STRUCTURAL APPRAISAL FOR FIRE DAMAGED BUILDINGS

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Introduction:

In recent years, considerable emphasis has been placed on architects and structural engineers to have a greater understanding on the impact that fires have on structures and the structural performance of materials used for constructing them. This has been achieved by extensive research, testing, experience and changes in legislation within the industry, developing regulations, codes of practice and technical guidance to assist designers when undertaking this particular task. The main requirements for the design of structures with regards to fire are to maintain adequate structural stability, consider means of escape, reducing the ability for the fire to spread through compartmentation and provide suitable access for fire fighting. These basic functions are to ensure the safety to all persons in and around a building in the event of a fire, to allow adequate time for persons to evacuate the building and to limit the extent of damage to the building and surrounding buildings. Another important aspect of designing buildings to reduce the impact of fire is to provide suitable fire resistance to the main structural elements, allowing the structure to remain stable for a required period of time. This can be achieved by using structural materials which are less susceptible to heat or by using protection measures to increase the materials performance.

Separate from designing buildings to limit the damage and impact of fire, Structural appraisals is procedure used to assess existing buildings. A structural appraisal can be defined as the physical assessment of an existing building in relation to its condition and structural adequacy. Also in relation to fire, this assessment can determine the buildings fire resisting properties, structural performance and behaviour in the case of a fire and compliance with current legislation to indicate the requirements for the protection of the structure against fire. The purpose for undertaking such an assessment could be due to a number of factors, i.e. prior to purchasing a property, for the change of use of a building, etc, however for the basis of this report, I will be focusing on the structural appraisal of different structures which have experienced fire damage and the way in which these structures typically react in the event of a fire. Also I will discuss fire protection procedures for each structural element, research case studies for each structure to support my investigation and identifying possible remediation action for the structures considered.

The materials which I have chosen to evaluate for the structures in this report include reinforced concrete, structural steel, timber and masonry as each material behaves differently when exposed to high temperatures.

Literature review

More so today than ever before, people are aware of the incredible force that can come from natural disasters. The damage and destruction caused, the loss of life and unimaginable cost of recovery. Fire does occur naturally at high temperatures in forest fires and dry vegetation. But it could be classed as a by product of natural disasters or human error / misadventure. Natural disasters break electrical lines and gas pipes producing fuel plus ignition for example. Human error could be anything from leaving the cooker on to a manufacturing accident. But what separates fire from other natural disasters like earthquakes, tsunamis and tornados, is a fire can strike anywhere. Earthquakes happen along fault lines due to friction of plates. Tsunamis happen due to a swift movement in the ocean floor, they can be caused by landslides but not to the same scale. They also affect coastal areas. Tornados happen due to weather front, they general have seasons and affect certain areas. Fire can be localized or vast in size but could happen in every household, factory, office or transport hub. Another difference is, fire can be managed, controlled and to a certain degree prevented, more so than the others. As engineers we need to see the dangers ahead, use the information that is at hand and always learn from mistakes. Fire safety has benefited greatly from accidents, the good thing about these events is that it highlights flaws; it provokes analysis and demands solutions.

From as early as the ١٢th Century measures were put in place to improve fire safety. Chimneys were made from non combustible materials to stop fires at he source. Boundary walls were made from stone to stop the spread of fires. London has been affected by fires for ١٠٠ hundreds of years. This was due to the cheap and popular building material at the time, which was wood. But the great fire of London in ١٦٦٦ was the event that pushed the government into a rethink about fire safety. The fire gutted parts of central London destroying ١٣,٢٠٠ homes and ٨٧ churches. The death toll is debated but some reports have being less then ١٠ but there are doubts over this number due to the amount of damage done. Regardless, the death toll was very low compared to the amount of property destroyed. The speed in which the fire spread due to the closeness of adjoining buildings, was a compelling factor in more stone structures being built. But the traditional wood and thatch construction had been prohibited for some time but carried on being used because they were cheap. Only the wealthy could afford stone houses. Fire fighting techniques were proven to be unless in the spread of the fire. Firefighters would demolish building in hope of creating fire breaks.

These measures were gradually made into legislation and slowly added to for example by the inclusion of non combustible floors in certain areas to aid escape from fire. From these simple and straight forward measures, science improved fire safety in the ١٩th and ٢٠th century by the invention and introduction of new materials / forms of construction. These now well known names like iron, reinforced concrete and steel; dramatically improved construction. Each of these materials had different properties but were to some degree stronger, lighter, more ductile and faster to construct. The result was a reduction in limitations and the increase of possibilities. But one by product was an improvement in fire resistance. But these materials didn't make analysis any easier because structures became more complex and composite. Structures are a blend of different materials which makes it even more problematic to analysis. So accidents played a big part in fire safety development because they provide real evidence of fire exposure. But despite the importance of real life feedback, testing provides the building blocks for any further development in science.

