Assessing fire damaged structures

Richard Read trained as a building surveyor with the Architect’s Department of the Greater London Council, and spent nine years dealing with means of escape in case of fire. In 1974 he joined the Fire Research Station and since that time has been in the Building and Structures Division, where he is mainly concerned with giving advice on structural fire protection matters. He is involved in a number of British Standards committees, and is the author of several BRE Information Papers and Digests.

D. M. Tucker left the Fire Research Station in 1980 after 14 years during which time he specialised in fires and regulations work. He is now with Dr Keith Gugan and Associates, a firm of consultants in Hampton, Middlesex, which operates in the field of investigation of fires and explosions worldwide.

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Buildings, or portions of buildings, look a sorry sight after a fire: some may have collapsed and be only twisted ruins, others may have mainly suffered damage from smoke. Between these extremes there is a wide range of degree of damage. This paper provides some guidance and references on the effects of fire on building materials and structural components so that decisions as to repairability are not based wholly on superficial appearances.

Where there is no visible damage such as charring of timber, spalling of concrete or distortion of steelwork, there is generally little likelihood of permanent loss of strength of the material although this cannot always be assumed.

It is essential to do a thorough inspection of the complete premises in order to ensure that damage, eg through thermal expansion or water leakage, has not occurred in those parts not directly involved in the fire.

Temperatures reached in fires and estimation of fire severity

Standard fire resistance tests determine the period of time for which elements of building construction should fulfill their design function of loadbearing and/or fire separation while exposed to heat in accordance with a predetermined time/temperature curve in which the temperature rises by 821°C in 30 min and by 1,133°C in 240 min. This time/temperature relationship is an idealisation of an uncontrolled growing fire in a room. It assumes an unlimited supply of fuel and its burning rate, being controlled mainly by ventilation conditions, follows a predictable pattern.

In real incidents, fire may have remained localised for a long time, the rate of temperature rise may have been faster, or slower, than in the standard test, or extensive spread may occur. Different rooms and different parts of a building may have suffered different fire intensities. A knowledge of the behaviour of building components under standard fire test conditions is useful in predicting likely damage if the fire severity can be determined. However, it is important to determine as accurately as possible the condition of each element of the structure following the fire. Particular attention also needs to be given to those features which are an indirect consequence of the fire, eg forces not considered in the original design.
Table 1: Assessment of temperature reached by selected materials and components in fires

<table>
<thead>
<tr>
<th>Substance</th>
<th>Typical examples</th>
<th>Condition</th>
<th>Approximate temperature °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polystyrene</td>
<td>Thin wall food containers, Foam, light shades, handles, curtain hooks, radio casings</td>
<td>Collapse</td>
<td>120</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>Bags, film</td>
<td>Softens</td>
<td>120-140</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>Bottles, buckets</td>
<td>Melts and flows</td>
<td>250</td>
</tr>
<tr>
<td>Polymethyl methacrylate</td>
<td>Handles, covers, ‘glazing’</td>
<td>Shrivels</td>
<td>120</td>
</tr>
<tr>
<td>Cellulose</td>
<td>Wood, paper, cotton</td>
<td>Softens and melts</td>
<td>150</td>
</tr>
<tr>
<td>Solder</td>
<td>Plumbing joints</td>
<td>Softens</td>
<td>130-200</td>
</tr>
<tr>
<td>Lead</td>
<td>Plumbing</td>
<td>Bubbles</td>
<td>250</td>
</tr>
<tr>
<td>Aluminium</td>
<td>Fixtures, casings</td>
<td>Melts</td>
<td>200-300</td>
</tr>
<tr>
<td>Glass</td>
<td>Glazing, bottles</td>
<td>Melts, sharp edges rounded</td>
<td>300-350</td>
</tr>
<tr>
<td>Silver</td>
<td>Jewellery, spoons</td>
<td>Softens</td>
<td>400</td>
</tr>
<tr>
<td>Brass</td>
<td>Locks, taps</td>
<td>Melts</td>
<td>850</td>
</tr>
<tr>
<td>Copper</td>
<td>Wiring</td>
<td>Softens</td>
<td>700-800</td>
</tr>
<tr>
<td>Cast iron</td>
<td>Radiators</td>
<td>Flowing easily</td>
<td>850</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Melts</td>
<td>950</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Melts (particularly at edges)</td>
<td>800-1,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Melts</td>
<td>1,100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Melts</td>
<td>1,100-1,200</td>
</tr>
</tbody>
</table>

may have been generated by expansion or damage to other members.

