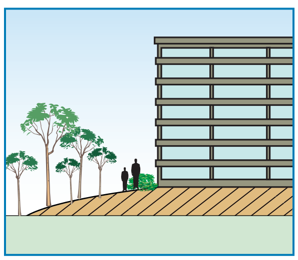
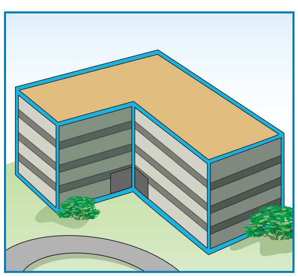
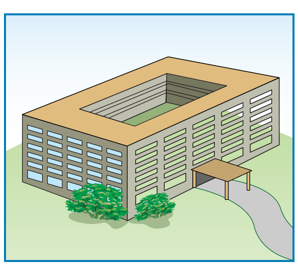
1.5.2 MULTI-HAZARD DESIGN MATRIX

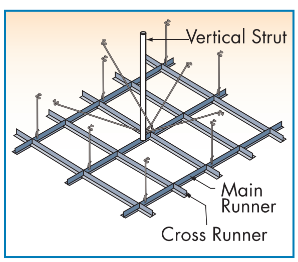
The Multi-hazard Design System Interaction Matrix highlights the interaction between a particular hazard and a building design component or system. Table 1-1 presents this system interaction matrix in a graphic form by adding small illustrations for each site or building characteristic listed. For each entry the matrix provides a description; a sample illustration; positive, negative, or neutral characterization of the interaction; and an explanation of the nature of interaction.

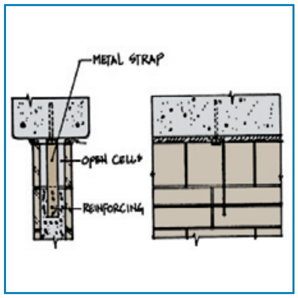
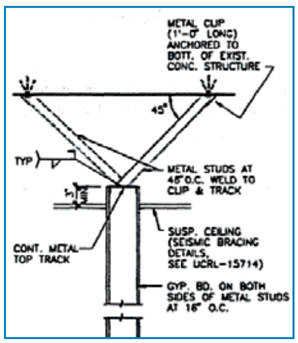
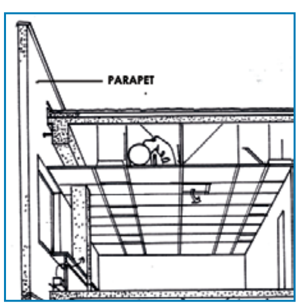
The explanations are general statements intended more to provoke thought and further analysis towards design integration, rather than to provide definite restrictions or recommendations. It is possible to overcome conflicts by sound, coordinated design between the consultants, starting at the inception of design. General cautions, such as the relationship between building weight and seismic forces, for example, are intended only as reminders of basic physical facts.

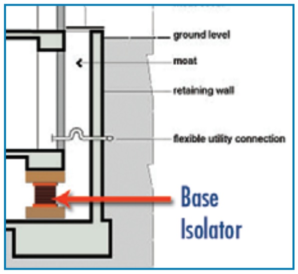
In order to facilitate comparison between hazards, the following convention has been used in Table 1-1.

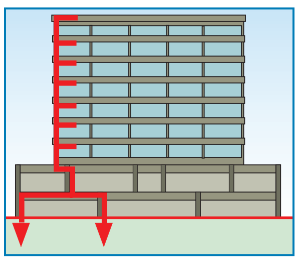
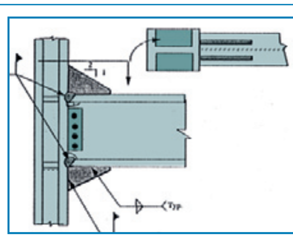
✔	Indicates a desirable condition or beneficial interaction between the designated component/system and a given hazard
✖	Indicates an undesirable condition or the increased vulnerability of a designated component/system to a given hazard
0	Indicates little or no significant interaction between the designated component/system and a given hazard

