Performance-Based Fire Safety Design

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SFPE
Engineering A Fire Safe World

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Preface

This book was assembled from lecture notes that the authors created for courses on performance-based fire safety design at the University of Maryland, Worchester Polytechnic Institute, and California Polytechnic University during the last decade. The authors are indebted to constructive feedback (and corrections of errors) by countless students.

We created this book to serve two purposes: (1) as a textbook for academic programs on performance-based design, and (2) as a valuable reference for practitioners who wish to learn performance-based design or hone their skills. Some of the material that we provided in this book is a summary of information that can be found elsewhere, but other parts are new information that is an original contribution to the knowledge base.

We have been impressed by the accelerating rate at which performance-based fire protection is being accepted. As we note in Chapter 1, performance-based design is not new. What is new is the large number of authoritative references that are available to assist fire protection engineers and code officials alike. Many more are now willing to embrace performance-based design than was the case at the onset of our careers.

We hope that this book contributes in a meaningful way.

Acknowledgments

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About the Authors

Morgan Hurley is a project director with Aon Fire Protection Engineering and serves as adjunct faculty at the University of Maryland and California Polytechnic University. He holds bachelor's and master's degrees in fire protection engineering. Morgan chaired the NFPA Life Safety Code Technical Committee on Fundamentals, which developed the performance-based design option in NFPA 101 and NFPA 5000. Morgan is a recipient of the Committee Service Award for distinguished service in the development of NFPA codes and standards from the National Fire Protection Association. He is a licensed professional engineer and a fellow of the Society of Fire Protection Engineers.

Eric Rosenbaum is a registered fire protection engineer with over 20 years of experience in fire safety. Eric served as the chairman for the Society of Fire Protection Engineers (SFPE) Task Group on Performance-Based Analysis and Design. He is also a fellow of the SFPE and a registered professional engineer. Eric is an adjunct professor at the University of Maryland. As a member of the National Fire Protection Association (NFPA) and its board of directors, Eric chaired the Life Safety Code Technical Committee on Fire Protection Features for 9 years. He is on the NFPA Technical Committee on Health Care Occupancies and Technical Correlating Committee of the NFPA Life Safety Code, and is also a member of the Technical Committee for Board and Care Facilities (Assisted Living Facilities) and Means of Egress of the NFPA Life Safety Code. In 2011, Eric received the Committee Service Award for distinguished service in the development of NFPA codes and standards from the National Fire Protection Association, and has been the recipient of the Hat's Off Award from the Society of Fire Protection Engineers multiple years.

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Chapter 1

Introduction

WHAT IS PERFORMANCE-BASED DESIGN?

The *SFPE Engineering Guide to Performance-Based Fire Protection* (SFPE, 2007) defines *performance-based design* as "an engineering approach to fire protection design based on (1) agreed upon fire safety goals and objectives, (2) deterministic and/or probabilistic analysis of fire scenarios, and (3) quantitative assessment of design alternatives against the fire safety goals and objectives using accepted engineering tools, methodologies, and performance criteria."

This definition identifies three key attributes of performance-based design. The first is a description of the desired level of fire safety in a building (or other structure) in the event of a fire. The second attribute includes definition of the design basis of the building. The design basis is an identification of the types of fires, occupant characteristics, and building characteristics for which the fire safety systems in the building are intended to provide protection. In the vernacular of performance-based design, these fires are referred to as design fire scenarios. The third element involves an engineering analysis of proposed design strategies to determine whether or not they provide the intended level of safety in the event of the design fire scenarios.

Nelson (1996) identifies four types of performance:

Component performance. Component performance identifies the intended performance in fire of individual building systems or components, such as doors, structural framing, or individual protection systems such as detection. In component performance analysis, individual components and systems are designed in isolation, without considering how their performance may impact, or be impacted by, the performance of other systems or components. Any system or component that meets the stated performance would be considered to be acceptable.

An example of a component performance-based approach would be a structural element that is designed to achieve a 1 h rating when exposed to the standard fire. In this case, the intended performance would involve maximum acceptable point and average temperatures, and the design fire scenario would be the ASTM E-119 time-temperature curve. While building codes typically require this performance to be achieved through fire testing, calculation methods are available as well (ASCE, 2005). Any assembly that achieves the intended performance when exposed to the design fire scenario would be considered acceptable.

