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Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/40001414
Paper (National Research Council of Canada. Institute for Research in Construction), 1987

National Research Council Canada
Conseil national de recherches Canada

Institute for Research in Construction
Institut de recherche en construction

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Appeared in
Proceedings
1987 CSCE Centennial Conference
Montréal, Québec, May 19-22, 1987
Vol. 1, p. 3-19
(IRC Paper No. 1529)

Price $3.00

NRCC 28877

Canada

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PROVISION OF FIRE RESISTANCE - EVOLUTION OF DESIGN APPROACHES

G.C. Gosselin and T.T. Lie[1]

ABSTRACT

The idea of making a building "fireproof" evolved late in the 19th century in an effort to cut down escalating property losses. The concepts of compartmentalization and structural fire protection now play important roles in the building codes' approach towards the provision of a minimum level of life safety in buildings. On the other hand, property protection against fire no longer appears to be an objective pursued by designers who instead rely on listings of tested assemblies to satisfy the minimum requirements of building codes.

Notwithstanding the emergence of new calculation procedures for assessing the fire resistance of building elements and assemblies, their use as an alternative to more conventional design approaches remains rare. It is suggested that formal training in this area and the development of user-friendly, PC-driven software would encourage the use of more scientifically-based methods and possibly lead to more cost-effective designs.

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PREVOIR DE LA RESISTANCE AU FEU - EVOLUTION DES MÉTHODES DE CONCEPTION

G.C. Gosselin et T.T. Lie[1]

RESUMÉ

L'idée de construire les bâtiments à l'épreuve du feu date de la fin du 19ème siècle alors que les propriétaires et les compagnies d'assurance décidèrent que les pertes matérielles devenaient trop importantes. Les concepts de compartimentation et de protection de la structure contre le feu jouent maintenant des rôles importants dans la façon que les codes du bâtiment assurent un minimum de sécurité au public dans les bâtiments. Cependant, la protection de la structure du bâtiment ne semble plus paraître parmi les objectifs des concepteurs qui se contentent de vérifier les listes d'assemblages mis à l'essai afin de satisfaire les exigences minimales du code du bâtiment.

Bien que plusieurs méthodes de calcul sont maintenant disponibles pour déterminer la résistance au feu des éléments et assemblages de construction, leur utilisation dans le processus de conception demeure l'exception plutôt que la règle. L'auteur suggère qu'une éducation accrue à ce sujet ainsi que le développement de logiciel simple et supporté par les micro-ordinateurs encourageraient considérablement l'utilisation de ces méthodes scientifiques et résulteraient peut-être à des économies de construction.

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INTRODUCTION

The idea of protecting our structures against the effects of fire dates back only a century, despite man's long history of loss and suffering due to fire's destructive force. Fire prevention codes have been in effect much longer than this, but they dealt primarily with inspection activities, the provision of fire fighting equipment and manpower, as well as ordinances aimed at preventing unwanted fires. These early protection measures simply could not handle the conflagrations which repeatedly struck our cities as a result of wars, earthquakes and human greed.

As property and human losses took their toll on society's tolerance, some designers started to make greater use of fire resistive materials (e.g. steel, plaster) for the construction of buildings, realizing that it would help minimize both the spread of fire and the amount of damage sustained by each structure. On the other hand, self-regulation of construction practices was far from being effective due to the lack of individual economic incentives. The insiduous notion that "it won't happen to me" was already very much ingrained in peoples' minds. Besides, if it were to happen, insurance companies would cover the loss, would they not?

Unfortunately, insurance companies were not beyond destruction themselves. As a result of the Great Fire of Boston in 1872, for instance, more than 70 insurance companies had to declare bankruptcy (National Fire Protection Association 1984). Needless to say, the eventual public outcry for more protection spurred the development of building codes that were administered locally as municipal bylaws. Since fire protection engineering practice was in its infancy (and still is today according to many), the principles of fire protection applied in the building regulations of the mid-1800's were quite basic: provide means of egress and make maximum use of noncombustible construction materials wherever you can.

EARLY EFFORTS AT PROVIDING FIRE RESISTANCE

The state-of-the-art in noncombustible construction in the middle of the 19th century consisted of masonry exterior walls with an interior structure of cast iron columns, girders and floor beams. The extensive use of metal in buildings had been made possible by the establishment of mills capable of rolling I-beams and other sections. It was soon realized, however, that even this type of construction possessed very little resistance to severe fires, as the iron members elongated and distorted when exposed to elevated temperatures, damaging the masonry walls in the process.

