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# 14 EVALUATION OF THE FIRE RESISTANCE OF THE STEEL STRUCTURE OF AN EXHIBITION CENTRE USING STRUCTURAL FIRE SAFETY ENGINEERING

Summary

This case study reports on the needs of passive fire protection to ensure fire resistance requirements of the steel structure of an exhibition centre. Due to the large dimension of the exhibition centre, with an average height of 13 m and a surface of about 6500 m$^2$ a prescriptive approach using the standard fire curve ISO834 for a required fire resistance of R120 revealed to be too severe, unrealistic and uneconomical. The analysis was made using the advanced calculation models allowed by the fire parts of Eurocode 1 and Eurocode 3. A performance-based analysis shows, in this study that, protecting the structure for a standard fire resistance of 60 minutes (R60), considering a critical temperature of 500ºC, the load-bearing function is ensured during the complete duration of the natural the fire scenarios used, including the cooling phase. Using a prescriptive approach and without making any calculation, the steel structure should have been protected, according part 1-2 of Eurocode 3, for a critical temperature of 350ºC and for R120 (the required fire resistance according the occupancy and the dimension of the building).

## 14.1 INTRODUCTION

It is the purpose of this paper to present a study performed on the fire resistance of the steel structure of an exhibition centre.

In the Portuguese Technical Regulations for Buildings Fire Safety, on the Decree No. 1532/2008 (MAI, Regulamento Técnico, 2008 and MAI, Regime Jurídico, 2008), which is now implemented, two approaches are recommended for assessing the safety of structures exposed to fire: a prescriptive approach using the standard fire curve ISO 834; and a performance based design using the natural fire development concept. The natural fire curve definition takes into account the size of the fire compartment, the ventilation conditions and the thermal properties of the fire compartment lining materials, in opposition to the standard fire curve that does not depend on any of these parameters.

In addition, in the last years several European projects (European Commission, 1999a, European Commission, 1999b, European Commission, 2007) have shown that in large compartments, the prescriptive regulation based on the standard fire curve is too conservative and unrealistic.

According to Part 1-2 of Eurocode 3 (EC3), the stability verification can be made verifying that:

a) with the standard fire, the structure collapse does not occur before the fire resistance time defined by the regulation; or

b) with the natural fire and advanced calculation methods the structure collapse does not occur during the complete duration of the fire, including the decay phase or during a required period of time, which may coincide with the fire resistance time defined by the regulation.

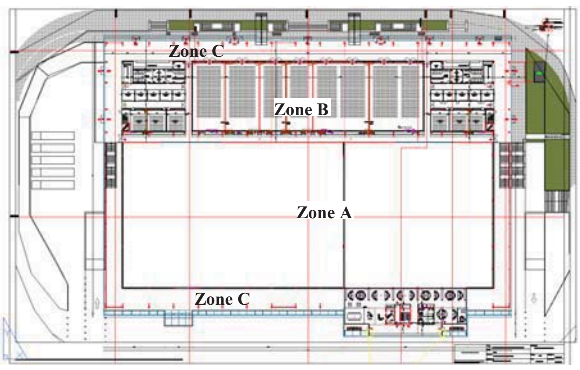
In this work, the studies, performed to assess the fire resistance of the steel structure of an exhibition centre in Oeiras (Portugal), are presented.

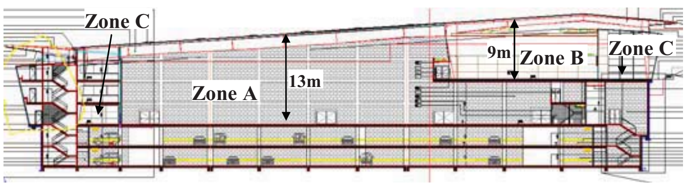
Advanced calculation methods were used (Franssen, 2010). For the natural fire simulation the programme Ozone (Cadorin, 2003a, Cadorin, 2003b), developed at the University of Liege was used and to simulate the thermo-mechanical behaviour the finite element program SAFIR (Franssen, 2005) also developed at the University of Liege has been used.

It was also considered the occurrence of possible localized fires, according with Part 1-2 of Eurocode 1 (EC1). This methodology from Eurocode was implemented in the program Elefir-EN (Vila Real, 2010) (developed at the Universities of Aveiro and Liege).

The fire compartment temperature definition was determined, as defined in Part 1-2 of EC1, with each of the following fire models: the localise fire and 1 or 2 zone models, according to whichever is more appropriate. These models correspond to different types of fire and different phases of the same fire.

According to the Portuguese fire regulation the Oeiras Exhibitions Centre (see Fig. 14.1), is considered to be of the Utilization-type VI « Theatres/cinemas and public meetings ». As its height is less than 28 m, has two floors below the reference plane and an effective is higher than 5000, it is classified with the 4th Risk Category. According to this regulation, the main elements of the structure must have a standard fire resistance of 120 minutes (R120). However, given their large plan dimensions and height, it can be classified as atypical hazardous being allowed the use of solutions of Fire Safety Engineering using performance- based design.




a) b)

Fig. 14.1 The Oeiras Exhibitions Centre a) plan; b) cross section

The Oeiras Exhibition Centre is, due its dimensions in plan and height, qualified of "Large compartment" (European Commission, 1999a). Moreover, the fact that the main structure is made of steel elements of class 4 cross-section (EN 1993-1-1), a prescriptive analysis would force the use of passive protection against fire designed for a critical temperature of 350°C and a fire resistance R120, as prescribed in EN 1993-1-2, if no structural analysis was performed.

This study, on the steel structure fire behaviour, aimed at determining the fire resistance of the building structure.

## 14.2 FIRE SCENARIOS

For definition of the most likely fire scenarios, it was considered three distinct zones shown in Fig. 14.1: the area for exhibitions and fairs (Zone A), area of auditoriums (Zone B) and the passage surrounding area (Zone C).

The temperature evolutions were determined using the calculation software Ozone V2.2 (Cadorin, 2003a, Cadorin, 2003b). The definition of the natural fire curves took into account the fire compartment dimensions, the ventilation conditions, including openings corresponded to the smoke exhaustion system (electrical control, considered calibrated to 70 °C) and walls lining materials, in opposition to standard fire curve that is independent of these parameters. Although, it was considered the beneficial effect of the use of sprinklers, other additional active fire fighting measures, such as the existence of fire detectors and alarms, automatic warning supported by the public phone network connected to the fire brigade, fire fighting devices among others, were not, on the safe side, took in to account when defining the fire load design value to be used.

### 14.2.1 Compartment fires

Although the EC1 allows the consideration of the beneficial effects of various measures of active fire safety, this study was chosen, as previous mentioned, by considering only the effect of sprinklers, and the design value of the fire load density value of is defined by

$$q_{f,d} = q_{f,k} \cdot m \cdot \delta_{n1} \qquad \left[MJ/m^2\right] \tag{1}$$

where: $q_{f,k}$ is the characteristic value of fire load density per unit area of the floor [MJ/m$^2$]; m is the combustion factor, considered in this study equal to 0.8; and $\delta_{n1}$ the factor that considers the effect of sprinklers, equal to 0.61.

The adopted fire load density characteristic values were:

- Rooms for the exhibitions (Zone A): $q_{f,k}$ = 400 MJ/m$^2$ (European Commission, 1999a)
- Auditorium (Zone B): $q_{f,k}$ = 365 MJ/m$^2$ (EN 1993-1-2)

- Fire located in the circulation zone (Zone C): $q_{f,k}$ = 1824 MJ/m$^2$ (same as for libraries), (EN 1993-1-2)

On the surrounding circulation zone (Zone C) it was admitted the possibility of occurrence of a localized fire in a stand for exhibition and books selling with an area of 12 m$^2$, which corresponds to the most severe situation in the fire load densities table given in EN 1991-1-2.

The openings (corresponding to the doors) were considered completely opened from the beginning of the fire (most severe situation resulted from a parametric study considering various openings percentages). It was also taken in to account in Zone A the existence of 21 smoke evacuation systems, with a net surface of 1.96 m$^2$, electrical controls and calibrated to 70 °C, being 12 located in the largest hall and 9 on the smaller. It was assumed that the walls were composed of concrete blocks. The cover was built of sandwich panels with profiled steel sheeting of 0.75 mm thick with rock wool of 40 mm thick. It was also used a rate of heat release $RHR_f$ = 500 kW/m$^2$ (EN 1993-1-2) with a fast fire growth rate $t_\alpha = 150$ s (EN 1993-1-2).