An examination of the debris may not give an accurate picture of the temperature of the fire as it is subject to local fluctuations. Nevertheless, Table 1 gives an approximate guide to the estimation of temperatures attained by various components in building fires, from an examination of debris.

The colouration of concrete at various depths is a clue to both the maximum surface temperature attained2 (Figure 1) and the time/temperature experience (Figure 2). Care and experience are required when considering spalled surfaces. The interpretation will depend on judgment as to whether spalling occurred during the period of maximum heat exposure or subsequently, and as to the allowance to be made for this factor. The extent of the change of colour varies with the type of fine and coarse aggregate but changes will occur to some degree in practically all types of concrete in the UK. Wetting the affected concrete surface will enhance the colours. Some types of stone show similar changes.

The depth of charring from the original surface gives a rough guide to the duration of fire attack on a timber member. Timber will char at a steady rate on each face exposed to heating. The rates which are given in Table 2 relate to BS 476: Part 8 conditions1 and allow an assessment to be made in terms of an equivalent fire resistance time. Increased values are appropriate for the rate of depletion of columns and beams when exposed on all faces. Due allowance must be made for areas which have been allowed to smoulder after the fire has been controlled.

With plasterboard of 9.5 mm thickness, the unexposed paper face will be charred if there has

Figure 1  Colour changes in concrete

<table>
<thead>
<tr>
<th>Temperature °C</th>
<th>Colour change</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>900</td>
<td>Buff</td>
<td>Weak and friable</td>
</tr>
<tr>
<td>600</td>
<td>Whitish grey</td>
<td>Apparently sound but strength significantly reduced</td>
</tr>
<tr>
<td>300</td>
<td>Pink</td>
<td>Unaffected</td>
</tr>
<tr>
<td>0</td>
<td>Normal</td>
<td>Unaffected</td>
</tr>
</tbody>
</table>

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been a fire equivalent in severity to about 10 min under BS 476: Part 8 conditions.

Main effects of high temperature on materials

The thermal, strength and deformation properties of building materials at elevated temperatures are discussed by Lie. In general, any material heated above 200°C is likely to show significant loss of strength which may, or may not, be recovered after cooling.

Brickwork Clay bricks withstand temperatures in the region of 1,000°C or more without damage but under very severe and prolonged heating the surface of a brick may fuse. Spalling can occur with some types of brick particularly of the perforated type.

A loadbearing wall exposed to fire will suffer a progressive reduction in strength due to deterioration of the mortar in the same manner as concrete. Severe damage is more likely to be caused by the expansion or collapse of other members. Small expansion cracks in the structure may close up after the building has cooled.

Cast iron Because of their heavy mass and low design stresses, cast iron members generally show good performance in fires. The members should be carefully examined for signs of cracking. A permanent loss of strength can occur when the temperature of a cast-iron member exceeds 600°C but because of their large thermal mass this requires a fire of such severity that rebuilding is probably necessary anyway.

Concrete The behaviour of concrete structures in fire is discussed elsewhere. The pink colour change at around 300°C which occurs with most natural aggregates used in the UK is very important as it coincides with the temperature below which the compressive strength is not significantly reduced. Higher temperatures up to approximately 500°C may be endured by lightweight concrete before significant loss of strength occurs. In a concrete member, only the temperature of the outside layers increases initially and the temperatures of the internal concrete will be comparatively low, unless the fire exposure is prolonged, as concrete is a poor conductor of heat (Figure 2). Temperature rise at a greater depth than indicated in that Figure will occur if extensive spalling occurs during fire exposure. Natural aggregate concretes heated to 300°C or above, and lightweight aggregate concretes heated to 500°C or above, may need to be replaced in critical areas during reinstatement.

Steel reinforcement loses strength at high temperatures as discussed below. Loss in effective concrete section in prestressed members may significantly alter the intended design stress profile in addition to permitting a higher temperature in any adjacent steel tendons with consequent increased stress loss.

Hollow clay tiles and woodwool cement slabs used in floors may be damaged but when these are used as formers for the structural concrete section they have no structural significance and the damage can be ignored.

Plaster Plaster tends to be loosened in a fire and...
may require replacement for this reason. If it is severely stained by smoke which is resistant to washing, it will probably be more satisfactory to replace the plaster than to overpaint the smoke stains.

Steel

The behaviour of steel structures is discussed elsewhere.7 When a building has been exposed to fire the structural steelwork may suffer from any or all of the following effects:

- expansion of heated members relative to others which restrain this movement, leading to distortion of the heated member or its neighbours—particularly at connections;
- increased ductility, reduced strength and plastic flow while the metal is at a high temperature;
- change, persisting after cooling, in the mechanical properties of the metal.

