University of Canterbury Fire Engineering Conference
A. Abu, M. Spearpoint (Eds.)
Christchurch, New Zealand, April 29, 2014

DESIGN OF REINFORCED CONCRETE SLABS EXPOSED TO NATURAL FIRES

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2 BACKGROUND

Concrete is used in the construction of many parts of a building from foundations, main structural frames, walls, floors, and ceilings. One of the main advantages of concrete is its relatively high compressive strength. However it has a low tensile strength; being about one-tenth of its compressive strength [4]. Steel reinforcing bars are used to form the fundamental tensile strength of the member to withstand bending loads [4]. These bars are located close to the external faces of the structural concrete members in order to distribute and carry tensile forces generated by bending loads applied to the member effectively.

The increase in steel reinforcing bar temperature caused by exposure of the concrete slab to fire has a significant impact on structural adequacy; this is due to the increased ductility and reduced strength of steel at elevated temperatures [5]. Insulation of the reinforcing steel from heating under fire loads is required in order to prevent the steel reaching a critical temperature which could cause member failure. Due to concretes noncombustible nature and low thermal conductivity it not only acts as part of the structural element but with sufficient cover of the steel bars also provides insulation to the steel reinforcing.

2.1 Fire Resistance

The fundamental concept in designing structures for fire safety using prescribed solutions is to verify the fire resistance of the structure is greater than the fire severity the structure is exposed too [5].

Fire resistance is a measure designed to prevent the spread of fire and structural collapse in fire, it is a measure of the ability of building elements to resist a fire. Fire resistance is most often quantified as the time for which the element can meet certain criteria during exposure to a standard fire [5]. The required fire resistance rating (FRR) in order to achieve structural adequacy is specified in tables giving minimum axis distance, the distance from the exposed face of the slab to the center of the reinforcing rods, in NZS 3101 [6].

Fire severity is a measure of the destructive potential of a fire and is often related to the standard test fire [5]. The damage caused to a structure is largely dependent on the amount of heat absorbed by the structural elements. Out of the three modes of heat transfer; conduction, convection and radiation, radiation heat transfer dominates in post-flashover fires. Radiative heat transfer from the fire and released gases is proportional to the fourth power of the absolute temperature. This means that post-flashover fire severity is largely dependent on the temperatures reached and the duration of the higher temperatures.

The time for which an element may need to meet the fire resistance criteria is referred to as the fire design time. The fire design time may not be clearly stated in regulations and may require engineering judgment based on the consequence of failure, the importance of a structure or the owners requirements. In performance based designs the fire design time is usually complete burnout of the compartment [5].

2.2 The standard fire and equivalent fire severity

Building elements are often evaluated in testing furnaces by exposure to a fire whose severity follows a varying temperature time profile curve known as a standard fire. This is also the case for the prescribed values given in NZS 3101 [7].

The National Institute of Standards and Technology (NIST) developed the concept of equivalent fire severity to define the severity of natural

5 HEAT TRANSFER AND SLAB TEMPERATURE DISTRIBUTION MODEL

To determine the capacity of a concrete slab we must first develop a model of the thermal gradients in the member throughout the duration of fire exposure. The temperature distribution through the slab thickness is calculated using a one dimensional heat transfer and temperature model based on the finite difference method (FDM).

In such a model the slab is divided it into a large but finite number of layers, Figure 3 [12]. The x. At the center of each of these layers is a node. Each node has a unique identifier based on its layer position and the temperature at each node is assumed to be representative of the average temperature throughout the layer. The bottom of the slab is exposed to the fire and the unexposed surface is exposed to ambient air. The finite difference method allows this problem to be solved either explicitly or implicitly. The explicit approach is easily implemented using a spread sheet software such as Microsoft Excel ©. Using the explicit approach the temperature of the node is computed directly based on the temperatures of the

$$\dot{}\ ^{+1} = \frac{(\ ^{+1} - \ )}{\Delta} \cdot \frac{\Delta}{2} \qquad (4)$$

For the surface node temperature Equation 1,

6.2 Bending moment

The design equation for a slab subjected to a bending load is given in Equation 10 [5]:

$$\leq \quad (10)$$

The flexural capacity under fire conditions is given by

$$= \quad {}_{,} \left(\; - \frac{}{2} \right) \quad (11)$$

Where A_s the area of the reinforcing steel in mm^2, $f_{y,t}$ is the yield stress of reinforcing steel for a given temperature in MPa and d is the effective depth of cross section in mm.

The stress block reduced by fire is given by Equation 12.

$$= \frac{\;{}_{,}}{0.85 \cdot \;' \cdot} \quad (12)$$

Where $'$ is the compressive strength of concrete in MPa and b the width of the slab in mm.

The reduction of flexural capacity for bending is solely

Comparison of the results show close agreement between the design procedures calculated fire resistance and the prescribe values in NZS 3101. The design procedure shows a strong linear relationship between axis depth and calculated fire resistance, this type of relationship has been identified by other researchers [12].

8.2 Natural fire exposure

The RC slab was exposed to three types of natural fire profiles

The time equivalent formulae and design method are in close agreement with each other for a ventilation factor of 0.07, were the Eurocode fire approximates the standard fire for the growth phase

10 CONCLUSIONS

Design processes such as the one presented in this paper are relatively simple to implement and provide significant insight into a fire development inside a compartment and the effects on structural capacity.

The Eurocode time equivalent formulae provides fire resistance values which are counter intuitive when compared to the behaviour demonstrated using minimum load capacity concept approach to determining fire resistance.

Short duration high temperature fires need to be specifically designed for where compartment temperature may exceed the standard fire temperature curve.

The possible failure of RC slabs exists after the fully developed fire begins to decay due to thermal lag.

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