1.1 INTRODUCTION

This chapter introduces the role of hazard mitigation in the planning, design, and construction of critical facilities. It describes the way building design determines how well a critical facility is protected against natural hazard risks, specifically the risks associated with flooding and high winds. Critical facilities, and the functions they perform, are the most significant components of the system that protects the health, safety, and well-being of communities at risk.

The devastating effects of recent hurricanes, especially Hurricane Katrina, underscored the vulnerability of coastal areas of the United States, the fastest growing regions of the country. The population pressure and the aggressive coastal development in areas subject to hurricanes and coastal storms created the conditions that require careful consideration of the effects of natural hazards on the sustainability of this development. One of the most important determinants of the sustainability of coastal communities is the reliability of their physical and social infrastructure. The communities that cannot rely on their own critical infrastructure are extremely vulnerable to disasters. This is why the design of critical facilities to improve their resistance to damage, and their ability to function without interruption during and in the aftermath of hazard events, deserves special attention.

To ensure safe and uninterrupted operation of critical facilities, which is vital in the post-disaster period, facility owners must incorporate a comprehensive approach to identify hazards and avoid them when feasible. In cases when exposure to hazards is unavoidable, it is recommended that they build new facilities, or rehabilitate the existing ones to resist the forces and conditions associated with these hazards.

1.1.1 CRITICAL FACILITIES

In general usage, the term "critical facilities" is used to describe all manmade structures or other improvements that, because of their function, size, service area, or uniqueness, have the potential to cause serious bodily harm, extensive property damage, or disruption of vital socioeconomic activities if they are destroyed, damaged, or if their functionality is impaired.

Critical facilities commonly include all public and private facilities that a community considers essential for the delivery of vital services and for the protection of the community. They usually include emergency response facilities (fire stations, police stations, rescue squads, and emergency operation centers [EOCs]), custodial facilities (jails and other detention centers, long-term care facilities, hospitals, and other health care facilities), schools, emergency shelters, utilities (water supply, wastewater treatment facilities, and power), communications facilities, and any other assets determined by the community to be of critical importance for the protection of the health and safety of the population. The adverse effects of damaged critical facilities can extend far beyond direct physical damage. Disruption of health care, fire, and police services can impair search and rescue, emergency medical care, and even access to damaged areas.

The number and nature of critical facilities in a community can differ greatly from one jurisdiction to another, and usually comprise both public and private facilities. In this sense, each community needs to determine the relative importance of the publicly and privately owned facilities that deliver vital services, provide important functions, and protect special populations.

Minimum requirements for the design of new critical facilities and for improvements to existing facilities are found in the model building codes and the design and construction standards. ASCE 7, *Minimum Design Loads for Buildings and Other Structures,* is the best known standard. Published by the American Society of Civil Engineers (ASCE), it classifies buildings and other structures into four categories based on occupancy. Most critical facilities fall into Category III or Category IV, described below:

Category I includes buildings and other structures whose failure would represent a low hazard to human life, such as agricultural buildings and storage facilities.

Category II includes all buildings not specifically included in other categories.

Category III includes buildings and other structures that represent a substantial hazard to human life in the event of failure. They include buildings with higher concentrations of occupants (i.e., where more than 300 people congregate in one area). These are typically educational facilities with capacities greater than 250 for elementary and secondary facilities, 500 for colleges and adult education facilities, or 150 for daycare facilities.

Category IV includes essential facilities such as hospitals, fire and police stations, rescue and other emergency service facilities, power stations, water supply facilities, aviation facilities, and other buildings critical for the national and civil defense.

This manual concentrates on a number of critical or, as they are sometimes called, essential facilities, that deal with health and safety in emergencies, and include health care facilities, police and fire stations, EOCs, and schools. These facilities are chosen because of their vitally important role in protecting the health and safety of the community. Although limited in scope to several specific types of facilities, the information and recommendations in this manual are valuable and applicable to other types of critical facilities located in areas prone to flooding and exposed to high winds.

1.1.2 HURRICANE KATRINA

Although not the strongest storm to hit the coast of the United States, Hurricane Katrina caused the greatest disaster in the nation's history. The hurricane made its first landfall on August 25, 2005, on the southeast coast of Florida as a Category 1 hurricane.

It then crossed Florida into the Gulf of Mexico, where it gained strength to a Category 5 hurricane. Before making its second landfall near Buras in southeast Louisiana, Katrina weakened to a Category 3 hurricane. Moving across southeast Louisiana, Katrina continued northward, pushing storm surge into coastal areas of Alabama, Mississippi, and Louisiana. After crossing over Lake Borgne, it finally made a third landfall as a Category 3 hurricane near Pearlington, Mississippi, at the Louisiana/Mississippi border (see Figures 1-1 and 1-2). The hurricane caused extensive devastation along the gulf coast, with southeast Louisiana and the coast of Mississippi bearing the brunt of the catastrophic damage.

