A Work Paper on- Effect of High temperature in Reinforced Cement Concrete Structure

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Abstract— With the increased incidents of major fires in buildings; assessment, repairs and rehabilitation of fire damaged structures has become a topical interest. This is a specialized field involves expertise in many areas like concrete technology, material science and testing, structural engineering, repair materials and techniques etc. Research and developmental efforts are being carried out in this area and other related disciplines. In this topic the experience of real life problems are presented which add immense value to this. This topic also gives a comprehensive knowledge on the overall strategy for the restoration of fire damaged buildings and also presents a critical appraisal of the assessment procedures by different nondestructive techniques, specifications and execution of repair techniques. The experimentation has been done to find out the impact of the fire on reinforcement steel bars by heating the bars to 100°,300°,600°,900° centigrade of 6 samples each. The heated samples are rapidly cooled by quenching in water and normally by air cooling. The change in the mechanical properties are studied using universal testing machine (UTM). The general conclusion is that majority of fire damaged RCC structures are repairable. But the impact of elevated temperature above 900°C on the reinforcement bars was observed that there is significant reduction in ductility when rapidly cooled by quenching. In the same case when cooled in normal atmospheric conditions the impact of temperature on ductility is not high. By heating the reinforcement bars, the mechanical properties can be changed without varying the chemical composition.

Keywords: Concrete, Steel, Fire, Design, UTM, Modelling, Review

I. INTRODUCTION

With the increased incidents of major fires and fire accidents in buildings; assessment, repair and rehabilitation of fire damaged structures has become a topical interest. This specialized field involves expertise in many areas like concrete technology, material science and testing, structural engineering, repair materials and techniques etc. Research and development efforts are being carried out in these related disciplines. Any structure can undergo fire accident, but because of this the structure cannot be denied neither abandoned. To make a structure functionally viable after the damage due to fire has become a challenge for the civil engineering community. The problem is where to start and how to proceed. It is vitally important that we create buildings and structures that protect both people and property as effectively as possible. Annual statistics on losses caused by fires in homes and elsewhere make for some unpleasant readings and sadly through these events we learn more about fire safety design. We are all aware of the damage that fire can cause in terms of loss of life, homes and livelihoods. A study of 16 industrialized nations found that, in a typical year, the number of people killed by fires was 1 to 2 per 100,000 inhabitants and the total cost of fire damage amounted to 0.2% to 0.3% of GNP. In the current specifically, statistics collected by the National Fire Protection Association for the year 2010-15 showed that more than 4,000 deaths, over 100,000 injuries and more no of property damage were caused by fire. INDIAN statistics suggest that of the half a million fires per annum attended by firefighters, about one third occur in occupied buildings and these result in around 600 fatalities (almost all of which happen in dwellings).

II. THEORETICAL BACKGROUND OF THE PROGRAM

In the 3D non-linear finite element procedure which is the theoretical basis of Vulcan, a reinforced concrete building is modelled as an assembly of finite beam-column and slab elements. It is assumed that the nodes of these different types of element are defined in a common reference plane, as shown below. The reference plane is assumed to coincide with the mid-surface of the concrete slab element. Its location is fixed throughout the analysis.

The beam-columns are represented by 3-noded line elements. The model is based on a formulation proposed by Bathe for geometrically non-linear modelling of elastic beams. The cross-section of the beam-column is divided into a matrix of segments, and each segment may have different material, temperature and mechanical properties. The complications of structural behaviour in fire conditions, such as thermal expansion, degradation of stress-strain curves, failure of concrete segments by cracking and crushing, and yielding of steel member or reinforcement segments, are included. The details of the formulations of beam-column elements and the constitutive modelling of concrete and steel at elevated temperatures have been presented previously.

III. WHAT HAPPENS TO CONCRETE IN A FIRE

Fires are caused by accident, energy sources or natural means, but the majority of fires in buildings are caused by human error. Once a fire starts and the contents and/or materials in a building are burning, then the fire spreads via radiation, convection or conduction with flames reaching temperatures of between 600°C and 1200°C. Harm is caused by a combination of the effects of smoke and gases, which are emitted from burning materials, and the effects of flames and high air temperatures.

(Concrete against fire)

(fire damaged slab)

IV. CHANGES OF CONCRETE IN FIRE:

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 the 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.

V. EXPERIMENTAL RESULTS

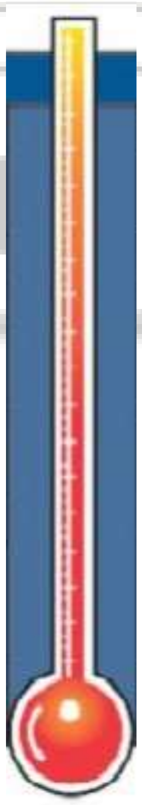
Temperature (ºC)		What happens
1000		
900		Air temperatures in fires rarely exceed this level, but flame temperatures can rise to 1200ºC and beyond.
800		
700		
600		Above this temperature, concrete is not functioning at its full structural capacity.
550-600		Cement-based materials experience considerable creep and lose their loadbearing capacity.
400		
300		Strength loss starts, but in reality only the first few centimeters of concrete exposed to a fire will get any hotter than this. and internally the temperature is well below this.
250-420		Some spalling may take place. with pieces of concrete breaking away from the surface

Table 1.1: concrete in fire – physiochemical process

The surface appearance of structural members give an idea on the extent of heat to which these members might have been subjected to during the fire. The structural conditions as observed give a great deal of information on its physical condition and help to assess the physical damage suffered by the members. As stated earlier, these information are very vital for assigning the appropriate damage classifications and planning the repair techniques. It is however to be kept in view that these are subjective observations and results would depend upon the experience and skill of the person carrying out the investigations.

