fire protection planning report

BUILDING CONSTRUCTION INFORMATION FROM THE CONCRETE AND MASONRY INDUSTRIES

NO. 5 OF A SERIES

An Introduction to Rational Design of Concrete and Masonry for Firesafety

Introduction

During the past 80 years valuable information about the fire resistance of concrete and masonry assemblies has been developed and gathered from the results of fire tests. This information has been used to develop and update building code requirements for fire resistance and safety.

Now there is another way, called rational design, to use this technology to design concrete and masonry structures to withstand the effects of fire. Rational design, or the analytical procedures for determining fire resistance, refers to an engineering method of calculating the duration that a structural element can be subjected to a standard fire test exposure while performing its function, both structurally and as a barrier to heat. The calculations used in this method are based on United States and Canadian standard fire tests and do not depart from current fire-resistance criteria.

The standard fire test for materials and construction used in the United States is ASTM E119. In Canada it is ULC S101.*

FIG. 1. Rational design was used in 1965 to provide adequate fire resistance for the offices of the Department of Housing and Urban Development in Washington, D.C.

Rational Design for Fire Protection

While not intended to replace the results obtained from tests or the listed fire-resistance ratings that have been used successfully for many years, rational design reduces the need for further fire testing of most types of concrete floors and roofs, and concrete and masonry walls. It can also be used to consider the effects of a large number of variables in determining structural fire endurance.

Designing structures for fire resistance in the same manner that structures are now designed to resist gravity loads and lateral loads is the logical extension of present-day structural engineering. Using analytical procedures, all components in a structure can be designed to have a uniform degree of fire resistance. The designer can evaluate the fire resistance of many different assemblies by calculation rather than by test.

Techniques are available for accurately predicting the temperatures within concrete elements exposed to fire. Either computer programs or empirical charts can be used.

Meeting Today's Needs

Rational design of concrete and masonry for fire safety is an extension to testing in accordance with ASTM E119, ULC S101, and the use of listed fire-resistance values. Rational-design methods can eliminate the need for some costly tests. In many cases they will allow a realistic consideration of the effect of a number of variables not included in test specimens.

*_Significance of Fire Ratings for Building Construction_, Fire Protection Planning Report No. 3, SR179H, Portland Cement Association.

Factors Influencing Fire Resistance

Many factors must be considered to determine the effects of fire on concrete and masonry. Some of the more important factors are

1. Type of concrete (aggregates used) or other materials
2. Cross-sectional dimensions of the structural element
3. Type of reinforcement (conventional, prestressed, etc.)
4. Type of support—whether simply supported, continuous, and/or restrained; load bearing or nonload bearing
5. Magnitude and distribution of load
6. Duration and severity of fire

Basic information on behavior of concrete and masonry structures during fire exposure is available from fire research work conducted in North America and Europe.

Considerable research data are available on expansion and other physical properties of concrete, masonry, and steel at high temperatures. Similar data are available on the fire-resistive (protective) properties of other materials used in combinations with concrete and masonry. Fig. 4 shows typical curves for the influence of temperature on the strength of concrete and steel. By knowing the temperature distribution within the concrete element and applying the corresponding material properties, structural engineering principles can be used to analyze the structure. Less complex data that enables an assessment of temperature rise on the unexposed face of floor or wall element is also available.

Designs Depend on Support Method

Tests of simply supported, reinforced (or prestressed) concrete beams and slabs have clearly shown that the structural capacities of beams and slabs can be accurately calculated for any given

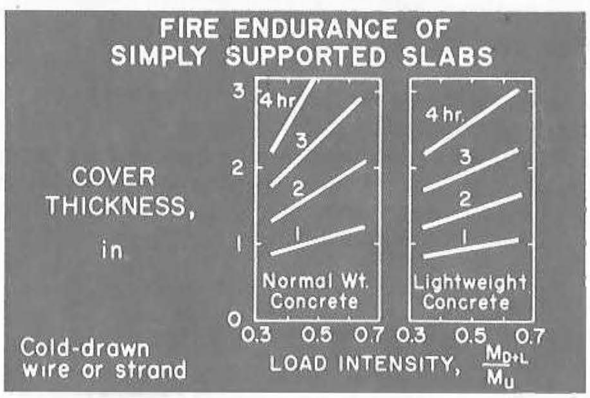


FIG. 2. These graphs show how the results of fire tests and rational-design procedures can be combined to form design aids. By evaluating the effects of cover and load, a rational solution can be obtained.

