



Performance Based Design

An Online Continuing Education Course for Engineers

Course Number: S-1001

Credit: 1 Hour / 1 PDH / 1 CPD

Performance Based Design for Buildings and Critical Structures

Introduction

The model building codes define the minimum design requirements to ensure the safety of occupants during specific design events. Recent natural disasters have prompted recognition that significant damage can occur even when buildings are compliant with the building code. Many critical facilities, such as school buildings, are closed after natural disasters, even if damage is relatively minor, suggesting that satisfying the minimum code criteria may not be sufficient to ensure continued functionality. Communities also depend on school buildings and other critical facilities to provide reliable shelter and critical services. In order to meet that need, school buildings should be designed and constructed according to criteria that result in continued and uninterrupted functionality.

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Building performance is an indicator of how well a structure supports the defined needs of its users. Acceptable performance indicates acceptable (or tolerable) levels of damage or condition that allow uninterrupted facility operation. Consequently, performance-based design is the process or methodology used by design professionals to create buildings that protect functionality and the continued availability of services.

The performance-based design approach is not proposed as an immediate substitute for design to traditional codes. Rather, it can be viewed as an opportunity to enhance and tailor the design to match the objectives of the project's stakeholders.

Performance-based codes define acceptable or tolerable levels of risk for a variety of health, safety, and public welfare issues. Currently, codes include the *International Code Council Performance Code for Buildings and Facilities* (ICC PC) produced by the International Code Council (ICC, 2009), and the *NFPA 5000®. Building Construction and Safety Code* (NFPA, 2009) and *NFPA 101®: Life Safety Code* (NFPA, 2008) produced by the National Fire Protection Association (NFPA). The ICC PC addresses all types of building issues, while the provisions of *NFPA 101®*, “Performance Based Option,” address only issues related to “life safety systems.” *NFPA 5000®* sets forth both performance and prescriptive options for design and construction.

The various prescriptive building, fire, and life safety codes all contain provisions for what is known as “alternative methods and materials” or “equivalency.” These 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. A performance-based design approach can be employed under these provisions. While the “alternative methods and materials” clause of the prescriptive codes allows the use of performance-based design procedures, the 2010 edition of the American Society of Civil Engineers (ASCE) Standard 7, *Minimum Design Loads for Buildings and Other Structures*, addresses performance-based design when the standard is used directly, without reference from a building code.

Within ASCE 7-10, “Performance-based Procedures” represent one of three approaches for design. Under the performance-based approach, both structural and nonstructural components and their connections must be shown to provide a reliability not less than that expected under the approach referred to as the “strength procedures.” A combination of testing and analysis can be used to demonstrate the achievement of target reliability that is described in the Commentary that accompanies ASCE 7. Factors that affect target reliability include Risk Category (or Occupancy Category), extent of structural failure, and whether loading conditions include or exclude earthquake.

In 2006, FEMA published FEMA 445, *Next-Generation Performance-Based Seismic Design Guidelines. Program Plan for New and Existing Buildings*. This document includes guidance for developing detailed modeling, simulation of building response to extreme loading, and estimates of potential casualties, loss of occupancy, and economic losses. The outlined 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. Although the process outlined in FEMA 445 is applied to seismic hazards, it can be generalized for application to other hazards.

Prescriptive vs. Performance-Based Design

Design and construction in the United States is generally regulated by building codes and standards. Building codes are intended to ensure the health, safety, and well-being of people in buildings by establishing minimum requirements to address structural strength, adequate means of egress, sanitary equipment, light and ventilation, and fire safety. Building codes may also promote other objectives, such as energy efficiency, serviceability, quality or value, and accessibility for persons with disabilities. These prescriptive standards are easy for architects and engineers to understand, and easy for community inspectors to monitor. This ease of use is their great strength.

Historically, building codes have been based on a prescriptive approach that limits the available solutions for compliance. Prescriptive or specification-based design emphasizes 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 building’s primary users and stakeholders.

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.

The ICC PC defines performance-based design as “An engineering approach to design elements of a building based on agreed upon performance goals and objectives, engineering analysis and quantitative assessment of alternatives against the design goals and objectives using accepted engineering tools, methodologies and performance criteria.”

