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Short communication

The international FORUM of fire research directors: A position paper on evaluation of structural fire resistance

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Abstract

The International FORUM of Fire Research Directors periodically takes positions on issues dealing with the direction and implementation of fire research with the potential for significant impact on safety and/or global standards and test methods. This short communication represents the FORUM's position on structural fire resistance test methods and evaluation procedures. It is proposed that the prediction of the performance of coupled building systems to the point of impending failure in a fire be established as an overriding goal for the construction and building products industries, and that research be channeled to produce the material data bases, the new instrumentation, the expanded test facilities, and the innovative analytical methods to support the changes to standards, codes and practices that are necessary to attain this goal.
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1. Introduction and background

Recently, the topic of structural fire resistance has jumped abruptly from the obscure vernacular of the fire protection engineer to family discussions around the dinner table. Even among many specialists, the drive to rigorously evaluate structural fire resistance had been relegated to a back burner for decades. Efforts to make progress in this arena have largely been limited to maintaining order, and implementing incremental improvements in building codes and standards.

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The unsolicited push of fire resistance into the limelight is a reaction to the enormous loss of life caused by the collapse of the World Trade Center on September 11, 2001. According to the Building Performance Study (BPS) sponsored by the Federal Emergency Management Agency [1], the Towers withstood the mechanical impact of the aircraft but succumbed to the thermal impact of the ensuing fire. Building 7, with unknown but significantly less structural damage, collapsed hours later, apparently due to the fire that burned unchecked, making it the first instance of a building of such a design to ever fully collapse by this method.

Even to the untrained observer, it appears that the fire resistance of these structures was central to their disastrous behavior. There may be logical answers to the question why the BPS did not discover calculations made ahead of time of how resistant to heat the World Trade Center buildings may have been in the event of an extreme fire. For example, the crash of a large jet aircraft into a high-rise building followed by severe fire had not occurred before. Structural engineers, indeed, did anticipate a possible accidental hit of the Towers by an aircraft, but there was no report in the BPS that the architect responsible for fireproofing did a fire analysis. There were no code requirements to include a realistic fire scenario in the development of the buildings' fire protection plans. In fact, high-rise buildings designed to the applicable fire resistance standard (i.e., ASTM E119 [2]) had demonstrated a history practically free from fire-induced collapse, and were felt to be conservatively designed. As well, when the buildings were designed, the engineering tools available to predict the performance of structural connections and assemblies in an actual large fire setting were primitive, and the prevailing mindset was "the engineer designs the structure and the architect specifies the fire protection." The investigation currently underway by the National Institute of Standards and Technology (NIST) should provide more answers to some of these technical questions surrounding the collapse of WTC 1, 2, and 7 [3].

Most in the structural engineering, fire protection engineering, and architecture professions recognize and accept the sea change in public attitude that has occurred with respect to fire safety in tall buildings, but all are struggling with how to respond in a technically meaningful and cost effective way. The International FORUM of Fire Research Directors (formerly the FORUM for International Cooperation on Fire Research) recognizes this challenge and presents its perspective on the activities and research needed to help guide the response of the design profession and standards making organizations.

2. Approach

The structural integrity of a building, and the safety of building occupants and first responders in an actual fire, will depend upon the quality of the structural design, the design of the active and passive fire protection and egress systems, and the procedures governing their installation, inspection, and maintenance. This paper focuses on the ability of test methods to assess building integrity under anticipated and extreme fire conditions, and the need to evaluate the impact of faulty installation and/or maintenance procedures on system performance. The concern, in the short term, is with improving current prescriptive test methods through international standards-making organizations. The fire safety committee of the International Organization for Standardization (ISO TC92) has, since 1995, been evolving a framework for the future standardization of fire safety that has begun to move us beyond prescriptive codes [4]. Sustained research will be required over the long term to nurture this approach and to realize the benefit of true science-based performance codes.

Current Test Methods: The standard test methods commonly used to characterize the fire resistance of building elements (structural and non-structural), and the properties of sprayed fire resistive materials are reviewed in the proceedings of a recent workshop held at NIST [5]. Full size structural elements, or portions of structural systems, are presently evaluated by mounting them in a fixture and exposing them to a flame in a furnace whose temperature rises as a specified function of time. The maximum temperature attained by the element (underneath any applied thermal insulation) and/or the element's ability to resist a prescribed load are the criteria upon which the system's fire resistance is rated. ASTM International, the National Fire Protection Association, the International Organization for Standardization, and Underwriters Laboratories are examining the adequacy of the current editions of their standards as part of normal, established review cycles. The FORUM supports these efforts and encourages the organizations to move expeditiously and in a coordinated fashion. An example of the type of change that could aid performance prediction with little impact on the cost or operation of the tests would be to require additional data on temperature and deformation of the structural elements up to the point of failure, not just to the end of the rating period. Also, a more complete record of the furnace environment (e.g., fuel flow, excess oxygen level, heat flux to test article) could assist the extrapolation of the test conditions to more realistic fire environments. In all cases, revisions should be based upon solid technical evidence and the results of research as described later in this paper. Collection of additional data should be accompanied by accepted techniques that provide clear guidance on usage for the betterment of structural fire safety.

The ratings of structural elements in standard fire resistance tests are based upon the maximum amount of time that the test article remains below the threshold temperature or the threshold limit of deformation. It is expected that a 2-h rated wall would resist failure in a real fire for a longer period of time than a 1-h rated wall, and this is invariably the case. What cannot be expected, however, is that a structure composed of elements that are 2-h rated would necessarily withstand an actual fire for 2 h, nor that it would necessarily fail after 2 h. The inability of the fire resistance rating to act as an absolute predictor of performance in an actual fire was recognized from the beginning when the forerunner of ASTM E119 was published in 1918. Over the years, however, the reference to fire resistance ratings in common time units has become interpreted to relate closely (or at least conservatively) to the actual expected time that a structure or element would be expected to resist a fire.