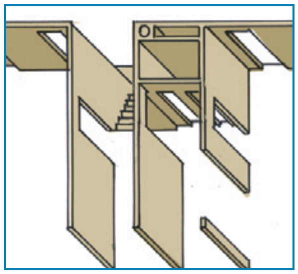
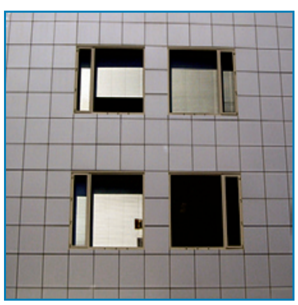
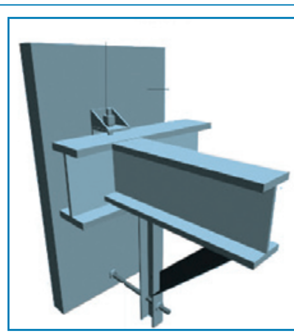
System ID	Site and Building Characteristics	Examples of Site and Building Characteristics	THE HAZARDS: Seismic	Flood	Wind	Fire	Explanation of Interaction
1	SITE						
1A	Site-specific and building specific all-hazard analysis.		✔	✔	✔	✔	Beneficial for all hazards.
1B	Two or more means of access to the site		✔	✔	✔	✔	Beneficial for all hazards.
1C	Site modification to elevate building on engineered fill.		✖	✔	O	O	Highly beneficial for flood, needs very careful site engineering for earthquakes. Not significant for fire. Probably not significant for wind but depends on topography.
2	ARCHITECTURAL						
2A	CONFIGURATION						
	2A-1 Re-entrant corner plan forms		✖	O	✖	O	May cause stress concentrations and torsional forces in earthquakes, and contribute to localized high-wind pressures.
	2A-2 Enclosed courtyard plan forms		✖	O	O	O	May cause stress concentrations and torsional forces in earthquakes.

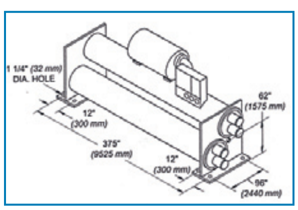
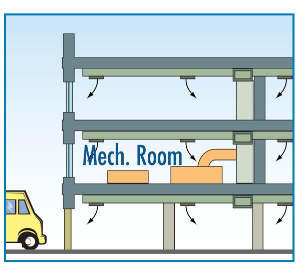
System ID	Site and Building Characteristics	Examples of Site and Building Characteristics	THE HAZARDS				
			Seismic	Flood	Wind	Fire	Explanation of Interaction
2	ARCHITECTURAL (continued)						
2A	CONFIGURATION (continued)						
	2A-3 Very irregular three-dimensional building forms		✖	O	✖	✖	May create indirect load paths, stress concentrations, and torsional forces in earthquakes. May contribute to localized high wind pressures, and aggravate evacuation during fire emergencies.
	2A-4 Large roof overhangs		✖	O	✖	O	Vulnerable to vertical earthquake and wind forces, needs careful engineering.
2B	CEILINGS						
	2B-1 Hung ceilings		✔	O	O	✔	If properly attached to structural components using diagonal braces, reduce damage from earthquakes.
2C	PARTITIONS						
	2C-1 Unreinforced CMU or hollow clay tile, used as partitions or infill between structural framing		✖	✖	✖	✔	High vulnerability to seismic and wind forces, but desirable against fire if not in seismic zone. If exposed, vulnerable to flood forces.