Wind damage was widespread and severe in many areas; however, the greatest damage was caused by Hurricane Katrina's storm surge flooding. Although the storm weakened from a powerful Category 5 to a Category 3 hurricane just before making landfall in Louisiana and Mississippi, the storm surge appears to have maintained a level associated with a Category 5 hurricane. The surge built by the stronger winds over open water could not dissipate as quickly as the wind speeds decreased, and the shallow depth of the off-shore shelf and the shape of the shoreline contributed to the high surge elevations. The Mississippi coastline experienced the highest storm surge on record. The storm surge also contributed to failures of a number of levees, notably the levee system that protects the City of New Orleans from Lake Borgne and Lake Pontchartrain. An estimated 80 percent of the city subsequently flooded.

The disaster was further compounded by the poor performance of critical facilities during and after the storm. Critical facilities typically did not perform any better than ordinary commercial buildings, but the extent of the damage to these facilities and the subsequent disruption of their operations caused much greater hardship. Facilities such as hurricane evacuation shelters, police and fire stations, hospitals, and EOCs were severely damaged and many were completely destroyed. Some facilities experienced a loss of function when critical support equipment, such as vehicles and communication equipment, were damaged or destroyed. While most of the damage to critical facilities was caused by the storm surge, wind damage also was widespread and substantial. In several instances, critical facilities were destroyed completely or damaged so severely that all the occupants had to be evacuated

Figure 1-1: Hurricane Katrina's path through Louisiana and Mississippi
(BASED ON HURRICANE STORM TRACK DATA FROM THE NATIONAL HURRICANE CENTER)

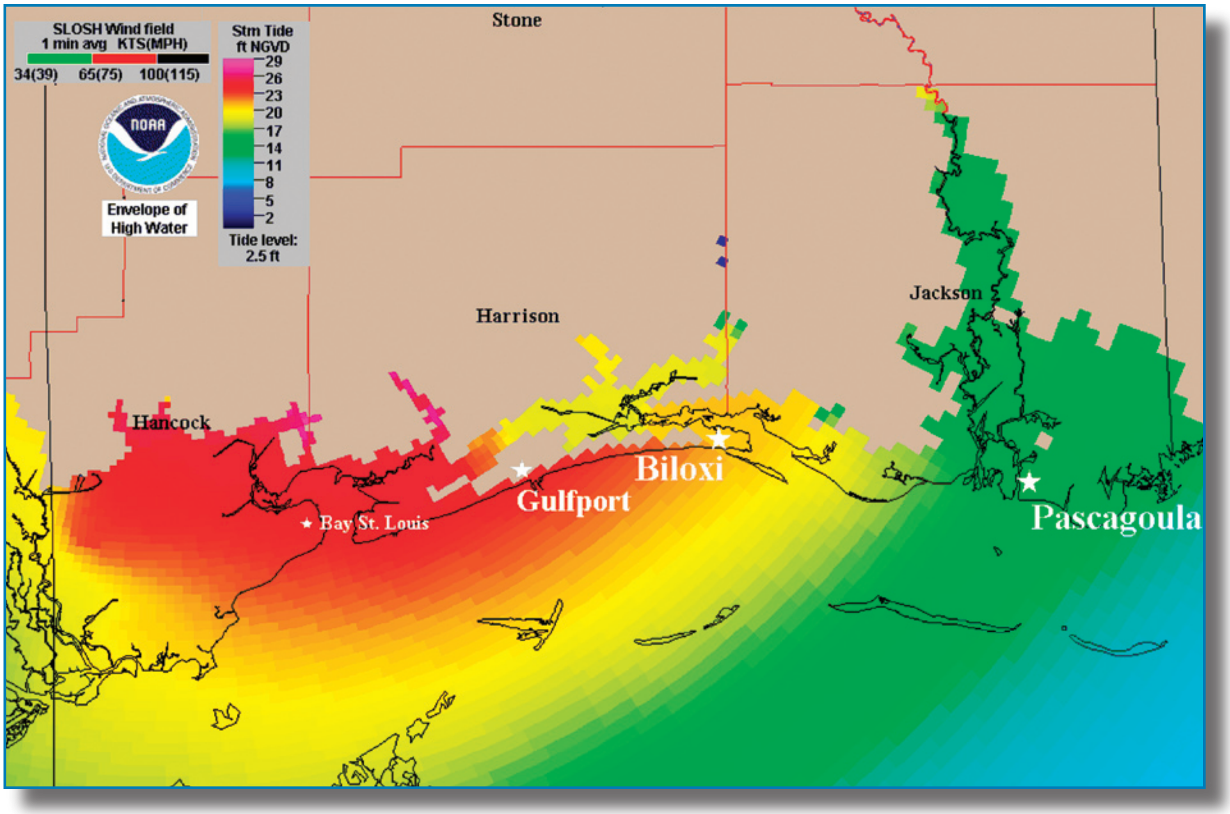

Figure 1-2: Mississippi coast SLOSH NOAA data
SOURCE: NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (NOAA)

after the hurricane had moved inland. The loss of so many critical facilities placed a severe strain on the emergency operations and recovery efforts.

