2.1 INTRODUCTION

This chapter introduces a performance-based design process that is recommended for adoption by a school district starting a program of school construction, addition, or repair. The principles of performance-based design can be applied to the design of a single school, of any size, or to a school construction plan for a large school district launching a major program.

Performance-based design seeks to augment current code approaches rather than replacing them. However, there is a significant drive to introduce performance-based codes and, particularly in the field of fire safety, performance-based codes are now used for many applications. In the natural hazards area, although performance-based design is well developed for seismic design, prescriptive approaches are still typical for floods and high winds. A sound multihazard design approach should provide an impetus to adopt a performance-based philosophy for design against risk.

2.2 DEFINITIONS OF PERFORMANCE-BASED DESIGN

Performance-based design is an evolving concept. The term as currently used has multiple definitions and three are presented below:

- ❍ A design approach that meets the life safety and building performance intents of the traditional code while providing designers and building officials with a more systematic way to evaluate alternative design options currently available in codes. In this regard, performance-based design facilitates innovation and makes it easier for designers to propose new building systems not covered by existing code provisions.

- A design approach that identifies and selects a performance level from several performance level options. Some provisions in the current version of the International Building Code (IBC) are sometimes called performance-based because they incorporate distinctions between performance goals for different building uses. These performance options are conceived to achieve higher-than-code-minimum design requirements.

- A design approach that provides designers with tools to achieve specific performance objectives such that the performance of a structure can be reliably predicted. In the hazards area, this approach has been highly developed for seismic design although considerable research is still necessary to ensure the requisite reliability and predictability that would allow a performance-based code to be possible.

2.3 THE PRESCRIPTIVE APPROACH TO CODES

The traditional approach used in building codes in the United States has been that of prescriptive-based codes. Prescriptive-based codes are quantitative and rely on fixed values that are prescribed by the codes and intended to achieve a reasonable level of fire and life safety as well as reasonable levels of safety from other hazards such as earthquakes, floods, and high winds. Prescriptive requirements are based on broad classifications of buildings and occupancies, and are typically stated in terms of fixed values such as travel distance, fire resistance ratings, allowable area and height, and structural design (e.g., dead loads, live loads, snow loads, rain loads, earthquake loads, wind loads, etc.).

Prescriptive codes provide limited rules for addressing various design and construction issues (e.g., establishing limits on the allowable area and height of a building, based upon construction type and occupancy classification). One of the current prescriptive building codes limits the basic area of a non-combustible, unprotected school building to 14,500 square feet. Why are this building and its occupants considered reasonably safe or acceptable at 14,500 square feet and unsafe or unacceptable at 15,000 square feet? This traditional approach is assumed to provide an "acceptable level of risk."

This is not to say that buildings designed and built under the prescriptive based codes are unsafe, but it is important to understand that the requirements in the prescriptive-based codes are judged to be only the minimum necessary to safeguard the public health, safety, and general welfare. In some instances, it may be desirable, appropriate, or even necessary to raise the level of safety above the prescribed minimums.

Under the prescriptive approach, all schools are essentially treated alike. Thus, the requirements for an elementary school with 500 students are the same as those for a high school with 500 students, although clearly there are differences in these buildings due to the age of the occupants and their ability to take proper and appropriate action under various emergency conditions.

Another issue involving school buildings is the use of the facility for purposes other than education. In many communities, school buildings are designated as emergency shelters to be used in the event of a natural or manmade disaster event. The "normal" prescriptive code approach does not address the building features and systems necessary for the continuity of service required for an emergency shelter (for security, flooding, high wind, or hazardous material release issues).

How can the issues such as these and others be addressed? An innovative procedure that is becoming increasingly adopted is the use of a performance-based approach to improve or supplement the prescriptive requirements.

2.4 THE PERFORMANCE-BASED APPROACH

Although having detailed requirements for "performance" is relatively new to the building and fire codes used in the United States, the concept is not. The various "prescriptive" building, fire, and life safety codes have all contained provisions for what was known as "alternative methods and materials" or "equivalencies." These code provisions allow for the use of methods, equipment, or materials not specified or prescribed in the code provided the alternative is approved by the code official. It is under these provisions of the traditional codes that the performance-based design approach can be undertaken.

Under the concept of an alternative method, material, or equivalency, the code official must approve the alternative or equivalency if it can be shown to be equivalent in quality, strength, effectiveness, fire resistance, durability, and safety. The proponent of the alternative method or equivalency is responsible for providing all necessary documentation to the code official. Based on the ability of the code official to permit alternate methods and materials in the existing prescriptive codes, performance-based codes simply offer the code official a system with which to accept alternative designs based on performance. In other words, this is nothing new to the code official, it is just a more formal way to review designs.

As mentioned previously, taking a "performance" approach is not new to building design because decisions based upon performance occur in all most every project. As an example, constructing corridor walls out of either gypsum board and steel studs or concrete masonry units (CMUs) will meet the prescriptive code requirements for a rated corridor in an educational occupancy. However, from a "performance" standpoint, the concrete masonry assembly is more desirable due to its ability to withstand the normal wear and tear of such occupancy. Another example would be the selection of the heating, ventilating, and air conditioning (HVAC) system. Although either rooftop units or central boilers/chillers might provide the requisite thermal performance, life-cycle cost analysis might support the choice of the central boiler/chiller.

Performance-based design provides a structured way of making decisions that is particularly applicable to the issue of life safety and damage reduction from natural and manmade hazards. From a designer's standpoint, the performance-based codes provide a more formalized system to develop, document, and submit alternative materials, methods, and equivalencies.

Unlike relying solely on a prescriptive code, performance-based design addresses an individual building's unique aspects or uses, and specific and "stakeholder" needs. "Stakeholders" include everyone who has an interest in the successful completion of a school project (i.e., the school board members, responsible officials, members of the design team, the builders, the community at large, parents, and the code enforcement officials). The design team is a sub-group of the "stakeholders," which includes individuals such as representatives of the architect, school district, and other pertinent consultants.

It is critical to the proper development, approval, and implementation of any performance-based design for all of the stakeholders to be actively involved in the process. Because the stakeholders establish the acceptable level of risk, it is crucial that all stakeholders be involved in the project from the earliest stages. It is also important that the stakeholders realize that an incident in a school facility can be measured in more ways than just monetary. The loss of a school facility for any reason can have organizational, legal, political, social, and psychological impacts.