By the end of the nineteenth century, there was a general recognition of the necessity to protect metal building elements against high temperatures (Schoub 1961). Flat hollow-tile arches were introduced in 1872 that allowed attachment of plaster protection to the bottom flanges of floor beams. A year later, porous terra cotta appeared on the market and, by 1880, was offered in the form of blocks that could be used to enclose and protect columns. These developments, combined with an increasing use of fire resistant partitions, doors and shutters to protect openings and create compartments, helped contain fire to a manageable size, prevent conflagration and minimize property and life losses (Shoub 1961).

NEED FOR FIRE RESISTANCE TESTING

As no means existed to assess and compare the performance of the various noncombustible materials being offered in the marketplace, building regulators were restricted to the development of lengthy and cumbersome specification-type requirements which essentially dictated to the designer which materials could or could not be used in the construction of a building. Naturally, this was the source of considerable frustration to designers and owners who were quite limited in their choice of materials. Concurrently, product manufacturers were continually developing new proprietary building materials and were pressing the authorities for fair and equitable recognition of their products.

The need for fire testing soon became evident as the only possible way of objectively evaluating the performance of new products and assemblies, so that they could be accepted as equivalents to more conventional constructions. Another impetus to carry out fire tests came from the fact that, though new methods of construction and the development of small passenger lifts and elevators made greater building heights (up to 45 m) economically achievable, fire fighting in the early skyscrapers presented tremendous problems given the equipment and means available at that time. Hence, it became necessary to verify that the building's skeleton or structure would remain standing even after a complete burnout of the combustible materials contained in the building, assuming that fire fighters would not be able to control and extinguish the fire at an earlier stage of its development.

In North America, the first floor test was conducted in Denver in 1890 on behalf of the Denver Equitable Building Company (American Architect and Building News 1891). The name of the company itself suggested that their business centered around the objective of developing and using new proprietary materials and products in building construction. The aim of this "landmark" test was to have the use of porous hollow tiles officially accepted in lieu of bricks for the floor arches spanning between iron beams. The floor specimen was subjected to static and impact loads, fire and water erosion tests. The fire test, conducted on a specimen with no superimposed load, consisted of a continuous exposure to a temperature of 700°C (1300°F) for a 24 hr period, an exposure which the arch construction managed to survive with little sign of damage.

In 1891, floors made up of cinder concrete arches, laid between I-beams and protected by a flat ceiling of tiles hung from iron bars, were tested in the hope of obtaining authorization for their use in a new office building in St-Louis (Freitag 1899). After having been subjected to a load test, the floors were exposed to an 815°C (1500°F) fire for a 6½ hr period and then cooled. The heating/cooling cycle was repeated three times before a 19 mm hose stream was finally applied from underneath to verify the post-fire resistance of the floor to the erosion effects of fire fighters' water sprays. With the exception of a few minor cracks, the floors were reported as being practically undamaged with no deflection.

It is interesting to note how conservative designers and regulatory authorities were in the absence of experience or knowledge of what might constitute a realistic fire exposure in terms of intensity and duration and what level of performance should be regarded as safe and acceptable. It was nevertheless pioneering work of this kind which opened the door to fire research and, eventually, to the establishment of less costly construction requirements.

Freitag (1899) also reported on what was likely the most comprehensive series of tests conducted in those early years, that is the New York Building Department tests in 1896. The Building Department constructed a number of kilns on vacant lots around the city and tested a total of 14 floor/ceiling assemblies submitted by private construction companies. Again, the purpose of the tests was to allow new and different floor structures to be recognized as offering a level of safety equivalent to those specified in the building regulations of the day. All assemblies were of the iron beam and arch form construction with ceilings plastered.

The test procedure employed was later incorporated in the 1899 New York City Building Code, representing the first-ever fire performance test legally recognized in North America. Out of this precedent emerged nothing less than a revolution in building design and construction. No longer being restricted to the types of materials and forms of construction specifically described in the regulations, designers finally had a means of applying their ingenuities to developing more efficient and less costly forms of construction, and taking advantage of the possibilities afforded by new construction materials and products.

For the first time, the procedure called for loading of the floor system to 7.2 kPa (150 psf) <u>during</u> the fire tests to simulate a more realistic condition. With the use of wood cribs temperatures were maintained as close as possible to 1100°C (2000°F) for 5 hrs. After the test, a 414 kPa (60 psi) hose stream was applied to the underside of the assembly. The load was then removed and the floor reloaded to 29 kPa (600 psf) for a 48 hr period with the load resting entirely on the arches. No ratings were assigned to the floor constructions tested. The merits of each respective assembly were apparently judged from observations of the damage sustained by the specimen.

