An Innovative Approach to Design Fires for Structural Analysis of Non-Conventional Buildings – A Case Study

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1. Introduction

Traditional structural fire safety analysis is based on simple temperature-time curves, like the *standard fire* and *parametric* temperature-time curves, developed for small, simple and rectangular enclosures. While both of these methods have great merits and represented breakthroughs in the discipline at their times of adoption, they have inherent limitations with regards to their range of applicability. For example, the Eurocode 1 curve is limited with respect to the compartment size and lining materials. As a result, common features in modern construction like large enclosures, high ceilings, atria, large open spaces, multiple floors connected by voids, and glass façades are excluded from the range of applicability of the current methodologies.

Figure 1. Do these fires have the same effect on the structure?

Figure 2. Would fire behaviour and the effect on the structure be the same in these real structures?

2. Travelling Fires

Another limitation of the existing methods is that they assume only uniform temperature conditions throughout the whole floor of the compartment. A fire that would cause these types of conditions burns uniformly within the enclosure and generates high temperatures for a relatively short duration. This is opposed to a travelling fire that burns locally but spreads through the enclosure with time, generating lower temperatures for longer times.

Real, large fires that have lead to structural failure, such as those in the World Trade Center towers 1, 2 and 7 in September 2001, the Windsor Tower in Madrid, Spain in February 2005 and the Faculty of Architecture building at TU Delft in the Netherlands in May 2008 were all observed to travel across floor plates, and vertically between floors, rather than burn uniformly for their duration. Travelling fires have also been observed experimentally in compartments with non-uniform ventilation.

3. New Methodology

The key aspect of the new methodology being developed is to characterise the thermal environment for structural analysis accounting for the fire dynamics specific to the building, including a wide range of possible fires. This is done with the following steps:

- Develop a "family" of fires
  - Accounts for challenging areas in terms of both the fire and the structure
  - Each fire has a burning area and duration
  - The smaller the fire, the longer it burns as it travels throughout the floor
- Select a tool to assess the thermal environment for each fire in the family
- Generate temperature-time curves for each fire, accounting for both near and far field
- Pass appropriate level of detail to structural fire model

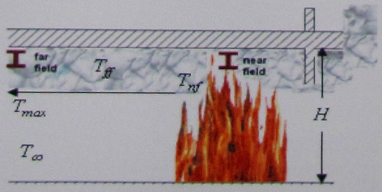

Figure 3. Illustration of near and far fields

4. The Case Study

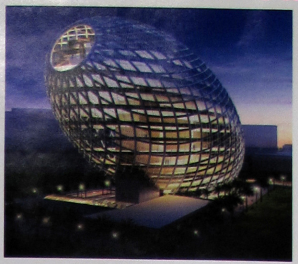

Figure 4. The Mumbai C70 building

A real building, currently being designed, was selected as a case study for this methodology. The building has:

- Large floor plates
- Complex architecture
- 13 storeys, 60m tall

The 9th floor was analysed due to the long spans of beams on that level. A range of burning areas was used between 1% and 100% to generate the family of fires

5. Temperature Field

The near field is when a structural element is exposed directly to the flames of the fire and the far field is when it is exposed to the hot gases, i.e. the smoke layer, away from the flames, as shown in Figure 3. The near field temperatures have been assumed to be 1200°C. The far field temperatures were determined as a function of distance from the fire by using a ceiling jet correlation. The use of such a correlation is deemed appropriate if the floor area is large and the smoke layer is thin relative to the floor to ceiling height. The far field is reduced to a single characteristic temperature, by means of a weighted average, which keeps the amount of information passed to the structural analysis manageable. An illustration of the generalised temperature field is shown in Figure 6.

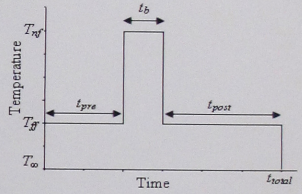

Figure 5. Representative temperature-time curve for one location

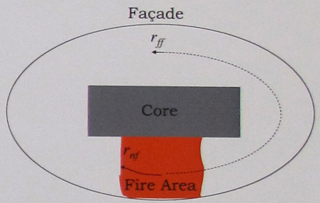

Figure 6. Plan view with fire area and travelling radius

Once the far field temperature is determined for a given fire size, the temperature time history of a point can be described, as shown in Figure 5. Determining both the time before the flame arrives at a point and the time after it leaves is dependant on the path of the fire and the exact position being examined. However, it is not possible to establish a fire's path of travel *a priori* to a real incident; therefore assumptions must be made for worst case conditions. For the present case study, it is assumed that the fire will travel in a ring around the building core in one direction only, as illustrated in Figure 5.

6. Results

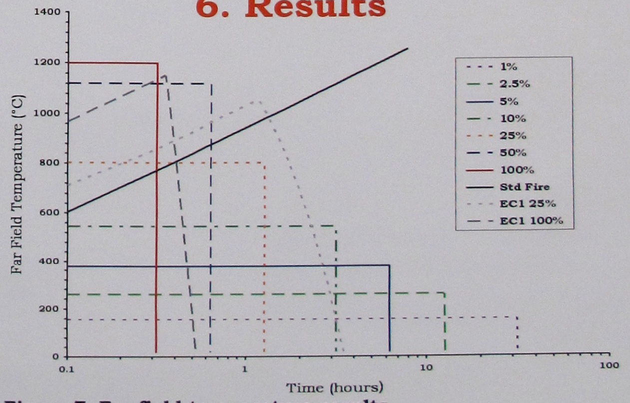

Figure 7. Far field temperature results

The far field temperatures are plotted in Figure 7 along with the temperature-time curves of traditional design methods. The growth and decay phases of the gas temperatures for the curves from this methodology are assumed to be very fast. This is because the transport of the hot gases in the smoke layer is faster than the heat transfer to the surfaces.

The standard temperature-time curve extends to a region of temperatures and burning times that for the present building cannot be explained in terms of the possible fire dynamics. Note that Figure 7 provides the far field values that need to be combined with the near field to produce curves of the type shown in Figure 5. Every point on the floor plate will at some point experience the near field temperature for the burning time and the far field temperature for the rest of the total burning duration.