The performance-based procedure provides the basis for the development and selection of design options, based upon the needs of the specific project, to augment the broad occupancy classification requirements. The approach structures a comparison of safety levels provided by various alternative designs, and also provides a mechanism for determining what level of safety, at what cost, is acceptable to the stakeholders. Performance-based design aims at property protection and life safety strategies in which the systems are integrated, rather than designed in isolation.

2.5 HAZARD, RISK, AND PROBABILITY

But what about “risk”? We often use the terms “hazard” and “risk” interchangeably. However, in the performance-based design environment, this substitution is incorrect. The definitions of these two words are distinctly different when assessing various challenges, and they must be used in the correct context when working with stakeholders, especially those not familiar with the terms.

No one should confuse “hazard” or “risk” with “safety.” “Safe” is a subjective condition that everyone views differently. Society establishes what it considers to be “safe” through a process of legal documents: both laws and court interpretations of them. Is a building that meets the prescriptive code requirements “safe?” Are you “safe” when you occupy a building that is entirely fire-resistant and protected by the latest in sprinklers and fire alarm technologies? “Hazard” and “risk” are recognized terms in the design, construction, engineering, architectural, and scientific worlds; “safe” is not.

The stakeholders must properly and thoroughly evaluate the risk or probability of a hazard event occurring in the performance designed facility. The basic questions they should ask are:

- What events are anticipated?
- What level of loss/damage/injury/death is acceptable?
- How often might this happen?

As they ask themselves these questions, and develop the variety of scenarios to which to apply them, the stakeholders must remember that obtaining consensus on acceptable levels of risk is essential to the successful outcome of the project.

Risk analysis incorporates the likelihood of a specific event and the severity of the outcome. This process combines both the severity and the probability of all relevant hazard loss scenarios. Remember that it is the intent of a performance-based code to establish the acceptable or tolerable level of risk. The overall analysis must consider not only the frequency of an events' occurrence, but the effectiveness and reliability of the entire building as a system. Risk analysis provides a quantitative measure of the risk. It also can establish the basis for evaluating acceptable losses and selecting appropriate designs.

Risk managers use two different evaluative methods in risk and hazard analysis: deterministic and probabilistic.

Deterministic analysis relies on the laws of physics and chemistry, or on correlations developed through experience or testing, to predict the outcome of a particular hazard scenario. In the deterministic approach, one or more possible designs can be developed that represent the worst possible credible events in a specific building. In this approach, the frequency of possible occurrences need not be evaluated.

Probabilistic analysis evaluates the statistical likelihood that a specific event will occur and what losses and consequences will result. This approach may use both statistics and historical information.

History from events involving similar buildings or equipment, building contents, or other items can be considered. The frequency of occurrences of a particular type of event is evaluated.

Any risk analysis method must anticipate a certain level of "uncertainty." Uncertainty describes those factors or circumstances that, if altered, affect the desired outcome.

Risk is the product of potential consequences and the expected frequency of occurrence. Consequences may include death, serious injury, or time lost from work, the extent of structural damage, monetary loss, interruption of use, or environmental impact. The occurrence frequency may be an estimate of how often the project loss might occur.

Risk binning is an alternative to the more classic risk analysis, and is considered to be much simpler. Instead of identifying and evaluating every possible hazard, it quantifies (measures) the consequences of the most severe events and matches them with an approximate event frequency. The concept is based on the idea that, if one prepares for the worst-case scenario, lesser damaging events will result in favorable outcomes.

For each type of event, the maximum consequence must be established. Consequences may include death or serious injury; or massive structural damage, absolute loss of production, severe environmental damage, or total business interruption. The consequences should represent the largest realistic event of each type.

The provisions of the International Code Council (ICC) *Performance Code for Buildings and Facilities (*2003 edition) describe this as the "magnitude of events." These range from small, medium, large, and very large. Table 2-1 shows the correlation between the "magnitude of events" and acceptable levels of damage

For seismic, flood, and wind events, the ICC *Performance Code for Buildings and Facilities* has established criteria for the various magnitude of events as shown in Table 2-1.

Table 2-1: ICC Performance Code Criteria for Seismic, Flood, and Wind Events

		Events		
		Seismic	Flood	Wind
Magnitude of Events	Very Large	2,475 years	Determined on a site-specific basis	125 years
	Large	475 years, but not to exceed 2/3 of the intensity of very large	Determined on a site-specific basis	100 years
	Medium	72 years	500 years	75 years
	Small	25 years	100 years	50 years

2.6 ACCEPTABLE RISK AND PERFORMANCE LEVELS

The performance-based design process begins with establishing the acceptable risk and appropriate performance levels for the building and its systems. The basic concept of acceptable risk is the maximum level of damage to the building that can be tolerated, related to a realistic risk event scenario or probability. For each hazard, there are methods of measuring the magnitude of events and their probability, as well as terminology to describe levels of damage or performance levels. There are four performance levels, each of which addresses structural damage, nonstructural systems, occupant hazards, overall extent of damage, and hazardous materials. The types of damage that are defined will vary according to the type of hazard that is being addressed. The ICC *Performance Code for Buildings and Facilities* formalized four design performance levels in terms of tolerable limits to the building, its contents, and its occupants that apply to all types of hazards. These levels are as follows:

Mild Impact. At the mild impact level, there is no structural damage and the building is safe to occupy; injuries are minimal in number and minor in nature; damage to the building and contents is minimal in extent and minor in cost; and minimal hazardous materials are released to the environment.

Moderate Impact. At the moderate level, there is moderate, repairable structural damage, and some delay in re-occupancy can be expected; injuries 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; and some hazardous materials are released to the environment, but the risk to the community is minimal.

High Impact. At the high impact level, it is expected that there will be significant damage to structural elements, but with no falling debris. Significant delays in re-occupancy can be expected. Nonstructural systems needed for normal building use are also 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. Hazardous materials are released to the environment with localized relocation required.