### 14.2.2 Fire scenarios definition

The considered compartment fire scenarios are presented in the following sections.

Zone A: exhibition halls

The Zone A (see Fig. 14.1) is divided into a large hall and a small hall. Thus three different fire scenarios were considered: fire in the large hall, fire in the small hall, and fire in two halls simultaneously. In these scenarios the average height is of 13.0 m, and the considered fire areas are present below.

**Scenario 1** - Fire in the larger hall
The considered maximum area was $A_{f,max}$ = 6525 m$^2$, and the fire area $A_{fi}$= 6525 m$^2$.

**Scenario 2** - Fire in the smaller hall
The considered maximum area was $A_{f,max}$ = 4410 m$^2$, and the fire area $A_{fi}$ = 4410 m$^2$.

**Scenario 3** - Fire in the two halls simultaneously
The considered maximum area was $A_{f,max}$ = 10935 m$^2$, and the fire area $A_{fi}$ = 10935 m$^2$.

The temperature evolutions of these compartment fire scenarios are plotted in Fig. 14.2a. The most severe is scenario 2.

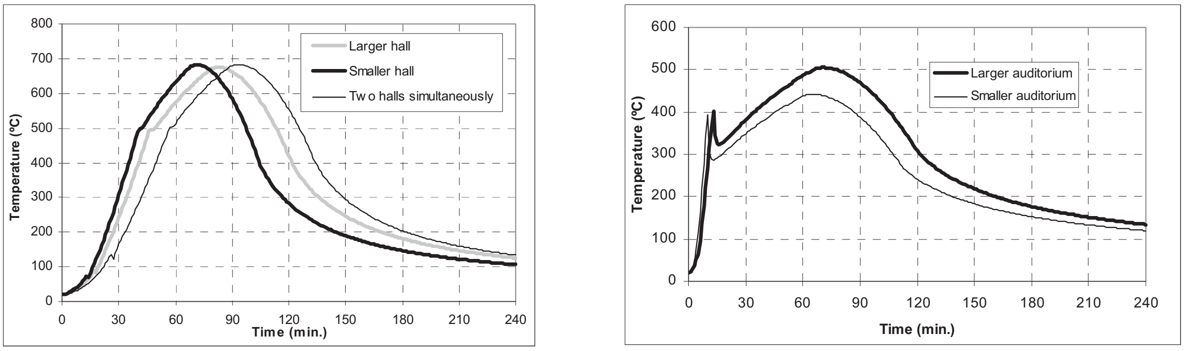
Zone B: Auditoriums

Zone B (see Fig. 14.1) is composed of several auditoriums. Two different fire scenarios were considered: fire in the smaller auditorium and fire in the larger auditorium. In these scenarios the average height is of 9.0 m, and the considered fire areas are present below.

**Scenario 4** - Fire in the smaller auditorium
The considered maximum area was $A_{f,max}$ = 194.88 m$^2$, and the fire area $A_{fi}$ = 194.88 m$^2$.

**Scenario 5** - Fire in the larger auditorium
The considered maximum area was $A_{f,max}$ = 409.92 m$^2$, and the fire area $A_{fi}$ = 409.92 m$^2$.

The temperature evolutions of these compartment fire scenarios are plotted in Fig. 14.2b. The most severe is scenario 5.




a) b)

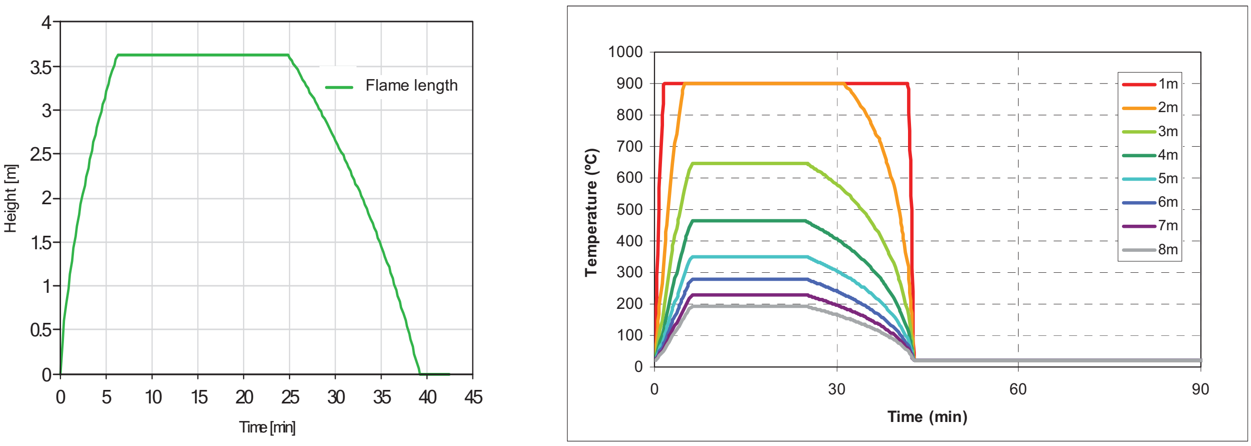
Fig. 14.2 Temperature evolution in the compartments: a) Zone A; b) Zone B

<u>Zone C: Localized fire in the surrounding circulation zone</u>

Zone C (see Fig. 14.1) is the circulation zone. As previously mentioned, it was considered the possibility of a localized fire, resulting in only one fire scenario. It was calculated the maximum height of the flames, in case of a localized fire according to the EC1 part 1.2 based on the Heskestad model (Heskestad, 1983). In this scenario the minimum compartment height is of 9.0 m and the maximum height of 11.4 m, the considered fire area is present below.

**Scenario 6** - Localized Fire in the circulation zone
The considered maximum area was $A_{f,max}$ = 12 m$^2$, and the fire area $A_{fi}$ = 12 m$^2$.

Fig. 14.3 shows the evolution of the flame length and the temperature development for different heights, obtained with the program Elefir-EN (Vila Real, 2010).




Maximum length of the flames: 3.63 m

a) b)

Fig. 14.3 Scenario 6: a) flame length; b) temperature development at different heights

### 14.3 MECHANICAL ANALYSIS

A 3D mechanical analysis using the software SAFIR (Cadorin, 2003b), with shell finite elements was used.

In the structural analysis the portal frame shown in Fig. 14.4 was used, which was representative of all the main frames. The frame comprises two main spans, one span with a length of 60 m (beams V2, V3 and V4), and another with 30 m length (beams V5 and profile IPE270).

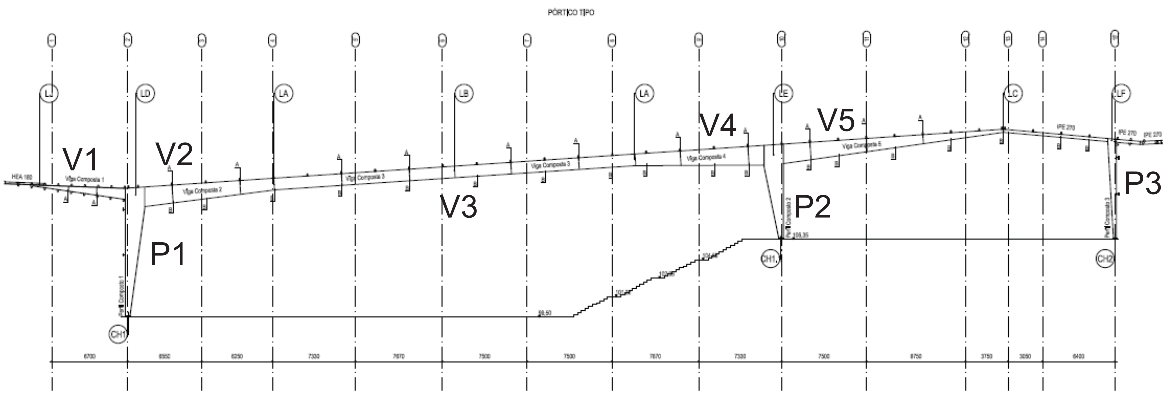



Fig. 14.4 Analysed portal frame

#### 14.3.1 Mechanical actions

Fire is considered an accidental action, which means that the design value of the action effects in fire situation, should be obtained using an accidental combination as defined in EN 1990 and according to the Portuguese National Annex of the EN 1991-1-2:

$$\sum G_k + \psi_{1,1} \cdot Q_{k,1} + \sum \psi_{2,i} \cdot Q_{k,i} + \sum A_d \qquad (2)$$

where $G_k$ refers to the permanent loading and $Q_k$ to the variable action.

