Fire Resistant Design of Concrete Structure

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***Abstract* – Concrete has very good behavior under fire due to its low thermal conductivity and non-combustibility. Concrete act as a protective cover to steel reinforcement and thus reinforced cement concrete shows good behavior under fire. Fire can cause damage in concrete structure. The level of damage depends on several factors like maximum temperature, duration of fire, constituents of concrete etc. Performance of concrete structures in fire depends upon several factors. These include change of properties of material due to the fire, temperature distribution within the members of the structure, type of reinforcement, and duration and severity of exposure. In many cases, these design methods fail to predict the true behaviour of concrete structures in real fires. A number of complex physicochemical reactions occur when concrete is heated, causing mechanical properties as strength and stiffness to deteriorate. Furthermore, the phenomenon of spalling causes pieces of concrete to break off from the surface, reducing the cross-section of an element and possibly exposing the reinforcing to the high temperatures. Spalling can be highly dangerous and is most common in high strength concrete. Design procedure is developed by considering various critical combinations of temperature. Different conclusions can be drawn based on various parameters. The Eurocode provides a number of procedures in order to design concrete structures for the fire situation, both prescriptive as performance based. This paper discusses steps necessary to perform a calculation of the fire resistance of a reinforced concrete structure.**

Keywords- Concrete; thermal conductivity; non-combustibility; spalling; Eurocode;

I. INTRODUCTION

In general, reinforced concrete structural members exhibit good performance under fire conditions. This is due to the fact that thermal conductivity of concrete is relatively low at room temperature and decreases with increasing temperature. As long as concrete is not damaged as a result of excessive cracking or spalling, it constitutes effective protection for reinforcing steel against high temperature occurring during fire. The comprehensive analysis of reinforced concrete structures under the specified fire scenario includes thermal analysis (determination of temperature distribution within each point of structural elements) and mechanical analysis (evaluation of structural response to determined temperature fields). In order to carry out these analyses, it is necessary to possess detailed information as to numerous material properties (physical, thermal, mechanical – both for structural concrete and for reinforcing steel) which are the functions of temperature. A properly designed reinforced concrete structure is characterized in normal design conditions by a certain reserve in bearing capacity:

$$R \geq E_d > E_{d.fi}(t=0) \qquad (1)$$

Where

R is the load bearing capacity,

Ed is a design value of an effect of actions according to eurocode,

Ed.fi(t = 0) is a design effect of actions in fire situations at the beginning of a fire.

It means that the structure has the ability to bear the loads by the certain time of fire which is called fire resistance. For the numerical analysis the software chosen is MATLAB.

II. FIRE AND ITS CHARACTERISTICS

Fire is an exothermic chemical reaction, essentially one of oxidation of hydrocarbons, which followed by generation of heat. The growth of the fire depends on the rate at which heat is liberated and the rate at which it is dissipated. The main factors that influence the temperature, magnitude, and distribution of the fire are

- Fire load
- Fire load display(the position of fuel within the room)
- Fuel type
- The dispersion factor and particle shape of the fuel
- Window opening area
- The temperature, pressure and relative humidity of air
- The dimensions of the room
- The thermal conductivity and diffusivity of the construction material
- Radiation levels from both within the compartment and through the windows

III. FIRE RESISTANCE

A fire resistance is a measure of the ability of the structure to resist collapse, fire spread, or other failure during exposure to a fire of specified severity. Resistance to fire applies to structural elements and is a measure of their capability of maintaining their function (e.g. separating or load-bearing function) during the course of a fire.

Fire resistance requirements should be based on the parameters influencing fire growth and development. These include:

- Fire [probability of Fire occurrence, Fire spread, Fire duration, Fire load, Severity of fire…]
- Ventilation conditions
- Fire compartment (type, size, geometry)
- Type of the structural element
- Evacuation conditions
- Safety of the rescue teams
- Risk for the neighbouring buildings
- Active fire fighting measures

IV. PHYSICAL AND CHEMICAL RESPONSE TO FIRE ON CONCRETE STRUCTURE

Concrete subjected to heat will undergo changes in its microstructural, thermal, hydral and mechanical behaviour. Strength loss occurs mainly due to the formation of internal cracks and degradation and disintegration of the cement paste. The cohesion between the cement paste and the aggregates is also affected. Understanding the different processes will help understanding how concrete is likely to behave under fire, but also how to optimize the composition of the material for better fire performance.

The physical and chemical changes inside concrete can be reversible or non-reversible upon cooling. When the changes are non-reversible, a concrete structure may be significantly weakened after a fire, even if no damage can be visually detected.

V.EFFECTS OF FIRE ON THE STRUCTURAL MEMBER

The material characteristics of the members are modified when the temperature rises. The strength as well as the stiffness of both the concrete and the steel is reduced. In fact, even the whole stress-strain diagram is modified. The thermal properties, as thermal conductivity and specific heat, are also altered by a thermal elevation. However, these changes are not particularly relevant for the reinforcement since its amount is generally too low to affect the overall temperature distribution.

VI. PROPERTIES OF CONCRETE AT ELEVATED TEMPERATURES

The concrete material properties required for thermal and structural calculations are thermal and mechanical properties. The thermal properties described include thermal conductivity, volumetric specific heat, and density as shown in fig. 1. The mechanical properties include concrete compressive strength, modulus of elasticity, shear modulus, tensile strength, and coefficient of thermal expansion. These properties are required for engineering analyses in typical design applications.

