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Short Communication

The International FORUM of Fire Research Directors ☆ A position paper on performance-based design for fire code applications

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Abstract

The International FORUM of Fire Research Directors (FORUM) periodically takes a position on a technical issue of international significance confronting the fire safety research community. The position of the FORUM on performance-based regulations, codes and design for fire safety applications, and the rationale leading to it, is described in this paper. Aspects addressed include current capabilities and challenges associated with the application of performance-based design, and possible enhancements (obtained through a coordinated and sustained global effort of research) in next generation tools leading to more certain predictions of the effects on performance of changes in building materials, active and passive fire protection systems, compartmentation, and egress systems; the structural response of a building to large fires including those leading to full building burnout; the impact of fire on neighboring buildings and infrastructure; and the uncertainty in deterministic predictions for incorporation into reliable probabilistic calculations of hazard and risk.
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1. Background

Fire codes and standards are developed and regulations implemented in most countries with the objective of protecting societies and reducing their losses from fire. For the majority of traditional buildings with low hazard occupancies, modern prescriptive building and fire codes, when enforced, achieve this objective. Nontraditional buildings include many of society's largest and iconic structures, such as opera houses, museums, sports stadiums, transportation centers, super-high-rise structures, and some government buildings. Prescriptive codes cannot anticipate all of the requirements that these nontraditional structures impose; prescriptive codes do not adapt rapidly to changing materials and methods of construction, nor to radical architectural designs; and prescriptive codes based upon historical loss experiences are not designed to deal with very low probability, very high impact events or other threats such as from terrorism.

Regulating the design, construction, and operation of buildings on the basis of performance is viewed as a means to overcome many of the shortcomings of prescriptive codes for nontraditional structures, as well as for more traditional buildings on unusual sites, or for an existing building undergoing renovation or a change of occupancy. While an additional up-front investment is required to design and evaluate a project on the basis of performance rather than prescription, performance-based codes provide much greater flexibility and promote innovation in building design, materials, products, and fire protection systems. Deemed-to-satisfy provisions provide continuity with prior prescriptive regulations and ensure that existing buildings do not come into violation. However, this assumes that the

☆http://www.bfrl.nist.gov/info/forum/. The International FORUM of Fire Research Directors (FORUM) was formed in 1991 with a goal to reduce the burden of fire (including the loss of life and property, and effects of fire on the environment and heritage) through international cooperation on fire research. Our members include many who were involved with writing PB codes; we have met and worked with regulators, practitioners, and educators worldwide; and we have carefully examined and discussed these factors in the effective application of PB design for regulation.

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prescriptive rules are sufficient in all cases to meet the performance objectives, which may not be the case.

ISO TC92 has established a framework for the long-term standardization of fire safety in support of performance-based design (PBD) [1]. A guide for conducting performance-based fire protection design has been developed by the Society of Fire Protection Engineers (SFPE), which spells out the steps from the definition of the design scope, through the expression of the performance criteria, selection and evaluation of design fire scenarios, and ultimately to the final design [2]. Even so, the success of PBD for fire code applications hinges on the establishment of critical solution-enabling tools, a profession properly educated to implement these innovations, and code officials capable of evaluating the safety of PBD. Further, when expressing the performance criteria, serious consideration should be given to public well-being as an appropriate overall goal of performance-based regulation. An approach committed to public well-being can broaden the beneficial societal impact with likely more reliability.

2. Challenges of performance assessment

Buildings are complex collections of systems, materials, and arrangements that are highly variable and interactive, and the performance objectives of the regulations relate primarily to the performance of the system as a whole. Deficiencies in one area can in some cases be compensated by use of other materials or systems and this is central to the flexibility afforded by performance-based regulation. However, compensation or substitution is not easily evaluated and not always proper or prudent. The ability to quantify the in-use performance of many fire safety systems is mixed, made difficult by the physics of the fire, the fire protection systems, and the response of the building to the fire; our incomplete knowledge of human behavior in a fire emergency; and the complexity of validating computational design tools over a wide range of fire scenarios.

Experimental tools, e.g., mid-scale and large-scale calorimetry, are well developed and widely available for measuring the heat release rate of real objects and fuels (along with the yield fractions of smoke and major species) under fully ventilated fire conditions, but how these may change for vitiated conditions or when impacted by external radiant heating cannot be predicted in a quantitative sense. Small-scale testing can be particularly helpful as an economical approach if implemented in a manner that is compatible with PBD [3]; clearly, though, more work is needed. Initial sprinkler activation times can be estimated to reasonable accuracy but the influence of the water spray on the fire environment and on the combustion process, along with subsequent sprinkler activation times, can be only crudely estimated.