The roof loads were determined, in accordance with Annex A1 of the EN 1990, adopting the category H for roofs, which corresponds to $\psi_1 = 1.0$ and $\psi_2 = 0.0$ for the wind actions and $\psi_1 = 0.0$ and $\psi_2 = 0.0$ for roof imposed loads.

For the building roof and facades 3 load combinations were adopted: Combination 1 - $1.0G_k$; Combination 2 - $1.0G_k + 0.2W_1$; and Combination 3 - $1.0G_k + 0.2W_2$, where $W_1$ and $W_2$ are the wind actions in the two orthogonal directions.

#### 14.3.2 Cross-sections thermal analysis

The thermal analyses of the cross sections were performed with the program SAFIR. From these analyses it was obtained the temperature field of the cross sections for each of the considered fire scenarios, which was later applied to the mechanical analysis.

The analysed structure is composed of class 4 I-sections (EN 1993-1-1). For example Fig. 14.5 shows the cross sections of two beams, one of non-uniform section (see V2 in Fig. 14.4) and another with uniform section (see V3 in Fig. 14.4). The fact that the sections are of non-uniform and of class 4 justified the use of structural modelling with finite shell elements, as illustrated in Fig. 14.5. The thermal analysis was, thus, performed with one-dimensional element for each different thickness and not for the entire cross-section. The used thicknesses varied between 6 mm and 18 mm in the profiles and reached 55 mm in the connections end plates.

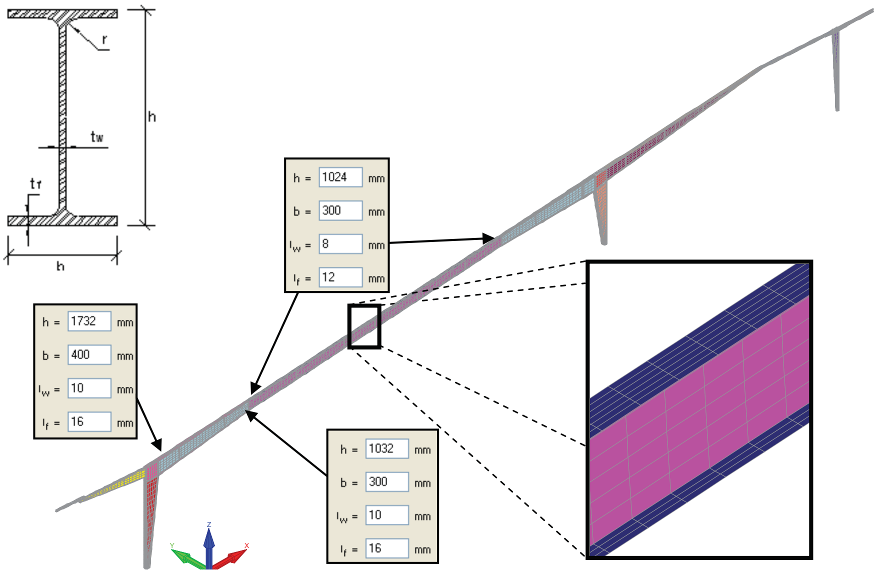



Fig. 14.5 Examples of the analysed cross-sections

It was considered, in the safe side, that all the shell elements were subjected to fire on their two sides, corresponding to fire on the four sides of the I cross-sections.

During the mechanical analysis it was found that it was necessary to protect the cross-sections to fire. The insulation thicknesses were chosen so that they would ensure fire resistance to the standard ISO834 curve for 60 minutes, considering a critical temperature of 500°C. Fig. 14.6 shows the temperature evolution in the steel sections with and without protection, due to fire scenario 1.

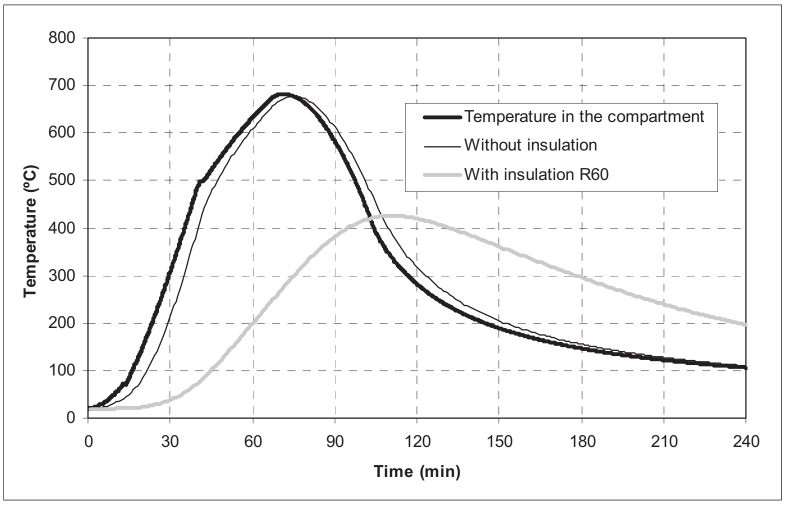



Fig. 14.6 Steel temperature evolution with and without protection

### 14.3.3 Analysed structural system

The structure was made of the steel grade S355. As mentioned above the structure has been modelled with shell elements. Fig. 14.7 shows the used model with some beam to column connections details.

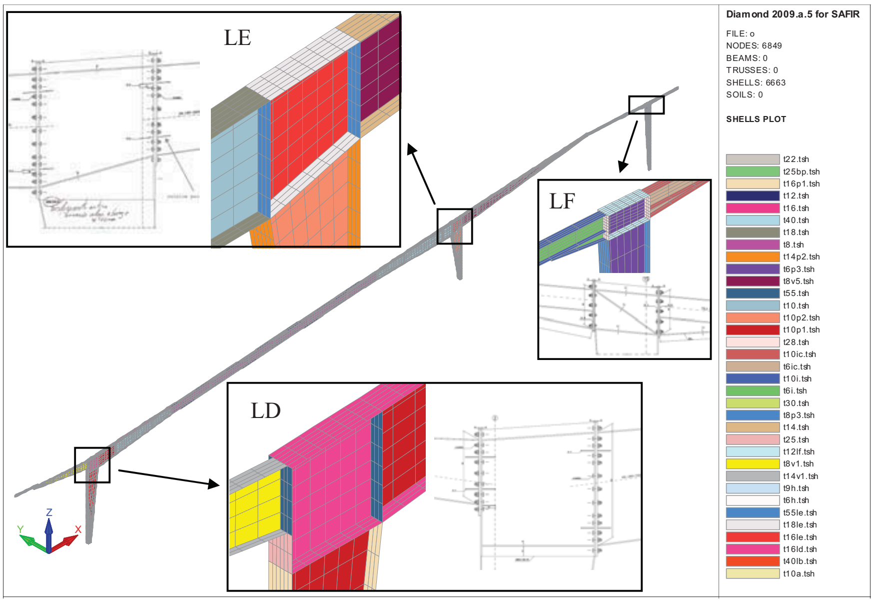



Fig. 14.7 Structural model and beam to column connection details

Fig. 14.8 shows the introduced restrictions to the structural model. It was considered that on the columns bases, the supports prevented the translations in all directions. Restrictions perpendicular to the frame have also been adopted. Figure 8 also shows the details of the beam to beam connections and of one of the transverse stiffeners considered in the analysis.