The estimated death toll of Hurricane Katrina exceeded 1,800. More than 85 percent of casualties were recorded in Louisiana and about 13 percent of victims lost their lives in Mississippi. Other deaths attributed both directly and indirectly to Katrina were reported in Florida, Alabama, Georgia, Kentucky, and Ohio. Hurricane Katrina ranks as the third deadliest hurricane in the United States, surpassed only by the Texas Hurricane at Galveston in 1900, where at least 6,000 and possibly as many as 10,000 lives were lost, and the Florida Hurricane at Lake Okeechobee in 1928, which claimed 2,500 lives. Estimated total economic losses from Katrina are in excess of $150 billion, and insured losses are $40 billion, making Katrina the most expensive natural disaster in the nation's history.

1.2 HAZARD MITIGATION

1.2.1 HAZARD MITIGATION FOR CRITICAL FACILITIES

Mitigation can reduce the enormous cost of disasters to property owners, communities, and the government. Since the late 1980s, hazard mitigation has become well known in many parts of the country for initiatives in land use planning, adoption of building codes, elevation of homes, floodplain buyouts, and retrofitting buildings to resist damage in flooding, high winds, or seismic events. Incorporating mitigation measures in the planning and design of buildings is recommended because these measures reduce injuries and damage resulting from building failures during hazard events. Incorporating mitigation measures in the design of critical facilities, however, is crucial for minimizing the disruption of their operations and protecting the uninterrupted provision of critical services.

> "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.

The first Federal program to support State and local mitigation programs was established by the Stafford Act in 1988. Growing support and recognition of the need to improve disaster resistance led to passage of the Disaster Mitigation Act of 2000, which amended the Stafford Act. This statute reinforces the importance of comprehensive, multi-hazard mitigation planning, and emphasizes planning for disasters before they occur. As part of the

> Since 1977, Federal agencies have been charged by Executive Order 11988 to provide leadership "to reduce the risk of flood loss, to minimize the impact of floods on human safety, health and welfare, and to restore and preserve the natural and beneficial values served by floodplains in carrying out their responsibilities for (1) acquiring, managing, and disposing of Federal lands and facilities; (2) providing federally undertaken, financed, or assisted construction and improvements; and (3) conducting Federal activities and programs affecting land use, including but not limited to water and related land resources planning, regulating, and licensing activities."

planning process, States and communities are encouraged to identify existing critical facilities and to evaluate their vulnerability to natural hazards. To qualify for certain Federal mitigation grant programs, projects to rehabilitate critical facilities must be consistent with State and local mitigation plans. Appendix C provides an overview of conditions and requirements for obtaining funding assistance from major mitigation funding programs administered by the Federal Emergency Management Agency (FEMA).

There is no single procedure mandated for the planning, site selection, and design of critical facilities, because none can be assumed to be universally applicable. The decision to build a critical facility depends on many factors and requires a rigorous and comprehensive analysis of all the conditions that may affect the operation of a facility. This manual primarily addresses the design of new facilities and measures to improve the disaster resistance of existing facilities exposed to flooding and high winds, based on the assumption that all other alternatives to minimize or avoid such risks have been thoroughly evaluated and rejected as infeasible or impractical. It is outside the scope of this manual to try to depict in detail this evaluation process in its full range and complexity. Communities, as well as the owners and operators of critical facilities, must evaluate all alternatives, assess all risks, and consider all short-term and long-term effects of proposed projects, whenever construction or rehabilitation of these facilities is considered. Careful analysis of alternatives and the potential adverse effects of exposing critical facilities to natural hazards is also intended to help identify the most appropriate hazard-resistant measures when avoidance is not practical.

1.2.2 SITE SELECTION

Site selection is a particularly significant step when planning new critical facilities or when planning substantial improvements to existing facilities in hazard-prone areas. The earliest steps in the planning process should be to identify hazards and assess the risks for the facility at the proposed site. In addition, alternative solutions should be considered in order to avoid site-specific hazards like floods. After decisions about the building location have been made, hazard mitigation involves acquiring a full understanding of the prevalent hazards and considering all appropriate hazard-resistance measures to ensure the uninterrupted operation of critical facilities.

> All work on critical facilities must meet the minimum requirements of building codes and related regulations. However, the importance of uninterrupted operation of critical facilities frequently makes it necessary to go beyond the code requirements to provide acceptable levels of protection for the facility's functionality during, and in the immediate aftermath of, a hazard event.

Typically, the selection of a site for a critical facility is based on specific functions of a facility and the characteristics of its service area. In cases where critical facilities may be exposed to flooding and wind hazards, it is recommended that the final site decision be made only after all alternative sites have been evaluated for hazard exposure and the resulting effects of the hazard exposure on the design, construction, and operation of a facility.

Considering that critical facilities should avoid hazard-prone areas, site selection may sometimes be a difficult and prolonged process. This is especially true in situations when the facility service requirements cannot be easily reconciled with requirements to minimize the exposure to hazards. Sometimes a facility, like a fire station for example, cannot fulfill its rapid response function if it is located outside the hazard zone, far from the area the facility is intended to serve. Additionally, site selection is not always controlled by the community. Many local jurisdictions report that the high cost and the scarcity of available land can severely limit the consideration of alternative locations. The consequences of accepting a flood-prone site include not only the potential physical damage, but also the loss of services provided by the critical facility. This loss of service can adversely affect the community as a whole, both in the immediate post-event period and during its long-term recovery. Section 2.5.1 contains a discussion and a number of questions that can help guide determinations about whether the risks associated with building a critical facility in a floodplain are acceptable.