Changes caused by heating of various types of natural stone that may be observed visually or microscopically

Heating temperature	Stone type			
	Limestone	Sandstone	Marble	Granlte
205 ºC 300ºC 400ºC	Pink or reddish-brown discoloration starts at 250-300 ºC but may not become visible until 400ºC Discoloration becomes more redish at 400ºC	Red discoloration starts at 250-300 ºC but may not become visible until 400ºC	Heating marble through a range of temperatures causes non-reversible expansion known as thermal hysteresis	At less than 573ºC, if heating rate is less than 1ºC per minute the thermal expansion is fully reversible. If heating rate is greater than 5ºC per minute the expansion is not totally reversible
600ºC	Calcination of calcium carbonate comences at 600ºC	Heating above 573ºC causes internal rupturing of quartz grains with associated weakening and friability	Above 600ºC complete disruption due to differential expansion, becomes friable and reduces to powder	Develops cracks or shatter at 573ºC due to quartz expansion
		Clay minerals in the cement disintegrate (kaolinite up to 600ºC, chlorite above 600ºC)		
800ºC	Calcium carbonate calcines to a grey-white powder at 800-1000ºC with associated loss of strength	Red discoloration may persist until 1000ºC Any calcium carbonate cement calcines to powder at 800-1000ºC causing disintegration		Differential thermal expansions at higher temperatures (900ºC) gives rise to tensile and compressive stresses causing permanent strain in the stone
1000 ºC +	Melting starts	Melting starts	Melting starts	Melting starts

VI. Criteria for Damage Classifications

Class of damage	Repair classification	Repair Requirements
Class 1	Superficial	For repair, use cement mortar trowelling using cement slurry bonding.
Class 2	General	Non-structural or minor structural repairs like restoring cover to reinforcement using cement polymer slurry as bonding layer and nominal light fabric reinforcement or using epoxy mortar over the primary coat of epoxy primer. No fabric for small patches of area less than 0.09 sq.m.
Class 3	Principal Repair	Where concrete strength is significant lyreduced, strengthening to be carried out with shot creting in case of slabs and beams and jacking in case of columns. For less damaged columns Shot creting is also proposed. The bonding material used shall be epoxy formulation. Additional reinforcement shall be provided in accordance with load carrying requirement of the member. Both residual and final strength to be checked by design procedure.
Class 4	Major repair	Repair method is demolition.

Table 1.2: Damage classifications

A. Method of Representing Class of Damages in the Drawings:

The information on class of damage, is tabulated in the grid sheets in the form of drawings for the site references The grid drawing plans are prepared in conformity with the original structural drawings for each floor i.e the same column nos. beam nos. and slab nos. are adopted as had been done in the original structural drawings. Each structural member like column, beam and slab is marked with class of damage in different colour for each floor in grid drawing and then these are consolidated in tabulated form under schedule of damage classification i.e. separately for columns, beams and slabs and members having same class of damage are grouped together. The grid drawing for a particular floor show damage classification of beams and slabs of that particular floor as seen from the bottom and of the columns supporting that particular floor.

1) Slab:

Structurally unaffected	Left as it is
Superficial repairs	yellow colour
General repairs	Green colour
Principal repairs	Red colour
Major repairs	Shaded black

VII. Experimental Results

s.no	Temperature in ° C	Ultimate load (kN)	Ultimate stress (kN/mm2)	Yield stress (kN/mm2)	Max. extension (mm)	Elongation (%)	0.2% proof stress
1	Room temp 27	67.1	0.583	0.466	1.63	28.3	0.465
2	100	66.1	0.584	0.469	1.66	15	0.461
3	300	65.5	0.582	0.451	1.422	30	0.44
4	600	68.4	0.606	0.453	0.972	23.3	0.456
5	900	78.3	0.692	0.469	0.206	11.6	0.534

Table 1.3: Properties for rapid cooing conditions

s.no	Temperature in ° C	Ultimate load (kN)	Ultimate stress (kN/mm2)	Yield stress (kN/mm2)	Max. extension (mm)	Elongation (%)	0.2% proof stress
1	Room temp 27	67.1	0.593	0.466	1.63	28.3	0.465
2	100	66.5	0.588	0.448	1.139	30.2	0.455
3	300	63.7	0.571	0.436	1.12	28.3	0.429
4	600	64.3	0.574	0.484	0.76	27.45	0.449
5	900	65.5	0.585	0.465	0.62	26.6	0.437

Table 1.4: Properties for ordinary cooing conditions

VIII. Conclusions

1) The impact of fire on the reinforcement bars heated at various temperatures of 100° C, 300° C, 600° C, 900° C, cooled rapidly by quenching in water and normally cooled in the atmospheric temperature were studied and it is observed that the ductility of rapidly cooled bars after heating to high temperature to 900 ° C.
2) Studying the characteristic changes in the mechanical properties of the bars by Tensile strength testing using Universal Testing Machine shows that the increase in ultimate load and decrease in percentage elongation of the specimen which mean that there is significant decrease in ductility of the specimen.
3) Study of micro structure of the bars using Scanning Electron Microscope (SEM) alsoshows that the microstructure of highly heated specimens varies without varying the chemical composition which would have negative impact on the structure.

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