Structural steel and fire

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Acier de construction et incendie

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In recent years there has been a large volume of research into the behaviour of Structural Steel in Fire situations and it is the purpose of this paper to indicate the extent of this and at the same time mention problems which still have to be resolved.

RECENT RESEARCH. The features which have received, and continue to receive, critical study are associated with:-

1) The behaviour of a fire, that is to say, the factors which determine its severity, and from this to suggest the circumstance or position in which structural members can be safely used:

2) the behaviour of steel in fire conditions, again to identify the safer situations, and

3) to compare the standard fire resistance test with real fire situations to see if there is any scope for amending the statutory fire resistance requirements.

In the United Kingdom a research programme, which was probably the largest yet undertaken, was jointly sponsored by the Joint Fire Research Organisation and the Steel Industry[1,2]. In this work twenty six fire tests were carried out in a specially constructed building which had two fire chambers, each 7.7m x 3.7m x 3m high, and two sizes of window opening were used in each. The fuel used in most of the tests was in the form of wood cribs and the fire load density was varied from 7.5 to 60kg/m^2. Other fuels, such as furniture, combustible linings, and liquid fuel in trays were also used in a few of the tests.

Unloaded structural steel members (29 beams and columns) were arranged inside and outside the fire compartments so that data was obtained for a variety of situations in fires. Their temperatures were observed in the fires and comparisons were made with their behaviour in the appropriate Fire Resistance tests.

Workers in other countries[3-6], have, in the main, concentrated on the behaviour of structural steel members used in typical structural circumstances when exposed to the time-temperature conditions of the standard test. The work carried out in the United

Kingdom is therefore complimentary to those investigations and all the results should be considered together in assessing the present position.

FACTORS WHICH CONTROL FIRE SEVERITY. No single factor is predominant in a given circumstance in determining the severity of a fire, and it can be shown that the size and shape of the fire room, the size and shape of the windows, and the thermal insulation of the building are just as important in determining the fire severity as are the nature, quantity, and disposition of the combustible contents of the room. Much information on this is now available as a result of an international programme of research carried out under the auspices of the Conseil International du Bâtiment [7].

Information on the combustible contents of modern office buildings has been obtained from recent surveys carried out in the U.K. and in Europe but information about the combustible nature of the contents of other types of buildings is still needed.

It must be recognised, however, that certain factors affecting fire severity will never be predictable, and it is here that statistical techniques may possibly be applied. For example, it is difficult to account for the occupant who stores abnormally large amounts of combustibles, and again, the behaviour of glazing, and hence the patterns of ventilation, depends on window design, weather conditions and the relative location of the glazing to the seat of the fire.

FACTORS AFFECTING THE BEHAVIOUR OF STEEL IN FIRES. Predicting the behaviour of steel under known fire conditions is, as a result of the recent work, now possible and the main factors affecting this behaviour are now known. Figure 1 shows the kind of data available from furnace tests and much is known about the performance of different materials for the fire protection of structural steel. Figure 2 gives data obtained in the U.K. and in Braunschweig for unprotected and encased steel and these results show the importance of the steel mass, the surface area and the protection thickness.

These results compare favourably with theoretical predictions made in Holland [5] and recent work in Canada [6] has extended the data to include massive constructions.

COMPARISON BETWEEN THE FIRE RESISTANCE TEST AND THE REAL FIRE. One of the most important aspects of the programme of research done in the U.K. has been the comparison that has been possible between real fire situations and the standard fire resistance test. This has shown that the heat transfer process in a real fire is different from that in a furnace test, the luminous flames of the fire giving greater heat transfer in the early stages. It follows, therefore, that even if the time-temperature curves (fire and furnace)are similar, a condition that in practice is very rare indeed, it is not possible to equate fire duration to fire resistance time; consequently other means of comparison must be sought.