Although the reason for the post-fire load test has not been documented, it is speculated that re-utilization of a building's skeleton or structure in the aftermath of a fire was a design objective considered desirable by owners and insurers. This way fire losses, including business interruption losses, could be reduced by allowing a quicker refitting of the building. At any rate, the importance placed on post-fire performance certainly suggests that property protection was the primary motivation in the carrying out of early fire tests.

DEVELOPMENT OF A STANDARD TEST METHOD

As a result of the increasing interest in fire testing spurred by the 1899 Building Code Amendment, a decision was made to have a fire test station constructed at Columbia University. Completed in 1902, the Station was capable of testing floors measuring 5.5 m × 6.7 m and partitions 3 m × 4.6 m (Woolson and Miller 1912).

While Columbia University was conducting tests under the direction of Professor Ira Woolson, a committee was organized by the American Society for Standard Testing and Materials in 1905 with the mandate to develop an appropriate test standard. Since Prof. Woolson also chaired this Committee (the predecessor of ASTM Committee E5 on Fire Standards), it is not surprising to find that the test procedure submitted for adoption as a standard resembled very closely that followed at Columbia University (Schoub 1961). The test method prescribed that a furnace temperature of 930°C be maintained for all but the first 30 minutes of a 4 hr test, and that the specimen carry a superimposed load of 7.2 kPa during the test and 414 kPa after cooling.

Eventually adopted in 1908, the standard specified the following acceptance criteria:

(a) no passage of smoke or fire through the floor,
(b) no collapse as a result of the hose stream test,
(c) no damage that would make the assembly incapable of sustaining loads.

The following year, test requirements for partitions were included in the standard. The furnace temperature was the same but the test was of a shorter duration (2 hr), suggesting that horizontal spread of fire by the collapse of a partition was not considered as hazardous to occupants and fire fighters as vertical spread by the collapse of a floor. The criteria for acceptance, or passing the test, were similar to those for floors.

Although these early tests contributed significantly to the development of essentially noncombustible and fire resistant floors and partitions, heavy losses were still suffered due to the inability of noncombustible steel columns to support loads at elevated temperatures. In 1917-1918, an extensive series of column tests were conducted at

Underwriters' Laboratories in Chicago in cooperation with the Associated Factory Mutual Companies, the National Board of Fire Underwriters and the U.S. Bureau of Standards (Ingberg et al 1921). A total of 106 structural steel, cast iron and timber columns were tested. Although most columns were protected with either hollow tiles, brick, gypsum block, metal lath and plaster, or reinforced concrete, some were left bare to serve as control specimens.

The historical significance of these tests lies in the utilization of a new temperature versus time heating exposure, which was incorporated the following year in the ASTM standard, and has since been adopted by other national and international standards writing organizations around the world in a slightly revised forms. The rapidly increasing temperature curve depicting the heat exposure (see Figure 1) is still the one used today as specified in the ULC standard CAN4-S101, Standard Methods of Fire Endurance Tests of Building Construction and Materials (Underwriters' Laboratories of Canada 1982). The curve was apparently established on the basis of maximum temperatures in real fires, observed by using as references the fusion of materials of known melting points (Pearce 1983).

Another significant feature of the 1918 edition of the ASTM standard was the new provision that tested specimens be classified according to their obtained degree of fire resistance, i.e. the length of time or period the specimen could sustain the prescribed fire exposure and still meet the performance criteria specified (Shoub 1961). We now denote this characteristic a "fire-resistance rating". That classification scheme offered a new design possibility whereby buildings could be erected with a level of fire protection or fire endurance judiciously selected to withstand the severity of an unwanted fire in some part of the premises.