There has been great progress in recent years with fire models that can predict the development and spread of fires and the fire's impact on the internal environment of the building. A number of computational models are available and are now routinely accepted for some regulatory applications. Some models have been adequately validated for specific applications, but many have not been validated for broad classes of complex problems because validation-quality data are available for only limited geometric arrangements and fuel conditions. Guidance exists for fire model verification and for documentation [4]; however, few organizations have pursued the rigorous verification and validation supported by the FORUM [5]. Therefore, application of these models typically requires extrapolation to the design of interest and the associated validation.

Given the thermal environment established by a fire model, finite element models are available for predicting the resulting temperature distributions within the structure; and models have been developed to predict the stresses and response of the structure to the changing thermal environment. However, combining these models to obtain a comprehensive picture of the response of the overall structure to, say, a full building burnout is problematic. The individual models operate on vastly differing time and length scales that pose significant problems for solution of the governing equations. Sequential calculation methods recently have been employed to solve this problem [6], but these are tedious and too costly for regular use in design and regulation. The prediction of incipient failure of individual elements is on relatively firm ground. The reaction of connections to thermally induced stresses and creep, the effects of high heating rates and thermal gradients (as well as numerical convergence difficulties near imminent structural collapse) were examined in the series of tests conducted in Cardington [7,8]; however, there is much yet to be learned.

Performance assessments generally involve the application of considerable engineering judgment and are subject to manipulation by the selection of calculation method and input data. This issue depends on two factors to assure confidence for regulation. First, individuals performing the calculations are generally required to be licensed or chartered and subject to the ethical constraints of a design professional. Second, most performance-based regulatory systems require third-party review of all calculations and assumptions. With a concerted long-term program to increase the educational level and minimum qualifications of regulators, the issue may be brought under control within the limitations of the design tools themselves. More, however, needs to be done to assure adequately accurate models, a better-educated profession, and more appropriate model application.

3. Research needs

Representatives from the FORUM membership and other technical experts were invited to develop a common, international vision for how the scientific foundation might be bolstered for the next generation of PBD tools [9].

Methods for the attainment of this vision were identified that included the establishment of

- a hierarchy of meaningful benchmark fire experiments and simulations;
- tractable combustion models that capture the essence of materials and finished products, and with simple multi-step reaction mechanisms for prediction of CO and soot;
- data sets and experimental facilities for unraveling the relationships within and interactions among fire dynamics, structural dynamics, and human behavior;
- efficient interfaces among fire, structural, human behavior, and risk models;
- data and means to track uncertainty in risk and hazard analysis, and to incorporate rare, high consequence events.

Five areas were identified at the top of the list of research priorities for the members of the FORUM:

- improvement of our ability to predict the impact of active fire protection systems on fire growth and the distribution of combustion products;
- estimation of uncertainty and the means to incorporate it into hazard and risk analyses;
- the relationship between aspects of the building design and the safety of building occupants;
- the impact of material and geometry changes on fire growth and products of combustion;
- the prediction of the response of a structure to full building burnout.

4. FORUM position

It is the FORUM's position that

- the level of understanding of fire science by practitioners and the capabilities of the current generation of FPE tools are useful and adequate to support some aspects of performance-based regulations, codes and design, although numerous practical design applications and requirements exist that remain beyond the limits of these tools, and uncertainties in the predictions have not been, and in some cases cannot be, quantified beyond these limits;
- accurate tools must be available and used expertly; and PBD must be applied uniformly and consistently by properly educated practitioners and evaluated uniformly and consistently by adequately trained authorities having jurisdiction;
- for performance-based regulation to be effective, a commitment must be made to public well-being, both in the public and private sectors.

A coordinated and sustained global effort of research among FORUM members, universities, and other research organizations in support of PBD can lead to enhanced and more certain predictions of the effects on performance of changes in building materials, active and passive fire protection systems, compartmentation, and egress systems; the structural response of a building to large fires including those leading to full building burnout; the impact of fire on neighboring buildings and infrastructure; and the uncertainty in deterministic predictions for incorporation into reliable probabilistic calculations of hazard and risk.

FORUM members are committed to documenting and disseminating to the international regulatory, codes and standards communities progress on these collaborative efforts as well as the results of their individual research programs in support of the beneficial aspects of performance-based codes and performance-based design for fire applications.

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