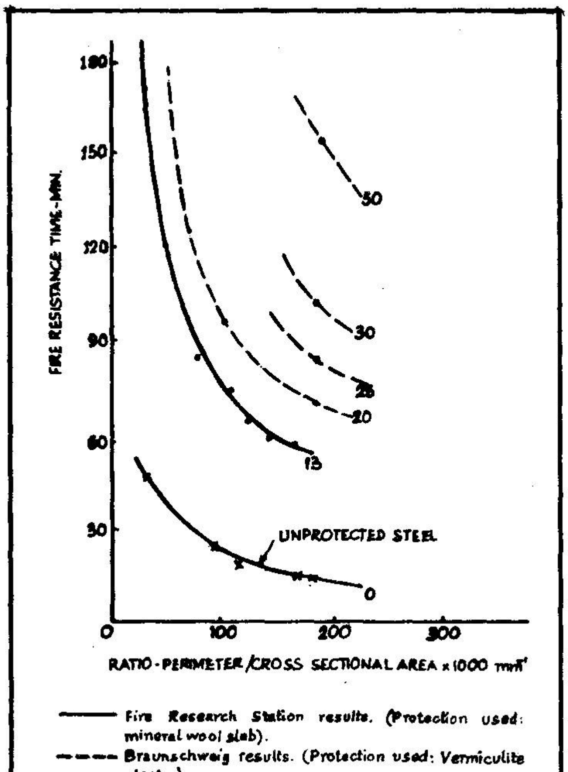

Fig. 2. Curves showing importance of steel geometry and thickness of protection.