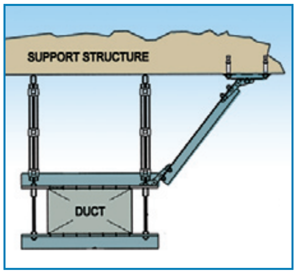
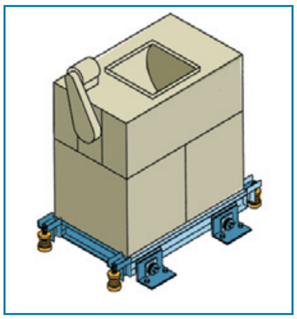
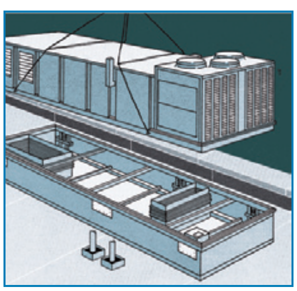
System ID	Site and Building Characteristics	Examples of Site and Building Characteristics	THE HAZARDS				
			Seismic	Flood	Wind	Fire	Explanation of Interaction
2	ARCHITECTURAL (continued)						
2C	PARTITIONS (continued)						
	2C-2 Non-rigid (ductile) connections for attachment of interior non-load-bearing walls to structures including extra-high and -heavy gypsum board walls		✔	0	0	✖	Beneficial for earthquakes but gaps between components may threaten fire resistance. Not significant for flood and wind.
	2C-3 Gypsum wall board partitions		✔	✖	0	✔	Gypsum partitions properly braced to structure beneficial in seismic zones. Susceptible to flood damage, but good for fire if proper resistance is specified. Not significant for wind.
2D	OTHER ELEMENTS						
	2D-1 Tile roofs		✖	0	✖	✔	Undesirable in seismic zones unless properly attached. On light structures, may cause poor seismic response. Good fire protection against external fire (wildfires) but undesirable in hurricane- and tornado-prone regions.
	2D-2 Parapets		✔	0	0	✔	Properly engineered parapet beneficial in seismic zones, but unbraced URM very dangerous in earthquake and wind. High parapets (>3 ft.) beneficial for wind. May assist in reducing fire spread to adjacent buildings.

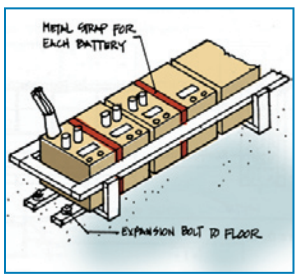
System ID	Site and Building Characteristics	Examples of Site and Building Characteristics	THE HAZARDS Seismic	Flood	Wind	Fire	Explanation of Interaction
3	STRUCTURAL SYSTEM						
	3-1 Base isolation and/or energy dissipating dampers		✔	✖	O	O	Beneficial for earthquake, but base isolation in basement should be dry floodproofed to reduce vulnerability to flood damage. Not significant for wind and fire.
	3-2 Wood frame structure, used for small hospitals and ancillary and service buildings		✔	✖	O	O	Light weight beneficial in seismic zones provided adequate connections and shear walls are used. Lightness and lack of moisture resistance a disadvantage in floods.
	3-3 Heavy structure with concrete floors, reinforced concrete moment frame, or frame with reinforced concrete or masonry shear walls.		✔	✔	✔	✔	Although weight increases seismic forces it is not a design problem. Requires special non-ductile detailing for large building frames. Generally beneficial for all other hazards.
	3-4 Reinforced concrete or reinforced CMU structural walls with concrete floors and roof deck		✔	✔	✔	✔	Very beneficial for wind, good performance for earthquake, flood, and fire when correctly designed and constructed.
	3-5 Steel structural frame		✔	✔	✔	✖	Lighter than concrete, needs properly detailed moment frame, steel braces, or shear walls in seismic and high-wind zones. Good in flood with proper detailing, especially for elevated structure. Vulnerable to fire.

System ID	Site and Building Characteristics	Examples of Site and Building Characteristics	THE HAZARDS: Seismic	Flood	Wind	Fire	Explanation of Interaction
3	STRUCTURAL SYSTEM (continued)						
	3-6 Unreinforced masonry load-bearing walls		✖	✖	✖	O	Very poor performance in earthquakes and high winds. Undesirable for all hazards because of possibility of collapse.
	3-7 Steel or concrete frame structure with open first floor		O	✔	O	O	Very beneficial for flood. Requires careful design for earthquake, wind, and fire.
	3-8 Indirect vertical load path	 Discontinuity at third floor	✖	O	✖	✖	Undesirable for seismic and wind hazards because poor structural integrity increases likelihood of collapse. Fire may further weaken structure.
	3-9 Large seismic separation joints in structure		✔	O	✖	✖	Improves seismic response, but creates possible path for toxic gases during fire. (Cause of deaths in Las Vegas MGM Grand fire.) Needs careful protection against wind-driven rain.
	3-10 Ductile detailing of steel and RC structure and connections		✔	O	✔	O	Provides better nonlinear response and a structure that is more resistant to collapse.

