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CBD 53

Fire Endurance of Building Constructions

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Please note

The fire endurance (or resistance) of the enclosing elements of a compartment in a building is the major obstacle to the spread of a fully developed fire. Modern building codes require building constructions to have varying degrees of fire endurance, depending on the quantity of combustible material normally found in the occupancy for which the building is designed. The quantity of combustible material per square foot of floor area is commonly referred to as the "fire load", a term that has been discussed in**CBD 33**.

Early Fire Tests

Prior to the turn of the century, fire tests were carried out in England and the United States in small buildings, the walls or roof of which were the constructions under test. Edwin Sach of England and Professor Ira Woolson in the United States pioneered this field of fire testing. Fuel was generally wood with a little pitch added, and drafts were adjusted by moving dampers on chimneys located on the roofs of the test structures. Temperatures were measured by thermocouples connected to indicating potentiometers. In early tests at Columbia University it was found that one cord of wood provided enough fuel for a one-hour test in these small buildings.

Development of Fire Endurance Tests

In the early 1900's a number of workers in various countries began the development of a standard time-temperature curve for use in fire endurance tests, taking advantage of the experience gained in the early fire tests. In 1918 such a curve was prepared in the United States by a conference sponsored by the American Society for Testing Materials, Committee on Fireproofing, and the National Fire Protection Association, Committee on Fire-resistive Construction. Subsequently, the curve was validated by burn-out tests conducted by the National Bureau of Standards under the direction of Mr. S. N. Ingberg. Additional tests established a relationship between fire load and the duration of a fire corresponding to a fire endurance furnace exposure (see **CBD 33**). The National Bureau of Standards also carried out surveys of ten types of occupancies to determine weights of combustibles per square foot of floor area. This information makes it possible to evaluate the severity and duration of a fire in terms of material available for burning.

Fire Resistance Tests

Fire endurance is defined by ASTM as "a measure of the elapsed time during which a material or assembly continues to exhibit fire resistance under specified conditions of test and performance. As applied to elements of buildings it shall be measured by the methods and to the criteria defined in the *Methods of Fire Tests of Building Construction and Materials* (ASTM Designation E119) or the *Standard Methods of Fire Tests of Door Assemblies* (ASTM Designation E152)." These methods of test attempt to reproduce to some degree the circumstances encountered in actual building fires. For example, a load-bearing element must be so loaded during the fire test that stresses approximating those contemplated in the design are produced in the structural members, a non-load bearing element must be restrained during the fire test as it would be in practice. In other words, a building element must continue to perform its structural function satisfactorily while subjected to fire exposure.

The test specimen should be of a size as representative as possible of the actual element for which an evaluation is desired. The ASTM specification requires a minimum of 180 square feet for a floor and ceiling specimen. When the specimen has been loaded or restrained, as the case may be, it is placed in a furnace and subjected to a fire exposure defined by a time-temperature curve. The ASTM curve has a steep section at the start, reaching 1000°F in 5 minutes and levelling off so that it will attain 1700°F in 1 hour. The curve then increases at the rate of approximately 150°F per hour. These temperatures are measured by nine thermocouples located in the furnace chamber at fixed distances from the specimen. The steep section of the time-temperature curve represents conditions in a rapidly developing fire. The flat portion of the curve is concerned with the duration of the fire and is related to the amount of combustible material available in an occupancy. Although the test terminates at some point on the flat portion of the curve, a time-temperature curve of a typical fire would also have a portion catering to the extinguishing or decay period of the fire. For the evaluation of building constructions this latter phase of a fire is neglected.

Three basic types of failure of the test specimen are specified in ASTM Standard E119:

(i) temperature rise of more than 250°F above the initial temperature on the side of the specimen not exposed to the fire;
(ii) collapse;
(iii) formation of wide cracks.

The temperature rise criterion ensures that combustible material piled next to that side of the wall or floor not exposed to the fire will not ignite. The temperatures on the unexposed side of the specimen are measured by thermocouples placed under asbestos pads. This procedure approximates the conditions that might occur if materials were stored on a floor or abutting upon a wall. The materials would serve as an insulating layer, allowing the surface temperature of the enclosing element to rise more quickly than if it were exposed to ambient air. If they were combustible then ignition would take place.