"Testing has always been a part of improving the understanding of the performance of buildings"
IstructE – Introduction to the fire safety engineering of structures

These early tests were generally carried out in real buildings, which is a costly exercise. An early test was carried out on a Hartley and Stanhope system in the late ١٨th Century. Also the 'British Fire Prevention committee' carried out tests, these tests were on building components and were done late in the ١٩th Century. Today standard tests are laid out in legislation like the British standards soon to be Euro codes. Standard testing dates back to ١٩٠٣, this is when the 'International Fire Prevention Congress' met in London. A standard heating curve was introduced in ١٩١٧ in the ASTM – C١٩ (later changed to E١١٩). British standard ٤٧٦ was on fire resistance testing and the first edition was published in ١٩٣٢.

"Fire resistance is a period of time for which an element of construction (beam, column, floor, wall, etc) will survive in a standard fire test carried out in an approved furnace under specified condition of temperature, imposed load and restraint."
IstructE – Introduction to the fire safety engineering of structures

Fire resistance as been mentioned a few times in this report, its importance is common sense. But no building materials are fire proof, each material reacts differently to fire and will be discussed in specific sections later in the report. Engineering is not based on hopefully assumptions so guidelines and are introduced. Building regulation ١٩٩١ – Approved document B – Fire safety states:

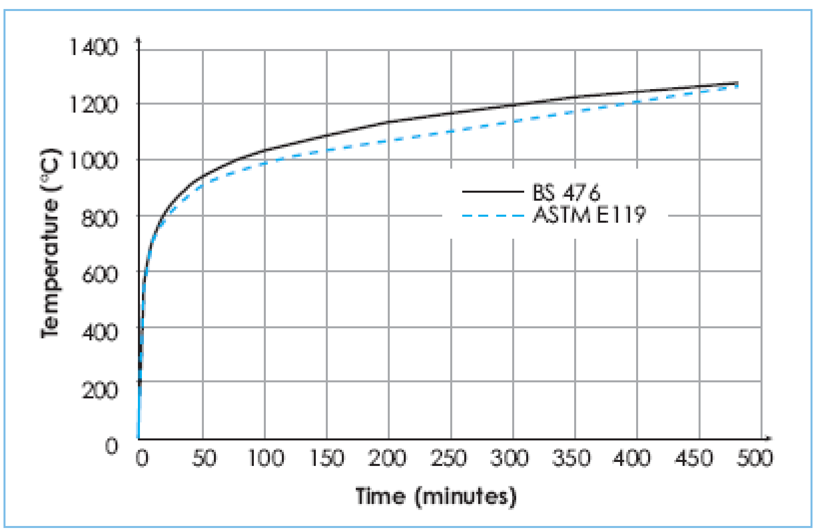
"The building shall be designed and constructed so that, in the event of a fire, its stability will be maintained for a reasonable period."

The reasonable period is stated in the approved document B (٢٠٠٠) and is presented in a table, please see the table below.

Purpose Group		Minimum periods of fire resistance (minutes)					
		Depth of lowest basement		Height of top floor above ground			
		more than 10m	not more than 10m	not more than 5m	not more than 18m	not more than 30m	more than 30m
Residential flats and maisonettes	Unsprinklered	90	60	30	60	90	120
Office	Unsprinklered	90	60	30	60	90	Not permitted
	Sprinklered	60	60	30	30	60	120
Shops and Commercial	Unsprinklered	90	60	60	60	90	Not permitted
	Sprinklered	60	60	30	60	60	120
Assembly and Recreation	Unsprinklered	90	60	60	60	90	Not permitted
	Sprinklered	60	60	30	60	60	120
Industrial	Unsprinklered	120	90	60	90	120	Not permitted
	Sprinklered	90	60	30	60	90	120

This table gives you the minimum amount of time certain types of buildings need to stay stable. The table clearly shows there are two major factors, which are height and sprinkler systems. The whole point of this time frame is to get people out and provide fire fighters a time frame of hopefully saving the building plus for their safety. Height is a factor because higher the building, longer it takes to go up and come down. Sprinkler systems reduce the ferocity and potentially stop or increase the time it takes for a fire to get to flashover. Flashover is a period in a fires life when it is at its most dangerous and damaging.

Another term mentioned already is the standard temperature – time curve. It is simply to use and as proven to be very successful with designers and regulators. Please see below for the graph.



