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FIRE PROTECTION OF OLD TIMBER ROOFS.

WOOD SCIENCE RESEARCH NEEDS

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ABSTRACT

This paper focuses the fire performance of timber and timber structures and discusses possible approaches to mitigate the fire risk in timber buildings, with special relevance to the case of timber roofs.

Furthermore, it highlights a number of issues concerning the implications for timber durability and mechanical properties resulting from the exposure to fire itself and high temperatures, active fire protection equipment and firefighting tactics, namely those involving the use of water, and passive fire protection measures, namely fire retardant treatments. These issues need be considered by those involved in the assessment and safeguard of ancient timber buildings.

INTRODUCTION

Timber combustibility is often mistaken with low fire resistance of timber structures. This often restrains the choice of timber as a structural material in new constructions or in interventions in existing ones, despite its many technical, architectural and environmental advantages.

Fire risk considerations may also be a strong draw-back to the safeguarding of old, common or historical, timber structures, even when they meet structural safety requirements, due to the fact that most practitioners and building owners don’t have sufficient knowledge on this subject.

Real life has often shown that timber structures may present very good fire endurance, especially in the case of massive timber constructions, composed by large elements, with low cross section perimeter/area ratios.

However, not only old timber structures are not always made of large cross sections, but also specific joint detailing, timber surface conditions, building geometry and occupancy, presence of special equipment or stored products may increase the risk of fire to levels where the employment of specific protection measures is required.

The adoption of some fire protection measures is not consensual, especially in the case of buildings of historical interest or with valuable content. Besides, the long-term durability and the implications to the timber properties given by a number of fire protection treatments that have been used in the past and those presently used are not fully known.

On the other hand, most fire safety regulations are intended to guide the design of new buildings and not to steer the fire protection of historical constructions, while maintaining their the historic authenticity.

There have been cases where buildings were only partly exposed to fire, or where fire was extinguished before structural failure or collapse, and managed to survive. Residual strength assessment of the load-bearing structure in such cases may be done by simplified methods; more refined (and less conservative) calculations could be based on a number of assumptions on the temperature distribution in the timber members and joints, thus requiring data on the post-fire strength reduction of timber due to exposure to fire and to high temperature.

That approach may involve great difficulties due to the lack of data concerning temperature distribution in old cracked timber members and in the joints' region during a fire event. Besides, data on the effect of high temperatures on physical and mechanical properties of timber of a given species may not be available.

The short and long-term consequences to timber's strength, stiffness and durability of active fire protection systems or firefighting tactics, especially those involving the use of water, which create a sharp temperature reduction in the surface and/or promote the increase of wood's moisture content after the fire, also require further investigation.

These and other issues need be clarified by the scientific community and need to be considered by those involved in the assessment and safeguard of ancient timber buildings.

FIRE PERFORMANCE OF TIMBER

Timber response to fire differs from most common structural building materials, this being a key point in the design and safety assessment of timber structures.

Due to its chemical constituents (mainly cellulose and lignin, which are formed by carbon, hidrogen and oxigen), timber is a combustible material, unlike stone, steel or concrete. It should be noted, however, that thick solid wood elements show longer ignition times and lower heat release rates when compared to other common building contents like upholstered furniture and books.

When exposed to fire, solid timber will first dry and split, and as its temperature raises above 200 ºC to 250 ºC thermal degradation (pyrolysis) occurs. Ignition will generally start when surface temperature is kept above 300 ºC for a reasonable period of time in the presence of a flame. In the absence of flame higher temperatures may be necessary.

Wood thermal degradation is accompanied by complex heat and mass transfers in the structural elements, declining its mechanical properties, followed by a cross section reduction as charring progresses from the exposed surfaces inwards. Because of its low conductivity, the char layer has some insulation effect on the unburned residual cross section, despite balanced by increased heat transfer due to moisture vaporisation and cracking. This may slow down pyrolysis, resulting that in some circumstances, when the fire is controlled (heat release rate is dropping) the combustion of timber elements may self extinguish.

During a fire event, after flashover (ignition of all combustible materials) construction elements should be able to continue carrying the loads and to avoid flames, hot gases and excessive heat to spread to neighbouring areas.
The ability of a building element to carry the loads when exposed to fire, measured by the time it still performs its structural function, is called fire resistance and it represents in practice the time available to evacuate the building and attack, confine and extinguish the fire. From this point of view, timber structures may exhibit a much better performance than that of equivalent concrete or steel structures.