Severe Impact. With severe impact, there will be substantial structural damage, and repair may not be technically possible. The building is not safe for re-occupancy, because re-occupancy could cause collapse. Nonstructural systems for normal use may be completely nonfunctional, and emergency systems may be substantially damaged and nonfunctional. Injuries to occupants may be high in number and significant in nature. Significant hazards to life may exist. There is a high likelihood of single life loss and a moderate likelihood of multiple life loss. Significant hazardous materials may be released to the environment, with relocation needed beyond the immediate vicinity.

2.7 CORRELATION BETWEEN PERFORMANCE GROUPS AND TOLERATED LEVELS OF DAMAGE

The provisions of the ICC *Performance Code for Building and Facilities* correlate the performance groups and the tolerated levels of damage. Table 2-2 shows this relationship. Events are classified as small, medium, large, or very large. Each hazard will have its own definitions that modify these generic magnitudes.

Building groups in the ICC *Performance Code* include:

- Group I - Buildings that represent a low hazard to human life in the event of failure
- Group II - All buildings except Groups I, III, and IV
- Group III - Buildings with a substantial hazard to human life,

including schools or day care centers with a capacity greater than 250

- Group IV - Buildings designed as essential facilities, including designated earthquake, hurricane, or other emergency shelters

Table 2-2: Performance Groups and Tolerated Levels of Damage

		Increasing Level of Performance (Performance Groups)			
Building Groups		Group 1	Group II	Group III	Group IV
Magnitude of Events	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

Using an elementary school with an occupant load of less than 250 as an example (Group II), it can be seen that there is a significant difference in the level of performance required when the building is to be used as a designated emergency shelter (Group IV). These performance levels clearly are not addressed by the prescriptive code requirements.

For hazards such as earthquakes and winds, it may be desirable to set different performance objectives for nonstructural versus structural design. Although the prescriptive code may provide acceptable structural safety, it may be cost effective to spend a small additional amount of resources to enhance the attachment and bracing of key nonstructural components and provide for independent inspection of their installation. Local information on the characteristics of flood may suggest that it is prudent to allow an increased factor of safety above the expected flood elevation at the property. Similarly, local experience may suggest that projects should be designed for higher wind speeds than the code values.

The flow chart shown in Figure 2-1 summarizes a typical performance-based design process for a major design and construction program. It can be used as a checklist for a single construction project to structure early discussion between the stakeholders and the designers to establish the acceptable risk, performance goals, and objectives for the design.

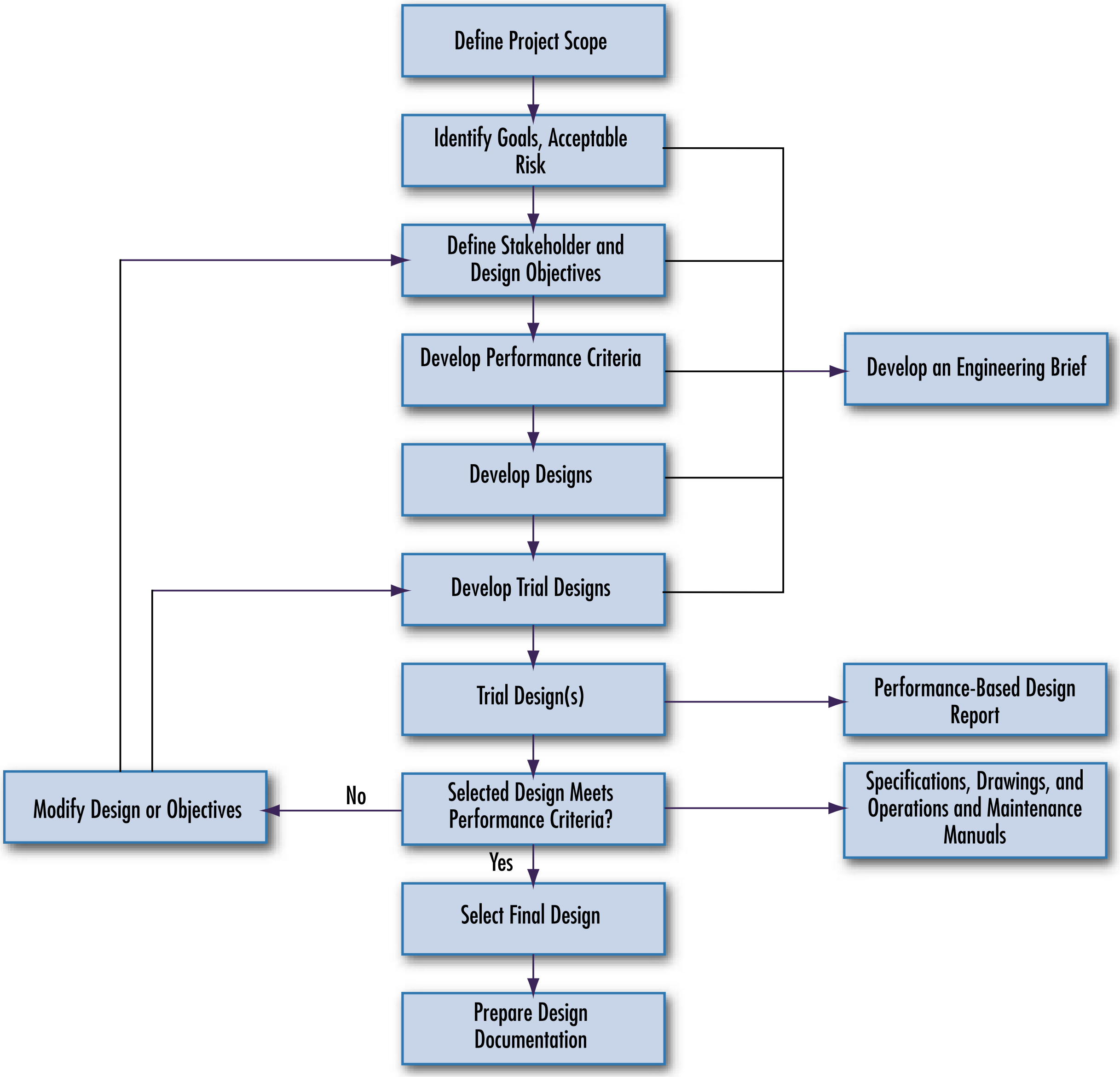

Figure 2-1 Performance-based design approach flow chart

SOURCE: BASED ON A CHART TAKEN FROM THE *SFPE GUIDE TO PERFORMANCE-BASED FIRE PROTECTION*, NFPA, QUINCY, MA, 2000

2.8 ROLES OF DESIGNERS, CODE OFFICIALS, AND THE SCHOOL DISTRICT

The school district is responsible for retaining the services of the design professionals and for the costs of any special services, including contract or third-party reviews and inspections required by the code official. The district must also retain all required documents and reports on the premises and is required to operate the building in accordance with the approved design throughout the life-cycle of the building.