A. Thermal properties

The thermal properties described include

i. Thermal Conductivity

It is defined as rate heat transferred through a unit thickness of material per unit temperature.

ii. Volumetric Specific Heat

The amount of heat required to a heat a unit mass of material by 1^{o}c

iii. Density

The mass of material per unit volumes.

B. Mechanical Properties

Concrete temperature-dependent mechanical properties, including compressive and tensile strength, modulus of elasticity, shear modulus, and coefficient of thermal expansion.

The values of the material properties shall be treated as characteristic values. These values may be used with simplified and advanced calculation methods. The mechanical properties of concrete and reinforcing steel at normal temperature are presented in EN 1992-1-1 for normal temperature design. Moreover, design values of mechanical (strength and deformation) material properties Xd,fi is given in Equation 1.

$$X_{d\,fi} = k_{\theta} X_{k} \; / \; \gamma_{M\,,fi} \qquad (2)$$

Xk is the characteristic value of strength or deformation property for normal temperature design as described in EN 1992-1-1

k is the reduction factor for a strength or deformation property dependent on the material temperature ($X_{k,\theta}/X_k$)

$\gamma_{M,fi}$ is the partial safety factor for the relevant material property for the fire situation. For thermal and mechanical properties of concrete and reinforcing steel, $\gamma_{M,fi}$ is taken equal to 1.

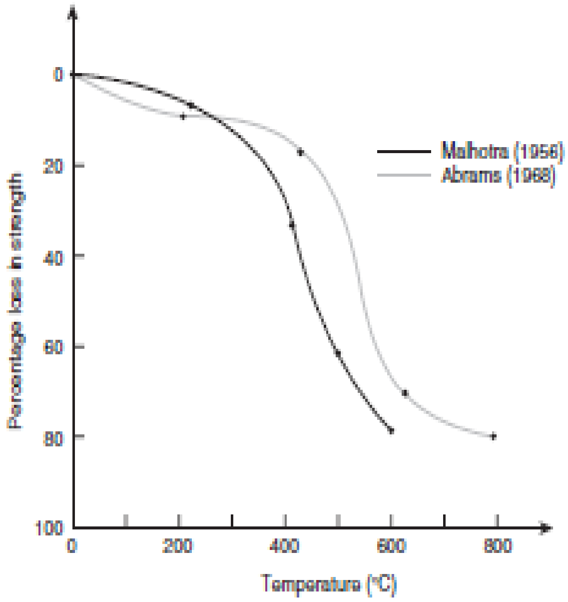

Fig. 1. Variation of concrete strength with temperature

VII. ANALYSIS OF CONCRETE STRUCTURE

different design approaches for mechanical response of structure in fire are given below:

- Member analysis
- Analysis of parts of the structure
- Global structural analysis

A.Member Analysis

Member Analysis**,** in which each member of the structure will be assessed by considering it fully separated from other members and the connection condition with other members will be replaced by appropriate boundary conditions.

B. Analysis of parts of the structure

Analysis of parts of the structure, in which a part of the structure will be directly taken into account in the assessment using appropriate boundary conditions to reflect its link with other parts of the structure.

C. Global structural analysis

Global structural analysis, in which the whole structure will be used in the assessment.

VIII. DESIGN METHODS OF FIRE RESISTANCE DESIGN OF CONCRETE STRUCTURE

The Eurocode describes the following design methods in order to satisfy Eq. (3):

$$E_{d,fi} \leq R_{d,t,fi} \quad (3)$$

A. *Simplified calculation methods*

A simplified calculation method uses the same procedure as normal-temperature design but taking in account the strength loss in both concrete and steel due to the high temperatures. The ultimate-load-bearing capacity of a cross-section under fire conditions is determined which then is compared to the relevant combination of actions. The methods serve mostly only members, but in some cases also parts of structures can be covered. The design can be based on both nominal and parametric fires, however, the standard fire curve is most often used.

B. *Advanced calculation methods*

Advanced calculation methods provide a more realistic analysis of a structure. A reliable approximation of the expected behaviour of the structure under fire conditions is achieved by modelling the fundamental physical behaviour. These methods may be used together with any type of design fire (nominal or natural fires), with any type of analysis (member, part of a structure or global analysis) and with any type of cross-section. Any potential failure modes not covered by an advanced calculation method (e.g. local buckling or shear and bond failure) must be eliminated by appropriate means or detailing in the design of the structure.

The Eurocode only gives the basic principles of this method. The designer applying this method must be an expert in the field of fire engineering.

An advanced calculation method exists out of two parts, which continuously influence each other, the thermal response model and the mechanical response model.

IX. CONCLUSION

- The fire resistant method is a new simplified approach based on Eurocode 2 part 1 and 2, which gives simple design basis by considering the various parameters for the fire resistant design of concrete structures.
- The assessment of the fire resistance of structural elements is based either on standard fire calculation.
- The heating up of a structural element depends on the type of element (e.g. pure steel or composite steel/ concrete) and of the nature and amount of fire protection.
- To know the temperature of the structural elements as a function of time, it is necessary to calculate the heat flux to these elements.

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