If the site selection process determines that no other practical and feasible alternatives are available and that a facility must be located in a hazard-prone area, the highest level of protection should be a design priority.

1.2.3 FACILITY DESIGN

The nature of services provided by critical facilities requires that designers and decisionmakers define a design objective of achieving building performance levels beyond the minimum requirements prescribed by the building code. While compliance with the building code may satisfy the requirements to protect the facility's occupants, it may be insufficient to ensure the continued operation of the facility. When designing or rehabilitating a critical facility located in an area subject to high-wind or flooding risks, this manual recommends a set of guidelines intended to minimize the interruption in operation of critical facilities, both during and in the aftermath of hazard events.

- ❍ Conduct an in-house assessment of the facility needs, with the assistance of decisionmakers and consultants. Public committees may contribute advice and guidance throughout the programming and design process. For large programs, committees may acquire specialists at different stages as necessary.

- ❍ Determine the size and scope of the proposed program. In a smaller area, an architect may be employed to assist the decisionmakers with this task, possibly later becoming the design architect.

- ❍ Assess the needs of the facility to determine the availability of suitable sites (and lease/purchase as necessary).

- ❍ Develop occupant specifications, seeking advice from facility managers and both in-house and consulting professionals.

- ❍ Assess financial needs.

- ❍ Identify financial resources, including alternative sources of funding (e.g., Federal and State programs, local taxes, bond issues, and utility fees).

- ❍ Ensure funding (e.g., bond issue, establishment of utility districts, etc.).

- Appoint a building program management staff (appointed officials or a committee).

- Determine the design and construction process (i.e., conventional design and bid, design/build, or construction management).

- Select and hire architects and other special design consultants or design/build team members. The timing of this phase varies depending on the number of variables.

- Develop building programs, including building size, room size, equipment, and environmental requirements. This may be done in-house, or architects and independent program consultants may assist.

- Appoint a local representative to the staff and a public stakeholders committee for the design phase.

- Develop designs with cost estimates. Hold public meetings, with the architects in attendance, and encourage public input into the design. Implement local area progress reviews.

- Complete the design and solicit a local review of the contract documents.

- Submit construction documents to the local jurisdiction and any permitting agencies for review and approval.

- Submit documents to the building department.

- Select the contractor (if bidding is used), or finalize design/build or construction management contracts.

- Undertake critical facility construction.

- Administer the construction contract.

- Monitor the construction progress and conduct inspections, as required.

- Complete contracted tasks.

- Conduct inspections and provide proof of the architect's acceptance.

- Inspect the critical facility and obtain concurrence/acceptance by the owner.

- Commission the facility and occupy it.

The sequence of the above steps may vary, depending on the complexity of the program; some steps may be implemented simultaneously. Figure 1-3 shows a flow chart of this typical process. Also shown (in the five boxes to the right) are specific activities related to designing for multiple hazards and how these activities fit into the construction process.