The design professional is an individual who is registered or licensed to practice his or her respective design profession as defined by the statutory requirements of the professional registration laws of the state or jurisdiction in which the project is to be constructed. The design professional must possess the required knowledge and skills to perform design analysis and verification in accordance with the code requirements and applicable standards of practice. Design professionals may include architects, civil and structural engineers, mechanical engineers, and fire protection engineers, to name only a few.

The design professionals and special experts must be able to apply performance requirements; provide appropriate analysis, research, computations, and documentation; utilize authoritative documents and design guides; and review (inspect) the completed construction elements to verify compliance with the prescribed design.

All design documentation must be prepared by the design professional. Required documentation includes a concept report, a design report, and an operations and maintenance (O&M) manual. The design professional must coordinate all plans and documents for consistency, compatibility, and completeness, and submit them to the code official for review and approval.

The code official is required to perform a “knowledgeable” review of the proposed design and is permitted to use a third-party or peer review. When such third party or peer review is used, the cost for such services may be passed on to the submitter. After the plans and specifications have been reviewed and approved, a permit is issued for the start of construction. During the construction process, inspections and tests must be conducted in accordance with the design documents, code official procedures, and applicable codes. Upon completion, acceptance testing must be undertaken prior to occupancy.

After completion of the project and acceptance testing, the design professional must prepare and submit to the code official documentation that verifies that all performance and prescriptive code provisions have been met. The code official is permitted to require a third-party or peer review of this documentation. After completion of construction, final inspection, and testing and submission of all required documentation, the code official must issue the certificate of occupancy. A temporary certificate of occupancy may be issued for a limited timeframe with specified conditions, provided that all life safety items are accepted. The code official may also require that a temporary certificate be issued for a specific period of time and/or be "renewable" on a periodic basis.

The school district is responsible for proper maintenance and operation of the building, in accordance with the O&M manual, throughout the life of the building.

The school district is also responsible for periodically verifying compliance with the approved design at a frequency approved by the code official. Documents verifying that the building, facilities, premises, processes, and contents are in compliance with the approved design documents must be filed with the code official.

2.9 CHANGES TO A BUILDING DESIGNED FOR PERFORMANCE

When a building that was designed and constructed using a performance-based design is remodeled or altered, or its use changed, a design professional must evaluate the existing building and applicable documentation. Any change that results in an increase in hazard or risk must undergo a full review and evaluation of the design. The review and evaluation must be documented in a written report and submitted to the code official for review and approval. Such written review must be submitted to the code official even when the proposed changes do not exceed the original conditions.

One area of change that can occur is in one or more of the original bounding conditions. Bounding conditions by definition are conditions that, if exceeded, invalidate performance-based design. These could be maximum allowable conditions such as fuel load or type and arrangement of fuel load that must be maintained throughout the life of a building to ensure that design parameters are not exceeded.

Some examples of a change in bounding conditions are:

❍ The original design assumed that the gym would be used only for spectator sporting events. Such an arrangement would present a relatively low HVAC load. The desire is to now use the same gym for a science fair with the display of many project and other related materials. The new use represents a much higher HVAC load than originally intended and thus would represent a change in bounding condition.

❍ The building was originally designed for use as a high school. Characteristics of these occupants to respond to an emergency situation are a bounding condition. The desire is now to change the school to one on the elementary level. Because the ability of these occupants to respond to an emergency is different, this would represent a change in bounding conditions.

2.10 CURRENT PERFORMANCE-BASED CODES

Performance-based codes are not based on broad or generic classifications, but are qualitative. They establish, by a consensus process, acceptable or tolerable levels of hazard or risk for a variety of health, safety, and public welfare issues. Three model codes that are currently available are the ICC *Performance Code for Buildings and Facilities*, the National Fire Protection Association (NFPA) 101 *Life Safety Code,* and the NFPA 5000 *Building Code*. Any one or a combination of these documents would be appropriate for use in a performance-based design.

Although the ICC *Performance Code for Buildings and Facilities* addresses all types of building issues, the provisions of the NFPA 101 *Life Safety Code*, "Performance-based Option," address only those issues related to "life safety systems." The provisions of the NFPA 5000 *Building Code* apply not only to life safety issues, but to all traditional "building code" issues as well.

This design approach is based on a life safety evaluation, which is a written review dealing with the adequacy of life safety features relative to fire, storm, collapse, crowd behavior, and other related safety considerations.

The performance-based design must be prepared by a person with qualifications acceptable to the code official. The code official is permitted to require an approved, independent third-party review of the proposed design and provide an evaluation of the design to the code official. All data sources are required to be identified and documented. The code official is empowered to make the final determination as to whether the performance objectives are met.

Design specifications and other conditions used in the performance-based design must be both clearly stated and shown to be realistic and sustainable. The characteristics of the building or its contents, equipment, or operations that are not inherent in the design specifications, but that can affect occupant behavior or the rate of hazard development, are required to be explicitly identified. The anticipated or expected performance of a fire protection system and building features must also be documented.

In addition, the selection of the occupant characteristics must be approved by the code official and must reflect the expected population of building users. Response characteristics of the occupants should include their sensibility (sensory awareness), reactivity, mobility, and susceptibility. Sources of data for these characteristics must be documented. It must also be assumed that, in every normally occupied room or area, at least one person will be located at the most remote point from the exits. The design must also reflect the maximum number of people that every occupied room or area is expected to contain.

In those instances where the ability of trained employees (occupants) is part of the overall performance design concept, the number of employees, and their training and abilities should be identified and documented.

2.11 THE O&M MANUAL AND THE OCCUPANTS' HANDBOOK

The last critical component of the performance-based design process is the O&M manual. The design professional is responsible for developing this important document, which can be described as an owners manual for the building and all of its systems. This document should clearly establish the requirement that the school official must ensure that all components of the performance-based design are in place, operational, and properly maintained for the entire life-cycle of the building.