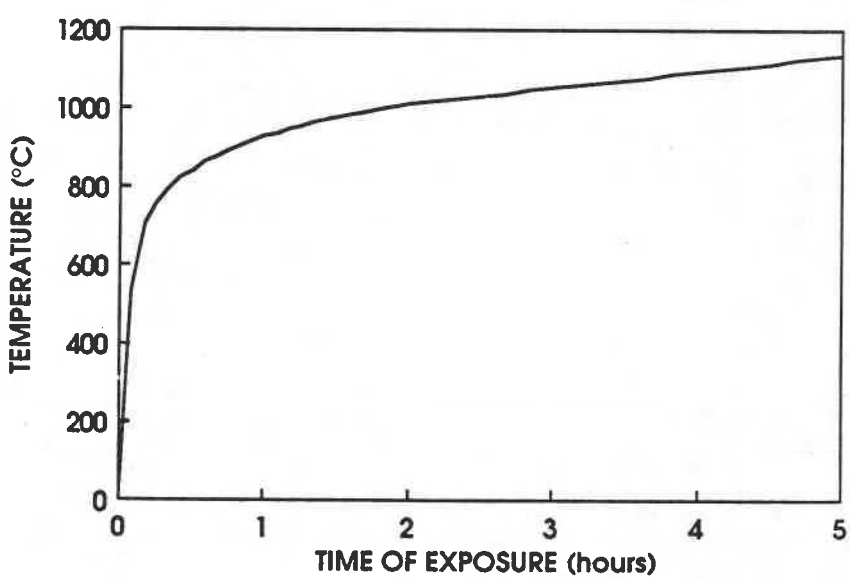

Figure 1. Standard temperature-time curve.

An economical consideration arose, however, which prevented the use of this fire design scheme in practice: a formidable number of fire tests, each utilizing a different severity of exposure, would have been necessary to determine the appropriateness of using a certain assembly of materials to counter the destructive potential of the various fires anticipated in real situations. Testing for the worst conditions, estimated to be equivalent to a 4 hour exposure to a fire that followed the standard temperature-time curve, would certainly have been adequate. However, it suggested considerable wastage of materials in the case of buildings in which less severe fires were expected because of small combustible contents. Building officials and designers likely surmised that a shorter exposure to the very severe fire simulated by the standard temperature-time curve would likely simulate a less severe fire, but no one could verify whether or not these test fires would actually bear any similarity for the real-world fires as far as their effects on building assemblies were concerned.

ESTABLISHMENT OF FIRE RESISTANCE REQUIREMENTS

It was not until 1928 that a means of determining a relationship between a "standard" fire and a real fire was proposed by S.H. Ingberg, Chief of the Fire Resistance Section at the U.S. National Bureau of Standards (Ingberg 1928). Ingberg had conducted a series of full-scale room burns with various amounts of combustible contents, or fire loadings, selected so as to be representative of office, record storage and household occupancies. On the basis of these tests, in which he recorded room temperatures as a function of time, he proposed the equal area hypothesis to compare the severity of a real fire to that of a standard fire of specified duration. The hypothesis essentially assumes that the severities of the actual and test fires are similar if the areas under their respective temperature-time curve above a base level are equal, as illustrated in Figure 2.

Although since having been demonstrated not to be scientifically correct (Harmathy and Lie 1970), the "rule of thumb" relationship proposed by Ingberg between fire load and equivalent duration of standard fire exposure was readily adopted by code authorities for lack of a better or more convenient way of assessing necessary levels of fire resistance (see Table 1). To assist in the application of the concept, numerous fire load surveys were conducted in the following years in existing residences, offices, schools, hospitals, as well as mercantile and manufacturing establishments (National Bureau of Standards 1942; Ingberg et al 1947). The surveys involved the actual weighing of all movable combustible contents and estimating the weight of fixed furnishings and combustible lining materials.

Armed with fire loadings deemed representative of each major occupancy, code writing bodies had a complete set of information which they could use, and indeed have used, to set fire resistance requirements for various buildings on the basis of their expected types of occupancy

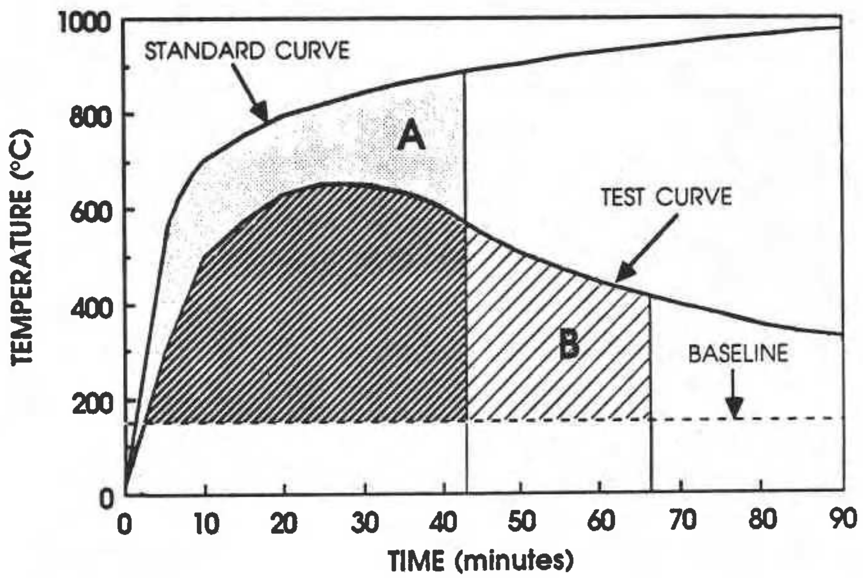

Figure 2. Ingberg's hypothesis - equal fire severities if A = B.