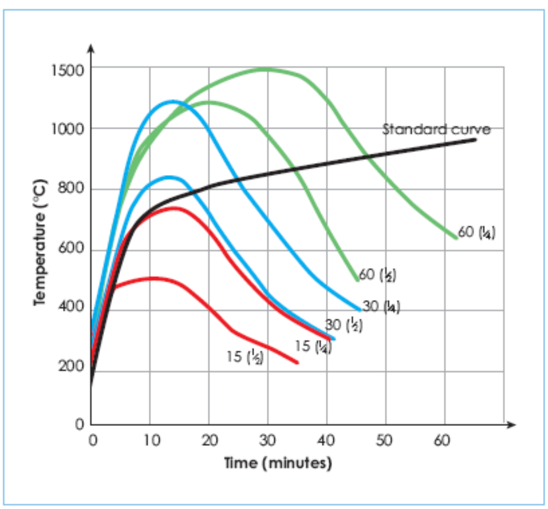
But for all the time, effort and research that was put into these methods. There are clear limitations to furnace testing and flaws with the temperature – heat curve.

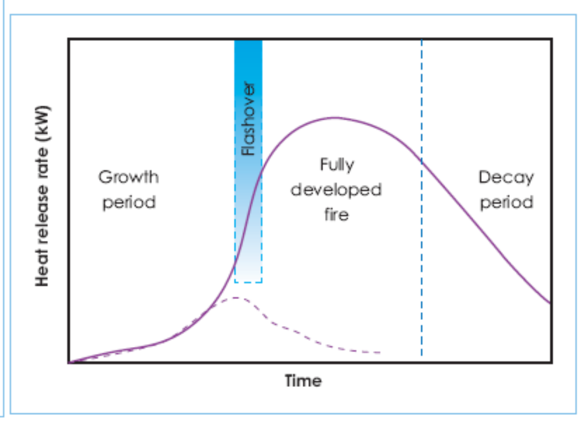
“It is often incorrectly assumed that there is a one to one relationship between survival of single elements in a standard fire resistance test and survival of actual buildings.”
IstructE – Introduction to the fire safety engineering of structures

Furnace testing is limited but it’s the best of a possible situation. One must be realistic and understand that with the large amount of varied types of buildings and different fire scenarios, it’s impossible to test real buildings. But furnace testing can’t accurately predict how a building is going to react to a number of fires and the chain reaction of a number of weakened components. A building is interconnected and not a large amount of single components. Another problem is the temperature in a furnace is uniform where the temperature in a real fire is varied. Temperature problems are a theme to the limitations of the standard fire curve.

“The standard temperature – time curve bears little resemblance to a real fire temperature time history.”
IstructE – Introduction to the fire safety engineering of structures

The standard curve is created from typical temperatures taken after flashover and does not represent any decay. These two graphs published by the IstructE shows a number of varied types of fire loads / amounts of ventilation compared to the standard curve. The second shows the stages of a fire.





The differences are clear and show a much higher temperature for a short period (flashover) and the exposure time is reduced (decay).

But as mentioned before, an engineer needs to use the information at hand and fire safety is always developing. More accurate methods / practices are being introduced all the time. Below are a few that will play a big part in designing for fire safety.

- The time equivalent concept – data taken from real fires taking a number of variables into consideration. There will be a time – equivalence calculation in Euro codes ١.
- Parametric fires – again real data helping to calculate atmospheric temperatures. Again calculations in EC١.
- Computational modeling.

The time equivalent concept uses real fire data, testing can only play a bit part in the development of safety. Accidents have been the driving force not just to fire safety but other work related legislation. In the book 'Industrial Fire Protection Engineering' a table is produced by the author. It displays ٨ large fires ranging from ١٩١١ to ١٩٨٩. The most interesting feature of this table is the ramifications columns at the bottom. Due to loss of life and / or the financial damage, these accidents had a bearing on all further legislation. Please see the next page for the table.