The ICC *Performance Code for Buildings and Facilities*, the NFPA 101 *Life Safety Code,* and the NFPA 5000 *Building Code* all provide for the continued use and maintenance of a performance-based design facility. Each building or facility designed and constructed using a performance-based design relies on certain conditions remaining stable throughout the life of the building.

The O&M manual documents agreements with stakeholders and clearly states that the building owner must ensure that the components of the performance-based design remain in place and in proper operating condition. The manual provides instructions that place restrictions on the building operations, and communicates to the building tenants and occupants the limits of building use and their responsibilities. It also provides a guide to renovation and documents what actions are to be taken if a fire protection system is impaired or removed. The importance of the O&M manual cannot be understated. It is the glue that holds the on-going use of the building together.

The O&M manual must be submitted with the final design documents, and all of the stakeholders must agree on its contents. The manual should contain the requirements for the testing, inspection, and maintenance of all systems; outline restrictions on building operations; and provide guidelines on how to address any changes in occupancy or use.

This manual also must be made part of the legal documents of the property so that they are transferred with any change in ownership. The O&M manual should include:

- Descriptions of the commissioning requirements of all fire protection systems
- Identification of all subsystems
- Descriptions of all inspections, testing, and maintenance procedures and schedules
- Information on emergency electrical power systems
- Details on building operations (e.g., critical fuels loads, sprinkler design requirements, building use and occupancy, reliability and maintenance of fire protection systems)
- Details of the maintenance plans for critical design components
- Qualifications of inspection personnel or inspectors
- Fee schedules for unique or third party inspections required by the code official and provisions of changes to the fee schedules
- Requirements to be followed if any fire protection system is impaired or out of service

- Testing criteria for initial acceptance, including pass/fail criteria, inspection/testing schedules, periodic testing criteria, and recordkeeping requirements

In addition, the manual should spell out any requirements or restrictions, such as storage height, commodity type, or fire protection system modifications.

The O&M manual should also contain the occupants' handbook. In the case of school occupancies, this is the portion of the O&M manual that would be provided to the faculty and support staff. Less technical than the O&M manual and similar to the handbook that comes with a new automobile, this publication informs all occupants of the specific building about the design features of the building and its equipment, as well as the occupants' responsibilities. It also serves as a guide for renovations and changes to workspaces. In addition, the occupants' handbook should provide details for the development and submittal of modifications for review and approval by the Authority Having Jurisdiction (AHJ), building owner, insurance carrier, or other appropriate stakeholders.

2.12 PERFORMANCE-BASED DESIGN FOR NATURAL HAZARDS

As noted in Section 2.4, a performance-based approach to building design is not new, because decisions based on performance occur frequently in almost any project. What is new is the attempt to formalize a decision-making process related to expected performance and, ultimately to develop performance-based codes to regulate building design and construction.

In the natural hazards area, "performance" is used to signify a level of damage or load. This, in itself, represents a major change in perception, because the building owner or occupant generally believes that adherence to building codes provides a safe environment and anticipated degrees of damage are not a normal source of conversation between an architect and owner, or even an architect and his engineer. Earthquake experience in recent years has forced recognition that damage (sometimes severe) will occur in a building designed in accord with the code.

The theory and practice of performance-based design currently is most advanced in seismic design and virtually non-existent in design for floods and high winds. Advanced seismic engineering practitioners have, for some time, recognized several performance objectives in relation to owner's needs, and have used them as a basis for establishing design parameters. These objectives, or performance levels, can be simply stated as follows:

- **Level 1:** The building is essentially undamaged and can be immediately operational.
- **Level 2:** The building is damaged, and needs some repairs, but can remain occupied and be functional after minor repairs (of a nonstructural nature) are complete.
- **Level 3:** The building is both structurally and nonstructurally damaged, but the threat to life is minimal and occupant injuries should be minor and few.
- **Level 4:** The building is severely damaged and will probably have to be demolished; it has not collapsed, although there is some likelihood of occupant injury.

In this spectrum, the code conforming building is fairly far down the scale (at Level 3) and many private and public owners are prepared to pay more to achieve a higher level of performance. A hospital should achieve at least Level 2, and preferably Level 1. A high-tech manufacturing plant might desire to achieve the same level, because of the high value of its contents and the business losses if the plant must shut down production. The owner of a warehouse that houses a modest and easily replaced commercial inventory, with very few occasional occupants, might opt for the economies of Level 4.

In the last decade or so, this informal pragmatic approach to performance-based seismic design has become formalized; the performance levels have been named and carefully defined. Detailed observation of damaged buildings, together with advances in materials science, experimental research, and analytical methods, have led to much more sophisticated understanding of building response and have enabled engineers predict more reliably how a structure will behave under various levels of shaking. This prediction is still far from a guarantee, but it has a scientific and engineering basis that was non-existent even 2 decades ago. Meanwhile, extensive studies of all aspects of performance-based seismic design are underway around the country, largely sponsored by FEMA and the National Science Foundation.

The same degree of research and development activity does not, however, apply to design for floods and high winds. One reason is that these fields have not had the same sophisticated (and fairly expensive) research support that the seismic community has enjoyed. Before performance-based design for floods and winds can become a reality, a solid research base must be established. The kind of research would be different from that of seismic engineering; the engineering problems are much simpler, but research into simulating the probabilities and effects of floods and winds could yield rich rewards. The objective is to reduce the uncertainties associated with these hazards, thus avoiding wasted money and resources. Wind design could benefit from materials and component research to improve exterior envelope design and construction: at present, many of the available protective methods are labor intensive in the most primitive way, often using only hammers, nails, and stapling guns.

If design for performance against floods and high winds is to approach the sophistication of seismic performance-based design, a new approach to thinking about buildings subjected to floods and winds is necessary, paralleling the new thinking that has occurred around buildings subjected to earthquakes. When engineers began to think about buildings from the owners' viewpoint, and the different ways in which buildings were occupied, it became clear that a seismic code that focused only on methods and technical design criteria instead of results was not responding to owners' (and society's) needs. Performance-based seismic design is still in its infancy, and much research needs to be done, but the essential shift in thinking has occurred.

