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A Review on Finite Element Analysis of RC Beam Exposed to Fire

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Abstract - *With more development, politics which includes terror attacks and rise in demands, as every other things building structures are also prone to various kinds of hazards apart from the natural calamities. Safeguarding structures against such hazards has increasingly become a common design requirement. These extreme loading conditions makes the generalized codes and standards guidelines for structural design unfeasible. Therefore, performance –based design is becoming more significant in the structural design field. Fire safety of a structural member is mostly measured as its ability to resist fire to an extent which is also called as the fire resistance of the structure. This is the length of time that a structural member can withstand structural integrity, stability and temperature transmission*

Concrete is considered as a fire resistant material in the list of any building material. Standard fire tests are utilized to measure the fire resistance of the various materials used in various fields. For carrying out a performance-based fire safety design of reinforced concrete (RC) structure to study the behavior of RC members exposed to fire it's important to have an accurate numerical simulation tool. This thesis presents a three-dimensional (3D) finite element (FE) model for predicting both the thermal and the structural behavior of RC beams in elevated temperature. With this FE model variation in temperature gradient, deflection and stresses can easily be found out. The FE model presented can be used in parametric studies.

***Key Words**:-ANSYS, Finite element model, Reinforced concrete beams, Fire resistance, Temperature gradient etc …*

1. INTRODUCTION

In the list of the most severe conditions to which a concrete can be subjected, fire has a very important role to play. It can burst anytime, at any intensity and cause damage to any of the parts that can cause critical damage to the entire structure. Apart from the massive destructive power that kills many lives and destroy properties it ends up damaging the entire structure in a manner which is even severely unsafe for its reuse. These kinds of hazards stays as a regular threat to the contemporary civilization because of their very short recurrence period along with the higher damaging capabilities in terms of life, structures and economy. All types of countries whether it be developed, developing or underdeveloped are under the threat of fire. It is mandatory for the engineers around the world to study the behavior of RC structures during extreme fire condition so that they could minimize damage to life and economy. It can also lead to a new technology too. As per the current design codes the fire resistance of an RC member is usually determined using a prescriptive approach, in the form of tabulated method which requires satisfying some of the minimum member dimensions and the minimum concrete cover for the reinforcing steel. The empirically derived requirements rely heavily on the limited results from fire resistance tests of RC members in which an RC member is commonly pre-loaded and exposed to a prescribed temperature-time curve as defined by BS 476-20, ISO 834-1 or ASTM E119. The prescriptive approach results in a conservative design, but it does not work based on accurate understanding of the thermal and mechanical behavior of RC members under high temperature. Therefore, prescriptive approach does not provide much information about effects of many important factors, which includes geometrical configuration, load level, restraint condition, temperature-dependent material properties, cracking and tension stiffening behavior of concrete and limit of failure pattern of RC members exposed to fire. Hence in modern researches there has been a gradual transition from the prescriptive approach to the performance-based approach in the fire safety design of RC members since the latter provides a more cost-effective, flexible and rational tool and allows designers to use multiple routes to achieve the required fire safety. With the help of numerical simulation tools with the desired capability the performance-based fire safety design approach can be carried out for the accurate fire resistance analysis of RC members (or systems). In these numerical models, heat transfer analysis is performed primarily using the finite difference method or the EF method, although empirical formulas have sometimes been used. The performance index can be based on the predicted resistance degradation, the deflection rate, etc., which can help define the fire limit state.

Determining the reduction of the strength properties of an RC structure exposed to a high temperature becomes one of the key steps of the analysis. Basic information on the problem is available in Euro code. Beyond physical (thermodynamic) changes, high-temperature concrete also undergoes various chemical transformations and undergoes mechanical damage that makes the process more complicated and unpredictable. These complexities could be of this variable range, because of which the results could be on a trajectory very different from conventionally established guidelines and should not be fully consistent with estimates based on these standard guidelines. All basic data relating to the phenomena occurring in heated concrete and the factors responsible for reducing the value of the strength characteristics of concrete in reinforced structures exposed to fire come exclusively from the standards of the euro code. When the study of high temperature concrete is the concern, there is virtually no chance that the RC structure behaves as it should behave at ambient temperature (20 ° C) which amplifies the complication and therefore the Simple changes applied to the models available for concrete at normal temperature will not be satisfactory.

Concrete is considered one of the best fire-resistant materials in building construction and this property is solely due to its constituent materials (i.e., cement and aggregates) which, has low thermal conductivity, high heat capacity, and slower strength degradation with temperature when chemically combined. This low thermal conductivity causes the slow rate of transfer of heat through the concrete material and hence makes concrete to act as an effective fire shield between adjacent spaces as well as to protect itself from damage. The combined action of all the three properties namely thermal, mechanical, and deformation properties of concrete of which the member is composed governs the behavior of a concrete structural member exposed to fire. These properties vary with respect to temperature and depend on the characteristics and composition of concrete. These properties at both the normal as well as elevated temperature also influences the strength of the concrete mostly.

