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Recent Developments in Structural Fire Resistance

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Fire-Resistance Requirements

The provision of structural fire-resistance requirements in building design and building codes is intended primarily to ensure building integrity for a certain period of time under fire conditions and to permit evacuation of occupants and access for firefighters.

To meet fire-resistance requirements specified in building codes, the fire resistance of individual building elements has to be determined. Often, this is done by subjecting specimens to costly and time-consuming fire tests. Recent developments, however, have made it possible in many cases to calculate fire resistance using mathematical models. Developed to simulate the behaviour of building elements exposed to fire, such as beams, columns, floors and walls, these models make it possible to predict the fire resistance of most building elements for a wide range of practical conditions.

Several models were developed and programmed for computer-processing at the National Fire Laboratory of the Institute for Research in Construction. Many computer runs were made to provide data for the derivation of simplified formulas for building elements' fire resistance as a function of the significant parameters. Some of these formulas have been incorporated into Canada's National Building Code, including those for determining the fire resistance of reinforced-concrete columns, multi-layer concrete slabs, laminated-timber beams and columns.

Models for Calculating Fire Resistance

There are many more formulas for calculating fire resistance of building elements, several of which were developed with support from major materials industries. There are formulas for predicting the fire-resistance of insulated steel beams and columns, unprotected steel, load-bearing steel stud walls, and solid and hollow concrete slabs.

All these formulas, which were scattered throughout various building codes and manuals, have been collected in a 'Manual of Practice,' edited by the National Fire Laboratory (NFL) and published by the American Society of Civil Engineers. Written to provide a basis for developing new standards for fire-resistance calculations, the manual discusses current techniques to improve fire safety in buildings. It also contains valuable information on the fire resistance of light frame assemblies, which can be determined by using a method known as the 'component additive method.' It involves calculating fire resistance by adding the contribution of each component of the assembly. Developed at the NFL, the method has both Canadian and U.S. code acceptance.

Another method, also considered in the manual, is a set of extension rules that use fire resistances previously obtained by testing or calculation and extend them to conditions that deviate from those obtained in the tests or calculations.

One chapter describes the mathematical models that have been developed over the years, some of which have been used to generate the simplified formulas and extension rules already mentioned. But the models are also useful for calculating fire resistance in other situations, particularly when testing is not feasible, such as in assessing installed building elements for the purpose of upgrading structural fire protection in a building rehabilitation. In addition, testing is often not feasible because the assembly is too large for test facilities.

Models for Gathering Information

Some of the new models being developed at the NFL are designed to obtain information either on the behavior of new materials, such as high-strength concrete, under fire conditions, or on new approaches in structural fire protection, such as the use of concrete filling in hollow steel columns to provide more strength and better fire resistance. In both studies, the NFL is using its unique test facility, which has a loading capacity of 1000 t, sufficient to produce the high loads for which the columns were designed.

The strength of concrete has increased from about 30 MPa for normal-strength concrete to 120 MPa and higher for high-strength concrete, the use of which has become more prevalent; it has now been used in several high-rise buildings, some more than 70 stories high.

But, concerns about the performance of high-strength concretes in fire, particularly their tendency to spall at elevated temperatures, have been raised, and the NFL and several other laboratories worldwide are investigating. In a collaboration between the NFL and the Portland Cement Association, full-size, high-strength concrete columns are being exposed to fire in the NFL's column furnace. Columns of various high-strength concretes with a compressive strength in the range of 70 to l00 MPa are being tested to generate fire resistance data and to develop general methods for calculating their fire resistance.

It is expected that the high-strength columns can carry a higher load than those made of normal-strength concrete, not only at room temperature, but also at elevated temperatures without sacrificing fire resistance. This is illustrated in Figure 1 where, for a column with a section of 300 by 300 mm, the maximum loads to ensure a fire resistance of 2 hours are shown for both high-strength (70 MPa) and normal-strength (35 MPa) reinforced-concrete columns.

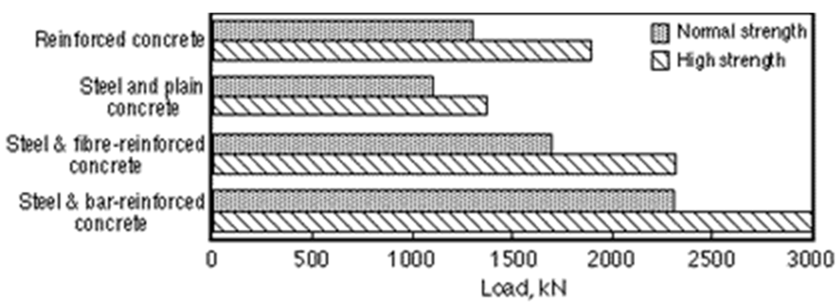

Figure 1.*Maximum load for columns made with normal and high-strength concretes to obtain a fire resistance of 2 hours (section: 300 x 300 mm)*

Models for Predicting Fire Resistance

For a number of years, the NFL has been developing methods for predicting the fire resistance of hollow steel columns filled with concrete (as discussed in "Concrete filling: Fire protection for steel columns". Hollow steel columns are very efficient structural sections for resisting compression loads, but a substantial increase in load-bearing capacity and fire resistance can be achieved by filling them with concrete.

Three types of filling - plain concrete, steel-fibre-reinforced concrete and bar-reinforced concrete - have been studied, and the maximum loads for columns with each filling are shown in Figure 1. The studies on high-strength concrete and concrete-filled steel columns have not yet been completed; therefore the values in Figure 1 are not exact. Some of the maximum loads were derived by extrapolation using experimental data and some by calculation using mathematical models. But the information in the graph does illustrate the order of magnitude of improvement in fire resistance or maximum load that can be obtained by various approaches.

At present, experimental and theoretical studies have been completed for reinforced-concrete columns and fibre-reinforced, as well as bar-reinforced, concrete-filled steel columns made with normal-strength concrete. Validated mathematical models for predicting the fire resistance of these columns as a function of the parameters that determine it have been developed. These models have been programmed by the National Fire Laboratory for computer-processing, in addition to those models already incorporated in the ASCE Manual. The programs can be used to assist designers and regulators to evaluate the fire resistance of building elements for cases where no specific data exist.