Performance-based design is not proposed as an immediate substitute for design to traditional codes. Rather, it is seen as an opportunity for enhancement and the tailoring of the design to match the objectives of the community. Design to the code remains as the minimum baseline to ensure safety for school occupants, but the special importance to our society of protecting the school population suggests that design to a generic code minimum is not sufficient.

To achieve a building code that regulates performance rather than easily inspected design construction methods will not be easy, but ultimately one can expect to see a rational mix of performance and prescription in the regulatory mix. That shift took place in advanced industries (e.g., airplane design) a few decades ago, and airplanes are now habitually designed to stringent performance requirements, specified by the military or the airline companies.

Designers and owners of buildings in flood or high wind-prone regions need to begin to think in terms of a few basic objectives:

- Can the real probabilities and frequencies of events during the useful life of the building be defined with a useful degree of accuracy?
- Can the extent and kinds of damage (if any) that can be tolerated be defined?
- Are there ways (if any) in which this acceptable level 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?
- Are these levels below, at, or above design to code enforced criteria?

Serious thought about these basic issues by all the stakeholders is the beginning of design for performance.

2.12.1 Performance-based Seismic Design

As discussed in Section 2-12, procedures for the application of performance-based design seismic design are well advanced. However the procedures are still evolving and issues such as terminology, analytical methods, and achieving reliable performance prediction are still subject of much research and development. This section outlines the general approaches that are current in performance-based seismic design; considerable refinement of the approaches and procedures that are outlined herein are expected to occur in the next few years.

Determining Acceptable Risk. The performance-based design procedure starts with the definition of acceptable risk. Prior to inception of design work for a new or retrofitted school building, discussions should be initiated between the design team, the school district, and community representatives to explain the level of seismic performance that will be achieved by conformance to the code, and other possible performance options that may be available. In these discussions, “seismic performance” refers to the extent of damage and loss that is likely to occur in earthquakes of differing magnitudes. These discussions focus on ensuring that all parties understand that “earthquake" or damage-free performance is not possible, and compromises must be made between seismic performance, cost, and design for learning. “Acceptable risk” refers to the extent and types of damage and loss that the school officials and community can tolerate. Clearly, avoidance of casualties is of the highest priority, but what are the priorities for issues such as damage to the building’s structure, nonstructural components, and systems and contents?

The discussion of acceptable risk begins with determining the answer to the following question: If the building is designed strictly to the minimum code requirements, are the damage and loss that might occur in the design level earthquake acceptable? If the answer to this question is positive, an implicit level of acceptable risk has been set and design can proceed. If the answer is negative or undecided, the following should be addressed:

- What lesser extent and types of damage can be accepted?
- What are the implications for long-term costs and benefits over the life of the school building?
- Is the desired performance level affordable within the first-cost resources of the district (minimum code requirements must always be provided)?

Issues of uncertainty must also be made clear. It should be noted that the degree of uncertainty in predicting performance will be dependent on the existing school design in addition to the application of code requirements. The design team for a new building has control over this issue; however, for a retrofit, some of the existing school characteristics may be less than desirable.

A new design in which key parameters of good seismic design are provided (i.e., continuous load path, structural redundancy, symmetry in plan and section, short spans, and well designed nonstructural connections and bracing) will be more economical and more predictable in performance than a design in which these characteristics are not present. (The simple concept design shown in the How Buildings Resist Earthquakes illustration in Section 4.6.1 represents an “optima” seismic design that incorporates these features.)

Discussions of these issues should lead to a formal conclusion on performance objectives that then serve as a target for the designers, but it is the school district representatives who must make the final performance objective decision. The implications of this decision must be fully understood and it is the responsibility of the design team to provide necessary information, to the extent that it is available.

Traditionally, the architect has been the source of all design information for the school authorities but, due to the technical sophistication of performance-based design, the structural engineer will probably be consulted. On large projects, the key consultants may be involved in early meetings, particularly when the school district is represented by a facilities manager or other technical staff. In these instances, the district's professional staff may be expected to be able to discuss the project on equal terms with the design team. Whether all parties are familiar with the language of performance-based seismic design may have significant impact on the extent to which seismic performance issues can be a subject for useful discussion and decision-making.

If community representatives or committees, whose technical expertise may be more limited, are involved, the design team should try to ensure that the issues are understood.

For most school districts and communities, the discussion of acceptable risk will be an entirely new kind of discussion and the language of seismic performance may be unfamiliar. Historically, it has not been common practice to initiate a discussion of damage tolerance for a new project. The seismic expectations checklist in Table 2-3 provides a basis for these discussions. The checklist takes the form of a matrix of design expectations that can assist design team members, the school district, and the community to agree on seismic performance goals that are reasonably in line with the available resources. Agreement on such goals and expectations can help achieve a desired level of performance and limit later surprises due to unexpected earthquake damage. Such performance objectives statements might properly be part of a project's building program and serve as the basis for a performance-based design procedure.

The checklist can be completed or used merely as a basis of discussion. The intent is for the school district to arrive at a seismic performance objective that is understood and approved, both as to its opportunities and its limitations.

Table 2-3: Seismic Expectations Checklist

Earthquake Performance of Structural Systems				
Damage				
Earthquake Magnitude	Severe: No life threat or collapse	High: repairable damage; building not usable	Moderate: repairable damage; building usable	Mild: no significant damage
Low-Moderate				
Moderate-Large				
Large				
Earthquake Performance of Nonstructural Components and Systems				
Damage				
Earthquake Magnitude	Severe: No life threat or system failures	High: Repairable damage; building not usable	Moderate: Repairable damage; building usable	Mild: No significant damage
Low-Moderate				
Moderate-Large				
Large				
Functional Disruption: Structural and Nonstructural				
Time to Reoccupy				
Earthquake Magnitude	6 months plus	up to 3 months	up to 2 weeks	Immediate
Low-Moderate				
Moderate-Large				
Large				

Notes: Earthquakes:

Low-Moderate: up to Magnitude 6.5 on the Richter scale
Moderate-Large: Magnitude 6.5 - 7.5 on the Richter scale
Large: Magnitude 7.5 plus on the Richter scale

SOURCE: (MODIFIED) ERIC ELSESSER: *BUILDINGS AT RISK*, AIA/ACSA COUNCIL ON ARCHITECTURAL RESEARCH, WASHINGTON, DC, 1992

The above classifications may be modified by poor soil conditions or specific seismological forecasts. Note that this table adds a short description to the four damage level categories identified in the ICC *Performance Code for Buildings and Facilities* outlined in Section 2.12.