A structural element when subjected to a defined temperature-time exposure during a fire causes a predictable temperature distribution in the element. When these temperatures increase, they cause deformations and changes of property in the materials constituting a structural element. Once this deformation pattern and this change of ownership are known to the situations mentioned above, the fire resistance capability and the means to improve it can be predicted. The thermal and mechanical analysis of fire-exposed RC beams is presented as a three-dimensional (3D) EF model in this paper.

2. LITERATURE REVIEW

There are a wide range of numerical models formulated simulate the thermal and mechanical behavior of RC beams exposed to fire. The analysis of heat transfer is mainly performed using the finite difference method or the FE method. Whereas the mechanical response of RC beams can be evaluated using sectional analysis or FE method. In the EF method, the beam elements will be modeled as four-node isoparametric quadrilateral elements. An almost accurate and reliable prediction of the degradation of the resistance to deviation can be made using such a simulation program. **Gergali & Tsakiridis** , by giving special concern towards the depths to which cracking penetrates within the concrete conducted a case study of cracking in a concrete building subjected to fire. He was able to find that the penetration depth was in relation with the temperature of the fire. Major damage was found to occur at the surface of near to the fire origin, but around the reinforcement reaching 700°C the nature of cracking and discoloration of the concrete was found distinctly. Cracks which extended more than 30 mm into the depth of structure were attributed to a short heating/cooling cycle due to the fire being extinguished.

While spalling during the event of fire has been observed and described by **Gary (1916**) almost a century ago, it only became a concern in the last few decades with the advancement in the concrete industry and the use of high strength concrete becoming more common. Ironically, what is considered as high performance concrete under normal conditions tends to behave more poorly under fire.

Studying the results of **Harmathy (1970), Harada et al. (1972), Hundt (1976),** and many others, **Schneider et al. (1982)** reached the conclusion that the decrease of thermal conductivity with the increase in temperature is attributed to the fact that the moisture content is at its highest level at low temperatures, but as temperature rises, water evaporates and is substituted by air, which has much lower thermal conductivity. This is followed by the loss of non-evaporable chemically-bound water, which results in even lower thermal conductivity. In addition, as cracks form in concrete due to fire, the air gaps increase; hence, the thermal conductivity decreases

The ASCE Manual of Practice (Structural Fire Protection by T. T. Lie, 1992) recognized the abrupt rises in the specific heat at temperatures between 400ºC and 600ºC for all types of aggregate used in the concrete mix and the higher rise at temperatures around 800ºC for concrete mixed with calcareous aggregates. It also recognized the lower specific heat of concrete mixed with light-weight aggregates. It presented the expressions shown below for the heat capacity. For concrete mixed with siliceous aggregates.

$SH= (0.005T + 1.7) \times 106$	for $20℃< T\leq 200℃$
2.7×106	for $200℃<T\leq 400℃$
$(0.013T - 2.5) \times 106$	for $400℃<T\leq 500℃$
$(-0.013T + 10.5) \times 106$	for $500℃<T\leq 600℃$
2.7×106	for $T>600℃$

For concrete mixed with calcareous aggregates:

$SH= 2.566 \times 106$	for $20℃<T\leq 400℃$
$(0.1765T-68.034\times 106$	for $400℃<T\leq 410℃$
$(-0.05043T + 25.00671) \times 106$	for $410℃<T\leq 445℃$
2.566×106	for $445℃<T\leq 500℃$
$(0.01603T-5.44881) \times 106$	for $500℃<T\leq 635℃$
$(0.16635T-100.90225)\times 106$	for $635℃<T\leq 715℃$
$(-0.22103T+176.07343) \times 106$	for $715℃<T\leq 85℃$
2.566×106	for $T> 785℃$

In the work done by **Venkatesh Kodur,** Dept. Of Civil and Environmental Engineering, Michigan State University, East Lansing, MI48824**,** USA stated that the fire response of concrete structural members is dependent on the thermal, mechanical, and deformation properties of concrete. These properties vary significantly with temperature and also depend on the composition and characteristics of concrete batch mix as well as heating rate and other environmental conditions.

Based on experimental results from tests carried out in China, **Lu (1989)** presented the following expressions, where he employed the commonly used approach of assuming the initial modulus of elasticity to be equal to the secant modulus at 0.4fcT′:

$$Ec1T/Ec1 = -1.50 \times 10-3T + 1.0 \quad for\ T \le 300°C$$

$$- 0.84 \times 10-3T + 0.87 \quad for\ 300°C < T \le 700°C$$

$$0.28 \quad for\ T > 700°C$$

Also**, Li and Purkiss** (2005) employed the experimental data published by Purkiss (1996) and the current version of the Euro code (EN 1992-1-2:2004, 2005) to develop the following formula:

$$Ec1T/Ec1 = 1 \quad for\ T \le 60°C$$

$$(800-T)/740 \quad for\ 60°C \le T \le 800°C$$

In **1985, Lie and Lin (1985)** used the results obtained from testing twelve column specimens under fire, along with the results obtained from the tests run by **Schneider and Haksever (1976),** to develop a model that simulates the behavior of normal-strength concrete under fire. In order to account for the transient creep strain Lie and Lin (1985) utilized the work done by Schneider and Haksever (1976) to modify the stress-strain curve by shifting it to higher strains as the temperature goes higher. Lie also adopted this model in the ASCE Manual of Practice (Structural Fire Protection by T. T. Lie, 1992)