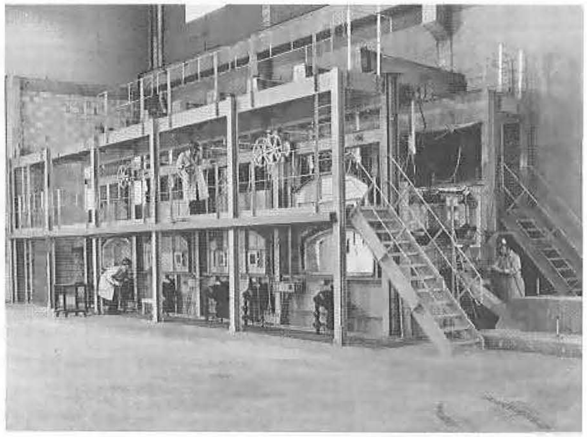


FIG. 3. Testing of beams in furnaces such as this provides valuable basic fire-resistance data but is costly

exposure period. Because the strength of the reinforcement diminishes during a fire test, the structural capacity also diminishes. Data are available that permit designers to determine the temperature of the reinforcement for any given fire-exposure duration. From data on strength-temperature relationships for reinforcing (or prestressing) steels, and from strength-design procedures, the structural capacities are calculated (see Fig. 2.)

However, for continuous (statically indeterminate) concrete slabs and beams, thermal deformations occur that cause changes in stresses in the reinforcement. Stresses in the bottom reinforcement near midspan diminish while stresses in the upper reinforcement over supports increase. This redistribution of stresses increases the fire endurance of reinforced concrete continuous members and frames because the upper bar reinforcement is located farther from the fire, thus retaining its strength better than the bottom steel. The concrete can readily accommodate changes or redistribution of compressive stresses.

Restrained and Unrestrained

Restraining a specimen during a fire test means that thermal expansion of the specimen is restricted. Unrestrained testing allows the specimen to expand. This makes a difference in the test results and in the determination of the reported fire rating for a building assembly. Floor or roof specimens that are restrained generally perform better than when they are unrestrained.

Due to the monolithic characteristics of concrete construction, most concrete structures are framed in a way that provides considerable beneficial restraint and improves fire endurance.

Estimating the Fire Endurance of Walls

In most cases the fire endurance of walls is determined by the fire test criteria for temperature rise of the unexposed surface (side of wall not exposed to fire). Theoretically, the time at which a given temperature will be reached on the unexposed surface of a solid wall of a given material that is subjected to a heat source varies as the square of the wall thickness.

Results of fire tests of concrete or masonry walls show that the test time at which a given temperature rise occurs is not related to the square of the thickness, but rather to a power somewhat lower than two. For solid walls of a given material, it was found that an increase in thickness of 50% resulted in a 100% increase in fire endurance. Thus the fire endurance, R, of masonry walls generally varies according to the thickness, t, raised to the 1.7 power:

$$R = ct^{1.7}$$

where c is a constant for each material.

Tests have also shown that the same formula is appropriate for masonry walls made of cored block or brick in which t is the equivalent thickness of the unit, that is, the net volume divided by the face area of the unit exposed to fire.

Further tests (Ref. 4) showed that the same basic relationship can be used to determine the fire endurance of multiwythe walls:

$$R = (R_1^{0.59} + R_2^{0.59} \ldots + R_n^{0.59})^{1.7}$$

where R = fire endurance of the composite wall in minutes, and R_1, R_2, R_n = the fire endurances of the individual wythes in minutes.

This method of calculation is widely accepted, and can be very useful in evaluating the fire resistance of existing walls and in determining modifications that can be made to these walls to increase their fire resistance.

Building Codes and Rational Design

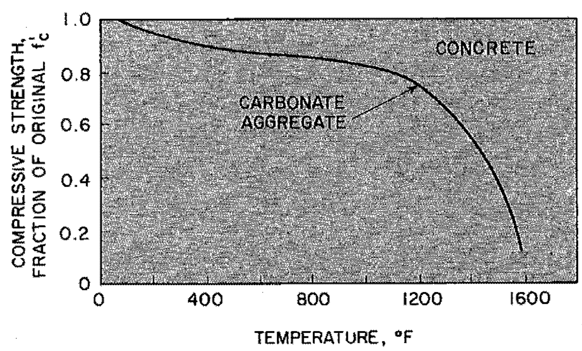
Most building codes contain provisions that permit the use of alternate materials and methods of construction. As a service to building officials, the code-writing organizations in the United States (Building Officials & Code Administrators International, Inc.; International Conference of Building Officials; and Southern Building Code Congress International, Inc.) have research committees that evaluate the alternate materials and methods. The evaluations are printed in research reports.