Table 1. Relationship between fire load and fire severity (Ingberg 1928)

Combustible content*		Standard fire exposure duration (hours)
(lb/sqft)	(kg/m^2)	
5	24.4	½
7½	36.6	¾
10	48.8	1
15	73.2	1½
20	97.6	2
30	146.5	3
40	195.3	4½
50	244.1	6
60	292.9	7½

*Combustible content expressed as equivalent weight of wood (with respect to calorific value) per floor surface area.

(i.e. office, residential, mercantile, etc.). However, the committees responsible for writing the codes recognized that fire load data were based on average rather than extreme conditions and, also, that other factors, such as the height and area of buildings, the ability of the occupants to evacuate quickly, degree of awareness of fire conditions, fire fighting capabilities, etc., should influence their decisions. Consequently, fire resistance requirements are often specified which in some cases are inflated over the levels or ratings which would be suggested by a strict application of Ingberg's guidelines.

In Canada, the structural fire protection requirements have been relaxed considerably since their introduction in the first edition of the National Building Code in 1941 (National Research Council of Canada 1941). Now rare are requirements which call for a fire-resistance rating exceeding 2 hrs (some firewalls and floor levels below grade are notable exceptions) (Associate Committee on the National Building Code 1985a). Although not well documented the relaxations may have been based on the following considerations:

(1) Requirements were tempered with the experience gained relative to the effectiveness of certain control measures; for instance, evidence that compartmentation requirements, which aim to either isolate fire to a small area (floor-to-floor fire separation) or protect an area of refuge from the effects of fire (fire separation of exits), were effective. The increased confidence in the control measures suggested that safety factors indeed were high and could thus be reduced.
(2) Better fire fighting capabilities meant that a fire suppression attack could be mounted earlier and more effectively, reducing the need for passive fire protection.
(3) It has been realized that less stringent requirements would still be sufficient to ensure safety to life, the primary objective of the National Building Code of Canada. Minimum property protection is not an objective of the NBCC and therefore need not be completely accommodated by current fire protection requirements.

The fact that little and sometimes no structural fire protection is required for smaller buildings, which people can evacuate before any collapse of the structure takes place, illustrates the third point well. But amidst all these changes, what has become of the design profession?

Since the early twenties, a tremendous amount of fire resistance tests have been conducted at laboratories across North America, yielding a wealth of data on the fire resistive properties of materials and assemblies. By and large, these data are mostly available to the design professional. Listings of the results of proprietary tests conducted on specific designs are available in Canada from testing organizations such as Underwriters' Laboratories of Canada and Warnock Hersey (Underwriters' Laboratories of Canada 1984; Warnock Hersey Professional Services 1986). Furthermore, where the fire resistance of an assembly depends strictly on the specification and arrangement of materials for which nationally-recognized standards exist, generic fire-resistance ratings have been developed by the Associate Committee on the National Building Code on the basis of supportive test results. These assigned ratings are published in Chapter 2 of the Supplement to the NBCC 1985 (Associate Committee on the National Building Code 1985b).

It seems, however, that the proliferation of available test results for conventional construction assemblies has been a mixed blessing for the design profession. It certainly has effected substantial savings in construction by reducing the need for costly fire resistance tests each time a new project is considered. On the other hand, it has also severely restricted design innovations by enticing engineers to specify already tested designs instead of engineering new systems. It is a fairly common practice now for the design professionals (architects or engineers) to discharge themselves of their responsibilities in meeting the fire resistance requirements of the Code by simply verifying that their design is covered by Chapter 2 of the NBC Supplement or one of the published proprietary listings. This practice has contributed significantly to the separation of fire resistance and structural design processes, with some unfortunate consequences. For example, designers (and owners) may not realize that current code requirements do not guarantee a satisfactory minimum level of property protection for buildings, an objective which may still be worthwhile to pursue strictly from an economic point of view.

