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DAMAGE ASSESSMENT & REHABILITATION OF FIRE AFFECTED R.C.C. STRUCTURES

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Abstract

Concrete is a widely used material in the construction of various kinds of structures. As one of the main construction materials, concrete provides resistance to various harmful actions. It acts as a load bearing material in the building components and protects the reinforcement within the concrete from rust & fire. Fire is a catastrophic event to which any building can fall victim during its lifetime. Not only does it pose a direct threat to the occupants through the release of harmful gases and devastating heat, but the elevated temperatures themselves also have seriously adverse effects on the structural integrity of the entire building. As a fire protection precaution, the thickness of concrete cover is to be determined from the consideration of fire. This is important considering the fact that though concrete in itself is incombustible, the steel reinforcement cannot be expected to retain its structural integrity at elevated temperatures. Reinforced concrete structures lose their load carrying capacity when reinforcement becomes hot. Fire in the structure causes higher temperature at the concrete surface, which causes reduction in compressive & flexural strengths & modulus of elasticity of concrete. This study tries to explore the effect of fire on concrete structures, both Active & Passive measures adopted to increase fire resistance, assessment of damage & the consequent repairs & rehabilitation. The intensity and duration of fire can be estimate by observing collateral damage. A variety of testing methods and tools are available to assess the effects of fire on both the materials and structural elements. The rehabilitation itself may consist of patch repairs by shotcreting, crack fillings by injecting grouts or more rigorous methods like using FRP sheets & steel jacketing. Though the broad measures are identical to any other retrofitting, care has to be taken to further shield FRP sheets & steel jackets as their fire resistance of suspect.

INTRODUCTION:

Fire is a catastrophic event to which any building can fall victim during its lifetime. Not only does it pose a direct threat to the occupants through the release of harmful gases and devastating heat, but the elevated temperatures themselves also have seriously adverse effects on the structural integrity of the entire building. Though undesired, fire can't be avoided altogether. Therefore fire protection efforts must be made to reduce the impact of such events. The primary goal of fire protection is to limit, to acceptable levels, the probability of death, injury and property loss in an unexpected fire. With respect to structural design, this means providing sufficient time for the occupants to exit the building and for firefighters to extinguish the fire before any structural collapse occurs. In order to do so, numerous methods of providing protection are available, often categorized by Active and Passive measures. Active measures refer to systems which become engaged or are used during a fire, such as alarms, sprinklers and provisions for fire fighters. Fire design codes typically allocate building fire ratings based on when key structural members reach the maximum acceptable temperature for that respective material

FIRE PHYSICS - BASIC CONCEPTS

Fire and "a fire"

Fire involves combustion. This is found in furnaces and boilers in the form of **controlled combustion**. "A fire" Involves **uncontrolled combustion**.

WHY CHOOSE A CONCRETE STRUCTURE?

Concrete is specified in buildings and civil-engineering projects for several reasons: questions of cost, of speed of construction, of aesthetic or architectural appearance. Nevertheless, one of the key inherent benefits of concrete is its performance in fire at no extra cost, an aspect which can prove decisive in relation to the factors affecting the decision-making process when designing a project

WHAT HAPPENS TO CONCRETE IN A FIRE?:

Fires require three components:

• Fuel

• Oxygen

• Heat source

Fires are caused by accident, energy sources or natural means, but the majority of fires in buildings are caused by human error (e.g. discarded cigarette butt, shot-circuit).

Fig.1: Concrete provides protection against heat from fire.

PHYSICAL AND CHEMICAL PHENOMENA

In the event of a fire, a very sharp rise in temperature may trigger physico-chemical changes in the concrete, such as dehydration by drying of the concrete and decarbonatation. These phenomena can cause shrinkage, losses of resistance and rigidity of the materials. builds up may generate tensile stresses in the concrete at this point such that the concretes limit of resistance is exceeded. This phenomenon is all the more pronounced because the humidity of the concrete is high and the rise in temperature rapid. Fragments of concrete can thus be thrown out from the surface of the element with more or less violence (spalling of concrete)

For concrete, the loss of resistance results mainly from the formation of internal cracks and the degradation/disintegration of the cement paste. The paste in fact contracts while the granulates expand. Apart from these internal cracks, at these very high temperatures cracks can be seen to form between the cement paste and the aggregates. As described above, several transformations resulting from the significant increase in temperature occur in the cement paste, causing a loss of cohesion.

The concrete changes in an extremely complex manner during a fire

Bulletin nr 37 [69] of the cement dossier published by FEBELCEM presents in two pages in §5 the physical and chemical phenomena encountered for concrete subjected to fire.

The residual resistances of concretes and steels are also given.

Generally speaking the negative effects of heat mentioned above only act on an external layer 3 to 5 cm thick.