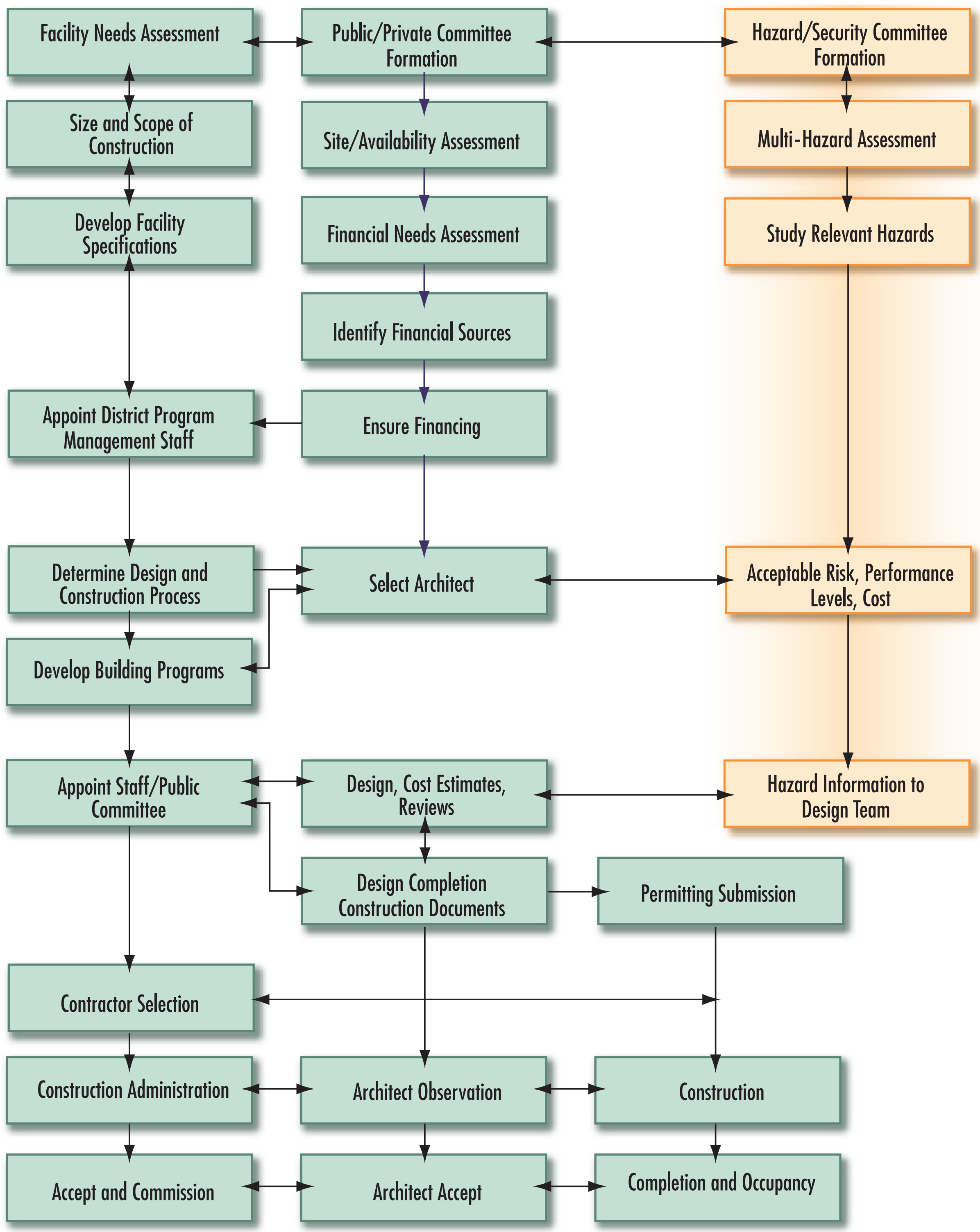

Figure 1-3: Process flow chart for decisionmakers

1.3 PERFORMANCE-BASED DESIGN

1.3.1 BACKGROUND

The model building codes define the minimum design requirements to ensure occupants' safety in critical facilities. Recent natural disasters have forced recognition that damage can occur even when buildings are compliant with the building code. The fact that a large number of critical facilities in communities affected by Hurricane Katrina were shut down (frequently as a result of minor building or equipment damage) suggests that satisfying the minimum code criteria may not be sufficient to ensure continued availability of critical services. Communities depend on the uninterrupted operation of critical facilities, especially during and immediately following natural disasters. In order to meet that need, critical facilities should be designed and constructed according to criteria that result in continued and uninterrupted provision of critical services.

Performance-based codes define acceptable or tolerable levels of risk for a variety of health, safety, and public welfare issues. Currently available are the *International Code Council Performance Code for Buildings and Facilities* by the International Code Council (ICC, 2006), *101 Life Safety Code* (NFPA, 2006a), and the *NFPA 5000 Building Construction and Safety Code* (NFPA, 2006b) by the National Fire Protection Association (NFPA). The ICC performance code addresses all types of building issues, while the provisions of the *101 Life Safety Code,* "Performance-Based Option," address only issues related to "life safety systems." The *NFPA 5000 Building Construction and Safety Code* sets forth both performance and prescriptive options that apply to all traditional building code issues.

Building performance indicates how well a structure supports the defined needs of its users. The term "performance," as it relates to critical facilities exposed to natural hazards, usually refers to a building's condition after a disaster, i.e., it signifies a level of damage or a load. Acceptable performance indicates acceptable levels of damage or a building condition ,that allows uninterrupted facility operation. Consequently, performance-based design for critical facilities is the process or methodology used by design professionals to create buildings that protect a facility's functionality and the continued availability of services. This approach represents a major change in perception that gives performance-based design considerations a greater importance in the decisionmaking process for design and construction of critical facilities.

The performance-based design approach is not proposed as an immediate substitute for design to traditional codes. Rather, it is seen as an opportunity for enhancing and tailoring the design to match the objectives of the community.

FEMA recently funded the development of next-generation, performance-based seismic design guidelines for new and existing buildings. This process includes detailed modeling; simulation of building response to extreme loading; and estimation of potential casualties, loss of occupancy, and economic losses. The process allows the design of a building to be adjusted to balance the level of acceptable risks and the cost of achieving the required level of building performance. Currently the process focuses on seismic hazards, but it is general enough to be used with other hazards, as soon as the development of performance-based design criteria for wind and other extreme loads advances to the point that they can be incorporated into standardized models.

1.3.2 PRESCRIPTIVE VS. PERFORMANCE-BASED DESIGN

Design and construction in the United States is generally regulated by building codes and standards. Building codes typically seek to ensure the health, safety, and well-being of people in buildings. Toward this purpose, the building codes and standards set minimum design and construction requirements to address structural strength, adequate means of egress for facilities, sanitary equipment, light and ventilation, and fire safety. Building regulations may also promote other objectives, such as energy efficiency, serviceability, quality or value, and accessibility for persons with disabilities. These prescriptive standards are easy to understand and follow, and easy to monitor. This is their great strength.