The criterion regarding collapse applies particularly to load-bearing elements such as beams and columns that do not act as enclosing elements but do support such elements. This provision is of particular significance to fire fighters attempting to extinguish a fire in a building.

The provision that wide cracks shall not develop ensures that during a fire cracks or fissures will not open in a building element to allow hot gases to pass through and ignite combustibles on the side of the wall removed from the fire.

In testing the fire endurance of doors or other closure devices used in openings in a building element, the temperature rise criterion is waived, but the door or other device must remain in place. This omission of the temperature rise requirement is based on the fact that materials should not be piled next to a fire door through which people or goods must pass. It is considered sufficient that the element of construction resist the passage of flames for a specified period of time.

Fire Endurance Test Facilities

At the Division of Building Research there are two large furnace installations for carrying out fire endurance tests in accordance with standard fire test methods of the American Society for Testing and Materials or the British Standards Institute. The wall furnace can accommodate specimens 14 by 14 ft. with an area 12 by 12 ft exposed to fire. Provision has been made in this furnace to impose loading by means of hydraulic jacks or restraint by means of frames and jacks. The floor furnace accommodates specimens 12 by 15 ft. Floor and ceiling and roof assemblies are built into frames and loading is applied to the top surface by means of hydraulic jacks. Although the Division does not have a separate column furnace, which would allow loads to be applied on a column during a fire test, the floor furnace is deep enough to allow an alternate ASTM test to be performed in which the criterion for failure is related to the temperature of the structural steel member protected. This alternate test also applies to structural steel beams that can thus be tested in the floor furnace. The Underwriters' Laboratories of Canada, Scarborough, Ontario, also maintain fire test facilities. They have furnace installations for testing floor or roof assemblies, including their structural members.

National Building Code Fire Endurance Requirements

The fire resistance requirements for building elements are an important part of all building codes. In the *National Building Code of Canada, 1960*, Part 2, Use and Occupancy, the heights and areas of buildings for various occupancies are regulated, depending on the fire resistance of the building elements. The fire resistance requirements depend, in general, on the nature of the occupancy. For example, the storage of combustible material in large quantities requires that a building construction have a much higher fire resistance rating than is required of an occupancy having a minimum quantity of combustible furnishings or goods. One exception to this principle is tall buildings where the load-bearing elements must have greater fire resistance than would be required of lower buildings. In the *National Building Code of Canada, 1960*there is also a requirement that for certain occupancies "fire resistive" construction must be used. Fire resistive, in this instance, means that the construction shall not only have a fire resistance rating of 1 hour or more but shall be noncombustible. The National Building Code requires that fire resistance ratings be assigned to constructions on the basis of tests carried out in accordance with the appropriate ASTM or BSI fire test methods.

Fire Resistance Ratings

Normally the building authority has the right to assign fire resistance ratings to constructions. All reports of standard fire tests contain information on which a rating can be established. In the National Building Code a supplement is published under the auspices of the Associate Committee on National Building Codes that assigns ratings to various common constructions, which are adequately identified by description. This publication is *Fire Resistance Ratings 1961*, Supplement No. 2 to the *National Building Code of Canada, 1960*. A number of other organizations publish lists of ratings, including the Underwriters' Laboratories both in Canada and the United States. The Underwriters' Laboratories of Canada publish a *List of Inspected Appliances, Equipment, and Materials*; the Underwriters' Laboratories Incorporated of Chicago publish a *Building Materials List*. These contain ratings for specific constructions. Unfortunately, in many instances proposed constructions vary to some extent from those tested and it may be necessary to evaluate a construction on the basis of information that is available, since it will seldom be possible to carry out a test on short notice. There are a number of rules based on known facts that may prove useful in the quick appraisal of the fire endurance of building elements.

Rules of Fire Endurance

1. The "thermal" fire endurance or resistance to temperature rise of a construction consisting of a number of parallel layers is greater than the sum of the "thermal" fire endurances characteristic

of the individual layers when exposed to fire separately. It may be noted that there are a few cases in which the above rule may not be applicable. If, for example, the unexposed surface is covered with a thin, shiny metal sheet, the heat transfer to the surroundings may become very low. As the insulating value of the sheet is negligible, the fire endurance of the construction might be lower than it would be without the presence of the sheet.