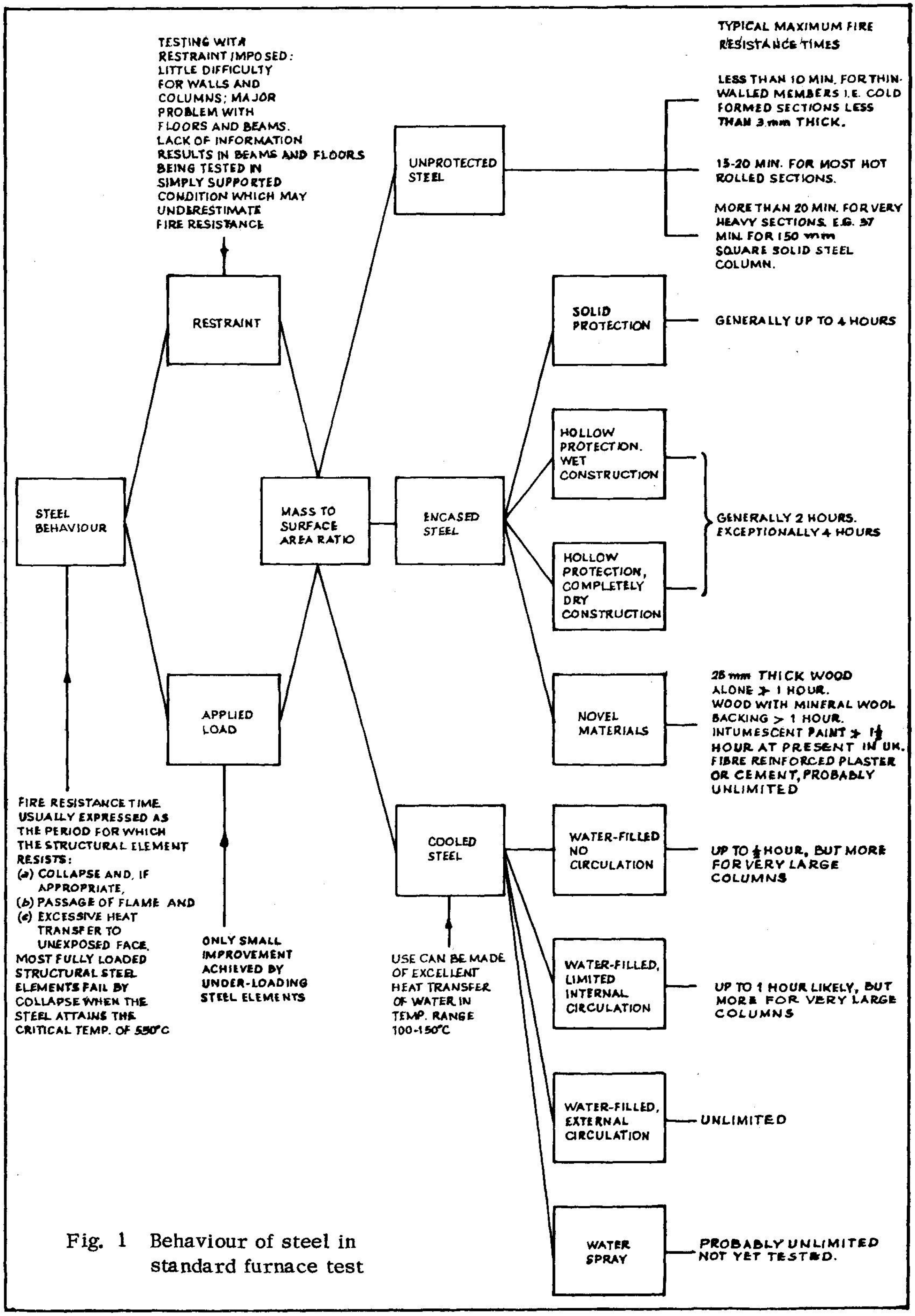

Fig. 1 Behaviour of steel in standard furnace test

However this work has shown that it is possible to establish a relation between fire resistance time and the likely severity of a fire in any given building. Fuller analysis of the C.I.B. work and the inclusion of more recent experimental data has enabled the conclusions to be extended to higher fire load densities and other sizes and shapes of compartments so that a basis has now been established for predicting the fire resistance required in any given building for it to resist a complete burn-out of its contents without structural collapse[9,10].

UNPROTECTED STRUCTURAL STEEL. It would be of enormous economic benefit if situations could be identified where unprotected steel could be safely used in building structures. One such situation is when the steel members are placed outside the building but even so care must be taken with their placing.

The research has shown that external unprotected steel columns continue to support their design loads provided they are protected from direct attack by flames or from severe radiation through windows. Some reservation is necessary here if the fire situation is very different from the experiment, for instance if the fire compartment has flammable linings, if more than one storey is involved, or if high fire loads are present[11].

With the present trend in building design to make the whole of the building facade of glass or of curtain walling, the question immediately arises as to how simple can the protection to the external steel be or how far must the steel be from the facade to be safe. It seems likely that a simple lightweight flame shield can be devised to give this protection. This approach, provided it can be made architecturally acceptable, will probably be more effective than reliance on spacing the structure away from the facade, since present indications are that such spacing would need to be larger than would be generally convenient.

The work on fire severity[7] is being studied in conjunction with Seigel's work[12] on flame profiles out of windows and with Bongard's experiments on external steel columns so that criteria for a safe location of external steelwork may be established for all buildings. However this is an area where more effort could be usefully applied since design standards for flame shields are urgently required by the architectural profession.

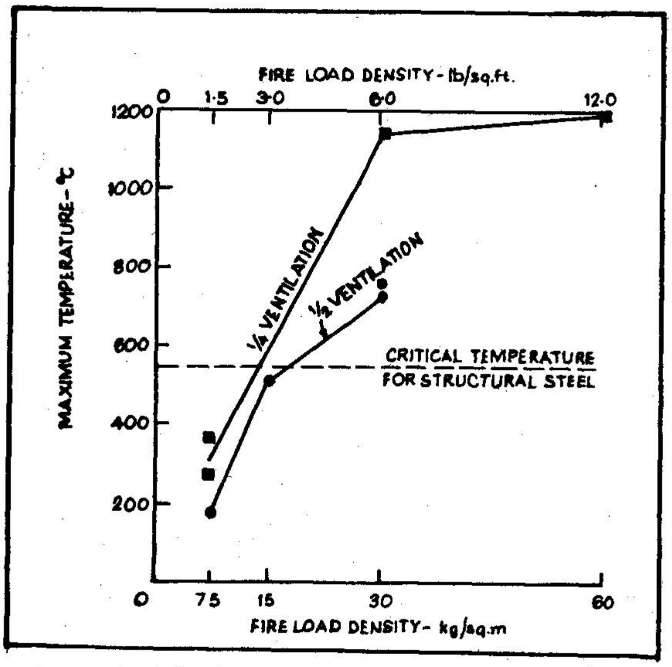

Fig. 3. Maximum temperatures reached by unprotected internal columns for fires of various fire load densities

The use of unprotected steel inside a building is more difficult to justify, but the work has shown (Fig. 3) that in fires with a low fire load density, particularly with large areas of window opening, structural steel will remain below its critical temperature. The size of such fire load densities is lower than those met in offices, housing, hotels, etc. but it is suggested that a car park building might well be in this low range. An analysis of the combustibles in an average car and the carrying out of additional tests[13] confirmed the suggestion and showed that the danger of fire spread from one vehicle to another was not high. This original work in the U.K. has now been confirmed by similar tests carried out in Japan, Germany, U.S.A. and Switzerland and the earlier reluctance of the authorities to allow internal unprotected steelwork for this type of building is now less apparent. In the U.K. an above ground, open sided car park building less than 16m high may be constructed of unprotected structural steel.

It is probable that when special categories of buildings, such as for instance car parks, can be identified as requiring minimal fire protection for the structure the authorities are more likely to be sympathetic to argument than they will be to requests to allow a general relaxation for unspecified buildings.