Historically, building codes were based on a prescriptive approach that limited the available solutions for compliance, which did not encourage creativity and innovation. Prescriptive or specification-based design emphasized the “input,” or the materials and methods required. In contrast, the focus of performance-based design is the “output,” or the expectations and requirements of the users of a building.

Performance-based design requirements define goals and objectives to be achieved and describe methods that can be used to demonstrate whether buildings meet these goals and objectives. This approach provides a systematic method for assessing the performance capabilities of a building, system, or component, which can then be used to verify the equivalent performance of alternatives, deliver standard performance at a reduced cost, or confirm the higher performance needed for critical facilities.

1.3.3 THE PROCESS OF PERFORMANCE-BASED DESIGN OF CRITICAL FACILITIES

The performance-based design process explicitly evaluates how building systems are likely to perform under a variety of conditions associated with potential hazard events. The process takes into consideration the uncertainties inherent in quantifying potential risks and assessing the actual responses of building systems and the potential effects of the performance of these systems on the functionality of critical facilities. Identifying the performance capability of a facility is an integral part of the design process and guides the many design decisions that must be made. Figure 1-4 presents the key steps in this iterative performance-based design process.

Performance-based design starts with selecting design criteria articulated through one or more performance objectives. Each performance objective is a statement of the acceptable risk of incurring different levels of damage and the consequential losses that occur as a result of this damage. Losses can be associated with structural or nonstructural damage, and can be expressed in the form of casualties, direct economic costs, and loss of service costs. Loss of service costs may be the most important loss component to consider for critical facilities. Acceptable risks are typically expressed as acceptable losses for specific levels of hazard intensity and frequency. They take into consideration all the potential hazards that could affect the building and the probability of their occurrence during a specified time period. The overall analysis must consider not only the intensity and frequency of occurrence of hazard events, but also the effectiveness and reliability of the building systems to survive the event without significant interruption in the operation of a facility.

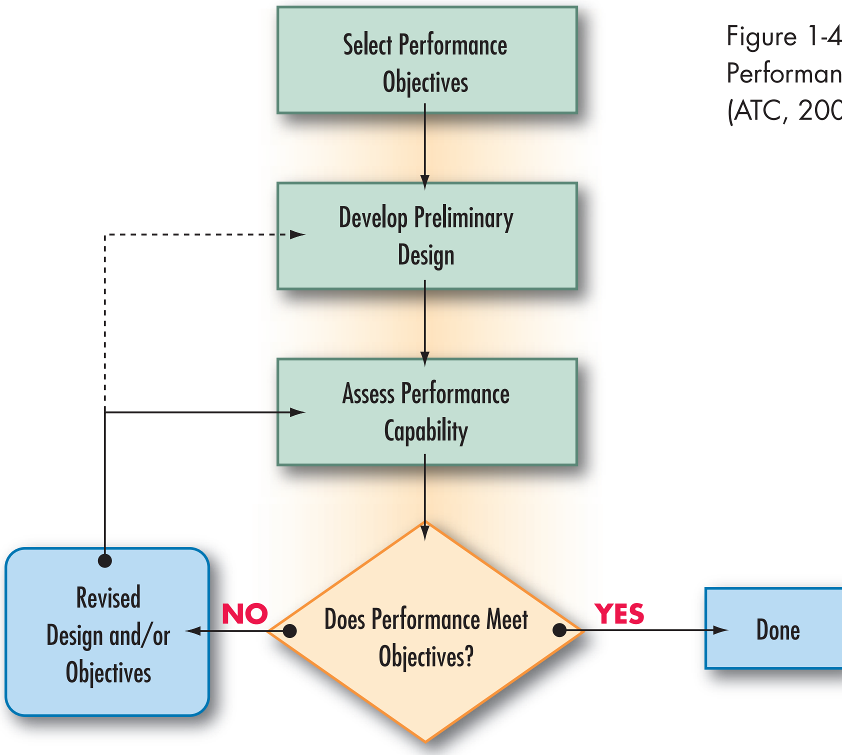

Figure 1-4:
Performance-based design flow diagram (ATC, 2003)

1.3.4 ACCEPTABLE RISK AND PERFORMANCE LEVELS

Performance-based design requires a quantitative measure of risk. It also establishes the basis for evaluating acceptable losses and selecting appropriate designs. While specific performance objectives can vary for each project, the notion of acceptable performance generally follows a trend corresponding to:

- Little or no damage for small, frequently occurring events
- Moderate damage for medium-sized, less frequent events
- Significant damage for very large, very rare events

Performance objectives should be higher and the corresponding acceptable levels of damage lower for critical facilities and other important buildings than for non-critical facilities. This trend is illustrated in Figure 1-5, taken from the ICC Performance Code for Buildings and Facilities (ICC, 2006). This document defines acceptable performance for facilities in one of four performance groups (I, II, III, and IV), using four damage levels (mild, moderate, high, and severe), and given four hazard levels (small, medium, large, and very large). The relative return periods (length of time between occurrences) commonly associated with the hazard levels for each type of hazard event (seismic, flood, and wind) are indicated in Figure 1-6.

