Loading-bearing Capacity Method for Structural Fire Safety Design

– A Case Study

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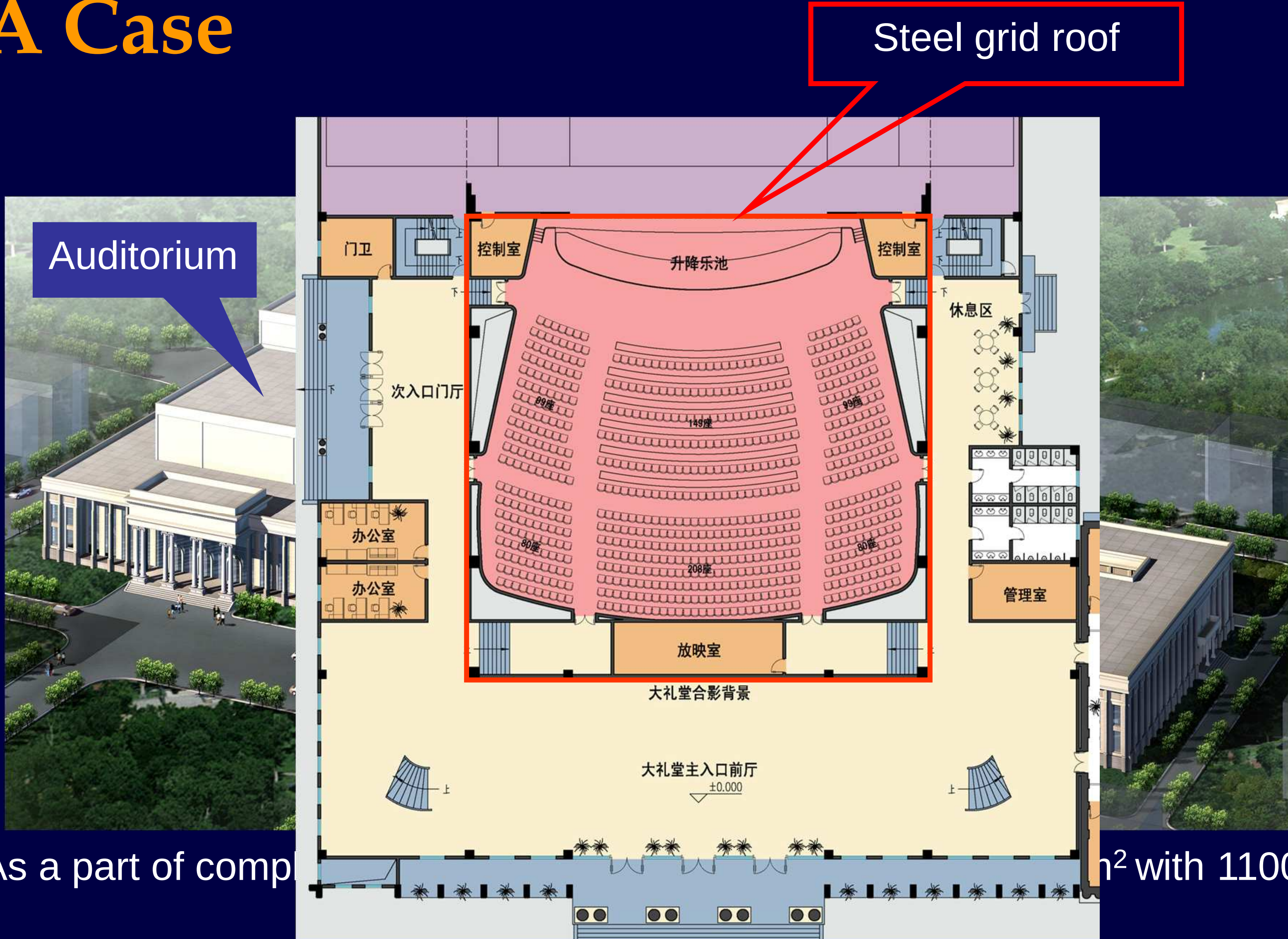
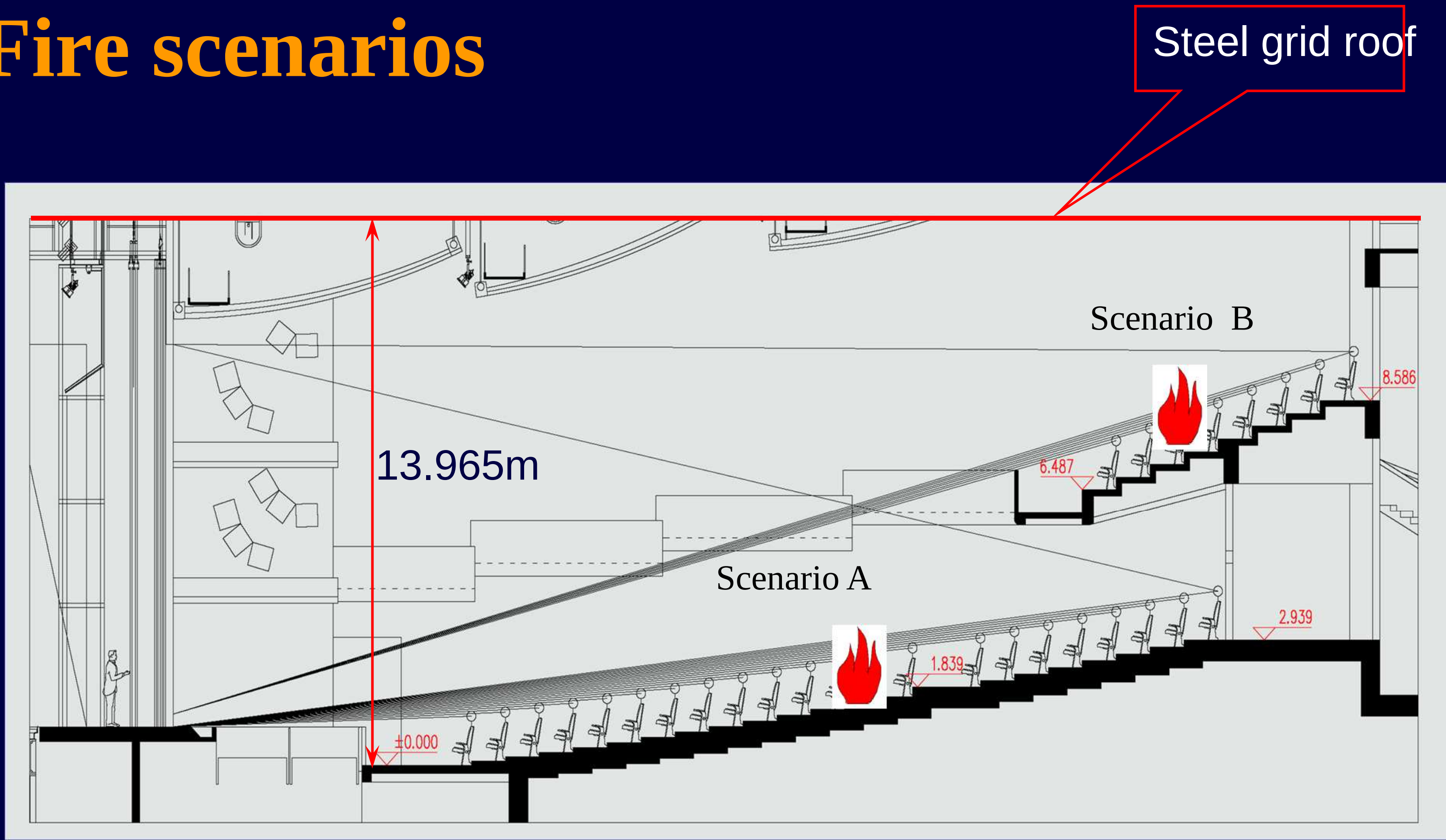
A Case