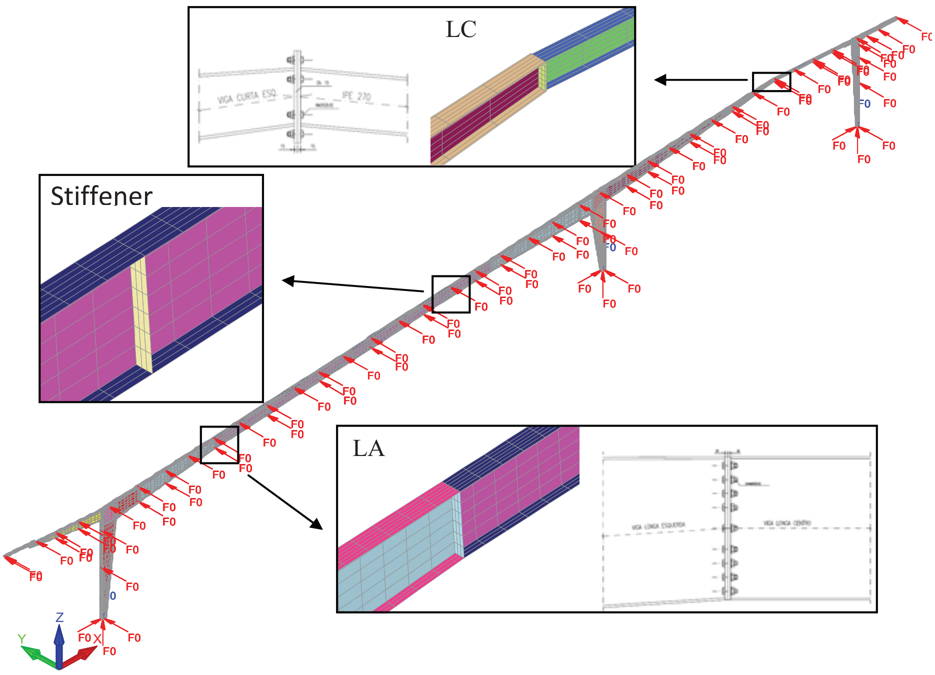



Fig. 14.8 Model restrictions and details of the beam to beam connections and of a transverse stiffener

Portal frame without insulation

On a first analysis it was considered that the portal frame did not have any fire protection, and that was subjected to the natural fire scenarios obtained from the thermal analysis (see Section 2). It must be mentioned that for the analysis of the portal frame subjected to natural fire curve in Zone A, and with actions combination 1, the collapse occurred at 41 minutes, being clear that fire protection is needed.

Portal frame insulated

Subsequently, the portal frame, insulated for 60 minutes of ISO834 considering a critical temperature of 500°C, was analysed, subjected to the natural fire scenarios obtained from the thermal analysis (see Section 2). For each of the fire scenarios (fire in Zone A, fire in Zone B and localized fire in Zone C) the three actions combinations, listed above, were considered.

**Fire in Zone A**

In structural analysis, it was considered that the fire in Zone A corresponds to having the beams V2, V3 and V4 heated and the other elements without any increasing temperature. There was no occurrence of structural collapse during all the fire, for the three actions combinations. The portal frame deformed shape, when subjected to the natural fire curve in Zone A and to the actions combination 1, at 120 minutes, is shown in Fig. 14.9.

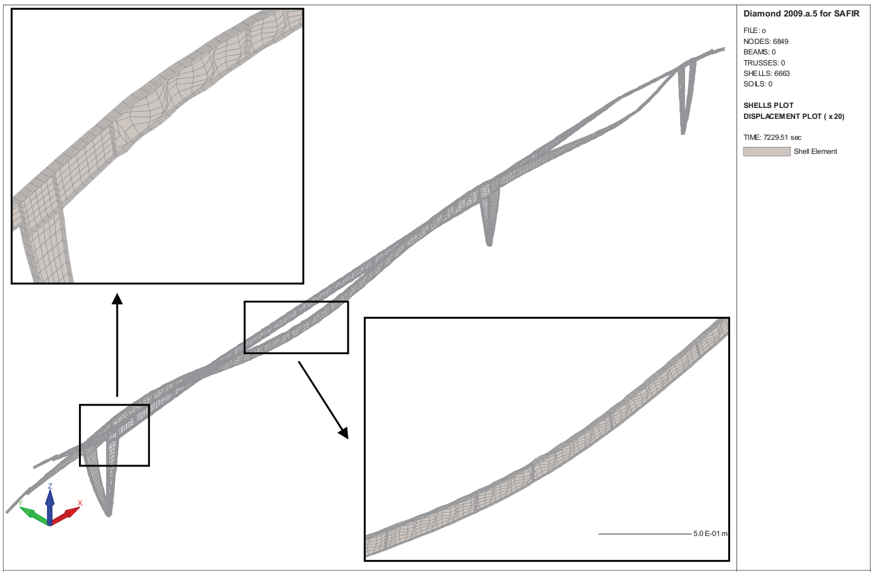



Fig. 14.9 The portal frame deformed shape, when subjected to the natural fire curve in Zone A and to the actions combination 1, at 120 minutes (x20)

**Fire in Zone B**

It was considered that the fire in Zone B corresponded to having only the column P2, the beam V5 and the IPE270 located between the columns P2 and P3 (see Fig. 14.4) heated. It was not observed structural collapse during all the fire, for the three actions combinations. The portal frame deformed shape, when subjected to the natural fire curve in Zone B and to the actions combination 1, at 120 minutes, is shown in Fig. 14.10.

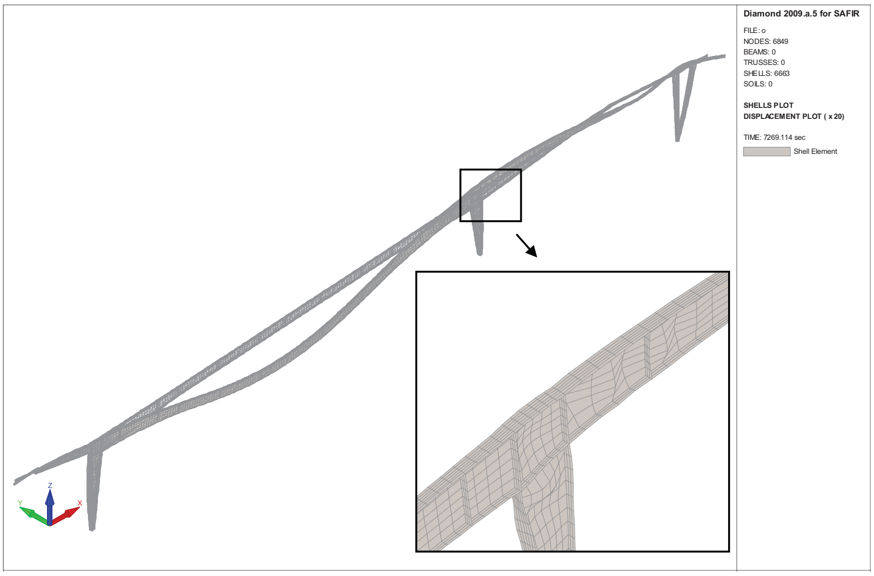



Fig. 14.10 The portal frame deformed shape, when subjected to the natural fire curve in Zone B and to the actions combination 1, at 120 minutes (x20)

**Localized fire in Zone C**

It was considered that the localized fire in Zone C would affect only column P1 (most severe case). As the temperature varies with the height along the axis of the flame (see Fig. 14.3), the columns was subdivided into 1 meter parts in the length, where it was applied, in which of them, the corresponded temperature evolution, as illustrated in Fig. 14.11.