Table 1.4. Key factors in eight historic fires

Fire factor	GM Livonia 1953	McCormick place Chicago 1967	K Mart Falls Township 1982	N.Y. Telephone 1975	Ford Cologne 1977	Triangle Shirtwaist N.Y.C. 1911	Hinsdale Telephone Exchange 1989	Sandoz Basel 1986
Occupancy	Automobile Transmission Manufacture	Exhibit Hall	General Warehouse	Telephone Exchange	Auto Parts Warehouse	Garment Factory	Telephone Exchange	Flammable Liquid Warehouse
Ignition source	Hot Work	Electrical	Lift Truck Wiring	Electric Motor	Cigarette	Cigarette	Arcing	Heat during Shrink Wrap
Primary fuel	Flammable Liquid	Plastic	Aerosol Cans	Electric Cable	Plastic	Cotton Fabric	Electric Cable	Flammable Liquid
Other combustibles	Asphalt Roof	Wood, Fabric	Flammable Liquid	–	Motor Oil	Oil Residue, Rags& Lint	–	Pallets
Sprinkler system	None in Fire Area	None in Fire Area	Inadequate	None	Inadequate	None	None	None
Fire wall	None in Manufacturing Area	None	Walls Breached	Cable Penetrations Breached	Effective	None	Effective	Partially Breached
Other factors	Exposed Steel	Aluminum, Inoperable Pumps & Hydrants	No Fire Doors	Smoke Damage, HCl Corrosion	Aisle Storage	Inadequate and Locked Exits	Delayed Response to Alarm	Rocketing Steel Drums, Environmental Disaster
Fatalities	6	0	0	0	0	145	0	0
Fire protection ramifications	Roof Tests, New Style Sprinklers, Many More Fire Walls	Heat & Smoke Vents, Water Supply Reliability, FPE Consultants	Aerosol Product Sprinkler Protection, Better Fire Walls	Smoke Control, Cable Penetration Seals	Large Drop & ESFR Sprinklers	Life Safety Code,	Fire Resistant Cables, Sensitive Smoke Detectors	Containment of Water Runoff, Improved Protection of Flammable Liquid Storage
Other ramifications	Multiple Manufacturing Sites	Electrical Code Enforcement	–	–	Sprinkler Protection in Europe	Labor Unions, Labor Laws	Reliability of Telephone Systems	International Environmental Regulation

The most noticeable is the 'Triangle Shirtwaist' disaster of ١٩١١ in New York city. The fire was started by a cigarette and toke ١٤٥ lives. The company was in the clothing production industry, their workers were generally women and children immigrants. The disaster exposed many issue with sweatshop conditions and changed not only fire legislation but labor laws.

All this as helped develop fire safety and the saving of further lives. But more recent accidents show us that there are always lessons to be learnt. The twin towers show us that fire safety is not over after design or construction. Maintenance plays a huge part in a buildings fire safety decades after construction.

“It is probably true to say that design for fire safety is where structural engineering was a ١٠٠ years ago. Expect technology and computers are enabling it to progress much more quickly”

IstructE – Introduction to the fire safety engineering of structures

Concrete structures

Concrete structures generally perform extremely well during and after a fire, resulting in the majority of fire damaged concrete buildings being repaired and reused. One of the main advantages of concrete and reason it is commonly used as a structural material is its inherent fire resisting properties and low thermal conductivity. For this reason concrete is used as fire protection to other materials, such as structural steel and reinforcing steel. When using concrete as a structural element, it will perform well in a fire providing it is designed, detailed and specified correctly. Specific guidance for the level of fire resistance for concrete is primarily based on the results of standard fire tests carried out on individual members and complete structures. This data relates to the grade of concrete, size of the member, nominal cover of reinforcement, exposure conditions and predicted temperature of the fire, to determine a duration which the member will remain structurally stable. A simplified version of this can be seen in table ١.١ which indicates the fire rating of concrete (in minutes) relating to minimum member sizes and concrete grades.

Table ١.١- typical fire rating for normal and high strength concrete

Standard fire resistance	Minimum dimensions, b_{min}/a for normal concrete	Minimum dimensions, b_{min}/a for high strength concrete
R30	300/27	316/35
R60	350/40	374/52

When concrete is subject to fire, similar to most materials, a degree of deformation occurs which needs to be allowed for, but the main consideration with regards to the structural stability of the structure after the event of a fire is dependant on the duration and temperature of the fire in which the concrete has been exposed to. This is because concrete undergoes a number of changes at different temperatures, this is shown in detail in table ١.٢ below. In basic terms the fundamental changes are as follows, when the fire reaches ١٠٠˚C the moisture content within the concrete evaporates and the cement paste dehydrates causing the aggregates to expand. When this temperature increases to ٣٥٠˚C then the compressive strength of the concrete reduces and begins to break up, known as spalling. Further increases in temperature continue to reduce the strength of the concrete and the steel embedded within in it and when it reaches ٨٠٠˚C the majority of the concretes strength is lost and results in a permanent reduction in strength. However after the fire has been extinguished, the concrete begins to undertake a cooling process, in which it regains its strength, although reduced, making the structure stable and able to be repaired and reused.