Another example would be an individual sprinkler used in a sprinkler system. Sprinkler design standards and approval standards might require a maximum actuation temperature and thermal response characteristics. Any sprinkler that met the performance identified would be acceptable.

It is noteworthy that the codes and standards that govern fire-resistant structural elements and sprinklers contain specific requirements that are not performance based, such as limitations on the types of materials that can be used in fire-resistant assemblies and sprinklers.

Environment performance. Environment performance involves identification of the maximum permissible fire conditions within a building or portion thereof. The specification of environmental conditions could involve temperature, heat flux, or products of combustion. Environmental performance approaches identify conditions that are tolerable if a fire were to occur. It is not possible to include fire prevention strategies within an environmental performance approach.

An example of an environmental performance approach would be a requirement that the smoke layer within an atrium not descend below a given elevation above the highest occupied level. Any design that could achieve this criterion would be acceptable, and the performance requirement does not specify or limit how this can be achieved.

Threat potential performance. Threat potential performance involves identification of the maximum acceptable threat to life, property, business continuity, or the natural environment. Unlike environmental performance requirements, which involve statements of maximum acceptable conditions in the environment surrounding items that are desired to be protected from fire, threat potential performance involves a statement of the maximum tolerable conditions of the item or items being protected.

An example of a threat potential performance requirement would be a fractional effective incapacitation dose (see Chapter 6). Another example would be an identification of the maximum permissible temperature of an object. As with environmental performance, threat potential performance identifies conditions that are tolerable if a fire were to occur.

Risk potential performance. In risk potential performance, the summation of the products of probabilities of occurrence of fire events and their consequences are specified. An example of a risk potential performance requirement would be that the average permissible property loss in a facility resulting from fire must not exceed an average of $10,000 in value per year. When applying this type of approach, a designer would evaluate all possible fire events and their potential consequences. This can be expressed mathematically as (SFPE, 2007)

$$Risk = \sum Risk_i = \sum (Loss_i \bullet P_i)$$

where $Risk_i$ is risk associated with scenario i, $Loss_i$ is loss associated with scenario i, and P_i is probability of scenario i occurring.

Nelson (1996) also identifies the typical prescriptive approach, which he defines as specification. Specification involves strict definition of dimensions, construction methods, and other features. An example of specification would be some of the requirements in the *Life Safety Code* (NFPA, 2012a) applicable to stairway construction. The *Life Safety Code* identifies specific dimensional requirements for stairs and handrails.

HISTORY OF PERFORMANCE-BASED DESIGN OF BUILDINGS

As can be seen in the preceding discussion, performance-based requirements are in no way new. Early (pre-1900s) fire protection requirements largely fit into the category of specification, with such requirements including the permissible materials from which building exteriors could be constructed or the minimum acceptable spacing between buildings. However, most modern building and fire code requirements have some element of performance associated with them.

Performance-based approaches for designing building fire protection can be traced to the early 1970s, when the goal-oriented approach to building fire safety was developed by the U.S. General Services Administration (Custer and Meacham, 1997). Other major developments in performance-based design include the following:

- Publication of the performance-based British Regulations in 1985
- Publication in 1988 of the first edition of the *SFPE Handbook of Fire Protection Engineering*
- Publication of the performance-based New Zealand Building Code in 1992 and the New Zealand *Fire Engineering Design Guide* in 1994
- Publication of the Performance Building Code of Australia and the Australian *Fire Engineering Guidelines* in 1995

- Publication of the *Performance Requirements for Fire Safety and Technical Guide for Verification by Calculation* by the Nordic Committee on Building Regulations in 1995
- Publication of the performance option in the NFPA *Life Safety Code* in 2000
- Publication of the *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings* in 2000
- Publication of the Japanese performance-based Building Standard Law in 2000
- Publication of the *ICC Performance Code for Buildings and Facilities* in 2001
- Publication of the performance option in the *NFPA Building Code* in 2003

The documents only represent the formalization of performance-based design. Performance-based design has long been practiced through the use of equivalency or alternate methods and materials clauses found in most, if not all, prescriptive codes and standards. These clauses permit the use of approaches or materials not specifically recognized in the code, provided that the approach or material can be demonstrated as providing at least an equivalent level of safety as that required by the code or standard.