CONTEMPORARY FIRE SAFETY DESIGN

In recent years, considerable research has been undertaken at institutions around the world with a view to developing analytical methods for calculating the fire resistance of structural elements and assemblies. This effort has produced a number of algorithms which rely on empirical or semi-empirical equations and are fairly well validated by test results. Calculation procedures are available for a wide spectrum of primary material/structural component combinations, such as reinforced concrete columns and slabs, prestressed concrete beams, laminated timber beams and columns, steel columns protected from the outside by an insulating membrane of gypsum wallboard or sprayed-on material or, from the inside, by plain or reinforced concrete. Most calculation methods are restricted to relatively simple loading cases such as concentric loads and pinned end conditions, but work is underway to extend the validity of the predictive algorithms to a wider array of design conditions including fixed or partially-fixed end conditions, eccentric loading, etc.

It is not the purpose of this article to offer a comprehensive review of the calculation methods now available. Excellent reviews, including comments on the limitations of each method, have been published by others recently (Malhotra 1982; Milke 1985; Barnett 1985). A brief description of the analytical techniques will be presented, however, to highlight the scientific principles utilized, and to encourage practicing engineers to explore the potential of these new design tools.

The complete problem of designing for fire resistance can be broken down into three components: characterization of the expected fire severity, estimation of the heat transmission in the construction, and knowledge of the effects of elevated temperatures on the performance of the load-bearing components of the construction.

Fire Severity

Of all the components of fire resistance design, the prediction and appropriate characterization of the severity of the fire to be expected in a particular area of the building being designed is undoubtedly the one area which structural engineers are most ill-prepared to address. Fire is a complex phenomenon and its understanding requires knowledge of chemical kinetics, fluid mechanics, heat transfer and thermodynamics. Realistically, one cannot expect designers to acquire an in-depth knowledge of all these branches.

Only two options are then available. The first is to rely on the validity and accuracy of preflashover and post-flashover computer models developed by others. (The term flashover refers to the rapid transition from a relatively steady burning, localized fire in a room to a fully-developed fire in which all exposed combustible materials burn due to their ignition temperature having been reached.) The development of preflashover fire models is in an embryonic stage, however, so that the preheating effects in the early stages of a fire on the performance of a structural member can only be taken into account by making some rough assumptions. By contrast, the development of post-flashover or fully-developed fire modelling is significantly more advanced due to the possibility of making certain simplifying assumptions that do not greatly alter the accuracy of the results. Reasonable accuracy appears to be achievable by some of the models under certain well-defined conditions with respect to quantity and type of combustible load, the presence of openings for ventilation and the thermal characteristics of the finish materials lining the room boundaries (Mehaffey and Harmathy 1985). However, the lack of control the designer has in practice over some of these parameters dictates that they must be carefully selected so as to reflect the worst conditions likely to occur during the design life of the building. This may not always be practical, e.g. in the case of a speculative building.

The second option open to designers is to utilize a numerical description of the heat exposure conditions prevailing during a standard fire test instead of one describing the expected severity of the real-world fire. Clearly, this is not optimal because an actual fire can follow a temperature versus time history quite different from that specified in the standard. Nevertheless, this design approach has the convenience of allowing a prediction of the fire-resistance rating the structural assembly would achieve if subjected to a standard fire test, a performance measure which authorities readily recognize.

Heat Transmission Analysis

Given a satisfactory characterization of the heat exposure, the designer may turn his/her attention to computing how quickly temperature will increase at various sections within the structural components. Isotherms or temperature profiles may then be plotted to give an instantaneous picture of the temperature distribution within the member at any given time in the course of the fire.

Here, the designer can benefit from the numerical help provided by calculational tools specifically developed for this purpose. For example, TASEF-2 and FIRES-T3 are two computer programs for calculating heat transfer from fires to structures (Wickstrom 1979; Iding et al 1977). Both rely on the finite element technique, one in two dimensions (TASEF-2), the other in three dimensions (FIRES-T3). Computer routines have also been developed based on a finite difference numerical technique (Lie 1984). The main difficulty underlying these approaches is the inadequate knowledge of the temperature-dependence of material properties. Still, in simple cases where the structural element is relatively homogeneous (e.g. steel), a great deal of accuracy is possible.

Although different fire exposures can be used, most calculation methods utilize the standard temperature-time curve to describe the heat exposure environment (for the reasons stated above). This approach normally entails adopting the temperature end-point criteria specified in the test standard as the failure criteria defining the fire resistance of the assembly.