2. The fire endurance of a construction does not decrease with the addition of further layers, although some exceptions exist for this rule. For example, the addition of a thin metallic layer to an unexposed surface does reduce the fire endurance of the existing construction because it restricts heat transfer to its surroundings. A new layer applied to the exposed surface must have thermal expansion characteristics similar to those of the adjacent layer so that thermal stresses are not set up in the construction. The new layer must be capable of contributing to the load-bearing capacity of the construction at least as much as is required to carry the increased dead load.
3. The fire endurance of constructions containing continuous air gaps or cavities is larger than the fire endurance of similar constructions of the same weight containing no air gaps or cavities. Constructions containing combustible materials along an air gap may be regarded as exceptions to this rule, because of the possible development of burning in the gap.
4. The further an air gap or cavity is located from the exposed surface the more beneficial is its effect on fire endurance.
5. The fire endurance of a construction cannot be increased by increasing the thickness of a completely enclosed air layer.
6. Layers of materials of low thermal conductivity are better utilized on the side of the construction on which fire is more likely to occur. This rule may not be applicable to materials undergoing physico-chemical changes accompanied by significant heat adsorption or heat evolution.
7. The fire endurance of asymmetrical constructions depends on the direction of heat flow.
8. Moisture increases fire endurance if it does not result in explosive spalling. The extension of fire endurance may be as high as 7.5 per cent for each per cent (by weight) of moisture. Materials of low permeability (dense concretes) are liable to explosive spatting if the moisture content is higher than a critical value. Is seems probable, however, that after a few years' aging in normal service the moisture content will always be significantly lower than this critical value.
9. Beams, girders, and joists incorporated as a part of a floor, roof or ceiling assembly have greater fire endurance than they have acting separately. During a fire test the beams and girders are exposed to very high temperatures at a stage when the floor or roof deck is hardly affected by the heat. As the beams deflect, an increasingly large proportion of the load is transmitted directly to the walls or columns by the floor or roof slab. Thus the load carried by the beams or joists gradually decreases. This is in contrast with what happens when the load-supporting elements are tested separately and the imposed load is constant and equal to the design load throughout the test.
10. Beams, girders, or joists of a specific type incorporated in a floor, roof or ceiling assembly can be replaced by other load-supporting elements provided the fire endurance of the new members, when tested separately, is not less than that of the original assembly. Replacement must not be made unless fire resistance test results are available showing the performance of the individual elements acting alone and not as a part of an assembly.

The framing members of light frame construction, whether wood or steel, will have relatively short fire endurance (often no more than 10 minutes) if exposed directly to fire. This applies to floor-ceiling assemblies as well as to walls. The cladding on the side exposed to the fire, whether in board form or plaster base and plaster, will largely determine the fire endurance of the construction. Failure occurs more commonly by collapse than by rise of temperature on the unexposed face and can occur rather quickly once the protection of the cladding has been lost either by rupture or because it has fallen out of place. Consequently the nature of the cladding and its ability to remain in place have a major influence on the fire endurance of such constructions. The spacing of supports, the manner of fastening, and the amount and kind of wire, mesh, or other reinforcement may be particularly important in this respect.

Load-carrying structural members such as beams and columns that depend upon steel for their structural performance will usually fail by collapse resulting from softening and accelerated creep of the steel under load once the temperature at the steel exceeds 1000 to 1200°F. The fire endurance of such members will depend on the rate at which heat is allowed to flow to the steel by the protecting material and by the heat storage capacity of the member. Together, these determine when limiting temperatures will be reached.

The fire endurance of reinforced concrete slabs may be limited either by collapse or by temperature rise on the exposed side. The total thickness and density of the concrete will govern the latter; the thickness of cover over the steel reinforcing on the side exposed to fire will in general govern the time to collapse. Thus, both become important considerations in assessing the probable fire endurance of these constructions.

Conclusion

With increased information about the response of materials to fire exposure it will ultimately be possible to predict the fire endurance of many constructions. Much remains to be done, however, before this can be achieved, and it is still necessary to rely heavily upon the results of large-scale standard tests in deciding how individual constructions will behave. It must be clearly understood that variations in dimensions, loading conditions, materials or workmanship may markedly affect the performance of constructions. As the extent of such effects cannot be evaluated solely from tests, individual experience and judgement must be brought to bear in rating their possible performance.