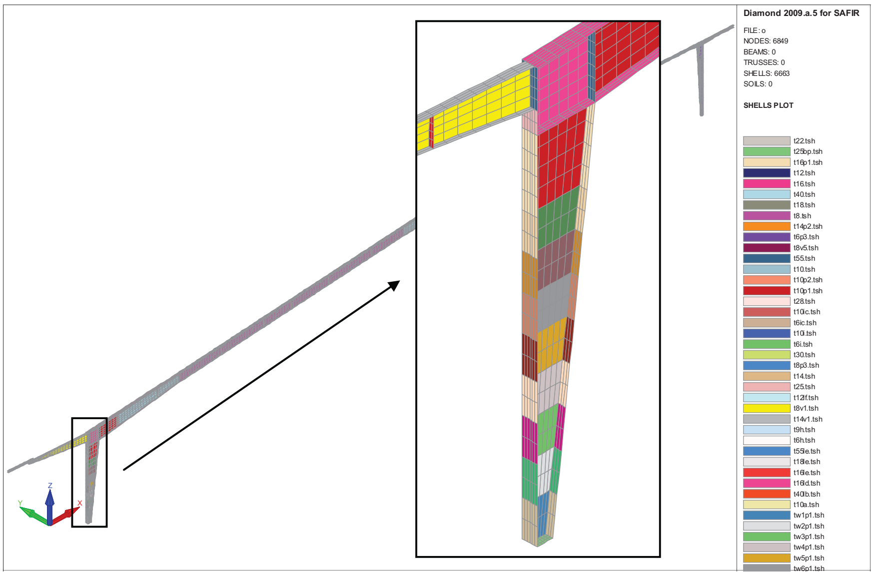



Fig. 14.11 Different temperature evolution in function of column P1 height for the localized fire

It was not observed structural collapse during all the fire, for the three actions combinations. The portal frame deformed shape, when subjected to the localized fire curve in Zone C and to the actions combination 1, at 120 minutes, is shown in Fig. 14.12.

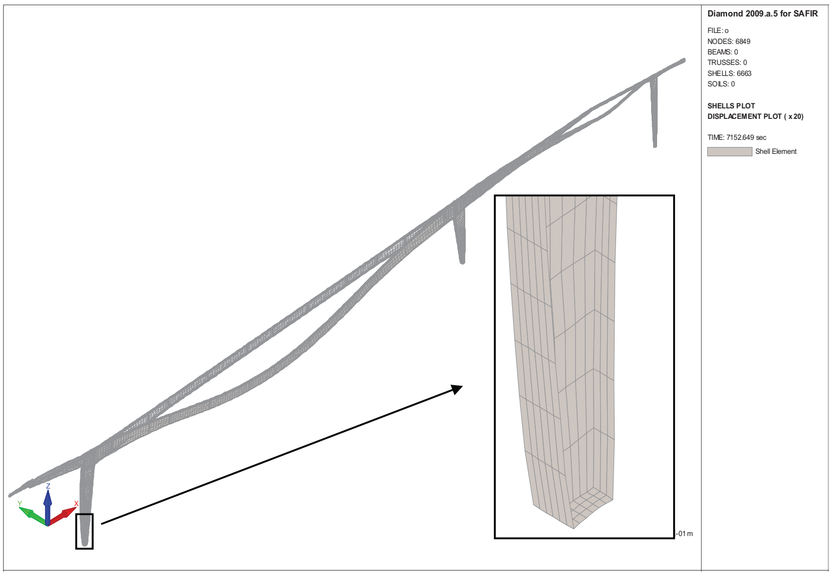



Fig. 14.12 The portal frame deformed shape, when subjected to the localized fire curve in Zone C and to the actions combination 1, at 120 minutes (x20)

Results

Tab. 14.1 summarizes the results of the described above analyses, indicating the collapse instance (tc) when this occurs.

Tab. 14.1 Results

| **Analysis** | Result |
|---|---|
| Unprotected portal frame subjected to natural fire in Zone A and the actions combination 1 | $t_c$ = 41 min |
| Protected portal frame: | |
| Natural fire in Zone A: | |
| Actions combination 1 | No collapse |
| Actions combination 2 | No collapse |
| Actions combination 3 | No collapse |
| Natural fire in Zone B: | |
| Actions combination 1 | No collapse |
| Actions combination 2 | No collapse |
| Actions combination 3 | No collapse |
| Localized fire in Zone C: | |
| Actions combination 1 | No collapse |
| Actions combination 2 | No collapse |
| Actions combination 3 | No collapse |

## 14.4 CONCLUSIONS

The steel structure of the Oeiras Exhibition Centre is composed of profiles with non-uniform class 4 cross-sections. A prescriptive analysis based on ISO834 standard fire curve, without evaluating the structural performance, would require the use of passive fire protection designed to provide a fire resistance of 120 minutes (R120) considering, according to EN 1993-1-2, a critical temperature of 350°C. This protection would be very expensive.

The Portuguese fire regulation states that: "Depending on its type, the buildings structural elements shall have a fire resistance to ensure their load bearing, thermal insulation and integrity functions during all stages of the fire fighting, or alternatively, must have the minimum standard fire resistance." In this case, the minimum fire resistance would be of 120 minutes.

A performance- based analysis has shown in this study that, without sacrificing safety, protecting the structure for a standard fire resistance of 60 minutes (R60), assuming a critical temperature of 500°C, is possible to maintain its load bearing functions during all phases of the fire, including the cooling phase.

It was proposed therefore that the main steel structure would be protected to R60 considering a critical temperature of 500°C.

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# 15 CAIRO EXPO CITY EXHIBITION CENTRE FIRE ENGINEERING

Summary

The Exhibition Centre at Cairo Expo City will comprise 4 large halls (in excess of 120m in dimension each) which will cater for very large numbers and will be accessed from a single continuous entrance foyer. Because of these features compliance with code guidance in relation to travel distances and exit capacity was not practical in the halls and entrance foyer. Therefore a comprehensive fire engineered solution was undertaken involving the provision of smoke extract to maintain tenable conditions during escape. This approach involved the use of CFD smoke modelling in combination with an analysis of escape times to ensure that occupants can escape before escape routes were rendered untenable. The CFD analysis was also used to inform a Structural Fire Engineering analysis of the space frame to ensure that premature collapse of the structure does not occur in a fire scenario. Outlined in this paper is a description of the approach adopted for both the escape and structural fire engineering aspects on this scheme.

## 15.1 INTRODUCTION

The exhibition centre at the new Cairo Expo City development comprises a curved roof structure sweeping over four internal exhibition halls and covering over 180,000m³ of plan area which will make it an exhibition hub in the Arab world. Each of the 4 rectangular column free halls is 120m wide and up to 360m long, and are all linked by a large continuous circulation zone/entrance lobby. Within the entrance lobby there are open balconies at first floor providing access to a large number of individual conference rooms. Buro Happold is the multi-disciplinary consulting engineer for the entire development, working with Zaha Hadid Architects.

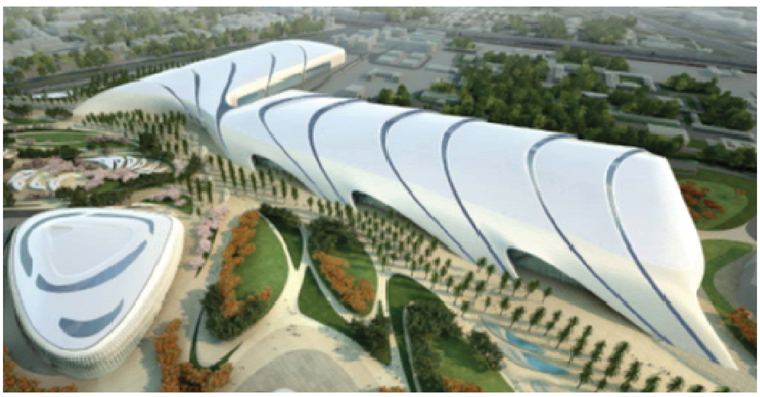


Fig. 15.1 Exhibition Centre – Exterior Render © Zaha Hadid Architects

Because of the sheer size of each of the halls and entrance lobby and the large numbers of expected occupants compliance with the relevant prescriptive codes NFPA 101 and Egyptian Building Code in terms of travel distances and exit capacity was not practical. The fire strategy for the Exhibition Centre does not follow the prescriptive requirements of NFPA or Egyptian Code as several key elements are too restrictive or do not result in a safe solution when taking the site constraints of the building into consideration:

- the maximum permitted 76m travel distance limit is not feasible without compromising the desired openness of the exhibition halls,
- using 5mm/p and a 50% limit for the horizontal exit width to the foyer would overload the fairly narrow rear service road to the West of the Exhibition Centre, potentially creating a conflict between emergency vehicle access and people evacuation,
- At least half of the stairs serving the upper level within the Exhibition Centre would have to exit to the outside to comply with code, which would require protected exit passageways within the foyer, again compromising the desired openness and connectivity of the foyer.

Therefore a project specific fire strategy tailored to the site constraints and client brief, which follows a fire engineered approach based on Chapter 5 of NFPA has been utilised.  The assumptions and relevant characteristics for this assessment are outlined below. This case study concentrates on the fire engineered analysis for means of escape from the halls.

