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Fire Resistance of Concrete Structures

Part 2: *The Role of Performance-Based Design in Concrete Fire Resistance*

The second in a two-part series that discusses the technical aspects of fire resistance and concrete structural components.

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One of the most significant changes in the field of fire-protection engineering in the last 20 years has been the introduction of the performance-based design. Historically, concrete structures and systems in regards to fire have been designed based on a set of prescriptive codes and standards where the performance values are provided for in tables or through a series of simplistic mathematical equations. Performance-based design utilizes engineering design to achieve a specified fire-protection goal for a whole building system.

Performance-based design has been integrated into building codes internationally for the last two decades. Only recently has the United States introduced this idea into code through the introduction of the International Code Council Performance Code for Buildings and Facilities and performance-based design provisions in the International Fire Code, NFPA 1 (the Uniform Fire Code), NFPA 101 (the Life Safety Code) and NFPA 5000 (Building and Construction Code).

Fire performance of concrete members, specifically walls, can be determined in one of three methods:

1. The most common test method for determining fire resistance in the United States is the ASTM Standard E 119 Test Methods for Fire Tests of Building Construction and Materials. ASTM Standard method E 119 is a fire test that exposes the structural member to a standard fire on one side of the wall. For the structural member to pass the test, three criteria must be met: structural stability, integrity and temperature rise on unexposed face.
2. Empirical methods can provide designers a method to calculate the fire resistance rating of concrete walls. ACI 216.1-97, Standard Method for Determining Fire Resistance of Concrete and Masonry Construction Assemblies, provides a simplistic empirical method for determining fire resistance of concrete walls.
3. Performance-based design can estimate the fire performance of concrete systems by analyzing a whole-building approach and applicable-design fire scenarios.

The fire resistance of the majority of concrete walls can be determined by the empirical methods or through meeting the requirements of a standard test method. However, several limitations to the prescriptive method of determining fire resistance exist. Fire growth and development is an integral part of whether the structure maintains stability during a real-world fire scenario. The prescriptive methods use a single fire scenario to evaluate all structural members and neglect factors such as fire load, ceiling heights, ventilation, geometry of the space, room size and sprinkler systems. As a result, the fire-resistance requirements defined by the prescriptive methods are often the same regardless of space, use or fire threat and often result in overdesigning the structural elements, costing the owner extra money and limiting design flexibility.

A performance-based design approach takes into account the whole building's performance during a fire rather than the fire-resistance rating of a single member. For the case where concrete is being utilized, the concrete structural members would be analyzed as part of a full-building system which would include any fire sprinklers, roof system and often interior finish. Before application of the performance-based design, the engineer must establish a series of performance objectives that may include life safety, property protection and business continuity. These fire scenarios must include the addition of fuel supplied by the building materials, such as timber or wood. Where concrete is utilized, the impact on the fuel load is negligible.

The second step in this method considers a series of fires, called design fires, that may occur in the space. The thermal response of the building, including that of the structural members, is found through advanced computer or mathematical modeling for each of the design-fire scenarios and specified loading scenarios. The results of the thermal response analysis are compared to the predefined performance criteria, and the design is submitted to the authority having jurisdiction for approval.

The use of performance-based design is of particular importance to the concrete industry. Individual concrete elements often perform better during a fire when examined as part of a structure or system than when analyzed alone. The use of the prescriptive methods is often limiting because the tables only account for four types of aggregate (siliceous, carbonate, semi-lightweight and lightweight), which does not reflect the range of concretes commonly used today.

For most buildings with simplistic design, the performance-based design would not be cost-effective and would be too-time consuming to perform. However, for concrete construction with unique architectural features or non-traditional applications, the performance-based design may be the best alternative. ■

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