Table ١.٢- chemical process of concrete at different temperatures

Approximate material temperature	Process
100°C	Hydrothermal reactions – loss of chemically bound water begins.
300°C	Start of temperature loss for siliceous concretes – some flint aggregates dehydrate, Thames river gravel breaks up
100–400°C	Critical range for explosive spalling
600°C	Marked increase in 'basic' creep
700°C	Dissociation of calcium carbonate
800°C	Ceramic binding. Total loss of water of hydration
1200°C	Melting starts

With regards to the assessment of damage to concrete structures as a result of fire, there are ٢ main methods for achieving this. These include physically testing various parts of the affected structure and estimating the severity of the fire in terms of the temperature it reached, to determine the residual strength of the structure. Due to reinforced concrete structures acting monolithically, they have the ability to use alternative load paths if part of the structure is weakened, therefore it is uncommon for them to have any structural problems as a result of fire damage. Also with regards to defects, as mentioned earlier when concrete is exposed to high temperatures the concrete surface spalls, this is where pieces of the concrete detach from the structural element exposing the aggregates or possibly reinforcement within. This however is simply a surface defect which is easily repaired and rarely any significance to the integrity of the structure.

Case study:-
a large fire broke out on a ten-storey to the reinforced concrete frame building, which occurred during construction. The fire swept through the three upper storeys while the soffit formwork for the slabs was still in place. Although the damage was widespread, it was confined to the outer ٥-٣٠mm of the

underside of the slab and some columns. Tests on samples of the reinforcement showed that the steel had not been significantly affected and hence, the slabs could be economically repaired. The damaged concrete was removed by hydro-demolition or manually, and was reinstated using sprayed concrete.

Steel structures:

When considering using steel as a structural element, one of the main factors which influence the design of steel buildings relates to the effects of fire on steel structures and the methods to provide adequate fire protection. The main disadvantage with steel as a material is it is susceptible to high temperatures and when steel is heated it expands and its strength and stiffness decreases. Also structural steel has a high thermal conductivity, meaning that it quickly reaches the temperatures it is subject to, giving limited amounts of time before the structure begins to fail. For steel structures to comply with current building regulations it must achieve a minimum fire rating of ٣٠ minutes before failure, whereas unprotected steel elements can fail within ١٠-١٥ minutes. It is for this reason that steel always requires some form of fire protection to improve its fire resistance. Also steel structures are restrained by means of their connections, whereas tests carried out to measure the fire resistance of steel members use the basis that the member is simply supported. Therefore major problems arise as the predicted level of fire resistance seriously under estimates the fire resistance of the actual structure. With regards to providing suitable fire protection for structural steel, this can be achieved in a number of ways, either by intumescent coating, encasement or insulating the structural member.

Intumescent coatings- this consists of an intumescent paint or mastic which surrounds the steel and possesses the ability to swell to many times its original thickness when subject to heat, acting as a form of encasement for the steelwork. This swelling provides additional insulation to the member, reducing its exposure to the heat and can achieve up to ٢ hours fire resistance. If specified this is usually applied to the steel after it has been fabricated, to ensure an even coat has been applied through out the section, however care must be taken not to damage this coating during transportation and erecting on site. Also the intumescent coating is available in a range of colours and to a high level of finish, making it an ideal choice is the steel is visible.

Encasement- there is a variety of methods for encasing structural steel to provide adequate fire protection. The most common method is by using a form of boarding, which completely surrounds the member, similar to that of a dry lining system. This is a very popular choice for protecting steel as it is extremely adaptable, conceals the structural members and provides a good finished article. The boards are composed of various materials such as fire resistant plasterboard, ceramic, mineral fibres, calcium silicate and vermiculite. This method protects the steel by acting as a form of insulation, reducing the heating rate and therefore improving its fire rating. The level of fire rating required can be achieved by varying the thickness of the boarding material and can provide up to ٤ hours protection.

Similar to concrete, structural steel undergoes changes at different temperatures, which drastically affect its structural characteristics. These fundamental stages are as follows, when steel heated it expands at a constant rate, however its strength is not really affected until it reaches ٣٠٠˚C and after this point its yield strength begins to rapidly reduce, when the steel reaches ٥٥٠˚C, known as it critical temperature, it strength has halved. When steel reaches ٧٠٠-٨٠٠˚C its yield strength is about ١٠% of its original strength and the steel undergoes a chemical transformation and begins to shrink, this process can be seen in figs. ٢.١and ٢.٢. However, although the steel structures strength is dramatically reduced during the event of a fire, after it will regain up to ٩٠% of its original strength once the structure has cooled down, therefore requiring minimal amounts of remedial actions