However, equivalency or alternate methods and materials clauses typically do not provide any detail as to how an equivalent level of safety can be achieved. Therefore, the approaches used by individual designers or regulatory officials were frequently developed on an ad hoc basis, with approaches varying among designers and regulatory officials. The effect of the documents identified in the preceding text was to standardize the practice of performance-based design.

The evolution of performance-based design has followed an evolution in the quantitative understanding of fire. Before fire science was well understood, proven technologies would be codified into regulations. Similarly, as major fires occurred, and the causes and contributing factors of those fires were identified, codes and standards were modified to prevent similar major fires from occurring in the future.

Specification codes have two disadvantages:

- They can only protect against events of a type that have occurred in the past. Major fires are low-probability, high-consequence events. Because of their stochastic nature, some types of rare events have not yet occurred.
- They can stifle innovation. By specifying certain types of methods and materials, it can be difficult to introduce new methods and materials into the marketplace.

As the science of fire became better understood, performance-based fire protection design has become possible. Other engineering disciplines have evolved in a similar manner—as the underlying science became better understood, their design approaches became more performance based.

ADVANTAGES AND DISADVANTAGES OF PERFORMANCE-BASED DESIGN OF BUILDINGS

Performance-based design offers a number of advantages and disadvantages over specification-based prescriptive design. As the design approach used moves from specification based toward risk based (see the "What Is Performance-Based Design" section above), these advantages and disadvantages are magnified.

Advantages:

- Performance-based design allows the designer to address the unique features and uses of a building. An example would be the types of stores that can be found in a shopping mall. Each might have an identical occupancy classification under prescriptive building and fire codes, and hence require similar fire protection strategies. However, the stores could contain significantly different fire hazards. Some could contain flammable liquids, while others might contain few or no combustible items at all. A corollary to this advantage is increased cost-effectiveness of performance-based designs.
- Performance-based design promotes a better understanding of how a building would perform in the event of a fire. Compliance with prescriptive codes and standards is intended to result in a building that is "safe" from fire. However, what constitutes safe is generally not defined. Similarly, the types of fires against which the building is intended to achieve fire safety are not identified. While most common fire scenarios would likely result in acceptable performance, the low-frequency scenarios that are not envisioned may not.

  Two fire scenarios can be used to illustrate this. Carelessly discarded smoking materials would likely be within the design basis for a code that is intended to apply to a high-rise residential building. However, a gasoline tank truck that accidentally crashes into the building's lobby likely is not. Within these two extremes are a large range of possible events. A corollary to this advantage is that increased thought and engineering rigor is brought to solving fire protection problems.

Disadvantages:

- Performance-based design requires more expertise to apply and review than does prescriptive-based design. Application of prescriptive codes only requires the selection of building features and systems that meet the code's requirements. Verification of the acceptability of a prescriptive-based design is equally straightforward. Performance-based design can take more time to conduct and review than prescriptive-based design.
- Performance-based design can be more sensitive to change than prescriptive-based design. Changes in use of a building or portion thereof can result in unacceptable performance in the event of a fire if the effect of the change on fire safety is not contemplated in the design. With prescriptive-based designs, changes in use may be acceptable if the portion modified stays within the original occupancy classification. This is not to say that prescriptive designs are completely tolerant to changes; even if a modification remains within the original occupancy classification, some types of changes could result in the modification not being compliant with prescriptive codes. For example, movement of walls during tenant renovations in an office building could result in the sprinkler system no longer being in compliance with governing codes and standards. If a building is designed according to a performance basis, then some changes in use may result in increased vulnerability in the event of a fire.

The process that is identified in the subsequent section provides methods of overcoming the limitations.

PROCESS OF PERFORMANCE-BASED DESIGN

The *SFPE Engineering Guide to Performance-Based Fire Protection* (2007) provides a process, or framework, for performance-based design. This process is identified in the flowchart in Figure 1.1. The process is intended to be flexible, so that it can be tailored to the individual requirements of individual performance-based design projects.

This process identifies the steps that are involved in performance-based design, without specifying which methods or models should be used in the development or evaluation of a specific design. While widely used references are identified within the guide, the references are not intended to be endorsed or comprehensive.