System ID	Site and Building Characteristics	Examples of Site and Building Characteristics	THE HAZARDS				
			Seismic	Flood	Wind	Fire	Explanation of Interaction
3	STRUCTURAL SYSTEM (continued)						
	3-11 Reinforced concrete or reinforced CMU around exit ways and exit stairs		✖	0	✔	✔	Properly designed, will preserve evacuation routes in event of fire. May create torsional response and stress concentrations in earthquakes unless isolated. If fully encloses staircases beneficial as wind shelter.
4	BUILDING ENVELOPE						
4A	EXTERIOR WALL CLADDING						
	4A-1 Brick veneer on exterior walls		✖	✖	✖	0	In earthquakes, winds, and floods material may detach and cause costly damage and injury. Careful detailing and quality control necessary for good performance.
	4A-2 Lightweight insulated cladding and EIFS		✔	0	✖	0	Light weight reduces structural response in earthquakes, but needs very careful engineering and application to prevent leakage and detachment in winds. Vulnerable to windborne debris impact. Not significant in floods or fire.
	4A-3 Precast concrete panels		✖	0	✔	0	Requires special detailing with ductile connections to structure in high seismic zones. Good for winds if well attached and joints are protected against wind-driven rain.

System ID	Site and Building Characteristics	Examples of Site and Building Characteristics	THE HAZARDS				
			Seismic	Flood	Wind	Fire	Explanation of Interaction
4	BUILDING ENVELOPE (continued)						
4B	GLAZING						
	4B-1 Metal/glass curtain wall		✔	0	✖	✖	Light weight reduces seismic forces, but needs special design and installation to prevent failure in earthquakes. Fire can spread upward behind curtain wall if not properly fireproofed. Vulnerable to windborne debris.
	4B-2 Impact-resistant glazing		0	0	✔	✖	Can cause problems during fire rescue operations, limiting smoke ventilation and access. Good against wind-borne debris but not significant for earthquake or flood.
5	UTILITIES						
	5-1 Anchorage/ bracing of system components	 Chiller Support	✔	✔	✔	0	Essential for earthquake and wind (especially exterior mounted), beneficial for flood, not significant for fire.
	5-2 Location of system components above flood level		✖	✔	0	0	Very beneficial for flood, if in upper floors may be subject to greater forces in earthquake, not significant for wind or fire.

System ID	Site and Building Characteristics	Examples of Site and Building Characteristics	THE HAZARDS				
			Seismic	Flood	Wind	Fire	Explanation of Interaction
6	MECHANICAL						
	6-1 Anchorage/ bracing of system components		✔	✔	✔	0	Essential for earthquake and wind (exterior-mounted), beneficial for flood.
	6-2 Vibration-isolated equipment designed for seismic and wind forces: snubbers prevent equipment from falling off isolators	 Isolators with "snubbers" and provisions for wind uplift	✔	0	0	0	Very beneficial for earthquake, not significant for flood or fire. If not designed to resist uplift inadequate for wind.
	6-3 Anchorage of rooftop equipment		✔	0	✔	0	Very beneficial for wind and earthquake (with seismic designed isolators where necessary), not significant for floods and fire.
7	PLUMBING						
	7-1 Anchorage/ bracing of system components	 Pipe Support	✔	0	✔	✔	Essential for earthquake and wind (for exterior-mounted systems), beneficial for fire.

System ID	Site and Building Characteristics	Examples of Site and Building Characteristics	THE HAZARDS				
			Seismic	Flood	Wind	Fire	Explanation of Interaction
8	ELECTRICAL AND COMMUNICATIONS SYSTEM						
	8-1 Anchorage/ bracing of system components	 Unbraced electrical cabinets	✔	o	✔	✔	Essential for earthquake and wind (for exterior-mounted systems), beneficial for fire.
	8-2 Emergency power supply adequate for essential services and equipment securely braced	 Braced emergency batteries	✔	✔	✔	✔	Essential for seismic, flood, wind, and fire.

1.6 REFERENCES

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