In August, 1977, the Research Committee of ICBO approved a research report that permits the use of rational design as an alternate to testing for determining the fire endurance of precast, prestressed concrete floors, roofs, beams, and walls.

The state of Wisconsin has permitted analytical procedures for determining the fire resistance of structural components since 1970. Code provisions adopted in 1970 were the first of this nature in the United States. The Wisconsin Department of Industry, Labor and Human Relations now routinely processes designs for fire resistance in much the same way that it processes designs for structures for gravity and lateral forces.

In a similar manner, Insurance Services Office (ISO) permits rational design methods as an alternate for establishing fire insurance rates on untested assemblies.

It is foreseeable that building codes in the future may also require the use of rational design for



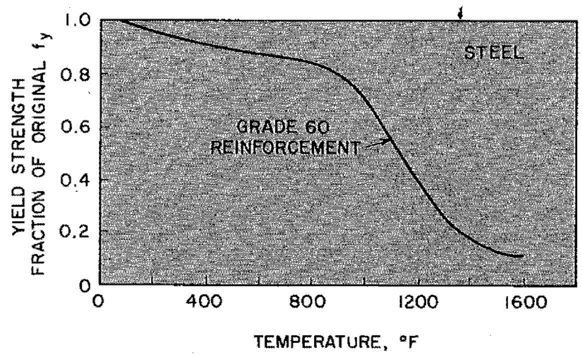


FIG. 4. Typical curves show influence of temperature on the strength of concrete and steel. This information is used for rational-design calculations.

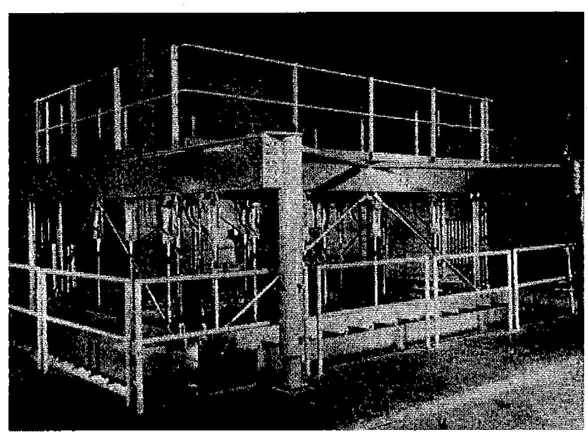


FIG. 5. To study the nature of restraint in concrete floors and roofs during fires, Portland Cement Association built this unique floor furnace. Photograph shows portion of the floor-furnace equipment above floor level. Elements on four sides of specimen serve to support specimen and provide restraint to thermal expansion.

determining the fire endurance of structures as a part of structural-stability calculation.

Building officials, fire officials, insurance rating agencies, architects, engineers, building owners, and government agency personnel should be aware of this technology.

Summary

Fire tests on walls, floors, columns, and roofs as well as the performance of actual buildings in fires have demonstrated that concrete and masonry are highly fire-resistant materials. Much information has been developed from these tests about the factors that determine the fire resistance of concrete and masonry assemblies.

This research information, together with the analytical procedures now available, make it possible to calculate the fire endurance of concrete and masonry components of a building.

The procedure, known as rational design, is becoming an accepted means of designing for structural firesafety. Rational design

1. Provides reliable fire-endurance information based on past research and application of structural engineering principles.
2. Provides opportunities for more economical construction because the designer can evaluate several possible solutions such as changes in cover thickness, slab thickness, quantity of reinforcement, and can modify designs with changing requirements or conditions.
3. Provides a method of determining fire resistance where no tests are available.

Applying well-established engineering principles and research data to a rational design method for structural behavior is a versatile approach for evaluating the effects of fire on concrete and masonry structures.

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Organizations represented on the CONCRETE AND MASONRY INDUSTRY FIRESAFETY COMMITTEE

BIA	Brick Institute of America
CRSI	Concrete Reinforcing Steel Institute
ESC&SI	Expanded Shale Clay and Slate Institute
NCMA	National Concrete Masonry Association
NRMCA	National Ready Mixed Concrete Association
PCA	Portland Cement Association
PCI	Prestressed Concrete Institute

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