This problem of misinterpreting a fire rating is unique to fire resistance tests because the use of time as the rating unit is easy to apply in a manner not reflected in the standard. By contrast, a common flame spread test, ASTM E84 [6], rates material on a scale normalized by the distance that a flame will spread over red oak in a defined configuration, which is given a rating of 100. If another material is rated 45, one expects flame spread to occur at a lower rate than red oak, but there is no way to extrapolate the rating to a specific performance criteria in an actual fire. In fire resistance tests, however, the end point (i.e., time to failure due to a certain temperature or deformation limit) is prone to misconception by a lay person. Other fire tests are couched in obtuse terms such as a heat release rate, light obscuration, or simply a subjective flammability classification (e.g., V0, HB, etc.).[1]

The FORUM recommends that the standards organizations consider a new rating system that is more immune to misinterpretation. It is critical that any change allow existing materials and the vast historical record to be directly related to the new rating. While there are many potential paths to improvement, one might use the performance of a highly fire resistant element (say, one with a 5-h rating by current standards) to normalize alternative designs, materials and systems. That is, a 5-h rated element would be classified as having a fire resistance factor of 100, while a 1-h rated element would be classified as having a fire resistance factor of 20, a $2\frac{1}{2}$-h rated element would have a fire resistance factor of 50, and so on. Corresponding guidance would describe the exposure conditions and provide how to interpret the resistance numbers for fire safe design.

The current rating of a structural element is often based upon a single test, which is insufficient to assign any uncertainty to the value. The FORUM recommends that enough replicates be conducted of similar elements, materials, or systems to establish a confidence level (that may include a band of uncertainty). The confidence level would ensure that the fewer the number of tests, the greater the level of required safety margin. Conversely, the greater the number of tests, the more freedom the designer should have to use the element or system up to its limit. Hence, the manufacturer would have incentive to conduct more tests to narrow required safety margins.

Research in Support of Performance-based Codes: The research needed to achieve scientifically based performance predictions of building materials, products, structural elements, and systems up to the point of imminent fire-caused collapse was discussed at the NIST workshop [5]. The specific developments below were seen as necessary to eventually reach the goal of predicting structural fire performance:

- experimental protocols and instrumentation for measuring, at elevated temperature, the thermal and mechanical properties of building materials that impact structural integrity during a fire, and accumulation of a consistent, reliable high temperature data base;
- experimental methods and protocols for measuring the thermal and mechanical behavior of fireproofing as installed and when degraded by aging, temperature, and stress;

[1] The FORUM is solidly behind objective and quantitative testing that accelerates the development of science-based prediction and design methods. The recommendation for use of a subjective classification in fire resistance ratings reflects the current prescriptive environment.

- experimental methods and protocols for measuring the response of structural connections (including welds, bolts, rivets and adhesives) when exposed to severe fire conditions and loads;
- large-scale test facilities to the extent necessary to extrapolate the behavior of connections and assemblies to the behavior of whole building frames; and
- innovative techniques to better educate building code officials, authorities having jurisdiction (AHJs), and the fire service of the capabilities and limitations of standard test methods and computational tools.

Following the workshop, a study was conducted [7] to identify all private and public facilities capable of testing the structural integrity under severe fire conditions of beams, columns, connections, and assemblies (with and without fire resistant materials) commonly used in building construction. The study also assessed the need for additional testing and/or experimental facilities to allow the performance of structural assemblies and fire resistance materials to be predicted under extreme fire conditions within actual buildings. While many organizations were identified that test the resistance of construction materials and structural elements to current building and fire standards using long-established methods, no laboratory was identified anywhere in the world capable of supporting all of the above required developments. The members of the FORUM support a coordinated upgrade of facilities to more fully characterize structural and non-structural materials at elevated temperatures, and to enable the conduct of real-scale structural system experiments under tighter control of initial and boundary conditions, with more precision measure of the thermal and mechanical loads, and with more precision measure of the response of the structure to these loads as a function of time. Such facilities would lead to new scaling laws where none currently exist in the realm of thermal–structural mechanics. This could have a profound effect on construction innovation and reducing the failure of buildings and systems in a fire.

3. FORUM position

The position of the FORUM can be summarized as follows:

- Expeditious and coordinated revisions to current structural fire resistance test methods are required, through procedures established by the respective national and international standards organizations, that address (i) the response of structural elements up to ultimate failure, (ii) the statistical uncertainty of failure, and (iii) an alternative classification or rating system in units other than time, and associated guidance.
- The capabilities and limitations of standard fire resistance test methods and computational tools must become more apparent to building designers, code officials, AHJs, and the fire service.
- The prediction of the performance of coupled building systems to the point of impending failure in a fire should be established as a goal for the building industry.

- A sustained, multi-national research effort is needed to support the move towards performance-based structural fire resistance design, specifically to develop (i) a comprehensive, high temperature database of the thermal and mechanical properties of building materials; and (ii) facilities beyond the current state-of-the-art for experimental methods and protocols for measuring the response of structural connections when exposed to severe fire conditions and loads, and to provide the knowledge required to predict the behavior of connections and assemblies as well as entire building frames.

This position is motivated by the desire to accelerate the development of improved, cost effective materials and technologies into building practices; to demonstrate to code bodies, regulators, AHJs, and other stakeholders that proposed changes to codes and standards are technically defensible; to establish a scientific basis for assessing the integrity of buildings and other structures that have experienced an extreme fire, and the performance of alternative remediation and retrofit approaches; and to support harmonization of best practices in testing laboratories worldwide and mitigate the potential for technically unfounded international trade barriers.

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