Since losses can be associated with structural damage, nonstructural damage, or both, performance objectives must be expressed in terms of the potential performance of both structural and nonstructural systems. The *ICC Performance Code for Buildings and Facilities* has formalized the following four design performance levels, each of which addresses structural damage, nonstructural systems, occupant hazards, overall extent of damage, and release of hazardous materials. These definitions are general to all hazards and are related to tolerable limits of impact to the building, its contents, and its occupants.

Mild Impact: At the mild impact level, the building has no structural damage and is safe to occupy. The nonstructural systems needed for normal building or facility use and emergency operations are fully operational. The number of injured occupants is minimal, and the nature of the injuries minor. The overall extent of the damage is minimal. Minimal amounts of hazardous materials may be released into the environment.

Moderate Impact: At the moderate impact level, structural damage is repairable and some delay in re-occupancy can be expected. The nonstructural systems needed for normal building or facility use and emergency operations are fully operational, although some cleanup and repair may be needed. Injuries to occupants may be locally significant, but generally moderate in numbers and in nature. There is a low likelihood of a single life loss and very low likelihood of multiple life loss. The extent of the damage can be locally significant, but is moderate overall. Some hazardous materials may be released into the environment, but the risk to the community is minimal.

		INCREASING LEVEL OF PERFORMANCE Performance Groups			
		Performance Group I	Performance Group II	Performance Group III	Performance Group IV
MAGNITUDE OF DESIGN EVENT Increasing Magnitude of Event	Very Large (Very rare)	Severe	Severe	High	Moderate
	Large (Rare)	Severe	High	Moderate	Mild
	Medium (Less Frequent)	High	Moderate	Mild	Mild
	Small (Frequent)	Moderate	Mild	Mild	Mild

Figure 1-5: Maximum level of damage to be tolerated (Table 303.3, ICC, 2006b)
Note: Performance Group I: Buildings that represent a low hazard to human life in the event of failure. Performance Group II: All buildings except those in Groups I, III, and IV. Performance Group III: Buildings with a substantial hazard to human life in the event of failure. Group IV: Buildings designed as essential facilities, including emergency operations centers and designated disaster shelters.

		DESIGN EVENT		
		Seismic	Flood	Wind
MAGNITUDE OF DESIGN EVENT	Very Large (Very rare)	2,475 Years	Determined on Site-Specific Basis	125 Years
	Large (Rare)	475 Years (Not to Exceed Two-Thirds of the Intensity of Very Large	Determined on Site-Specific Basis	100 Years
	Medium (Less Frequent)	72 Years	500 years	75 Years
	Small (Frequent)	25 Years	100 Years	50 Years

Figure 1-6: Relative magnitude and return period for seismic, flood, and wind events (ICC, 2006b)

High Impact: At the high impact level, there is significant damage to structural elements, but no falling debris. Significant delays in reoccupancy can be expected. The nonstructural systems needed for normal building use are significantly damaged and inoperable. Emergency systems may be damaged, but remain operational. Injuries to occupants may be locally significant with a high risk to life, but are generally moderate in numbers and nature. There is a moderate likelihood of a single life loss, with a low probability of multiple life loss. The extent of damage can be generally significant and at some locations total. Hazardous materials are released into the environment, with localized relocation required in the immediate vicinity.

Severe Impact: At the severe impact level, there is substantial structural damage. Repair may not be technically possible. The building is not safe for re-occupancy due to the potential for collapse. The nonstructural systems for normal use and emergency systems may be nonfunctional. Injuries to occupants may be high in number and significant in nature. Significant risk to life may exist. There is a high likelihood of single life loss and a moderate likelihood of multiple life loss. Overall damage is substantial. Significant amounts of hazardous materials may be released into the environment, with relocation needed beyond the immediate vicinity.

Once the preliminary design has been developed, a series of simulations (analyses of building response to loading) are performed to estimate the probable performance of the building under various design scenario events. Using fragility relationships (vulnerability functions defining the relationship between load and damage) developed through testing or calculation, building responses are equated to damage states expressed as levels of performance. If the simulated performance meets or exceeds the performance objectives, the design is completed. If not, the design must be revised in an iterative process until the performance objectives are met. In some cases it will not be possible to meet the stated objective at a reasonable cost, in which case the team of decisionmakers may elect to relax some of the original performance objectives.

Continued and uninterrupted operation is the most important performance requirement of any critical facility, regardless of the level of structural and nonstructural building damage. In other words, the acceptable performance of a critical facility is achieved as long as the structural and nonstructural damage to the building does not disrupt or impair the continued operation of that facility. In recent hurricanes, however, undamaged structures were frequently rendered inoperable as a result of nonstructural damage resulting in unacceptable performance (FEMA, 2006).

In terms of affecting the ability of a facility to function, the failure of nonstructural systems (roofing; exterior envelope; heating, ventillating, and air conditioning [HVAC]; emergency systems) can be as significant as the failure of structural components. Performance-based design provides a framework for considering the potential hazards that can affect a facility or site, and for explicitly evaluating the performance capability of the facility and its components.