As a part of compl ... m^2 with 1100 seats

A long span steel grid roof was employed

Fire scenarios

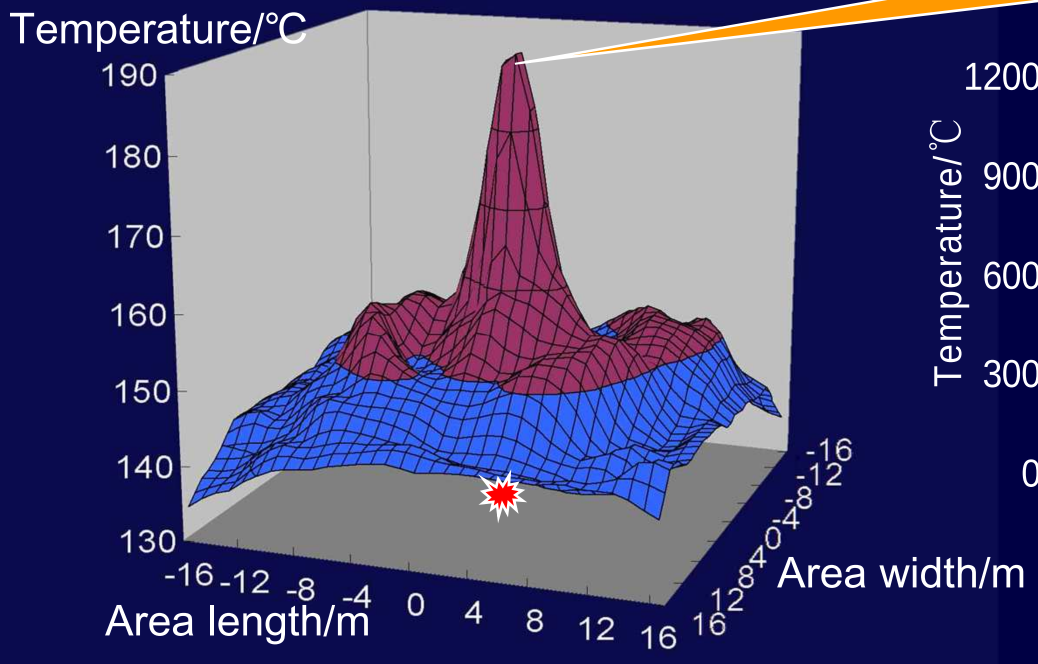


A – The auditorium has an area of 32m×28m=896 m^2 and the height of 13.965m. The localized fire is in the middle of the compartment.

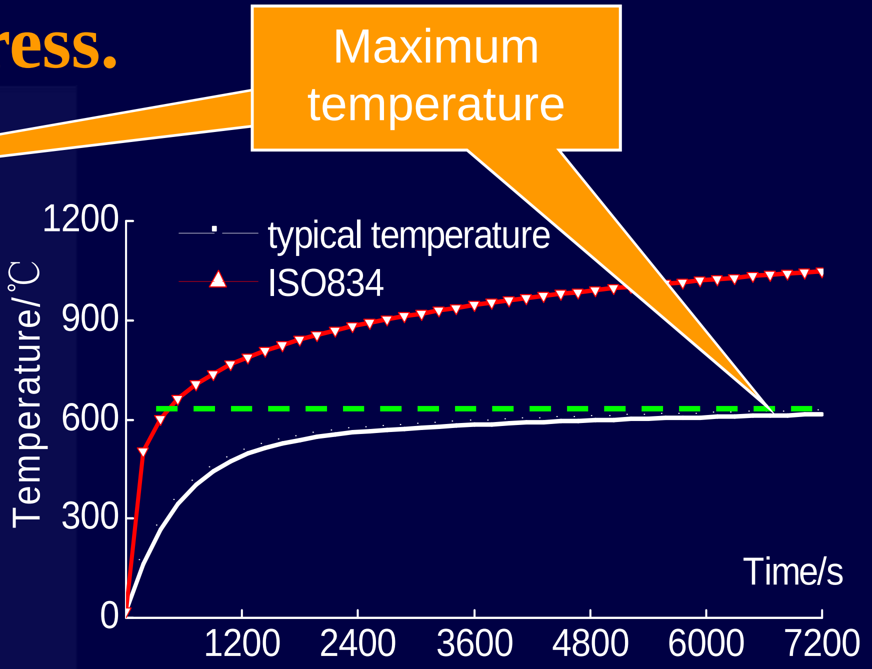
B – the balcony has an area of 32m×10m=320 m^2 and 6.487m from the auditorium level. The localized fire is in the middle of the balcony .