The coefficient of linear thermal expansion of steel is nominally $14 \times 10^{-6}/\degree C$. In a fire this may be sufficiently small for it to be taken up by elastic deformation, expansion joints etc, or may be severe enough for the movement to cause permanent distortion of the framework or extensive cracking of bearing walls.

The temperature at which the flow stress of mild steel falls to the design stress is generally taken to be about $550\degree C$—for a design factor of safety of about 2. At stress levels less than the maximum permitted in design, this ‘critical’ temperature will rise. The effects of constraint and continuity can also raise the ‘critical’ temperature. Unless temperatures of $650\degree C$ are exceeded, there will be no deterioration in the mechanical properties of mild and micro-alloyed steels on cooling. After heating cold-drawn and heat-treated steels lose their strength more rapidly than mild and micro-alloyed steels and, on cooling from temperatures in excess of about $300\degree C$ and $400\degree C$ respectively, part of this loss of strength will be permanent.

In general, any steel members which have not distorted can be considered to be substantially unaffected by the heat to which they have been subjected. However, it must be realised that in certain cases some degradation in strength will have occurred. Members should be examined for cracks around rivet or bolt holes if expansion movements have taken place. It will usually, however, be the cleats, rivets and especially bolts which will have suffered and not the main members.

Decisions on reinstatement may need to be taken in the light of expert engineering and metallurgical advice.

Tiles and slates

Clay tiles that have survived a fire unbroken may be reused; as can slates that appear sound.

Timber

Behaviour of timber in fire is predictable with regard to the rate of charring and loss of strength. It is free from rapid changes of state and has very low coefficients of thermal expansion and thermal conductivity. For practical purposes, it can be assumed that full strength is maintained below the charred layer. For assessment of fire resistance of structural timber, BS 52683 provides calculation methods for flexural, compressive and tensile members.

Woodwool cement

The material below the crumbly fire damaged layer will be sound. If a sufficient depth of sound material is present the slabs may be retained. The fire problems associated with permanent shuttering are reviewed elsewhere.8

Assessment of extent of damage and possible reinstatement

A design procedure for the reinstatement of fire damaged buildings is given elsewhere;5,9 also a case study on building reinstatement.9

The problems caused by fire will of course include damage from water used in fire fighting as well as from heat and smoke.

The initial consideration of fire damaged premises should classify the damage to building components in terms of superficial, repairable or requiring replacement. In any investigation, it is essential to determine the exact form of construction of each element, eg filler joist floors, reinforced walls, etc as well as the materials used, eg grade of steel. Wherever possible, therefore, copies of the original details should be obtained.

Specialist advice may be needed in cases where there is much borderline repairable damage or where the construction is sophisticated.

The final decision on the extent of repair or demolition may include consideration of costs, time and possible improvement.

REFERENCES

Letters to the Editor

Sir, Whilst welcoming the publication of your new magazine and wishing it all possible success, I feel I must express some disappointment that the title 'Structural Survey', which I understand it is to be given, appears to indicate a restricted range of subject matter.

There is a real need for a magazine designed to be of interest to the established professional in the field of Building Surveying and of help to the student anxious to develop his understanding of practical problems in a way which is not possible (or, at any rate, does not appear to be achieved) during the course of academic studies.

I hope the style of your magazine will be light so that its contents make good bedtime reading inducing sweet dreams of methods of construction, modern building materials, forms of contract, refurbishment, dilapidations, the role of the expert witness and the intricacies of party walls and rights of light and, only occasionally, nightmares from consideration of professional negligence and the responsibility to supervise building works.

Good luck!

Yours sincerely

B. P. Holland
Drivers Jonas

Sir, I note with interest the introduction of your new quarterly journal Structural Survey. While you mention proposed features on such subjects as materials, law and building elements, which will no doubt be of interest, there is, I feel, a need for debate on the procedures relating to surveys and in particular, those relating to the survey of flats. I will be interested to hear if you propose to cover topics such as this in the journal.

D. R. Toogood
James Anthony & Co

We welcome Mr Toogood's remarks as we, too, want to see these subjects covered in the journal. It is intended that each issue will carry a 'model' or comprehensive survey with a checklist of points to be covered, by individual specialists. The first of these appears in this issue, by Malcolm Hollis of Baxter, Payne and Lepper, and can be read starting on page 62. We intend to cover flats of different sorts in later issues.