Dwaikat and Kodur (2009) argued that employing the model presented by the Euro code (ENV 1992-1-2:1995, 1996) and its current version (EN 1992-1-2:2004, 2005) leads to unrealistic prediction of spalling at relatively low temperatures (below 600ºC), because the model postulates that concrete completely loses its tensile strength at a temperature of 600ºC. Therefore, they provided the model presented in equation as a modification of the Euro code model, where a small value is maintained for the tensile strength of concrete for temperatures up to 1200ºC. This model is also preferred for analytical finite element computer programs, as it avoids the computational instabilities that my result from analyzing the response of concrete with absolutely no tensile strength

$$\boldsymbol{ftT'/ft'} = 1.0 \quad for\ T < 100°C$$

$$(600-T)/500 \quad for\ 100°C \le T < 550°C$$

$$(1200-T)/6500 \quad for 550°C \le T < 1200°C$$

$$0.00 \quad for\ T \ge 1200°C$$

Neha S. Badiger (2014) conducted a "Parametric Study on Reinforced Concrete Beam using ANSYS. FEA was utilized to understand the responses of the structural element present in an RC building during the crucial loading time. Here a four point bending problem analysis is carried out using reinforced concrete beam with varying mesh density, varying depths, use of steel cushions for support and loading points, effect of shear reinforcement on flexure behaviour, impact of tension reinforcement on behavior of the beam. The **Finite** element software used is ANSYS 13.0 for modeling and analysis and have adopted nonlinear static analysis. Problem considered for the Study is the experimental analysis carried out to study individual component members and the concrete strength under various loading conditions. This method provides the actual behavior of the structure which can be carried out easily and without less time consumption using the finite element analysis which can provide accurate prediction of the component's response subjected to various structural loads. I t is also quicker when compared to experimental analysis.

Mr. C Sangluaia , Mr. M K Haridharan, Dr. C Natarajan, Dr. A. Rajaraman, India studied the behavior of the fire-exposed reinforced concrete slab by performing a two-step analysis using the ABAQUS finite element module, namely thermal analysis and structural analysis to find the thermal response of the structural elements. The first step is to spread the temperature over the depth during the fire and the next step involves the mechanical analysis in which these distributions are used as temperature loads. The type of concrete and the interaction of the structural element generally decodes the responses of the structure.

Modelling of slab was done by varying its slab thickness, percentage of reinforcement, width of slab and different boundary condition when expose to fire loading. Effects for both materials in RCC slab at elevated. Mechanical behavior of the constituent materials are discussed here thoroughly.. The temperature input was made possible using the Dynamic temperature displacement explicit analysis with which the temperature distribution obtained from thermal analysis was able to be input in to the structure analysis so as to obtain the required stress, strain and displacement. Fire is usually represented by a temperature-time curve ISO-834 fire (BS 456 part 20). It gives the average temperature reached during a fire in a small compartment or in the furnaces used for the fire resistance tests. Thermal analysis is performed on the basis of steady state in three-dimensional members. Temperature distribution is found in thermal analysis and by using the thermal result in structural static analysis.

Yufang Fu and Lianchong Li provide a review on the explosive spalling behavior of RC structure when exposed to elevated temperature, The thermal cracking effects on the RC structure where investigated by using a numerical model which they have proposed. Considering the effect of heterogeneity of the material property. Pore pressure causes the built up of internal stresses along with the thermal stresses derived from the thermal gradient and water escape. When this internal stress developed exceeds the maximum allowable tensile stresses thermal cracks and spalling occurs.

Takeshi Morita, Akira Nishida, Nobuyuki Yamazaki, Ulrich Schneider and Ulrich Diederichs -By conducting two series of fie tests on reinforced concrete elements spalling behavior and effect of spalling on the fire endurance of reinforced concrete elements were studied. In the test PP fiber for spalling reduction it was found that heated PP fiber had a weight loss in the furnace of a TG-DTA equipment which was more than 80% during heating up to 500°C. They conducted the test for degree of spalling under different water cement ratio because higher the strength of concrete, higher the spalling rate.

Yufang Fu and Lianchong Li presented a review on the explosive spalling of concrete at elevated temperatures. Using the experimental investigations they showed thermal cracking causes the corner and surface spalling, and found that a coupled effect of thermal cracking and pore pressure causes explosive spalling.

3. CONCLUSION

1. Previous works have detailed all the thermal properties of concrete in order to build up a numerical model of fire exposed concrete structure.
2. Euro code helps in understanding the behaviour and constitutive model for both concrete and steel under fire.
3. Further study is required in almost every angle of this field.
4. Mechanism and causes of spalling need to be understood more deeply for structural fire safety.
5. Large-scale fire testing of concrete structures, in order to study the behaviour of whole concrete structures under real fires attacks is also required.

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