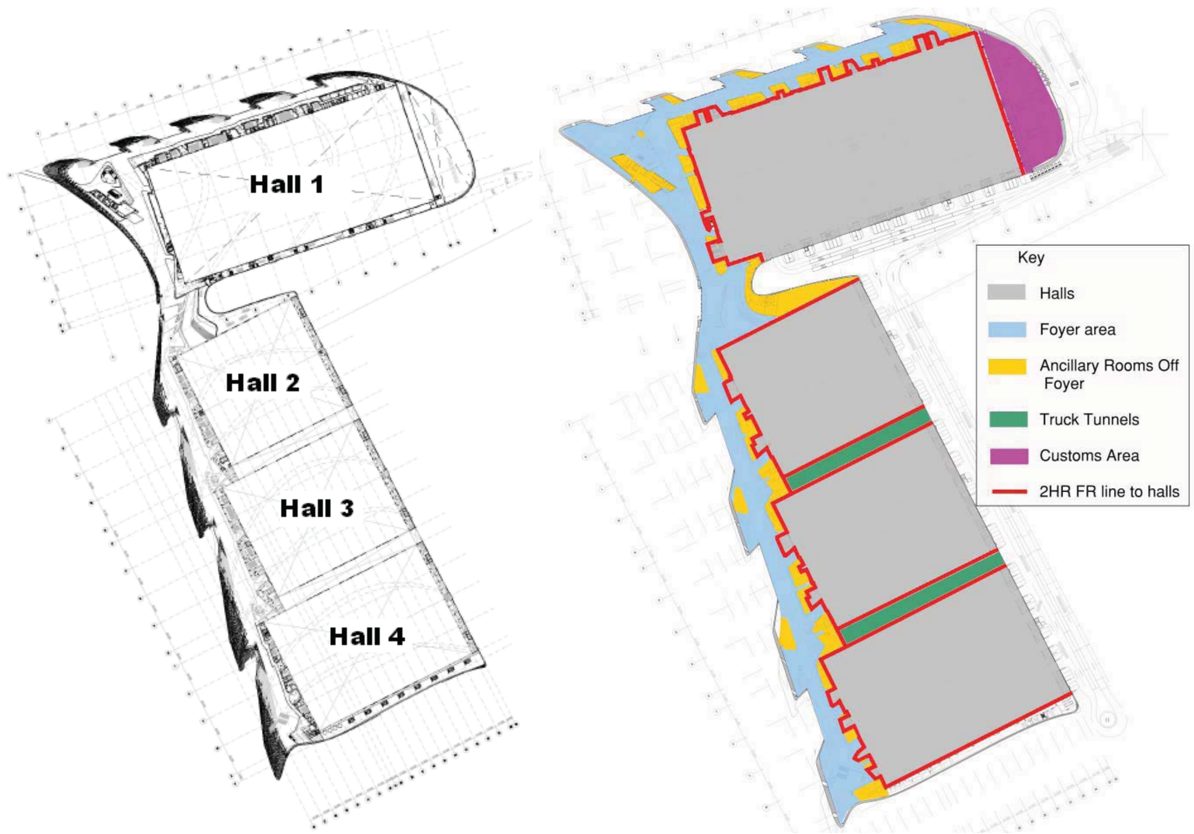



Fig. 15.2 Exhibition Centre Plan and Evacuation Zones

## 15.2 FIRE STRATEGY PRINCIPALS

The main principal was to split the Exhibition Centre into separate evacuation zones/compartments whereby only the zone on fire will be evacuated initially. The Foyer and each of Halls 1 to 4 each form separate evacuation zones. This approach was chosen to limit the numbers of occupants escaping at any one time in order to enable more effective and easier evacuation management and more efficient escape design. This also enabled each of the halls and foyer to be assessed individually.

The Exhibition Centre will be fitted with sprinklers and smoke control systems, automatic smoke detection for early notification, which together with management requirements form an essential part of the fire safety strategy.

## 15.3 PERFORMANCE BASED APPROACH PROCESS

There are four key processes to the fire engineering as described below. These components also relate to the NFPA frame work for performance-based options.

Tab. 15.1 Outline of the processes to the Fire Engineering Brief (FEB)

| Process | |
|---|---|
| Define and agree objectives and criteria | The fire safety goals and objectives are defined and agreed amongst all stakeholders at earliest stage possible. These include regulatory requirements and client and insurance requirements for property protection and business continuity as well as Civil Defence requirements. |
| Design specification – part 1 | This includes a brief description of the buildings, the assumptions made, hazard identification, retained prescriptive requirements, fire scenarios (including occupant characteristics, design fires and proposed systems and response). |
| Design specification - part 2 | The detail of the fire strategy covering proposed systems and management assumptions will be documented in the Fire Strategy Report. The strategy outlines the initial trial design. |
| Define and agree performance assessment | The acceptance criteria, assessment methods and tools, safety factors and output are defined and agreed that will be used in the analysis. Once a trial design has been agreed and shown to be acceptable, it becomes the Proposed Design. |
| Define and agree outputs and documentation | Effective and clear documentation is an important part of the fire engineering process. The output provided from the analysis and the final documentation are also agreed in the Fire Engineering Brief upfront. |

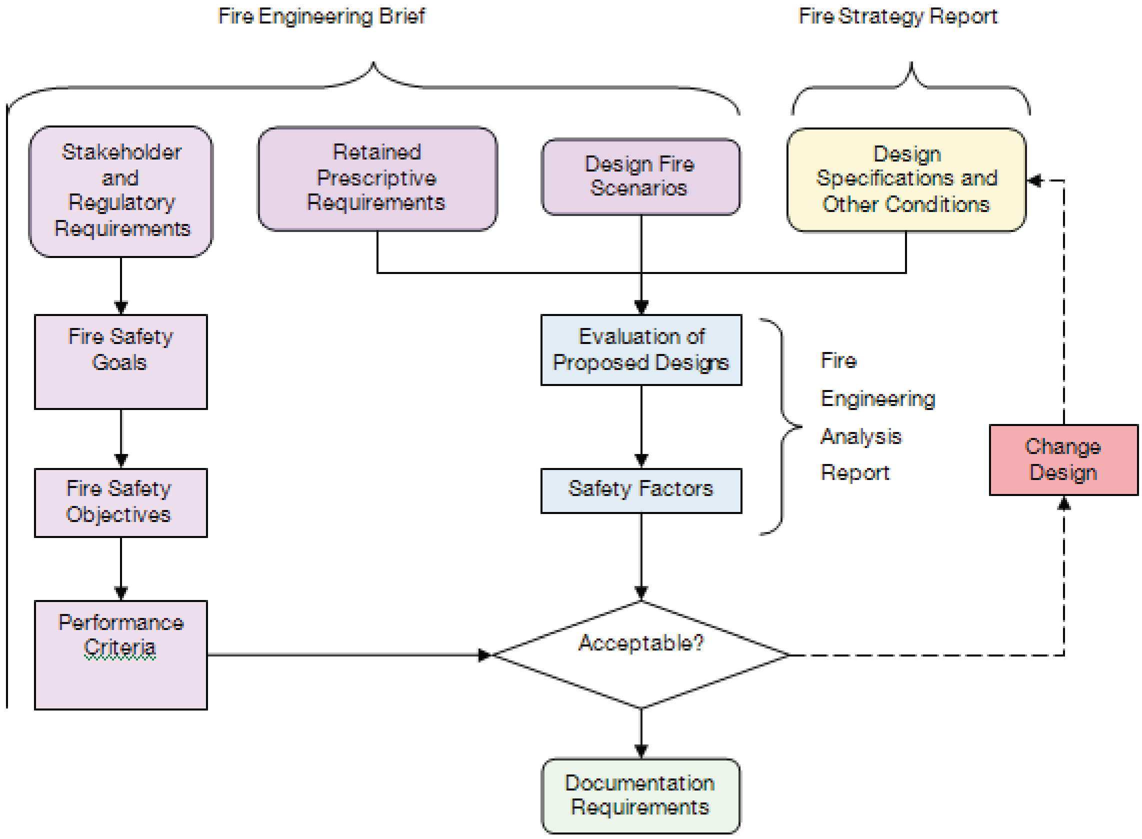



Fig. 15.3 Performance Based Life Safety Code Compliance Process

### 15.4 ASSESSMENT STRATEGY AND ACCEPTABILITY CRITERIA

A detailed assessment was carried out to demonstrate that the smoke control provisions are sufficient to ensure that all occupants can evacuate to a place of safety before the condition in the building becomes untenable by way of comparing the Available Safe Egress Time (ASET) with the Required Safe Egress Time (RSET), and applying a suitable margin of safety as shown below.

