Structural Design for the Fire Condition

The Role of the Design Professional

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The collapse of the World Trade Center, and the subsequent engineering analysis of the structural behavior of these buildings in the fire condition, have led to a new appreciation of the respective roles of the fire protection and structural engineers in structural fire safety design. Recognizing this fact, the FEMA sponsored report on the WTC collapse made the following recommendation: "An improved level of interaction between structural and fire protection engineers is encouraged to consider behavior of the structural system under fire as an integral part of the design process…"

This article reviews the traditional roles of the fire protection and structural engineers in the design of structures for fire, the current design methods available, and addresses these roles in analytical approaches to structural fire safety.

Upper Left and Lower Right; Disasters are devastating to the natural and man-made environment. FEMA provides federal aid and assistance to those who have been affected by all types of disaster. NOAA News Photo

State of the Practice

Today, structural fire safety is typically determined through a combination of prescriptive code requirements and standard fire test results for different structural assemblies. Code requirements specify required hourly fire resistance ratings of assemblies, either as fire separations or as structural elements. Structural assemblies are tested in accordance with the standard fire test, ASTM E-119 or equivalent, to obtain these hourly ratings. If an assembly proposed for a structure differs from a tested assembly, simple engineering "rules of thumb," empirically verified with fire tests, are used to vary size of members, protection or cover thickness, etc.

Because fire resistance is typically expressed in terms of hourly ratings, there is a tendency to assume that the fire resistance rating of an assembly is equivalent to its period of performance in an actual fire. While the exposure conditions in the standard fire resistance tests are relatively severe, they do represent only a single exposure history, so the relationship between the fire resistance rating and the performance of an assembly in an actual fire may not be one-to-one in terms of the actual period of fire endurance. However, the standard fire test is useful for comparisons between assemblies; in general, assemblies with higher fire resistance ratings would be expected to perform longer before failure than assemblies with lower fire resistance ratings in actual fires.

For many structures, fire protection strategies, including structural fire protection, are designed by the architect of record on the project. Periodically, when unique architectural situations exist, a fire protection engineer is called upon to advise on structural fire protection. Rarely is the structural engineer involved in these decisions in current practice.

In certain situations, where the proposed structure does not bear any resemblance to tested assemblies, or is a unique structure whose expected fire exposure differs from that assumed by the standard test, fire protection engineers and others are asked to evaluate the proposed fire protection design to ensure that it meets the intent of the code. This evaluation may involve a structural evaluation, a thermal evaluation, or an overall fire safety evaluation of the fire protection systems which are proposed for the project.

Current State of Knowledge

Today's understanding of the behavior of structures in fire goes well beyond that of simple interpretation of fire test results used in prescriptive building codes. In particular, the influences of load and restraint on fire resistance of structural members are relatively well understood, and the overall structural behavior of frames and assemblies can be modeled. Analytical methods exist to predict the transfer of heat through insulation materials, and design fires for structural elements have been characterized. This state of knowledge permits the use of analytical approaches to structural fire protection.

The National Institute of Standards and Technology has embarked on a major program to benchmark and develop best practices for structural fire safety design. Internationally, structural design standards for the fire condition have been developed and adopted by several jurisdictions.

Current Efforts

To facilitate the performance-based design of structural fire resistance, the Society of Fire Protection Engineers, in collaboration with the American Society of Civil Engineers and representatives from the steel, masonry, concrete and timber industries began developing a series of standards on structural fire resistance. The first standard developed under this collaboration, a standard on calculation methods and substitution rules given the standard fire exposure, is complete.

The next standard planned under this collaboration is the development of a performance-based standard on structural fire resistance that considers the actual fires to which a structure might be exposed.

Performance-based design of structures for fire resistance entails three steps:

1. Determine the fire boundary conditions to which a structure could be exposed.

2. Determine the thermal response of the structure, based on the fire boundary conditions

3. Determine the structural response, based on the thermal response.

The Society of Fire Protection Engineers is developing the portion of this standard that addresses the first step, while it is anticipated that other ASCE partner groups will develop the portions on structural response and on thermal response for specific structural materials. Independent of the ASCE standardization activity, SFPE plans to publish the portion of this standard on fire exposures as an engineering guide.

Role of the Engineer in the Design of Structures for Fire

In considering the fire safety design of a structure, the design team should consider the merits of an engineered solution to structural fire safety. The approach can provide a better understanding of how a structure will actually perform in fires compared to the traditional prescriptive approach.

The decision to use a performance-based approach should be based on:

- The architectural layout of the project, and its variation from typical building construction which may result in unique fire exposure conditions for the structure
- The structural system of the building, focusing on any unique structural features
- The occupancy of the building and any unique fire loading conditions that may lead to unique demands on the structure.
- The overall importance of the structure, with respect to special occupancies, size or height, or other features which, after exceeding a threshold value, may dictate special attention to structural fire protection

Professional Practice Considerations

In today's construction practice, it is typical for the architect to call on the services of a fire protection engineer for major projects where fire safety issues require consideration beyond the simple application of prescriptive code requirements. In the case of structural fire protection issues, the expertise of a structural engineer may also be required.

Once the decision has been made to design a fire protection solution which includes structural fire safety design, the following roles and responsibilities may be appropriate:

- Assessment of design fire loads, unique fire exposure conditions and thermal inputs to the structure – fire protection engineer
- Analysis of thermal response of structural members and their protection means, if any – fire protection engineer
- Analysis of the response of the structural system – structural engineer

Future Issues for Discussion…

How will structural fire safety design be integrated into today's overall building fire safety design approaches?

Should the engineer play a formalized role in the structural fire safety design on a routine basis?

What are the threshold levels that might call for the analysis/design of structural elements for fire?

Should there be structural design standards for the fire condition?

New York, NY, September 27, 2001 -- New York City firefighters battle smoldering blazes from a fire truck at the World Trade Center. Photo by Bri Rodriguez. FEMA News Photo

How will they be integrated into today's prescriptive approach to determining structural fire safety?

How will they be integrated into today's structural design practice for other design conditions?

What are the education and training needs of the structural engineer to take on this relatively new role in the design process?

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