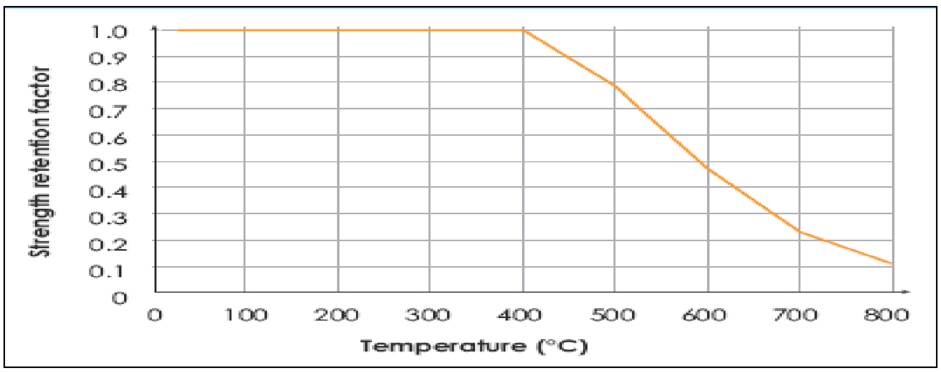


Fig ٢.١- strength of steel in relation to temperature

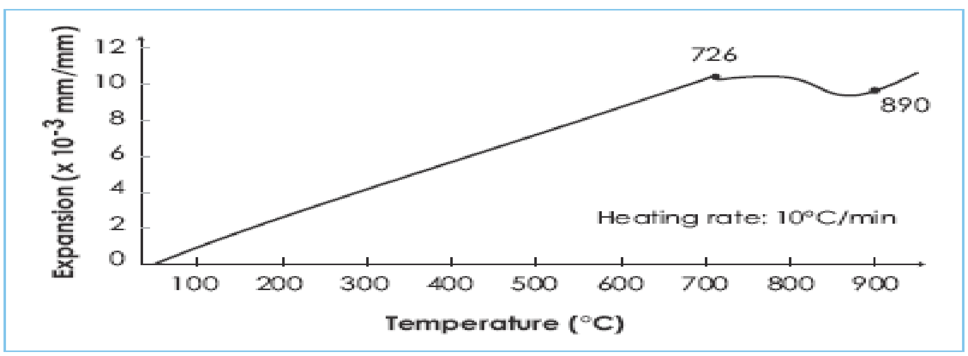


Fig. ٢.٢- expansion characteristics of steel in relation to temperature

Usually in the case of a fire, only a number of steel members will be affected and subject to a reduction in strength. As mentioned above, this is dependant on the duration of the fire and temperature in which the steel has been exposed to. If the steel has been subject to between ٥٠٠-٦٠٠˚C then once it has cooled it regains ٩٠% of it strength, whereas if exposed to higher temperatures then the residual strength of the steel is reduced meaning some members will need to be replaced. Also as the connections in steel structures are vital for providing it rigidity and strength, these are commonly what causes the structure to fail and will require testing to determine there adequacy. However the type of connections and bolts used in steel structures have had numerous tests carried out on them to determine there performance during a fire and have proven that they should remain adequate after the event of a fire. The first stage for assessing the degree of fire damage to a steel structure is by means of a visual inspection, looking for signs of defects such as buckling, bowing, twisting and distortion to the elements. Also non destructive tests can be carried out such as distortion measurement, straightness checks and hardening testing to give an indication to the temperature which the steel has encountered.Also small pieces of the steel can be taken from the member and bolts can be removed to perform laboratory tests to examine its properties and hardness. Also the fire protection used must be assessed by visual inspection to determine whether it is still acceptable or if it needs to be replaced to ensure adequate protection to the steel members.

Case study- in ١٩٩١ a fire took place in the mercantile credit insurance building in Basingstoke. The building was constructed in ١٩٨٨ and comprised of a ١٢ storey steel framed building with composite metal flooring. The steel frame had passive fire protection in the form of boards and the composite floor beams had spray applied protection and the structure was designed to have ٩٠ minutes fire protection.
The fire started on the eighth floor and spread rapidly to the tenth floor once the glazing failed. The fire protected materials performed well in the fire and there was no permanent deformation to the steel frame and connections. A load test was conducted on the worst affected areas of the structure which demonstrated that the columns beams and slab had adequate load carrying capacity and could be reused without repair. The fire protection to the main structural element was replaced although visually it appeared undamaged.

Timber structures

When we consider the properties of timber in relation to fire, we know that timber is a combustible material and one that is used to as a heat source to fuel a fire. Therefore we assume timber to act poorly as a structural material in the event of a fire, however it can actually perform as well as other structural materials due to its low thermal conductivity. The performance of timber and its fire resistance mainly depends on its section size, density and moisture content, which varies considerably depending on the species.
With regards to section size, the rate and ease of combustion is dependant on the surface area to volume ratio, which is why wood shavings will burn readily and large timber sections will not support fire growth unless an additional heat source is present. Therefore large structural members can perform well in the case of a fire. In relation to the density of timber, this is the main factor which determines the time period for the wood to ignite and the extent of fire spread. In basic terms, the more dense the timber is, the greater its fire resistance, which is expressed in fig. ٣.١.