Localized fire

- The fire temperature fields in large space buildings are non-uniform, and the maximum temperature is lower.
- The cooler parts can provide restraints for the hotter area, and lead to thermal stress.



Non-uniform temperature field



Typical temperature curve for localized fire versus ISO-834

Loading-bearing capacity method

(1) Design fire scenarios based on fire performance and determine the fire temperature distribution

(2) Determine critical temperature based on FE calculated

(3) Guess the thickness of fire protection for members (without fire protection is permitted)

(4) Calculate the maximum temperature in members exposed to fire scenario

(5) Check the fire limit state

The maximum temperature of structures (or elements) in the duration exposed to fire scenario

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given by clause in CECS200:2006 (China)

$$t_{\mathrm{d}} \geq t_{\mathrm{m}} \quad \text{or} \quad T_{\mathrm{d}} \geq T_{\mathrm{m}}$$

(6) Repeat step 3~5 if the fire limit state can’t be satisfied

Design fire

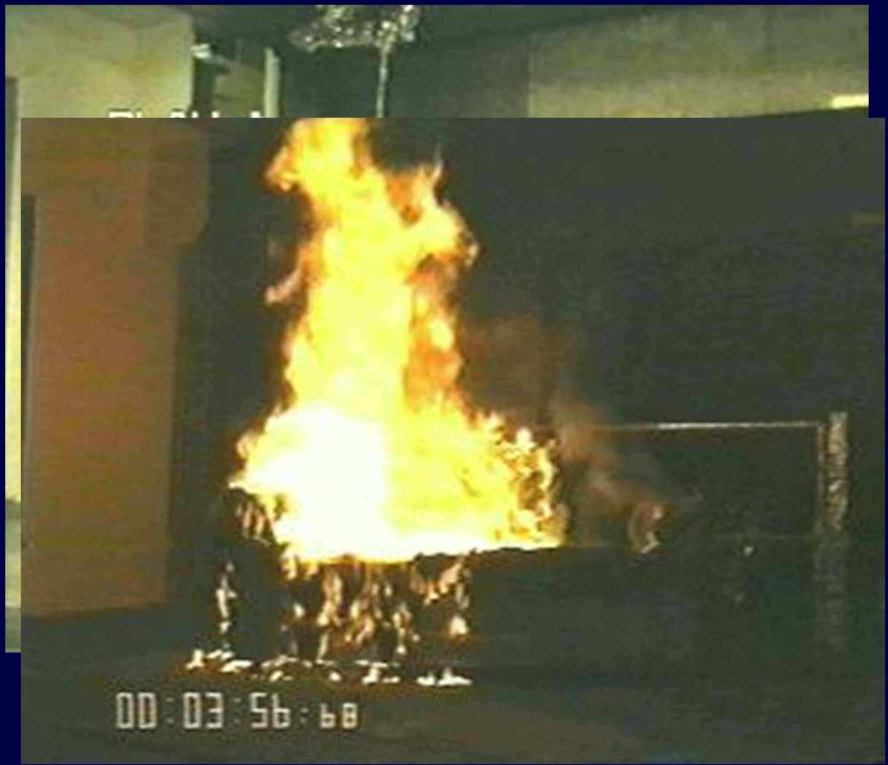
- **Hypothesis**

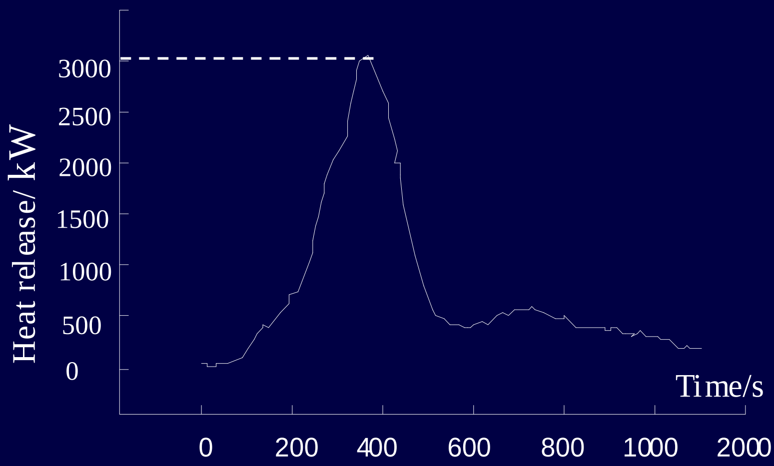
(1)Thermal boundary condition is the adiabatic wall without heat energy exchange with outside. The ambient temperature is 20℃

(2) The fire doors are open as ventilators and the fire is fuel controlled

(3) The fire grows as the t-squared fire and fire growth coefficient for the fast fire is 0.04689 kW/s^2

Estimating rate of heat release





NIST fire test in full development period

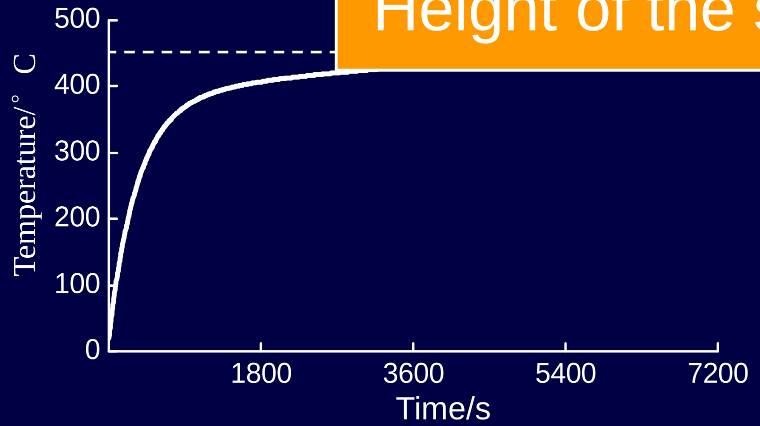
Smoke temperature history

$$T_g(t) - T_g(0) = T_g^{max}\left[1 - 0.8e^{(-\beta t)} - 0.2e^{(-0.1\beta t)}\right]$$

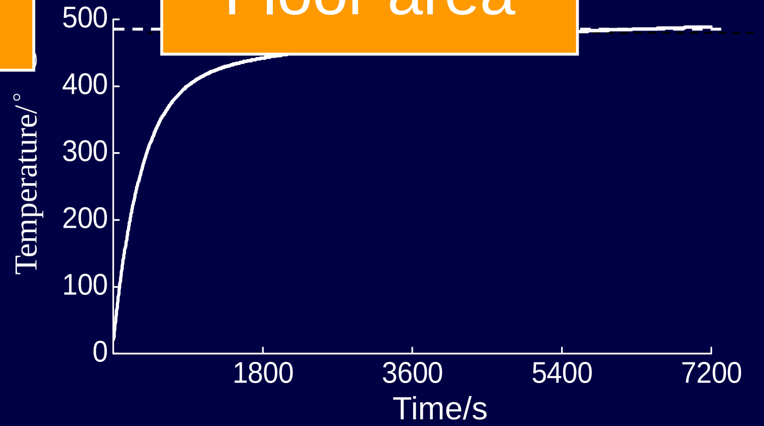
$$T_g^{max} = (20Q+80) - (0.4Q+3)H + (52Q+598)\times 10^2 / A_{sp}$$