Fire performance of timber is highly predictable. Although time to ignition increases and charring rate decreases with the timber density, a charring rate of 0,65 mm/minute may be assumed for fire resistance design, disregarding specific fire duration and conditions. Moreover, due to its low thermal conductivity, the heat flux thru the char to the inner layers of the timber member is small, and the uncharred material will be kept “cold” and reasonably unaltered. In fact, the transition layer that is chemically altered due to high temperature (pyrolysis) although yet uncharred, is only about 5 to 7 mm thick under the charred layer.

This overall response is highly beneficial, not only because thermal expansion of timber under fire is negligible, but also because strength reduction of timber members may be assumed as a function of the loss of cross section (easily assessed).

TIMBER STRUCTURAL FIRE DESIGN

Current legislation requires that the fire endurance of a structure ensures enough time to evacuate the building and to attack, control and extinguish the fire.

Eurocode 5 Part 1-2 (EN 1995-1-2) covers structural fire design of timber structures and provides three calculation methods to determine the fire endurance of timber members when exposed to accidental fires.

The first two (simplified) methods assume that at any time the load is sustained by a residual cross section calculated on the basis of empirical charring rates. The first method assumes an effective cross-section, where the charred layer is deducted from the initial cross section, which kept its cold strength and stiffness values (strength loss in the heated layer bellow the charred material is taken into account by an increase of 7 mm in the char depth). The second method assumes the initial cross section but reduced mechanical properties, by applying reduction factors to compressive, tensile and bending strength and modulus of elasticity. Such reduction is a function of the specific surface (perimeter/area) of the residual cross section.

A third (advanced) calculation method is also provided, consisting in the use of more accurate but somehow complex models. For that purpose Eurocode 5 provides the thermal properties (thermal conductivity, specific heat and density as a function of temperature) and the mechanical properties (strength and stiffness) necessary to establish temperature profiles in the cross sections, assuming at the char front a temperature of 300 ºC.

A comparison (Cachim, 2008) between the simplified and the advanced calculation methods of Eurocode 5 revealed some inconsistencies, namely regarding the strength reduction factors for compression, tension and bending. Surprisingly, the advanced method led to lower strength values than the simplified methods, stressing the need for improvement.

Other limitations were identified in Eurocode 5, namely in the way the given charring rates were derived (König, 2005; Janssens, 1994); a number of studies also evidence that proposed charring rates may strongly deviate from test data obtained on hardwood species, treated or glued laminated timber, or on elements with relatively small cross sections.

Besides the timber members, knowledge is required on the fire behaviour of joints (assemblies), known to be more sensitive to fire, due to high stress concentration, complex behaviour and the use of adhesives or metal fasteners that respond to fire and heat in a different manner than timber do.

Tests on joints have shown the influence of joint geometry and fasteners dimensions, on the char layers and fire endurance of the joints, as well as on the different charring rates in the direction parallel and perpendicular to the grain and results seem to vary with the fire load duration.

Design rules presented by EN 1995-1-2 cover only timber-steel symmetrical joints with inserted metal plates and steel dowel type fasteners, leaving aside all other joint types, including bonded joints and specially carpenter joints that still represent the large majority of joints in traditional (current or historical) timber structures.

In recent years, efforts have been put in the development of fire resistance models, thus reducing high costs and time-consuming fire resistance testing. For the numerical models be used with confidence, they need reliable parameters. Information existing in EC5 for mechanical and thermal modelling of timber structures in fire situations is limited to standard conditions and, sometimes, this information is not very coherent.

FIRE RISKS IN OLD TIMBER STRUCTURES

Old timber structures may present specific problems regarding the fire hazard risks..

One major reason for concern is their frequently poor state of conservation. Not only water intake from degraded roofs and the presence of rodents is likely to provoke short-circuits in old electrical appliances and installations, as they are prone to human intrusion and vandalism.

If abandoned, any fire breakout will most likely be detected only too late. Fire brigades may not be able to succeed due to late call, difficult access conditions to the building, locked doors and blocked entrances.