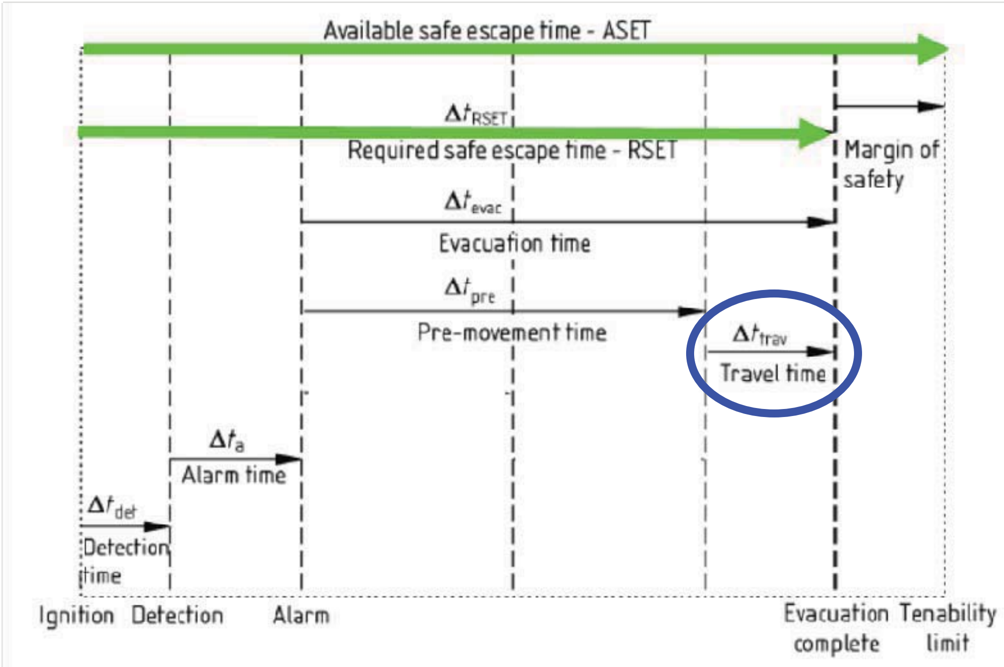



Fig 15.4 ASET - RSET Design Approach

The design further ensures for Crowd Comfort that the movement or travel time, i.e. the time taken to walk to a place of interim safety which is highlighted in the figure above by a blue circle, does not exceed 6 minutes. The acceptance criteria for the assessment are outlined below.

Tab. 15.2 Acceptance Criteria for Fire Engineering Analysis

| | **Value** | **Reference & Comments** |
|---|---|---|
| Hot Layer depth | maintain smoke layer at least 1.83m (measured to 2m within the CFD analysis) above floor level | applies to zone model calculations and CFD analysis (NFPA 92B) |
| Temperature | if smoke layer descends closer than 2.1 metres above floor then smoke temperature is not to exceed 60 deg C | exposure for no more than 10 minutes, measured 1.83m above floor level (NFPA 92B, NFPA 130) |
| Visibility | Optical density not to exceed 0.1 m-1 (i.e. 10 metres visibility). Refer note 1 | applies on escape routes for the required safe egress time, measured 1.83m above floor level |
| Toxicity | Exposure to toxic and irritant products is not considered separately. Criteria for visibility are used to control limits on exposure to smoke and toxic products as both are a function of smoke production and dilution | Applies to CFD and zone models at early stages of a fire. Does not apply during fire fighting. Refer Wade in Chapter 8 of FEDG, Buchanan, 2001 |
| Radiant Heat | for smoke more than 1.83 metres above floor, radiation is not to exceed 2.5 kW/m2 (typically 200 deg C). Refer Note 2 | measured at 1.83m above floor; applies to zone model calculations only. NFPA 130 |

## 15.5 DESIGN FIRE SIZE

A number of Design Fires were considered as outlined below:

Tab 15.3 Design Fires Considered

| Design Fire | Scenario | Design Fire Characteristics |
|---|---|---|
| 1 | Occupancy specific, accounting for the occupant activities, furnishings and room contents, fuel properties, ignition sources and ventilation conditions. | 1.1 Fire in multi-storey exhibition booth, sprinkler controlled. Max HRR 1MW, height of fire at floor level, slow growth.<br>1.2 Fire in multi-store exhibition booth, not sprinkler controlled. Fire at top level, 9m above floor level or at floor level, max HRR 6MW, medium growth.<br>**1.3 Fire at floor level, by small car or art exhibit, with maximum HRR of 6MW, and fast fire growth.** |
| 2 | Ultrafast developing fire in primary means of egress, with interior doors open at start of fire. | Fire at floor level, by small car or art exhibit, with maximum HRR of 6MW; fire growth initially ultrafast to 1.1MW, then medium fire growth. |
| 3 | Fire start in normally unoccupied room, potentially putting large numbers of people at risk in adjacent space. | Building is fitted with automatic smoke detection and sprinklers throughout, and adjacent spaces are fire separated from exhibition halls. This scenario is therefore adequately addressed by qualitative analysis and does not require further assessment. |
| 4 | Fire start in a concealed wall or ceiling adjacent to large occupied room. | Refer above – spaces are fire separated and fitted with automatic detection & sprinklers. |
| 5 | Slowly developing fire, shielded from fire protection, in close proximity to high occupancy area. | Building is fitted with automatic smoke detection for early notification. Analogue addressable system will allow exact identification of location and timely intervention by trained staff / fire service. Halls are fire separated from surrounding areas. |
| 6 | Most severe fire resulting from largest possible fuel load characteristic of the normal operation of the building. | **Fast growing very large fire, representing a large exhibition item such as a truck on fire. $Q_{max}$= 30MW (unless controlled earlier due to sprinkler activation or fire service intervention). Height of fire at floor level, fast fire growth.** |

Based on the above, two worst case fire scenarios were chosen as the design basis:

- a fast growing fire up to 30MW representative of a truck fire; and
- a fast growing retail exhibit fire up to 6MW. This was chosen to ensure that the smoke control system was also capable of dealing with a smaller fire which would result in reduced some temperatures but a less buoyant smoke layer.

Due to the high ceilings both fire sizes have assume that sprinklers do not act sufficiently early to control the size of the fires.

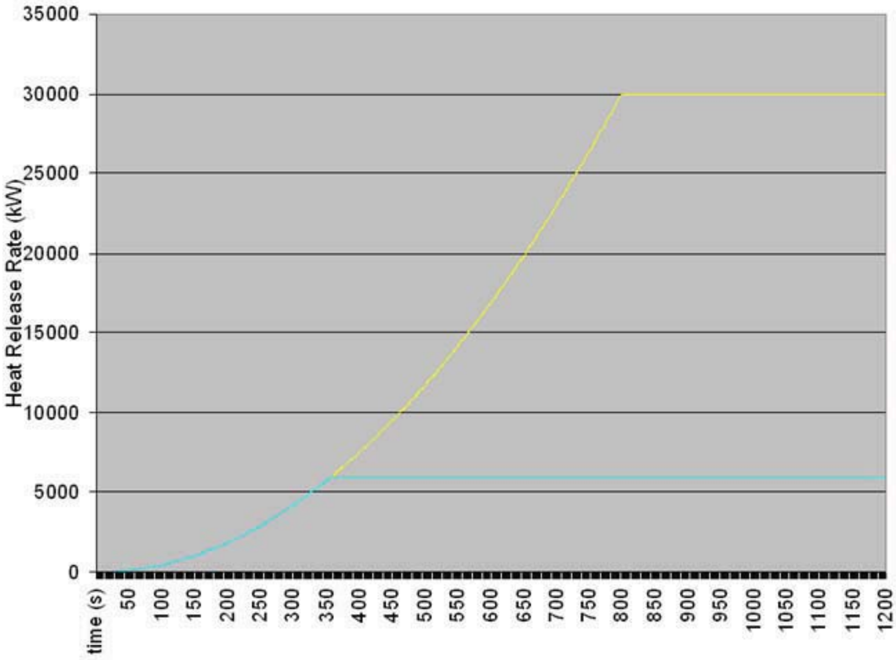



Fig. 15.5 Graph of HRR vs Time for Chosen Design Fires

**15.6 SMOKE CONTROL METHODOLOGY**

Halls 2 to 4 were divided into at least two smoke reservoirs by the inherent hall subdividing dividing downstand feature in the centre of each hall. Similarly Hall 1, due to its size was subdivided twice to form three separate reservoirs. Due to the hot climate in Cairo, a natural smoke extract system would not be suitable as it relies on the buoyancy of the smoke for venting. Therefore a mechanical smoke extract system was chosen with at least twelve extract points located throughout the roof of each reservoir. Inlet air to the system is provided by automatically opening the large service entrance shutters on the external facade.