Changes To Concrete In A Fire:

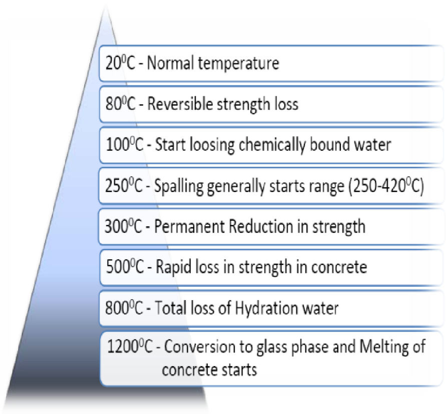

Fig.2: Effect of rising temperature on Concret Concrete does not burn – it cannot be ‘set on fire’ like other materials in a building and it does not emit any toxic fumes when affected by fire. It will also not produce smoke or drip molten particles, unlike some plastics and metals, so it does not add to the fire load. For these reasons concrete is said to have a high degree of fire resistance and, in the majority of applications,concrete can be described as virtually ‘fireproof’. This excellent performance is due in main to concrete’s constituent materials (i.e. cement and aggregates) which, when chemically combined within concrete, form a material that is essentially inert and, importantly for fire safety design, has a relatively poor thermal conductivity. It is this slow rate of heat transfer (conductivity) that enables concrete to act as an effective fire shield not only between adjacent spaces, but also to protect itself from fire damage. The rate of increase of temperature through the cross section of a concrete element is relatively slow and so internal zones do not reach the same high temperatures as a surface exposed to flames.

After The Fire:

Inspection of fire-affected structures is based on a visual check and comparison with similar cases. Any concrete exposed to temperatures above 300°C is removed and replaced. Below this temperature, concrete can be repaired by increasing the overall dimensions to take the design load. Often all that is required is a simple clean up.

Speed of repair is an important factor in minimizing the loss of business after a major fire. Repair is preferable to demolition and reinstatement for cost reasons.

In reality, the behavior of concrete in fire can be rather complex and will very much depend on a number of factors including mix design, imposed loads and structural design.

Repair of concrete structures

In general, concrete structures that are burnt can be restored whereas structures made from other materials would be irremediably damaged, even by lesser fire loads. A construction made from concrete exposed to high temperatures can be damaged. In certain cases, the damage can be repaired. In other cases, it is irreversible and the construction must be demolished.

Inspection methods;After a fire, the first thing to do is to proceed with an assessment of the structural integrity of the construction in concrete. This assessment will determine if it is possible to safely enter the building. Then, it is necessary to assess the extent of the damage and see whether the building can still be repaired.

Following Flow-chart summarizes the process:

Verify if the Structure is Safe to Enter
Perform preliminary sight visit 1) Identify Follow-up Area. 2) Note Temperature indicators. 3) Determine the Cleaning method.
Perform Detail Evaluation 1) Visual 2) Non-Destructive Testing. 3) Partially Destructive Testing
Analysis: 1) Compare allowable And Applied stresses. 2) Identify Extent of Repair.
Design Repair:- 1) Select Material. 2) Develop Details.

Visual observations

During an initial inspection, spalling, the flaking of the concrete, the formation of major cracks and the distortion of the construction are relatively easy to detect. This can be seen just by looking at it. colour changes when subjected to heat. The change of colour is due to the presence of certain ferriferous component

Subsequently, it varies according to the type of concrete. This modification in colour is permanent: it is therefore possible, on the basis of the colour of the concrete, to make an approximate assessment of the maximum temperature reached during the fire. The different colors of the concrete are as follows:

− Pink or red for temperatures between 300 °C and 600 °C;

− Grey-white for temperatures between 600 °C and 900 °C;

− Dull or light yellow for temperatures over 900 °C.

This means that it is also possible to assess the resistance of the concrete after a fire. In practice, we can confirm that any concrete that turns pink is suspicious. A temperature of 300 °C corresponds, more or less, to concrete that has lost a permanent part of its resistance. A grey-white colour indicates concrete that is fragile and porous. Furthermore, a permanent distortion of the construction indicates an overheating of the reinforcement.

Repair options

After a fire, it is sometimes necessary to carry out major repair works. To repair a construction made from concrete, it is practically impossible to provide standard solutions. Each situation must be examined individually and the best solution chosen for each case. − The resistance of the construction after the fire;

− The permanent distortions;

− The durability after the fire and repairs;

− The aesthetic aspect.

The choice of the solution is largely dictated by economic considerations: what is the most advantageous economic solution? Replacing or repairing damaged elements? In general, for a construction in concrete, which is distorted in some way following a fire, the most logical solution consists of replacing the elements of construction or demolishing the building.

If the reinforcement has not been subject to high temperatures, stripping the damaged concrete back to the healthy concrete is largely sufficient. In practice, a good solution consists of repairing the damaged concrete using shotcrete, though work o this type must be performed by professionals. By sticking metal plates or carbon fibre strips to the surface of the damaged concrete, it is sometimes possible to strengthen a reinforcement that has been weakened locally. This type of work must also be carried out by specialists. In the case of damage to the aesthetics of a building, the most obvious solution is to apply a rendering.