Ancient timber buildings frequently have irregular geometry and odd circulation ways, as well as complex inaccessible structural solutions, especially roofs. In some cases, successive improvements and alterations led to hidden rooms, blocked passages and false floors; in other cases merging of adjacent buildings resulted in unlevelled floors being connected in more or less creative ways. Such buildings are often not fully understood even when building plants are available (rarely the case), turning the elaboration of emergency plans and the intervention of fire brigades almost impossible tasks.

Lack of building users' awareness combined with lack of the building maintenance may also create conditions for disaster. Roof attics are frequently used for storing papers, old furniture, paints and solvents, all combustible materials which represent a significant amount of fire load (Claret and Andrade, 2007). Accumulated dust and debris may be ignited if coming into contact with a cigar or a hot or sparkling electrical appliance.

It should also be born in mind that old structural elements may have low moisture content, rough surfaces due to workmanship, fissures or insect attack, for instance, or may have been treated with oily products intended as preservative treatment or water repellent. Although these surface characteristics are thought to have an effect on ignition and flame spread of the timber members, there is not enough information available.

Periodic cleaning of enclosed less accessible areas, clearing of unnecessary (especially combustible) materials, revision of electrical installations with replacement of useless, defective or otherwise unsafe equipment, and fire protection of any cables and appliances that should remain in place, strict restriction to smoke in those areas, are all sensible measures easy to implement, that may highly reduce the risk of fire.

PROTECTION TECHNIQUES AND FIREFIGHTING

Current passive fire protection measures include architectural interventions like the introduction of horizontal and/or vertical partitions inside the building to restrain the spread of smoke, heat and fire itself. They may also include thermal insulation of structural elements (beams, columns, slabs) to control their exposure to high temperatures, replacement of the exposed materials by others with a better fire performance (less flammable or non combustible materials, for instance), or surface treatment with suitable products to delay materials' ignition, reduce flame spread or smoke release and combustibility.

Not only such measures may not be technically feasible or efficient in some cases, but the alterations they bring to the building are often unacceptable, as regarding the maintenance of genuine character. The durability of surface fire retardant treatments, their performance when applied to preservative treated and/or aged timber surfaces, as well as their long-term effect on the timber properties, is not clear and should also be addressed.

Active fire protection of timber structures consist in the installation of detectors (smoke, temperature, or others) and of manual and/or automatic fire suppression systems, respectively fire extinguishers and water sprinklers or water mist fire protection systems.

The bad influence of water used by fire brigades on the buildings' content and structures, particularly timber structures, is well known. In the case of newer and supposed less invasive techniques like water mist, the experience is rather scarce and there is not yet enough information on their consequences for timber members and joints.

Besides several issues related to the efficacy of each one, or combinations, of such techniques, the short and long-term effect of water in its various forms and the effects of fire retardant products applied or coming into contact with timber have to be addressed.

In spite of the uncertainties and problems which might arise from the application of some passive or active fire protection techniques, the conservative posture of not using available measures to mitigate the risk of fire hazards, because their effects and effectiveness are not yet totally clear, might be harmful to historic buildings and structures (and their content). The risk of not intervening might be higher than the risk of intervening.

CONCLUSIONS

The following topics outline some of the identified conclusions and present tangible research needs in regard to the fire risk mitigation in historic timber structures:

- Conservation of timber structures doesn't make any sense without fire risk considerations and due fire protection measures.

- Buildings of historical interest or with valuable cultural content may pose specific difficulties as regarding fire risk management, due to enhanced risk factors and possible inadequacy of a number of current approaches to mitigate it.

- In most countries there is no legal or technical guidance on these issues and the existing European code on structural fire design (EN 1995-1-2) is not meant for ancient structures assessment and do not apply to old (carpentry) timber joints.

- Detailed analysis of fire performance of timber members and joints requires information on temperature related mechanical properties for high temperatures and most used timber species. Besides, the assessment of residual strength of timber structures requires information on the post-fire properties of wood. Such data is rather scarce.

- Data is required concerning the long-term effects of fire retardant products on the physical and mechanical properties of timber members.

- Data is required on the efficacy and durability of passive fire protection systems when applied to aged and/or preservative treated timber members.

- Data is required on the short and long-term effects of water based fire suppression systems on timber members and joints.

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