Structural Response to Elevated Temperatures

The selection of the standard temperature end-point criteria implies that the temperature-dependent material properties will have undergone changes that reduce the load-carrying capacity of the structural component to a point where failure is imminent. This condition can be calculated using a structural engineering analysis, if sufficient data exist to characterize the temperature dependency of the material properties of critical interest.

For example, the important mechanical properties for a steel member are yield stress, ultimate stress, modulus of elasticity, proportional limit and creep parameters. A knowledge of these properties at elevated temperatures could enable the designer to perform a stress, stability and deformation analyses for fire conditions. Again, the analyses normally require the use of a finite element program to discretize the continuum and to account for the non-uniform temperature distribution within the structural member. Another consideration is the effect of thermal expansion of a member on the loading conditions when that member is fully or partially restrained. Such constraints will induce normal stresses that can reduce or increase those generated by the applied loads and ultimately affect the fire resistance of the assembly.

THE FUTURE

As we have seen, design approaches for providing fire resistance have evolved considerably over the last hundred years. Early regulatory efforts concentrated on specifying noncombustible materials and resulted in very limited design flexibility. The development of a standard test method for evaluating the fire resistance characteristics of structural elements and assemblies has permitted a more performance-oriented design procedure. However, full-scale fire testing is an expensive way of verifying that a design solution complies with the life safety objectives of the building code. Moreover, little attention is now being paid to economically-desirable property protection. More recently, the emergence of calculation procedures for predicting the fire performance of structural members has afforded a design alternative to the engineer. Even though these numerical tools necessitate validation by test results, they at least draw maximum benefit from the wealth of data accumulated over the years.

As engineers celebrate 100 years of existence in an organized fashion in Canada, it may be worthwhile to ponder what role, if any, civil engineers should play in the field of fire protection. The potential return for developing a more cost-effective way of providing structural fire protection can be estimated by considering some newly-released statistics. The American Iron and Steel Institute and the British Steel Corporation have estimated that the provision of structural fire protection alone amounts to between 3 and 5 percent of the initial construction cost of a steel-framed building (Lie 1986). According to Statistics Canada (1986), the total value of new construction in Canada (labour and materials) for the year 1985 amounted to $40.7 billion. This figure includes $16 billion worth of small residential construction (1 and 2 family dwellings and row housing). By subtracting this amount and estimating the value of steel-framed buildings at approximately 10 percent of the remaining $24.7 billion (Frost 1987), one obtains a figure of $2.5 billion to which the 3 percent structural fire protection cost can be applied. If this cost could be reduced by only 10 percent through the use of a more refined engineering analysis, the savings would be of the order of $7 to 8 million.

The above estimate provides only a rough idea of the savings that could ensue from designing structural fire protection in a more cost-effective manner than, for example, strictly conforming to the conservative provisions of Chapter 2 of the Supplement to the NBCC. Admittedly, that a 10 percent saving may be realizable is speculative, but surely some attempt should be made to investigate what savings the new technology can afford. Designers may have been reluctant to use the new calculation procedures for a number of reasons.

First, the ability of structural engineers to assume a leading role in the development and application of new structural fire protection design methods is currently limited by their lack of education and training in the area of fire protection. At present, no Canadian engineering school teaches the basics of fire protection design. Most do not even address the rationale behind the requirements of building codes with respect to fire protection. The knowledge of heat transmission fundamentals would also help the designer appreciate the applicability and accuracy of the new algorithms for calculating the fire resistance of structural elements, allowing him or her to select the appropriate confidence level (safety factor) that should be applied. Courses on heat transmission, however, are not normally part of the undergraduate curriculum for civil engineers, who will likely shun heat transmission calculations later in practice. Yet, some level of familiarity with heat transmission principles is essential if only to appreciate the assumptions underlying the calculation methods that are becoming available and, thereby, the limitations as regards their applicability in a particular design situation.

It is also commonly held that a tool is only as useful as its ease of operation. Many fire resistance calculation software can now only be supported by large mainframes and do not come with an elaborate documentation manual. The development of more user-friendly, PC-driven software could encourage the use of the new numerical techniques, provided the user understands the technology.

In conclusion, it would appear that the implementation of more cost-effective ways of designing for structural fire protection could be facilitated through education and training. Certainly, it can be argued that it behooves the structural engineer to consider the provision of fire protection as a key element of structural design. After all, fire is an external phenomenon that acts on the structure in a way not dissimilar to other elements (wind, snow and earthquakes). Historically, engineers have ignored this design component due to the poor predictability of the effects of fire on the structure. However, this excuse is less tenable today with the recent inroads made into quantifying fire and its impact on the intended performance of structural members.