Even though some parts of a building may have a fire load density which is in excess of that for which bare steel would be safe, there will be, nevertheless considerable areas of that building where combustibles would not normally be found or indeed, could not be placed if the law is to be satisfied. The possibility of siting the unprotected steel members so that they come within such areas has been suggested and might possibly be allowed if it can be shown that fire from other parts of the building could not spread to these areas under any circumstances. This could be achieved by the intelligent use of compartmentation and function separation and consideration of such possibilities could be most fruitful if initiated early enough in the design process of a building. However for such ideas to be successful the building design must be such that change of use of any part of it will not nullify the original arguments which were advanced for the use of unprotected structural steel.

METHODS OF KEEPING STRUCTURAL STEEL COOL.

1. Conventional cladding. The protection of structural steel by encasement in conventional materials, such as concrete, asbestos, etc. is a familiar and well established process. The U.K. investigations confirmed two important features:-

a) That the size and shape of the steel section inside the casing is an important factor in designing the protection needed, and

b) that the design of that protection can be satisfactorily achieved by calculation[14].

The diagram given earlier in Figure 1 shows the order of the periods of fire resistance obtainable by conventional encasement.

2. New materials. The use of conventional methods of encasement may not always be acceptable for economic or other reasons and consequently new materials and methods are being constantly sought.

It has been suggested[15] that timber may be used as a protective casing in order to achieve fire resistance of up to one hour and furnace tests in Holland and in the U.K. have been reported which support this idea. The information given, however, indicates that the method of fixing the timber encasement around the steel member is likely to be a critical feature of this method.

The use of a paint or mastic to give fire resistance to a steel structure has been developed and at present a fire resistance of 90 minutes has been achieved in the U.K. However there are currently some problems associated with its use, such as the need to ensure correct adhesion to the steelwork by the use of suitable original protection by the fabricators, the need to apply the intumescent system in several coatings with a drying period in between each, and finally to ensure that exposure to weather conditions outside or normal ageing inside the building does not render the foaming agent ineffective with time.

3. Water Cooling. Perhaps one of the most interesting ways of providing protection for structural steel in fires is by the use of water as a coolant. A few furnace tests sponsored by the steel industry[16,17] have been carried out in the U.K. and in Germany a full scale fire test has been staged in a Dusseldorf building[18]. A considerable amount of theoretical analysis[19,20] has been brought to bear on this technique and as a result of it

and with the support of the tests this method has now been incorporated into more than twelve buildings in the U.S.A. in Germany, in France and in the U.K.

This method of providing fire protection for steel members is very valuable since if correctly designed it should be possible to provide fire resistance for an unlimited time. In addition it does not have the disadvantage of giving a large increase in weight to the structure as would be the effect of concrete cladding.

This advantage is exploited to the full in a building erected in London which had extreme limitations on the foundation loading because of the proximity of an underground railway tunnel. In this building the use of a framework built to a geodetic design, using stainless steel tubes filled with water, enabled the foundation loads and the very strictly prescribed piling positions to be used successfully to support an eight storey office building. Without the use of water cooling it is certain that this building could not have been built.

THE FUTURE. If steel is to be competitive as a structural material, then the methods of protecting it against fire must be as economical as possible, and thoughts should perhaps be directed towards the following:-

1. to seek out the buildings, or the places inside and outside buildings, where unprotected steel can be safely used;

2. to explore economical methods of keeping structural steel in buildings cool in case of fire; and

3. to collect as much information as possible about the design trends in buildings and the factors likely to affect the fire hazard in them.

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SUMMARY

During recent years there has been, in U.K. and elsewhere, research and investigation into the behaviour of structural steel in fires. This paper draws together all the information now available. Lines along which future work should be directed are suggested.

RESUME

Au cours des dernières années, des recherches et des essais ont été entrepris en Grande Bretagne et ailleurs, sur la tenue au feu de l'acier de construction. Cette contribution rassemble les informations disponibles jusqu'à présent. Des directives pour les recherches futures sont suggérées.

ZUSAMMENFASSUNG

Während der letzten Jahre hat man in Grossbritannien und anderswo Forschungen und Untersuchungen über das Verhalten von Baustahl in Bränden durchgeführt. Dieser Beitrag fasst die bis heute auf diesem Gebiet verfügbaren Informationen zusammen. Anhaltspunkte für zukünftige Nachforschungen werden vorgeschlagen.

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