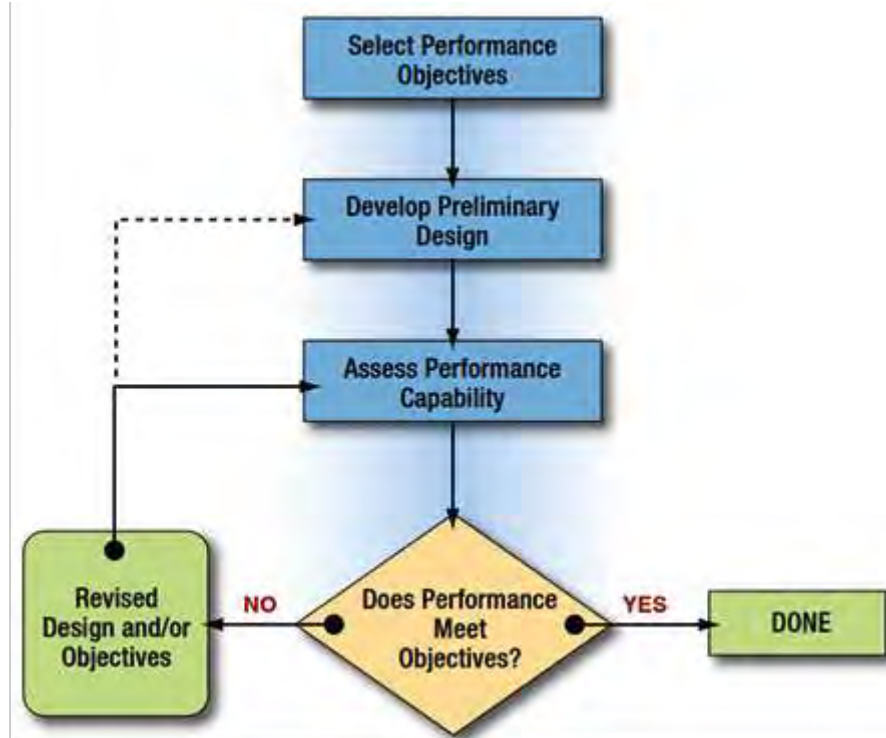
The Performance-Based Design Process

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 the frequency and magnitude of potential events and assessing the actual responses of building systems and the potential effects of the performance of these systems on the functionality of buildings. 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 presents the key steps in this iterative 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, especially for critical facilities.

Figure 1: Performance-based design flow diagram

SOURCE: HAMBURGER, 2003



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.

Acceptable Risk and Performance Levels

Hazard. A source of potential danger or adverse conditions. Natural hazards include events such as floods, earthquakes, tornadoes, tsunamis, coastal storms, landslides, and wildfires.

Risk. The estimated impact that a hazard event would have on people, services, facilities, and structures in a community, or the likelihood of a hazard event resulting in an adverse condition that causes injury or damage.

The performance-based design process begins with establishing the acceptable risk and appropriate performance levels for the building and its systems. Acceptable risk is the maximum level of damage to the building that can be tolerated from a realistic risk event scenario or probability. The ICC PC formalizes four performance levels in terms of tolerable levels of damage to the building, its contents, and its occupants that apply to all types of hazards. Types of damage vary according to the hazard. The four performance 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. Nonstructural systems needed for normal use and emergency operations are fully functional. Damage to contents is minimal in extent and minor in nature. Significant amounts of hazardous materials are released to the environment.
- **Moderate Impact.** At the moderate impact level, there is some structural damage, and some delay in re-occupancy is expected. Significant structural components are needed for building use are fully operational. Emergency systems are required. Emergency systems remain functional, but are generally damaged. Injuries to occupants are moderate in number and significant in nature. The likelihood of multiple life loss is low and the likelihood of single life loss is moderate. Significant amounts of hazardous materials are released to the environment.
- **High Impact.** At the high impact level, there is significant structural damage, but no structural elements are needed for building use. Delays in re-occupancy are significant. Emergency systems may be significantly damaged and inoperable. Injuries to occupants are significant with a high likelihood of multiple life loss. The likelihood of single life loss is high and the likelihood of multiple life loss is moderate. Significant amounts of hazardous materials are released to the environment.
- **Severe Impact.** At the severe impact level, there is significant structural damage and the building is not safe for re-occupancy. Significant structural components are needed for building use are inoperable, and emergency systems may be substantially damaged and inoperable. Injuries to occupants may be high in number and significant in nature. Significant hazards to life may exist. The likelihood of single life loss is high and the likelihood of multiple life loss is moderate. Significant amounts of hazardous materials may be released to the environment and relocation beyond the immediate vicinity is required.

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The 2012 edition of the ICC PC uses the same system to classify performance groups that is used in ASCE 7-05 to classify structures. The groups are based on use or occupancy and each has different requirements. For example, prior to the 2010 edition, the ASCE 7 classification of structures included schools in Occupancy Category III and Occupancy Category IV, based on capacity. ASCE 7-10 categorizes buildings and structures into "risk categories" and no longer includes occupancy type. The risk categories are equivalent to the "performance groups" that are used in the ICC PC. The performance groups that apply to schools include: