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Fire resistance of historic iron structures in multi-storey buildings

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Abstract

To ensure that there is adequate fire resistance, iron and steel structures in multi-storey buildings (with the exception of the top floor) are usually provided with cladding. However, in historically valuable buildings more often than not it is considered desirable to expose the structure, rather than covering it by a protective layer of insulating material. To achieve this, different philosophies and methods are needed to ensure that there is adequate safety. In the Netherlands the requirements relating to fire resistance in relation to the failure of structures are laid down in the Building Decree. In the stipulations of the Building Decree a distinction is drawn between categories of building that is based on function and also between new buildings and existing buildings. Some questions arise when the stipulations contained in the regulations of the Building Decree are applied to historic buildings. The basis of these regulations is the 'standard fire'. However one can question whether this 'standard fire' is representative for some cases. When the function of a building changes are the stipulations for newly constructed buildings or existing buildings applicable? Must historically valuable buildings always meet the stipulated requirements? It is not always possible to give a cut and dried answer to these questions. In buildings such as warehouses and industrial premises that acquire a new function, the floor loading may often be reduced. With lower floor loading the same construction has a greater fire resistance than with high loading. If the stipulations still cannot be met when the difference in floor loading has been taken into account, supplementary regulations are needed. The provision of second bearing structures that will provide additional supporting elements in the case of fire may provide a solution. Construction elements can be filled with concrete or water and spaces can be equipped with sprinkler installations. Structural elements can also be protected by applying a layer of intumescent paint.

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Introduction

Up to the end of the 18th Century multi-storey buildings were constructed with masonry inner and outer walls and joisted wooden floors. During the industrial revolution, especially in Great Britain, to accommodate the machinery it became necessary to construct buildings with wider roof spans. The wooden floors were often saturated with the oil as a result of the lubrication of the machines. Moreover the lighting was provided by oil lamps and candles and, especially in the textile industry, there was a great deal of flammable material. It was therefore not surprising that frequent fires occurred. To satisfy the functional demands and to make the floors more fire resistant a different means of construction, using non-flammable materials was sought.

At the end of the 18th century the fireproof structure emerged. This consisted of an internal skeleton of cast iron columns and beams with brick or stone vaults between the beams. Although the use of floors with wooden joists persisted for a very long time, fire proof structures increased in number. Many 19th century factory buildings were of this type. While cast iron is virtually incombustible, at temperatures above 450° C it very quickly loses its strength.

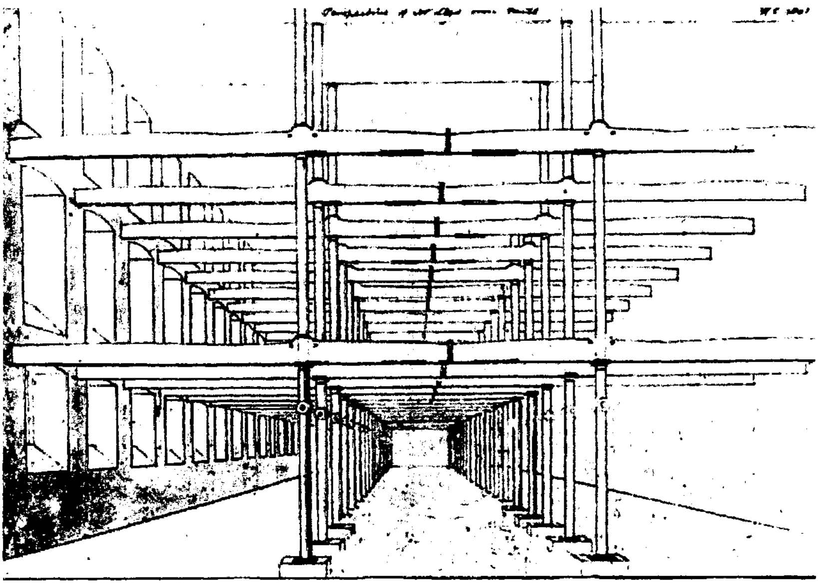

Figure 1: Internal skeleton of Mr. Lee's Iron Mill (1801). Brick-vaulted floors have been constructed between the cast iron columns and girders, while the outer walls are also made of masonry

To ensure that fire resistance was adequate, in later multi-storey buildings iron and steel elements were usually covered by fire resistant material. In historic buildings with a still unprotected structure however, there must be some relaxation of the current safety requirements. When a valuable historic structure is concerned it is preferable that no covering layer should be applied, since this would obscure the parts of the structure that should remain visible. For such buildings other means are necessary to meet the stipulated safety demands.

Building decree

The stipulations relating to fire safety are encompassed in the Building Decree and are included under the heading Constructional Safety. These stipulations relate to fire resistance relating to collapse. They stipulate the time during which a constructional element that is exposed to a standard fire should be able to withstand the resulting load.

In the Dutch Building Decree a distinction is made between three types of building:

a. residential buildings
b. non-residential buildings
c. constructions that cannot be considered to be buildings

In the decree a distinction is also made between new and existing buildings. Usually lower stipulations are made for existing buildings; these are laid down in Ministerial Rules. These stipulations relate to the main bearing structure. By this is meant those parts of the structure of which the failure would lead to progressive collapse. The maximum stipulations relating to the fire resistance of the main bearing construction of existing buildings are shown in Figures 2 and 3.

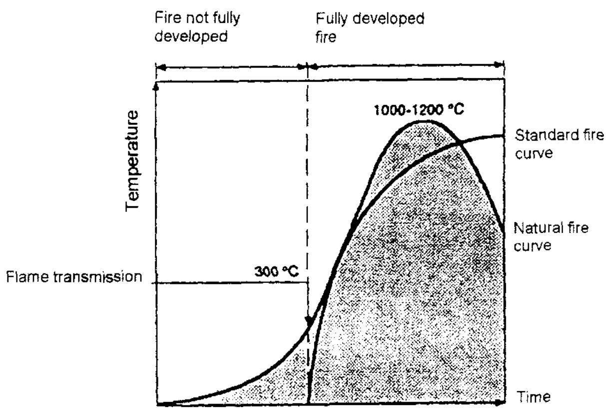

Figure 2: Standard fire curve and a natural fire curve.

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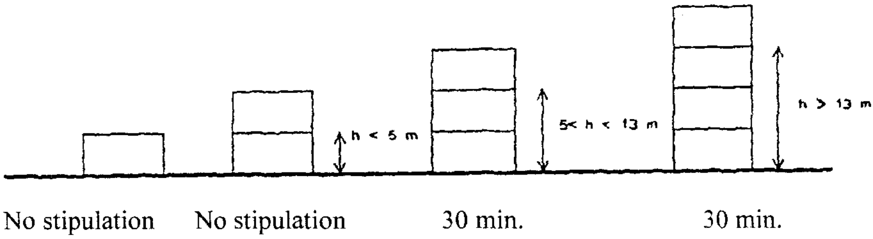

Figure 3: Maximum fire resistance stipulations for the main bearing structures of existing buildings

For these buildings no distinction is made between categories a. and b. In addition, with a view to emergency exits and the prevention of spreading of the fire, fire resistance demands can be placed on structural elements. These can apply to both structural elements forming part of the main bearing structure and to other bearing elements. For existing buildings intended for residential use these requirements stipulate a maximum of 20 minutes, but for a non-residential buildings the Building Decree is satisfied with functional stipulations. For new housing there are more stringent stipulations, requiring a maximum fire resistance time of 60 minutes.

Comments

Several comments can be made in relation to the above. The question arises of whether the 'standard fire' can be considered representative. When the function of a building changes do the stipulations relating to existing buildings or to new buildings apply? Should listed buildings also conform to the requirements of the Building Decree?

There is no ready-made answer to these questions. If the fire loading is low possibly the normally stipulated demands may be modified. When the function of buildings is changed the policy affords the possibility to make agreements for individual cases. For listed buildings the stipulations based on the Historic Buildings and Ancient Monuments Act (Monumentenwet) prevail over those of the Building Decree and exemption from or mitigation of the stipulations of the building Decree can be tenable.

In Figure 4 the relation between compression strength and temperature for cast iron and for steel is shown. The behaviour of wrought iron will differ very little from this. In addition to the reduction in the strength, special attention should be paid to cast iron, since during fire extinguishing activities a heated element may be exposed to greater cooling on one side than on the other, as a result of which it may crack or fail. It must also be remembered that if a fire occurs the buckling length of the columns may be reduced.

Because heating weakens a column, connections that have been taken as hinges in the strength calculations may become relatively stiff as a result of exposure to fire. Plastic deformation of the construction causes the redistribution of the forces so that not only the various elements, but also and even more importantly, the behaviour of the entire structure must be examined. This has been made possible by the use of recently developed computer software.

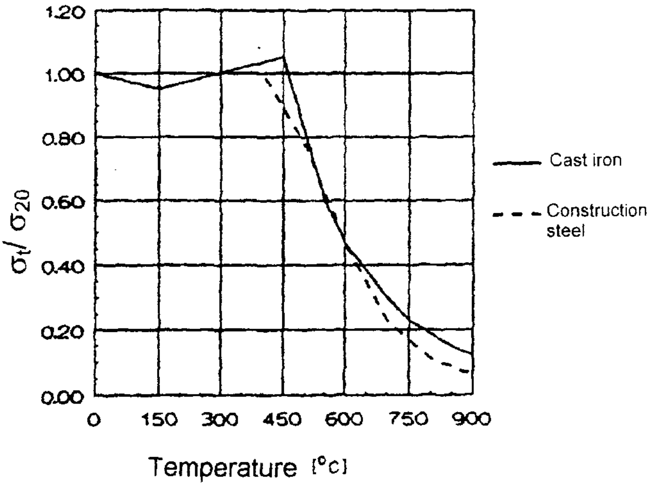

Figure 4: Relation between the compressive strength with increased temperature (σ_t) and the temperature for cast iron and steel.

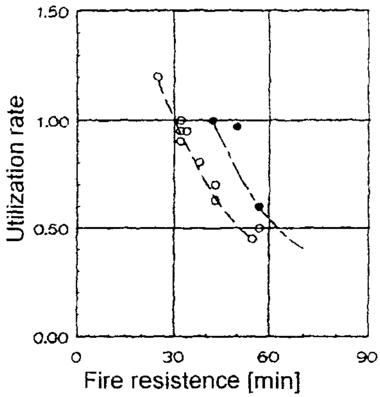

Figure 5:Relation between the utilization rate and fire resistance for an unfilled (o) and a concrete filled cast iron column (•). The effect of the concrete filling depends on the profile factor and the cross sections

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When restoration, renovation or change of function are contemplated the utilisation rate is important. This is the relation between the actual normative load and the maximum load that the structure can bear. When the function of a warehouse is changed this utilisation rate provides for some flexibility. Formerly the floor could bear several tons per square metre, while the load on the floor of a residential or office building is considerably less, even though it is possible that the floor may become heavier as a result of supplementary measures relating to noise insulation and fire resistance. In Figure 5 the relation between utilisation rate and fire resistance is given for cast iron columns with a profile factor of 30 m^{-1}. The profile factor is the relation between the circumference and surface area of the profile. Figure 5 also shows the experimentally determined values for cement filled tubular cast iron columns.

Current developments

For many years in order to obtain adequate fire resistance, strong emphasis has been placed on the building regulations governing the protection of the construction, the compartmentalisation and the provision of emergency exits. In recent years there has been a shift towards the making of risk analyses and fire resistance designs. The latter are extensive packages comprising regulations relating to construction, service installations and organisation. The regulations for service installations cover detection and alarm installations and the ducts for the removal of heat and fumes. Organisational rules cover escape training and planning for emergencies.

These rules were formerly based on the standard fire, which may differ considerably from a natural fire. Now computer programs that can give a good approximation of the propagation of a natural fire in a given situation, as well as the resistance of a structure against collapse are available.

Constructional measures

When, despite the above measure, an exposed structure does not conform to the requirements; the following measures may be considered.

- the provision of a second bearing structure
- filling structural elements with cement
- filling structural elements with water
- fitting sprinklers
- the application of an intumescent coating to the structural elements

Provision of a second bearing system

A new structural element that can take up the entire load can be added to the original construction. The old structure remains present, but is reduced to serving a decorative

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function. Ideas include the cladding of part of the structure or the addition of new elements in such a way that the load can be transmitted in a different way. A bearing wall can be built under a beam as in the proposal for the new use of the warehouse 'De Vijf Werelddelen' in Rotterdam.

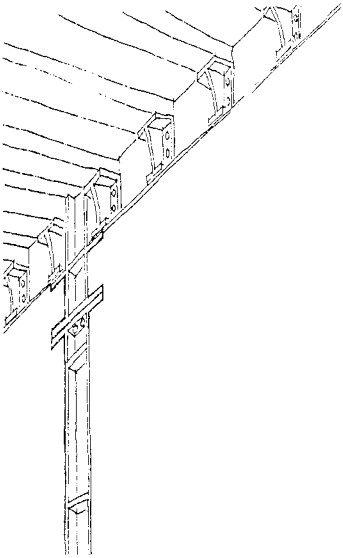

Figure 6: Warehouse 'De Vijf Werelddelen', Rotterdam (1878). Design for the construction of a bearing wall under the beam and between the columns

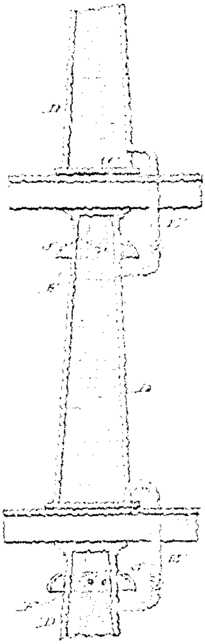

Figure 7: Patent water-filled column from 1884. The openings J, from which the steam can escape, are closed with wax.

Filling constructional elements with concrete

H and I profiles can be partially covered by concrete. The spaces between the flanges are filled by concrete so that to some extent the character of the element is retained. With this measure the area exposed to heat radiation is considerably reduced and the heat capacity is increased. When reinforcement is added to the element the concrete, the concrete also contributes to the strength and stiffness when the temperature increases. New prefabricated elements that can increase the fire resistance time to 120 minutes are also made in this way. Tubular columns can be filled with concrete.

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Non-shrink mixture must be used and holes must be bored to permit the escape of steam. The effect of this type of filling depends on the profile factor and the dimensions of the columns. In Figure 5, which shows the utilization rate, there is only a very slight improvement for this cast iron column. The addition of steel fibres results in a spectacular improvement of the fire resistance.

Filling constructional elements with water

Already in 1884 there was a patent for water-filled cast iron columns. The columns on each floor were interconnected. In at least 30 modern buildings, including the Pompidou Centre in Paris and the Fire Station in Breda, steel structures have also been filled with water A low circulation speed is adequate to ensure that sufficient heat is removed. A distinction is made between systems with natural circulation and those with forced circulation. If a fire continues for a long steam may form and this must be able to escape. When this happens in the area where the seat of the fire is located it causes an increase in the temperature. The installation of such a system in existing hollow cast iron columns would seem to be a difficult, but not impossible procedure.

Sprinkler Systems

As early as 1824 an automatic sprinkler system had been installed in England. A piping system with wax covered holes was connected to water tank positioned high above it. In 1870 the foundations were laid for the sprinkler technique that is used today. The sprinkler head usually consists of a liquid filled glass. At a triggering temperature between 60° and 80° C the glass breaks so that water can be dispersed. Sprinklers serve to extinguish fires and to control fires that have gained a hold and also to restrict the development of smoke.

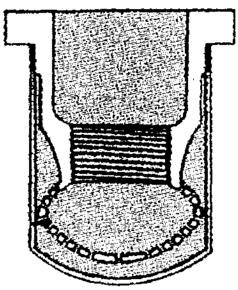

Figure 8: Automatic Sprinkler head from 1870

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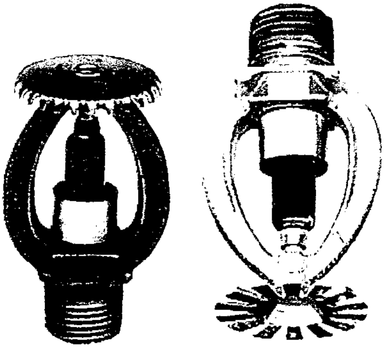
A distinction can be made between wet and dry systems. In a wet system the pipes are permanently filled with water. In the dry system the pipes are filled with air or nitrogen. In the dry variant water is admitted to the system by the triggering of the sprinkler heads. Instead of liquid filled glasses, a bimetal systems can also be used to trigger the system. Besides conventional sprinklers there are various other kinds, the heads of which are countersunk in walls and ceilings. In buildings with fine finishing detail the positions of sprinklers and those of smoke and other detectors should be incorporated in the design. Because of the relatively high cost, sprinklers are used almost exclusively in areas that are accessible to the public.



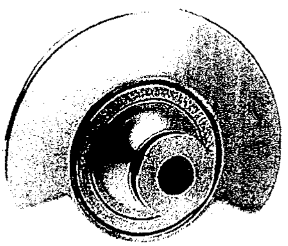


Figure 9: Conventional sprinkler heads. Figure 10: Sprinkler with counter sunk head.

Structural elements covered by an intumescent coating

The principle is based on the application of a layer of paint that starts to form foam at a temperature of 220° C, as a result of which an insulating covering layer is created. Formerly this type of paint consisted of a mastic-like substance that was several millimetres thick and that damaged the finishes, while the surface was not even smooth. Now a smooth 0.5 – 2.0 mm thick layer is applied and this can be provided with any desired outer coating. The thickness of the layer can be examined by using a very simple layer-thickness meter. Given the profile factor and the thickness of the layer the fire resistance can be determined. Depending on the profile factor, a fire resistance up to 120 minutes can be attained. The TNO Institute of Industrial Technology, The Netherlands, was commissioned by paint manufacturers to investigate this subject and the reports of their research are available. The paint does not appear to age, but mechanical damage must be repaired. A maintenance contract would seem to be a good means to guarantee that the fire resistant properties of the paint will not deteriorate.

Conclusion

It is not considered desirable to use fire resistant cladding to increase the fire resistance of historically valuable multi-storey buildings. Whereas formerly attention was focussed on constructional measures, now more often attention is directed towards the formulation of a fire-resistance plan after the completion of a fire risk analysis. With the aid of a computer, both the development of a fire and the behaviour of the construction can now be approximated. When constructional measures are necessary the provision of a second bearing structure, the filling of elements with concrete or water, the fitting of sprinklers and the application of intumescent paint are options. In particular the use of intumescent paint is simple and effective. If necessary, these different constructional measures can possibly be combined. In addition to the existing Building Decree, which focuses on the safety of people, now the formulation of a separate decree that is directed towards the maintenance of the buildings themselves is under consideration.

Reference

Material for the archives of the History of Structural Design Group, Faculty of Architecture, Delft University of Technology.