Height of the space

Floor area

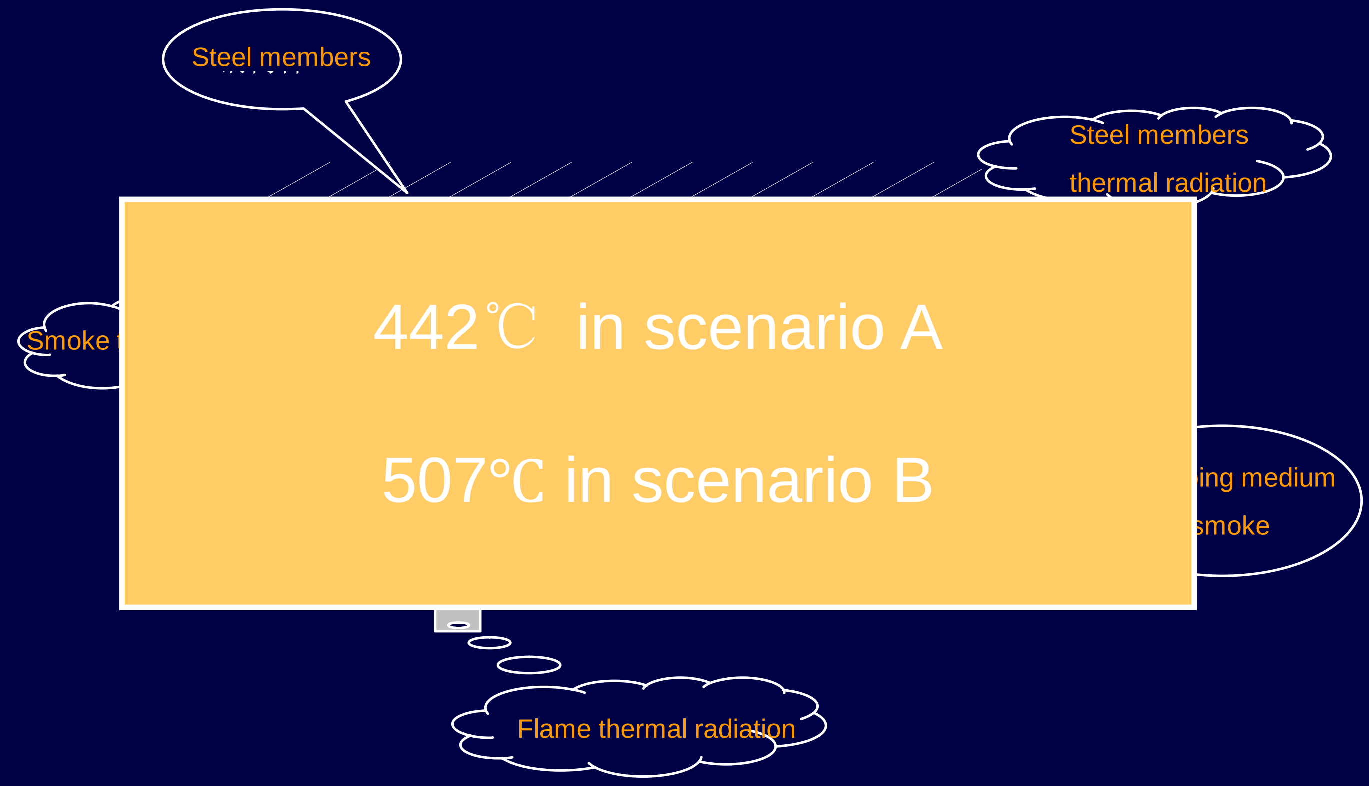


The maximum temperature history in scenario A



The maximum temperature history in scenario B

Temperature in steel members



$$\frac{\Delta T_s}{\Delta t} = \frac{\varepsilon_g \varepsilon_s C_0 F_s \left[(T_g + 273)^4 - (T_s + 273)^4\right] + \varepsilon_f \varepsilon_s \varphi_{sf} \xi F_s (1 - \varepsilon_g) C_0 \left[(T_f + 273)^4 - (T_s + 273)^4\right] + F_s \alpha_c (T_g - T_s)}{V_s \rho_s C_s}$$