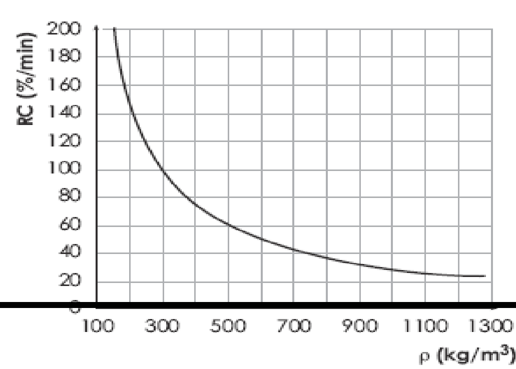


Fig.٣.١- showing the relationship between density and the rate of combustion

One of the most interesting aspects of timber in relation to fire is the phenomenon known as charring and how this improves the timbers fire resisting properties. This occurs when the timber is exposed to fire, the outer face of the wood begins to burn and continues to burn at a constant rate. This creates a form of natural insulation around the member as the thermal properties of charred timber are ٦ times that of normal timber. The depth of charring layer is usually minimal, but obviously is affected by time, therefore leaving the bulk of remaining timber unaffected.
As mentioned above one of the main factors that affect the fire resistance of timber is the size of the member, therefore to achieve the required fire rating to comply with current building regulations the member must be sized accordingly. Table ٣.١ shows some typical thicknesses of timber and there fire ratings.

Table ٣.١ shows the relationship between the type of timber, size and fire rating

Species		Charring in	
		30min (mm)	60min (mm)
(a)	All structural species expect those in items (b) and (c)	20	40
(b)	Western red cedar	25	50
(c)	Oak, utile, keruing, gurjun, teak, greenheart, jarrah	15	30

Although this shows how to achieve the minimum level of fire resistance to satisfy legislation, commonly in the construction industry today the choice and size of material is usually governed by cost. Meaning that we usually select the cheapest option of timber to achieve the strength which we require, not considering its particular properties with respect to fire resistance. For this reason timber usually has some form of fire protection applied to it, either by means of surface treatments or encasement. These protection measures include,

- *Fire retardants*- chemical substances are impregnated into the timber which improve it fire resistance, only effective a temperatures of ٢٠٠-٤٠٠°C
- *Intumescent coatings*- similar approach as structural steel, a thick foam coating is applied to the timber which expands when subject to heat. This insulates the member, reducing the temperature exposed to the timber

- *Encasement*- again similar to that of structural steel, fire resisting boarding can fixed around the member, to reduce the direct effect of the fire.

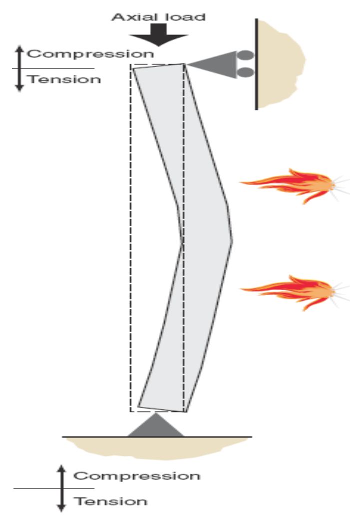
Usually in the case of a fire to a timber structure, the fundamental stages of timber are as follows, at ٢٠٠-٢٥٠°C the wood blackens and a slight reduction in strength occurs, then at ٣٠٠-٤٠٠°C combustible vapours are released and the surface ignites causing the charring process to begin. This process continues at a steady rate and will continue for a period of time after the fire has ceased. However, although timber performs well in the case of a fire, due to the temperatures which are reached in actual building fires, unless the structure is fully fire protected or the fire is quickly extinguished the buildings will fail.

With regards to assessing the damage to the structure, the amount of charring that has occurred will give an indication to the duration of the fire. Also more importantly the extent of charring, in relation to the size of the original member, must be calculated to determine the remaining structural capacity of the element and whether it is still fit for purpose. If the member is deemed to be inadequate to withstand the intended loads applied to it, then it can be simply replaced. Another important aspect to the residual strength of the structure, similar to steel, is the condition of the connections which provide rigidity and stability. Where timber connections usually consist of steel plates and steel fixings, i.e. screws and nails, these will conduct more heat and behave in a different way to the timber during a fire. This is commonly the main cause of failure in timber structures, therefore careful inspections must be carried out at the joints and connections to check for adequacy and replace where necessary.

Case study- Sorting House, Manchester ٢٠٠٥, A fire broke out in this four storey timber framed building containing luxury apartments. The fire started on the top floor in one of the apartments, where it was contained. The fire was fairly serious, consuming all the furnishings with in the room and blowing out the windows. Luckily the fire brigade managed to extinguish the fire before it spread to the other apartments within the building. Upon carrying out an assessment of the fire damage to the property, the main structural elements were completely un affected by the fire and the only damage that had occurred was aesthetic.