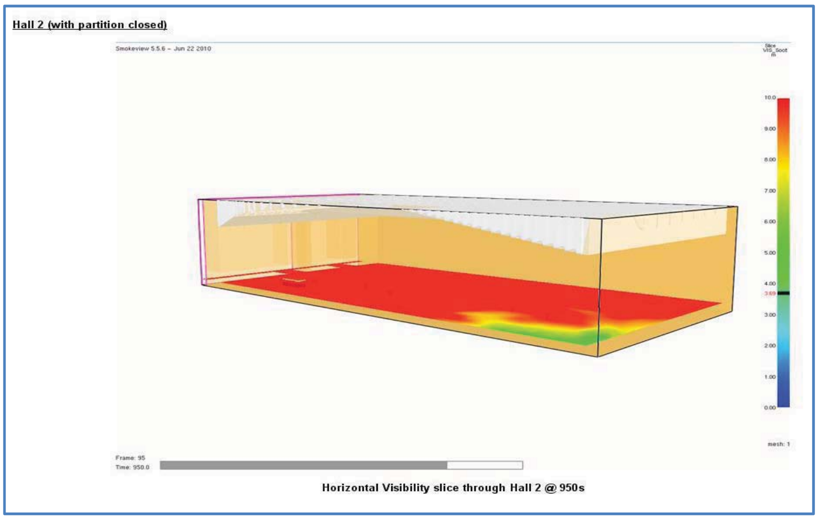
The CIBSE Guide E: Fire Engineering zone model approach was used to calculate the required extract rates for the above design fires. Due to the unusually large reservoir sizes it was necessary to carry out a CFD analysis of the smoke modelling to ensure that the system was capable of maintaining tenable conditions during escape.

**15.7 CFD ANALYSIS TO VERIFY AVAILABLE SAFE ESCAPE TIME (ASET)**

A number of CFD models were run for both a 30MW and 6MW fast growing fires using NISTs FDS program. The fires were modelled in a number of different locations to determine the worst case scenario, for example:

- Both remote and in close proximity to the inlet air openings
- In Hall 2 typical smallest reservoir, and Hall 4 typical largest smoke reservoir

A sensitivity analysis was also carried out for a medium growth rate.



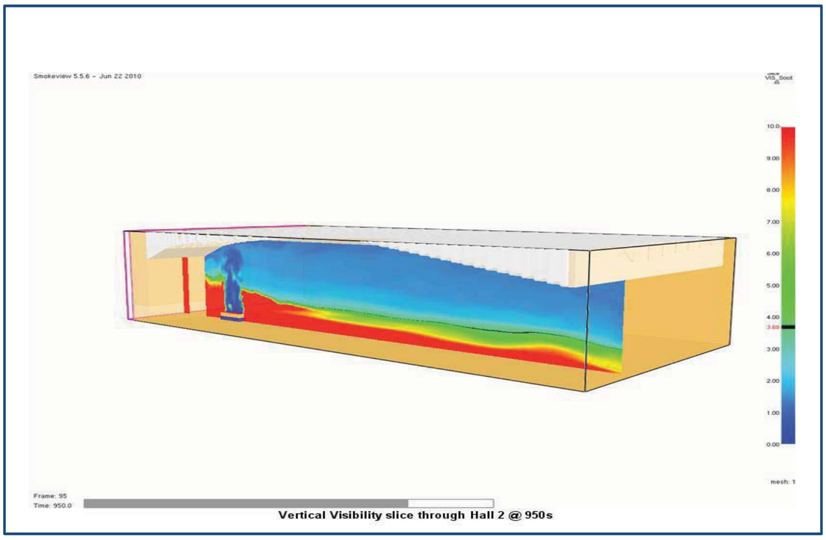




Fig. 15.6 CFD Model Slices of visibility at 950s in typical Worst Case Scenario at Tenability Limit

### 15.8 ASET VS RSET ANALYSIS & RESULTS

The CFD analysis has demonstrated that in the worst case scenario, visibility was the limiting factor on ASET with visibility being reduced below 10m at head height in one corner of Hall 2 after 950 seconds (almost 16 minutes). Therefore 950s has been taken as the benchmark ASET. It should be noted that this is considered a conservative approach given the following:

- This worst case scenario is for a 30MW fast growing fire which is intended to represent a very large display fire (e.g. a bus, boat or truck or similar sized display) and ignores the effects of sprinklers on the fire growth and size.
- Even with this conservative fire size, after 950s, the visibility is only reduced in one corner of the hall, the remainder of the hall remains within tenable limits.
- It is highly unlikely that the halls will be occupied to a level of 1.4sqm/person at the same time there is very large displays such as boats trucks etc. present.

The goal is to achieve an available safe egress time that exceeds the required safe egress time:

**ASET > = RSET**

The calculation of the required safe egress time (RSET) contains adequate safety factors to compensate for uncertainties within the evacuation assessment such that no further safety margin is required in the assessment. The results are summarised below for the typical worst case Hall which an occupant load of 20160 occupants.

When considering an extended pre-movement time (which has been set to 90 second, based on BS 7974) and alarm activation time and after incorporating a safety factor of 1.5 on the travel time, the last person is expected to leave after 10.4 minutes, with a safety margin of at least 5.4 minutes to the safe egress time. This 10.4 minute evacuation time also incorporates an additional factor of safety as the travel time has been increased by a factor of safety of 1.5. The flow and travel times are assessed based on the recommendations of NFPA130.

Tab. 15.4 Calculation of Available Safe Egress Time

| Description of Event | Time [sec] | Time [min] |
|---|---|---|
| Fire starts | 0 | 0.0 |
| Fire is detected (double knock activation) | 70 | 1.2 |
| Evacuation signal is raised immediately after double knock | 70 | 1.2 |
| First person starts to move | 160 | 2.7 |
| First person reaches exit | 248 | 4.1 |
| *Fire Service begins to fight the fire* | *630* | *10.5* |
| Last person leaves the hall | 470 | 7.8 |
| .. - with safety factor | 625 | 10.4 |
| Available Safe Egress Time (worst case Hall 2 used as benchmark ASET) | **950** | **15.8** |


Fig. 15.7 Timeline of Fire in Hall Worst Case Scenario

### 15.9 CONCLUSION

Due to the large open spaces required to meet the desired functional and architectural aspirations for the Exhibition Centre, compliance with prescriptive code was not possible in terms of travel distance and exit capacity. It was therefore necessary to use an alternative fire engineered approach whereby smoke control was used to maintain tenable conditions during escape for a worst case credible fire scenario. A CFD analysis was carried out for a number of different credible worst case fire scenarios to demonstrate that the smoke control system was capable of keeping escape routes tenable for at least 16 minutes (ASET). This is significantly greater than the estimated required safe escape time of 10.4 minutes (RSET). The CFD analysis was also used to inform a Structural Fire Engineering analysis of the space frame to demonstrate that premature collapse of the structure does not occur in a fire scenario. This case study has clearly demonstrated that the latest sound fire engineering techniques can be used as a powerful tool to ensure that a high level of safety can be achieved without limiting the flexibility in design of large and complex public buildings by prescriptive code approaches.

Acknowledgement

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