SHOTCRETE

Dry-mix shotcreting

Damp-mix shotcreting

Rehabilitation of Fire Damage:

The Three Stages of evaluation are Visual Assessment, Non-destructive testing and Partially Destructive Testing.

Stage 1: a) Visual Assessment : Cleaning

Soot hides most cracks, spalls and distortion in the structure. The structure may be cleaned by means of dry ice blasting, grid blasting, water blasting, or chemical washing. Chemical wrapping or dry ice blasting tends to generate the least collateral damage to the structure. Grid

Temp	Color change	Change in Physical appearance and bench mark temperature	Concrete condition
0^{o} to $300^{0}C$	None	Unaffected	Unaffected
$300^{o}$to $600^{0}C$	Pink spots	Surface Crazing, Deep Cracking, Popouts over charts or Quartz Aggregates	Sound but significantly reduced.
600^{0} to $1000^{0}C$	Whitish Grey to buff	Spalling, Powdered, Light colored, Dehydrated paste.	Weak and Friable
($1000^{0}C$+....)	Buff	Extensive Spalling	Weak And Friable

blasting tends to produce large amount of blasting medium.

Water blasting can cause collateral damage to finished areas below the fire (beyond the firefighting water damage).

b) Visual Assessment: Coloration

Intense heat may cause chemical reaction that form crystals or change the properties/color of the matrix and aggregates in concrete. Following table summarizes the changes in concrete:

Table1: Change of colour with temperature

It has to be mentioned; however, that post-fire colour depends on many factors & may not be a reliable tool for assessing the temperature reached.

Stage 2:Non-destructive testing of concrete:

The extent of delamination can be determine by means of chain dragging for large horizontal areas such as slab, and by means of hammer sounding for vertical and overhead surfaces. Impulse response can be used to rapidly screen large areas of potential damage.

Impact eco testing can also be used to determine the depth and extent of internal fractures. Finally, rebound hammers are frequently used to compare the surface hardness of concrete to locate potential damage. Selecting the appropriate material is a critical step in the repair process.

The repair material must be compatible with best material, Project needs, technical recourses available, financial constrains and multiple other project specific criteria

Stage 3: Retrofitting:

Concrete Patch Repairs:

The spalled areas of slab, wall panels are patched using conventional concrete repair methodologies. Patch repairs for corner spalls of the stems generally consist of the removal of loose and unsound concrete, preparation of the exposed steel reinforcement, installation of stainless steel threaded rod anchors, and form-and pour application of a polymer-modified Portland cement-based patching material.

Fig.3: Application of spray-applied mortar

A limited structural analysis should be performed to assess the possible effects of the fire damaged concrete on the overall load-carrying capacity of the structure. The analysis can be performed using design information indicated on structural drawings provided by the designer. Flexural and shear capacities can be determined using proprietary software for the analysis and design of structural member on the basis of their damage.

If results of the structural analysis indicate that the flexural capacity of the affected structural member is inadequate to resist code-required design loads, then a decision has to be taken to retrofit the portion or a whole member.

Common techniques for retrofitting include steel plates. In last few decades, repair techniques using externally bonded fiber-reinforced polymer (FRP) sheets have emerged as an effective means to repair and strengthen concrete structures. By & large, the techniques are identical to what is being done for repairing a structure damaged due to earthquake. Lot of literature & first hand information is available about seismic retrofitting.

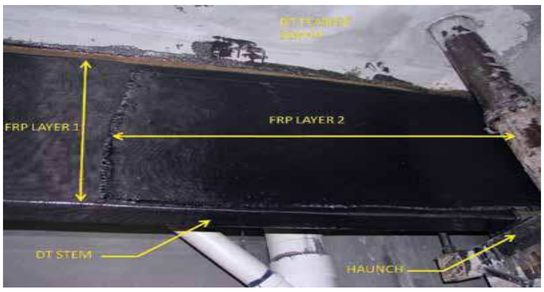

Fig.4: Application of fiber-reinforced polymer (FRP) sheet

Columns damaged during fire can be retrofitted by jacketing. Again, the jacketing may either consist of steel angles & plates or FRP sheets. One important precaution in case of columns is to repair them one by one especially if they are lye adjacent or if they support the same compartment.

Conclusion:

All structures subjected to fire should be evaluated in a systematical manner to determine the extent, if any, of required repairs. The intensity and duration of fire can be estimated by observing the collateral damage & colour of concrete (not very reliable). A variety of testing methods and tools are available to evaluate the effects of fire on both the materials and structural elements. This evaluation combined with an engineering analysis allows effective and economical details to be developed and installed as needed. The retrofitting itself may consist of patch repairs by shotcreting, crack fillings by injecting grout or more rigorous methods like using FRP sheets & erecting permanent props/supports

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