Masonry structures

With regards to this report discussing the fire resistance of masonry, I am solely considering clay bricks and concrete blocks, not natural stone. Masonry is a composite of natural elements which are extracted from the ground such as, stone, clay, shale, calcium silicate, gypsum, etc, making it a completely incombustible material. Also with regards to bricks, during the manufacturing process they are fired in a kiln at temperature of ٢٠٠٠˚C, making them completely impervious to any temperature experienced by building fires. Masonry in the form of walls has be used as a structural material for hundreds of years due to its inherent properties, such as its durability, compressive strength, sound and thermal insulating properties, fire resistance and aesthetic properties Similar to that of concrete, masonry has excellent fire resistance properties and low thermal conductivity making it an ideal for protecting other elements from fire. With regards to the fire resisting properties of masonry, this is directly proportionate to its thickness. This is commonly between ١٠٠-٢١٥ mm which will provide up to ٦ hours fire resistance. A method for further improving the fire resistance to masonry walls can be achieved by applying a plastered finish to the internal walls to enhance the insulating properties.



The behaviour of masonry walls and the effect of fire are affected by temperature distribution and the thermal stresses in the wall. This is because masonry walls are predominantly subject to heating on one face, (for internal fires) creating a thermal gradient through the thickness of the wall. This temperature distribution through the wall induces thermal stresses, causing the wall to lean inwards towards the fire. This deflection in the wall results in further stresses due to eccentric loading and if not sufficiently restrained may result in failure. Another problem with regards to the effect of fire on masonry structures is the fact that walls are only constructed of masonry and relies on other structural elements to form the floors and roof. Therefore even though the fire has little impact on the masonry, if the roof members are constructed of timber or steel, then this individual failure can cause the entire structure to fail.

In terms of assessing the damage to masonry structures after a fire has occurred, this is usually achieved by a visual inspection to check for any signs of cracking, spalling and deflection to the walls. Any discolouring to the walls should be ignored as this will not affect the structural capacity of the masonry. Also core samples can be taken from the suspect masonry and mortar to check if its compressive strength has been compromised. With regards to repairing damaged masonry, as a masonry wall is made of individual components, these can simply be removed and replaced locally without having to take down the entire wall. If the internal load bearing wall has excessively deflected in a particular area, i.e. on the floor that the fire broke out, as mentioned this could make the wall unstable due to eccentric loading. Again as this is only localised damage, this is the

only area that needs to be repaired. In order to carry out the repair, the loads that are acting on the wall in question should be temporarily supported using needles, bearers and props, and then the damaged wall can be taken down and rebuilt.
If there are no visual signs of damage then the strength of the masonry can be taken as it was originally and will not require any remedial work.

Case study- Following an arson attack, an investigation was undertaken to determine the extent of fire damage at a school gymnasium. The fire was caused by a car being crashed into the emergency doors and then set alight. The construction of the building was a single storey masonry structure and comprised of a cavity wall with a concrete blockwork inner leaf and a clay brickwork outer leaf.
On-site visual inspection revealed that the brickwork mortar around the door exhibited red discoloration. A number of core samples were diamond drilled from the brickwork around the door to determine the residual strength of the masonry and the extent of the damage within the cavity. A boroscope inspection of the cavity was carried out to look for masonry damage and check the condition of the wall ties. The masonry samples were then tested in a laboratory and petrographic examination of the core samples determined that the mortar comprised of quartz sand fine aggregate, bound by a hardened Portland cement matrix that incorporated a yellow pigment. Red discoloration and micro cracking were observed up to ٢٠mm from the outer surface. The clay brick appeared to be undamaged by the heating in all cases however it was concluded that the masonry around the doorway was significantly compromised and an area up to one metre around the doorframe was dismantled and rebuilt with new materials.

Conclusion

As identified in this report, each material behaves differently and has its own characteristics in relation to fire and heat. These need to be considered when designing structures so that a suitable material can be selected and the necessary protection measures implemented. Research into the behavior of structures in fire has been ongoing for many years, however substantial development has been made in the past ١٠ years, considering the effects of real fires on complete structures as apposed to the individual materials. This can only lead to more consistent safety levels, more robust designs and increase the opportunity for new technologies and innovative designs.
With regards to structural appraisal process, all structures that have been subjected to fire should be evaluated in systematic manner, to determine the extent of the damage and a necessary repair strategy if required. The intensity and duration of the fire needs to be determined by observing the damage to the building and testing the materials and structural elements. These evaluations, combined with good engineering judgement, allow for effective and economical repairs to be established.

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