Consideration must also be given to the likely possibility that at least a portion of the distribution systems for critical infrastructure services (e.g., electrical power, communications, potable water, and sanitary sewer) could be interrupted. The impact of such an interruption in service should be assessed for the facility, along with an estimate of the time it would take until service could be restored or supplemented. For protecting the continued operation of critical facilities, the most reliable approach is to provide alternative onsite sources for critical infrastructure needs in the form of: (1) emergency power generation capabilities; (2) local wireless communications; (3) potable water supplies; and (4) temporary onsite storage for sanitary waste.

While the practice of performance-based design is currently more advanced in the field of seismic design than the fields of flood and high-wind design, the theory of performance-based design is completely transferable to all hazards. The practice of performance-based design will prompt designers and owners of buildings in flood- or high-wind-prone regions to begin thinking in terms of a few basic objectives:

- Can the real probabilities and frequencies of high-wind and flood events during the useful life of the building be defined with an acceptable degree of accuracy?

- Can the extent and kinds of damage that can be tolerated be defined?

- Are there ways in which an acceptable level of performance can be achieved?

- Are there alternative levels of performance that can be achieved, and how much do they cost over the lifetime/ownership of the building compared to the benefits of reduced damage and improved performance?

- How do these levels compare to the performance levels of designs using the minimum requirements of the applicable building code?

1.3.5 PERFORMANCE-BASED FLOOD DESIGN

The performance levels and objectives for flood hazards, first outlined in FEMA 424 (2004), have been expanded and generalized for performance-based flood design of critical facilities as follows:

Level 1 (Operational): The facility sustains no structural or nonstructural damage, emergency operations are fully functional, and the building can be immediately operational. The site is not affected by erosion, but may have minor debris and sediment deposits.

Level 2 (Moderate Impact): The facility is affected by flooding above the lowest floor, but damage is minimal due to low depths and short duration of flooding. Cleanup, drying, and minor repairs are required, especially of surface materials and affected equipment, but the building can be back in service in a short period of time.

Level 3 (High Impact): The facility may sustain structural or nonstructural damage that requires repair or partial reconstruction, but the threat to life is minimal and occupant injuries should be few and minor. Water damage to the interior of the facility requires cleanup, drying, and repairs, and can prohibit occupancy of all or a portion of the facility for several weeks to several months.

Level 4 (Severe Impact): The facility is severely damaged and likely requires demolition or extensive structural repair. Threats to occupants are substantial, and warning plans should prompt evacuation prior to the onset of this level of flooding. Level 4 is applicable to facilities affected by all types of flooding, including those that result from failure of dams, levees, or floodwalls.

Planning and design to achieve an appropriate level of flood protection for critical facilities should include avoidance of flood hazard areas and adding a factor of safety (freeboard) to the anticipated flood elevation. Performance evaluation of a facility affected by flooding needs to include consideration of the building response to the following load conditions (fragility functions must be developed to relate calculated response to actual damage states):

- Lateral hydrostatic forces
- Vertical (buoyant) hydrostatic forces
- Hydrodynamic forces
- Surge forces
- Impact forces of flood-borne debris
- Breaking wave forces
- Localized scour

1.3.6 PERFORMANCE-BASED HIGH-WIND DESIGN

The performance objectives for wind hazards, outlined in FEMA 424, have been expanded and generalized for performance-based flood design of critical facilities as follows:

Level 1 (Operational): The facility is essentially undamaged and can be immediately operational.

Level 2 (Moderate Impact): The facility is damaged and needs some repairs, but can remain occupied and be functional after minor repairs to nonstructural components are complete.

Level 3 (High Impact): The facility may be structurally damaged but the threat to life is minimal and occupant injuries should be few and minor. However, damage to nonstructural components (e.g., roofing, building envelope, exterior-mounted equipment) is great, and the cost to repair the damage is significant. If rain accompanies the windstorm, or if rain occurs prior to execution of emergency repairs, water damage to the interior of the facility can prohibit occupancy of all or a portion of the facility for several weeks to several months.

Level 4 (Severe Impact): The facility is severely damaged and will probably need to be demolished. Significant collapse may have occurred, and there is a great likelihood of occupant casualties unless the facility has a specially designed occupant shelter. Level 4 is applicable to facilities struck by strong or violent hurricanes or tornadoes. For other types of windstorms, Level 4 should not be reached.

The challenge with respect to performance-based high-wind design is assessing the wind resistance of the building envelope and exterior-mounted equipment, and the corresponding damage susceptibility. This is challenging because of several factors:

- Analytical tools (i.e., calculations) are currently not available for many envelope systems and components, and there is a lack of realistic long-term wind resistance data.

- Because of the complexity of their wind load response, many envelope systems and components require laboratory testing, rather than analytical evaluation, in order to determine their load-carrying capacity.

- It is likely that finite element analysis will eventually augment or replace laboratory testing, but substantial research is necessary before finite element analysis becomes available for the broad range of existing building envelope systems.

- Before performance-based design for high winds can become a reality, a solid research base on the response of buildings and components to the effects of high winds must be established.

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