Table 2-4 shows the expected overall and nonstructural damage for the four building performance levels defined in FEMA 273, *NEHRP Guidelines for the Seismic Rehabilitation of Buildings.* These performance levels are developed versions of the four general performance levels described on page 2-20. The bottom row relates the damage levels to those expected for a building designed to a conventional code. FEMA 273 contains six such tables that show expected damage to vertical and horizontal structural elements; architectural, mechanical, electrical, and plumbing components; and building contents. These expectations refer to a building designed using the appropriate analytical tools available in FEMA 273, which provides the necessary methods of analysis and detailing to achieve these performance levels for high, moderate, and low earthquake intensity regions. Some of the terminology in these tables may be expected to change as a result of studies now underway.

Table 2-4: Damage Control and Building Performance Levels

	Building Performance Levels			
	Collapse Prevention Level	**Life Safety Level**	**Immediate Occupancy Level**	**Operational Level**
Overall Damage	**Level 4 (Severe)**	**Level 3 (Moderate)**	**Level 2 (Light)**	**Level 1 (Very Light)**
General	Little residual stiffness and strength, but load bearing columns and walls function. Large permanent drifts. Some exits blocked. Infills and unbraced parapets failed or at incipient failure. Building is near collapse.	Some residual strength and stiffness left in all stories. Gravity-load bearing elements function. No out-of-plane failure of walls or tipping of parapets. Some permanent drift. Damage to partitions. Building may be beyond economical repair.	No permanent drift. Structure substantially retains original strength and stiffness. Minor cracking of facades, partitions, and ceilings as well as structural elements. Elevators can be restarted. Fire protection operable.	No permanent drift. Structure substantially retains original strength and stiffness. Minor cracking of facades, partitions, and ceilings as well as structural elements. All systems important to normal operation are functional.
Nonstructural components	Extensive damage.	Falling hazards mitigated, but many architectural, mechanical, and electrical systems are damaged.	Equipment and contents are generally secure, but may not operate due to mechanical failure or lack of utilities.	Negligible damage occurs. Power and other utilities are available, possibly from standby sources.
Comparison with performance intended for buildings designed, under the *NEHRP Provisions,* for the Design Earthquake	Significantly more damage and greater risk.	Somewhat more damage and slightly higher risk.	Much less damage and lower risk.	Much less damage and lower risk.

SOURCE: *NEHRP GUIDELINES FOR THE SEISMIC REHABILITATION OF BUILDINGS* (FEMA 273)

Reducing Seismic Risk Through Performance-based Design. The general principles of performance-based design are discussed in earlier sections of this chapter. For seismic risk reduction, performance-based design starts with the recognition that some damage will be incurred in a severe earthquake even in a well designed and constructed building. Prior to the seismic design, the school districts and the design team reach agreement on the desired seismic performance of the building (i.e., the extent and type of damage that the school district can tolerate). The extent of this damage can be reduced by seismic design measures based on more precise analysis of the earthquake forces that the building will encounter, rather than relying on the simplified analytical methods of the current seismic code.

These more precisely estimated forces may, in some instances, be less than the forces determined by a simple code analysis because less allowance will need to be made for uncertainty in the calculations, and the seismic design and construction cost may be reduced. Increased protection beyond the minimum code expectations, however, will almost inevitably add to the initial cost of the building. The trade-off that the school district must consider is that damage reduction will probably result in design and construction cost increases.

The value to the district of increased investment in seismic protective design and construction is dependent on the likelihood of damaging earthquakes, and some economic analysis can assist in arriving at an affordable solution with satisfactory safety and damage control characteristics. This implies that the cost of protection must be evaluated over the life of the building, rather than only as an item of the initial building cost. As with design to the current code, performance-based design starts with the assumption that the basic purpose of seismic design is to protect the building occupants from collapse and damage that may be life-threatening.

The performance-based design procedure uses inputs from the information evaluations previously described to develop designs that balance the desired performance levels with the available resources.

2.12.2 Performance-based Flood Design

The performance objectives (or performance levels) for flood hazards can be stated as follows:

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

Level 2: The school building is affected by flooding above the lowest floor, but damage is minimal due to shallow depths and short duration. 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. Site improvements such as bleachers and fences are damaged, and athletic fields are damaged by erosion and deposition of sediment and debris.

Level 3: The school building may sustain structural damage that requires extensive repair and partial reconstruction. If the school is used as a shelter, threats to occupants are minimal. Nonstructural damage to equipment and finish materials requires cleanup, drying, and repairs. Site improvements such as bleachers and fences are damaged, and athletic fields are damaged by erosion and deposition of sediment and debris.

Level 4: The school building 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. (Note: Level 4 is applicable to schools affected by flooding due to failure of dams, levees, or floodwalls.)

In addressing the question "what level of loss/damage/injury/death is acceptable?", an assessment of the probable magnitude and frequency of flood events during the life of a school is relatively straightforward. With the exception of floods caused by or exacerbated by failure of dams and levees, an examination of available information regarding mapped flood hazard areas, predicted flood elevations, and historic floods should identify an adequate estimation of the flooding that may affect a school site. It is reasonable to exceed the minimum design flood elevation and loads for essential and critical facilities, including schools.

Flooding of buildings rarely results in loss of life and injuries, although that is a likely consequence of extreme and unpredictable flooding caused by events such as dam or levee failures. Beyond identification of the normal design flood magnitude, further examination is required to identify those contributory hazards. State water resources agencies can identify the high hazard dams and significant hazard dams that are present in the watershed and the failure scenarios that may result in catastrophic consequences. Similarly, local agencies or authorities that maintain and operate levee and floodwall systems can characterize failure scenarios for protected areas. Schools located in areas threatened by these very low probability, high consequence events should have emergency response plans that are closely coordinated with the appropriate emergency management authorities.