REFERENCES

ASSOCIATE COMMITTEE ON THE NATIONAL BUILDING CODE. 1985a. National Building Code of Canada 1985. National Research Council of Canada, Ottawa, Ontario. NRCC No. 23174.

__________ 1985b. The Supplement to the National Building Code of Canada 1985. National Research Council of Canada, Ottawa, Ontario. NRCC No. 23178.

BARNETT, J.R. 1985. Uses and limitations of computer models in structural fire protection engineering applications. Fire Safety Journal, 9, pp. 137-146.

FREITAG, J.K. 1899. The fireproofing of steel buildings. John Wiley and Sons, New York, pp. 51-75.

HARMATHY, T.Z. and LIE, T.T. 1970. Fire test standard in the light of fire research. American Society for Testing and Materials, STP 464, pp. 85-97.

IDING, R., BRESLER, B. and NIZAMUDDIN, Z. 1977. FIRES-T3, a computer program for the fire response of structures - thermal. University of California, Report No. UCB FRG 77-15, Berkeley, CA.

INGBERG, S.H., GRIFFIN, H.K., ROBINSON, W.C., and WILSON, R.E. 1921. Fire tests of building columns. Technologic Papers of the National Bureau of Standards (U.S.), No. 184.

INGBERG, S.H. 1928. Tests of the severity of building fires. Quarterly, National Fire Protection Association, 22(1), pp. 43-61.

INGBERG, S.H., DUNHAM, J.W., and THOMPSON, J.P. 1947. Combustible contents in buildings. Building Materials and Structures Report BMS 149, National Bureau of Standards, Washington, DC.

LIE, T.T. 1984. A procedure to calculate fire resistance of structural members. Fire and Materials, 8(1), pp. 40-48.

__________ 1986. Private communication. Data presented at the American Iron and Steel Construction Fire Modeling Technology Advisory Group Meeting, Worcester, Conn.

MALHOTRA, H.L. 1982. Design of fire-resisting structures. Surrey University Press, London, England.

MEHAFFEY, J.R. and HARMATHY, T.Z. 1985. Thermal response of compartment boundaries to fire. Fire Safety Science — Proceedings of the First International Symposium, Gaithersburg, M.D., pp. 111-118.

MILKE, J.E. 1985. Overview of existing analytical methods for the determination of fire resistance. Fire Technology, Technical Notes, 21(1), pp. 59-65.

NATIONAL BUREAU OF STANDARDS. 1942. Fire resistance classifications of building constructions. Building Materials and Structures Report BMS 92, Superintendent of Documents, Washington, DC.

NATIONAL FIRE PROTECTION ASSOCIATION. 1984. Legends and Lore, Fire Almanac, Quincy, Mass.

NATIONAL RESEARCH COUNCIL OF CANADA. 1941. National Building Code of Canada 1941. Prepared jointly by the Department of Finance and the National Research Council of Canada, Ottawa, Ontario. NRC No. 1068.

PEARCE, N.S. 1983. Fire testing and the building codes. Introductory lecture given at CSCE Short Course on Calculation of Structural Fire Resistance, Ottawa, Ont.

SHOUB, H. 1961. Early history of fire endurance testing in the United States. Fire Test Methods, ASTM STP 301, pp. 1-9.

STATISTICS CANADA. 1986. Revised Construction Expenditures for 1985, Canadian Secioeconomic Information Management Series #64-201.

THE AMERICAN ARCHITECT AND BUILDING NEWS. 1891. 21(796).

UNDERWRITERS' LABORATORIES OF CANADA. 1982. Standard methods of fire endurance tests of building construction and materials. ULC Standard CAN4-S101, Scarborough, Ontario.

__________ 1984. List of equipment and materials. Volume II Building Construction, Underwriters' Laboratories of Canada, Scarborough, Ontario.

WARNOCK HERSEY PROFESSIONAL SERVICES LTD. 1986. Fire Laboratories Listings 1986. Warnock Hersey, Coquitlam, B.C.

WICKSTROM, U. 1979. TASEF-2, a computer program for temperature analysis of structures exposed to fire. Lund Institute of Technology, Report No. 79-2, Sweden.

WOOLSON, I.H. and MILLER, R.P. 1912. Fire tests of floors in the United States. International Association for Testing Materials. Proceedings of the Sixth Congress, Second Section, 27(2).