Smoke thermal radiation

Flame thermal radiation

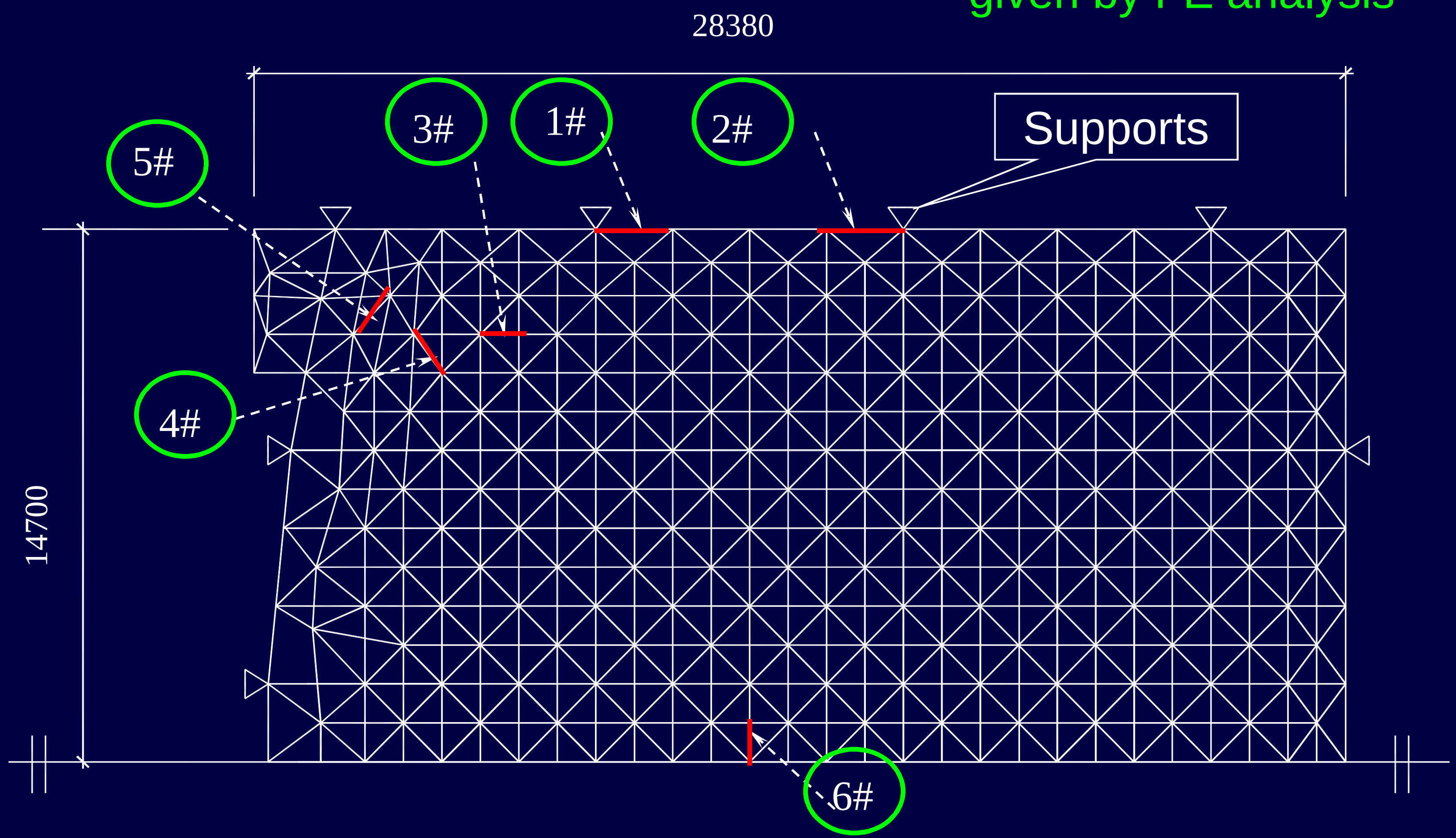
Smoke thermal convection

$$T_s^{j+1} = T_s^j + \Delta T_s$$

Structural fire analysis

- **Global FE model**

There are six key chords given by FE analysis



The space truss global FE model in half size

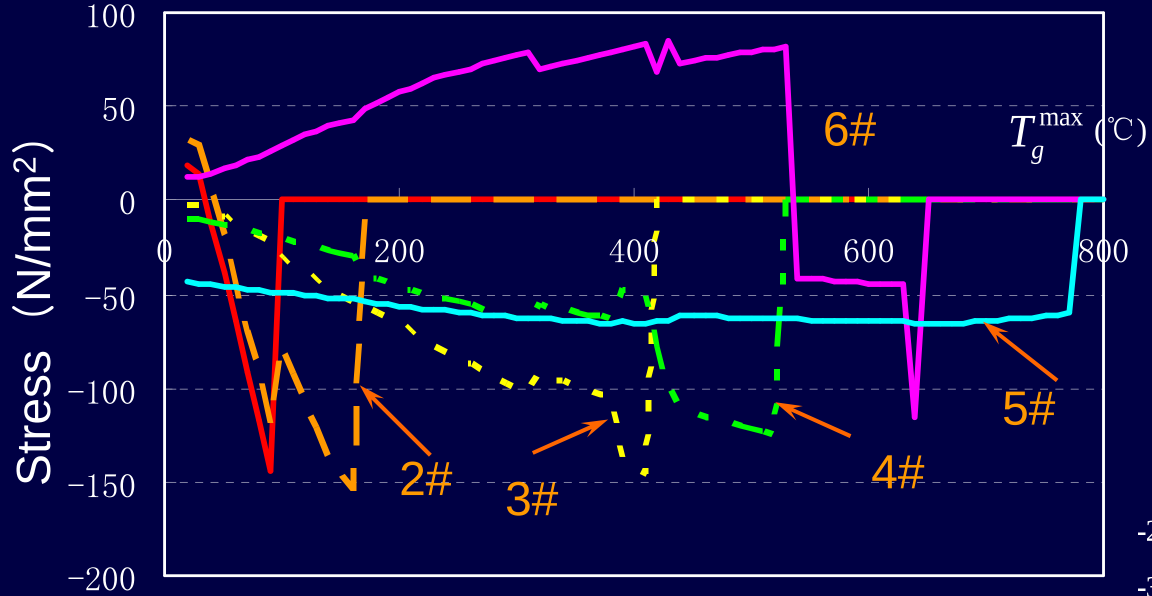
- **Failure criteria**

$$T_d \geq T_m$$

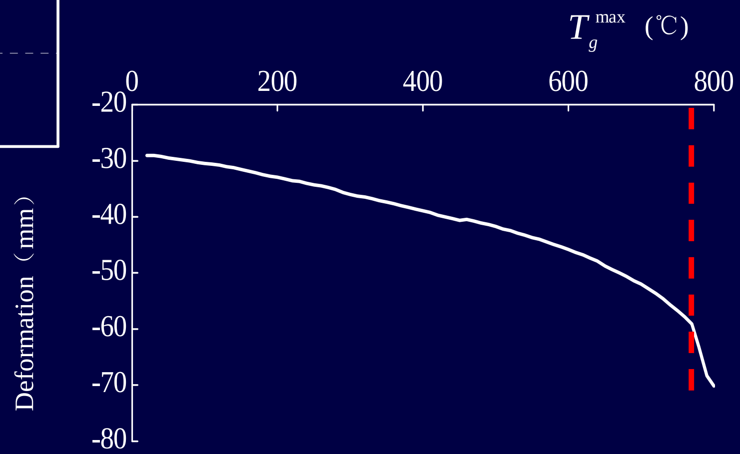
T_m is the maximum temperature of structures (or elements) in the duration exposed to fire scenario

T_d is the critical temperature given by FE analysis, at which structures (or elements) fail under Loading combination rule

- # Mechanical behaviour analysis



Stress history curves for six key chords



Collapse at 770℃

The great displacement history curve

Conclusions

- This paper provides a snapshot of information and analysis to demonstrate the loading-bearing capacity method is sufficient for fire safety design.
- A detailed FEA of the space truss with a credible design fires was carried out to determine the deflections and forces in the space truss.
- The performance- based structural fire safety design showed that the space truss above the auditorium can maintain its structural loading capacity without fire protection while the active fire protection is out of work in design fire scenario.

Thanks for your attention