Chapter 5 identifies a number of recommendations to exceed minimum flood-resistant requirements to achieve an appropriate level of protection for essential and critical facilities, primarily avoidance of flood hazard areas and adding a factor of safety to the elevation requirement. Consideration of these recommendations is in the spirit of performance-based design. To some degree, the benefits can be quantified: the National Flood Insurance Program’s (NFIP's) statistics on building that exceed the minimum requirements indicate lower damage. It is notable, however, that there is insufficient experience with nonresidential buildings that are exposed to extreme flooding to quantify the benefits.

2.12.3 Performance-based High Wind and Tornado Design

The performance objectives (or performance levels) for the wind hazard can be stated as follows:

Level 1: The school building is essentially undamaged and can be immediately operational.

Level 2: The school building is damaged, and needs some repairs, but can remain occupied and be functional after minor repairs (of a nonstructural nature) are complete.

Level 3: The school building may be structurally damaged, but the threat to life is minimal and occupant injuries should be minor and few. However, nonstructural damage (i.e., the building envelope or rooftop 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 school can prohibit occupancy of all or a portion of the school from several weeks to several months.

Level 4: The school building is severely damaged and will probably have to be demolished. Significant collapsing may have occurred, and there is great likelihood of occupant deaths and many injuries unless the school has a specially designed occupant shelter. (Level 4 is applicable to schools struck by strong or violent tornadoes. For other types of windstorms, Level 4 should not be reached.)

For the wind hazard, loss of life and injuries due to collapsing building components or wind-borne debris is quite rare. Except for strong and severe tornadoes, the major threat posed by high winds is damage to the school itself, which can be very costly to repair and may prohibit use of the school for a considerable period of time.

In addressing the question “what level of loss/damage/injury/death is acceptable?”, an assessment of the probable magnitude and frequency of wind events during the life of a school is relatively straight forward. With the exception of strong and violent tornadoes, complying with the design procedure in ASCE 7 should typically result in adequate estimation of the wind loads that a school will experience. (For strong and violent tornadoes, wind and wind-borne debris loads derived from FEMA 361 should typically provide an adequate estimation.) However, the great challenge with performance-based wind design is the assessment of the wind resistance of the building envelope and rooftop equipment and the corresponding damage susceptibility.

Assessment of the true performance of the building envelope and rooftop equipment is challenging because of several unrelated factors:

- ❍ Analytical tools (i.e., calculations) are currently not available for many envelope systems and components. 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. Unfortunately, current test methods typically have many limitations. For example, test assemblies normally test unaged materials. Hence, the test may adequately indicate how the system will perform during the first few years of its life, but it may not indicate how the system will perform after being exposed to sunlight (which may result in heat and/or ultraviolet radiation induced degradation), water (which may degrade the system via corrosion or dry rot), or repeated modest wind events (which may induce fatigue failure). Also, tests are typically static (i.e., uniform pressure distribution), rather than dynamic (i.e., cyclically-induced loading). In addition, test assemblies are not typically subjected to wind-driven water while simultaneously being subjected to design-level wind pressures.

  It is likely that finite element analysis (FEA) will eventually augment or replace laboratory testing, but substantial research is necessary before FEA becomes available for the numerous building envelope systems from which architects are able to choose.

- Architects have traditionally given little attention to wind resistance of building envelopes, and mechanical engineers have given little attention to wind resistance of rooftop equipment. For those architects and engineers that try to give attention to envelopes and rooftop equipment, their task is hampered by lack of comprehensive design guides, lack of analytical tools and lack of realistic long-term wind resistance data as discussed above.

- Building envelopes are often constructed by several different trades. For example, an exterior non-load bearing wall may be framed by one subcontractor, another subcontractor may install the insulation and wall covering and another subcontractor may install the windows. It is challenging to successfully integrate these various subsystems so that wind-driven water infiltration is inhibited and load-path continuity is maintained.

- Because the building envelope is exposed to weather, it is natural for various envelope components to lose strength over time. If naturally-deteriorated components are not replaced before they become overly weak, they can be damaged during storms that are well below design wind speed conditions. Although appropriate maintenance and repair criteria may be included in the O&M manual, it is often difficult to determine if serious corrosion, dry rot, or termite attack has occurred in concealed portions of the envelope.

- Modifications may inadvertently weaken the resistance of the building envelope. For example, if a roof system incorporates an air retarder, and a future penetration (such as an exhaust fan) through the roof does not maintain the continuity of the air retarder at the penetration, the roof system could receive a sufficiently high unexpected load to result in roof covering damage. In this example, even though maintaining air retarder continuity should be included in the O&M manual, compliance with this O&M requirement could easily be overlooked.

Because of the great uncertainty of the true resistances of the building envelope and rooftop equipment on a given school, the level of wind and subsequent water infiltration damage that could be reasonably expected to result from a design-level windstorm at some future time is difficult to quantify at this time. With development of comprehensive wind design guidelines for building envelope systems and rooftop equipment, development of greatly enhanced test and analytical methods, and greater awareness on the part of designers and construction trades on basic design and installation techniques to inhibit water infiltration and practices necessary to achieve load-path continuity, the magnitude of the uncertainty can be decreased. However, significant research funding is needed in order to reduce the uncertainties associated with the wind and water resistance of building envelopes and rooftop equipment.

Except for strong and violent tornadoes, schools designed and constructed with one of the current model building codes (and adequately maintained and repaired), typically present a low risk of casualties and injuries. However, some existing schools may present higher risk. For example, a glass curtain wall at a cafeteria, or tall unreinforced and inadequately braced CMU wall at a gym may be blown in or out during a strong thunderstorm. If students or faculty are nearby, they could be injured or killed. Or, a roof could blow off and injure students that are on their way to the buses. There is also increased risk of casualties and injuries to people seeking refuge in a school during a hurricane if the school was not originally designed for this purpose.

By considering the recommendations provided in Chapter 6, and implementing those that are appropriate for a given school, the spirit of performance-based design can be achieved, with respect to both casualties/injuries and building damage/interrupted use, for new construction, as well as existing schools. However, because of the limitations discussed above, it is not possible at this time to quantify the actual performance that the various enhancement recommendations will offer. In some cases, the recommendations may be overly conservative and, in others, they may be non-conservative. The recommendations will result in enhanced performance, but additional research is needed to quantify the magnitude of the enhancement.