A NEW DESIGN METHOD FOR INDUSTRIAL PORTAL FRAMES IN FIRE

Y. Song[a], Z. Huang[b], I. W. Burgess[c], R. J. Plank[d]

[a] SAFE Consulting Limited, Croxley House, 14 Lloyd Street, Manchester, M2 5ND, UK Email: yuanyuan.song@safe.eu.com
[b,c] Department of Civil and Structural Engineering, University of Sheffield, UK
[d] School of Architectural Studies, University of Sheffield, UK

INTRODUCTION

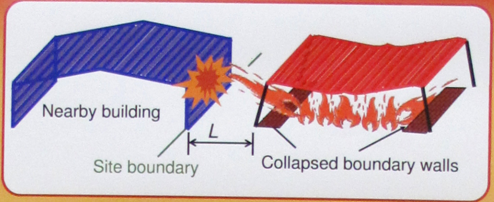
- **Requirement of the UK Building Regulations**

Reasonable Design Solution
"The building shall be so constructed that in, in the event of fire, its stability will be maintained for a reasonable period."

Adequate Space Separation
"The external walls of the building shall offer adequate resistance to the spread of fire over the walls and from one building to another, having regard to the height, use and position of the building."

- **Portal Frames in Fire Boundary Conditions**

"If the building is constructed near the site boundary (L<15m), the external wall of the building will require a degree of fire resistance to stop fire spreading to nearby buildings."



- **Fire Safety Requirement for Steel Portal frames**

Portal frames are a special case in fire because:

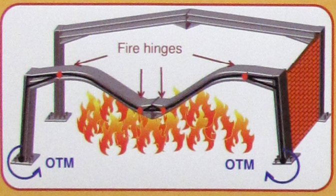
- All elements of structure built into or supporting a boundary wall must have the same fire resistance;
- Rafters and columns are rigidly connected to each other, so the portal frame is considered as one piece structural element in Fire;
- The whole portal frame needs to be protected in fire as an entire element of structure if any part of it needs fire protected.
- The boundary walls are supported by the steel columns.

As a result, the whole portal frame has to be fully fire protected.

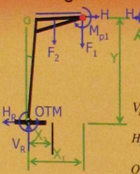
CURRENT DESIGN METHOD

According to a current design guide: ***Fire and Steel Construction: The Behaviour of Steel Portal Frames in Boundary Conditions (2001)***

The frame could be unprotected in fire as the boundary wall, but the column base should provide sufficient resistance to the overturning moment (OTM) caused by the collapse of the roof in fire.



- **Design Model**



$V_R = F_1 + F_2$

$H_R = H = \frac{F_1 R_1 \cos\theta - 2(M_{p1} + M_{p2})}{2R_1 \sin\theta}$

$OTM = HY + F_1X_1 + F_2X_2 + M_{p1}$

$V_R = \frac{1}{2} W_f SL + dead\ weight\ of\ wall$

$H_R = K\left(W_f SGA - \frac{CM_p}{G}\right)$

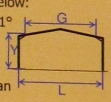
$OTM = K\left[W_f SG\left(A + \frac{B}{Y}\right) - M_p\left(\frac{CY}{G} - 0.065\right)\right]$

W_f = load at time of collapse; S = distance between frames;
Mp = plastic moment resistance of rafters;
K = 1 for single bay frame;
A, C are take from Table 1 & 2 in *SCI P087.*

- **The Simplified Method**

In practical design the calculation model is simplified by the assumptions below:

- The column leans inwards by 1°
- The rafter elongation is 2%
- $M_{p1}=M_{p2}=0.065\ M_p$
- The haunch length = 10% span



- **Problems of the Current Design Method**

- The maximum inclination of the masonry wall is only 0.2° which is much smaller than 1°.
- 2% elongation is relative to the steel property at 1200°C but the strength reduction factor 0.065 corresponds to a temperature around 890°C.
- In practical design, haunches could be any size.

- **Is it conservative for all portal frames?**
- **Do we need a rigid base connection?**

FIRST PHASE MECHANISM

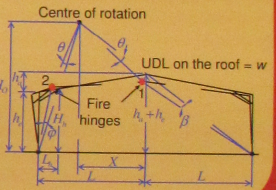
A simple method was developed by S. Y. Wong on the basis of fire tests and numerical studies, to predict the initial collapse of portal frames in fire.

According to the plastic theory for *the combined mechanism*, an equation can be set up equating the work done by the external and internal forces: $wL^2\beta - wL_h^2\varphi = M_p[\eta_1(\theta+\beta) + \eta_2(\varphi+\theta)]$
where η_1 and η_2 are the strength reduction factors for the fire hinges at corners 1 and 2.

If whole roof is heated, $\eta_1 = \eta_2$

$$\eta = \frac{w\left[LX - L_h^2\left(\frac{H_O}{H_h} - 1\right)\right]}{M_p\left(1 + \frac{X}{L} + \frac{H_O}{H_h}\right)}$$

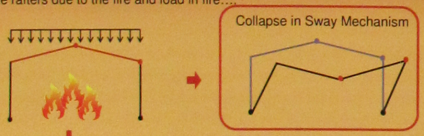
Obtain the limiting temperature from *BS5950 Part 8 Table 1*

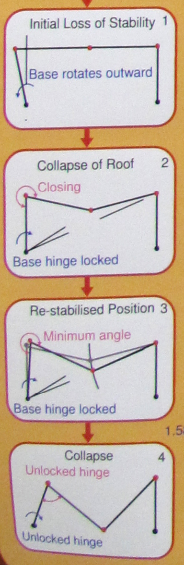


RE-STABILISED POSITION

- **Collapse Mechanisms**

Two or three fire hinges are generated on the rafters due to the fire and load in fire....





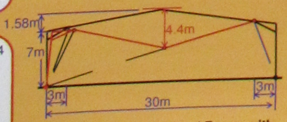
- **Estimation of the Initial Loss of Stability (T1)**

Wong's simple method (mainly based on the initial configuration of the portal frame) can be used to predict the temperature when the frame initially loses stability in fire.

- **The Re-stabilised Position**

If the frame does not fail in the initial sway mechanism, it may re-stabilise when the two plastic hinges near the base and eaves are locked due to the elastic unloading of the hinges as shown in Figure 3.

Re-stabilised Position (Frame without haunches)



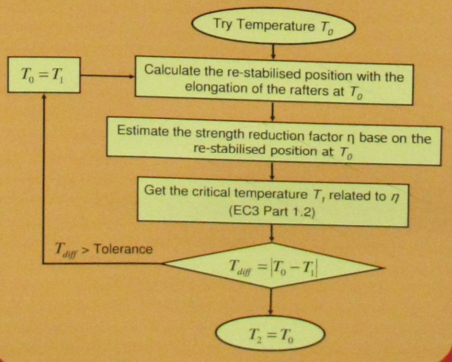
Re-stabilised Position (Frame with haunches)

SECOND PHASE MECHANISM

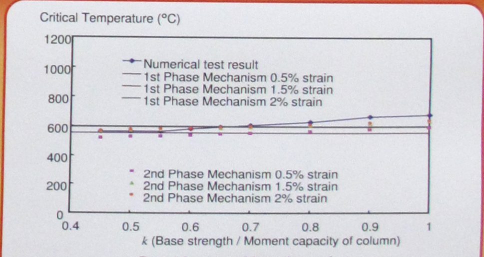
- The plastic moment equilibrium is based on the re-stabilised position
- Estimation of the failure temperature requires:

Strength of the bases
Elongation of rafters
Fire hinge moments on the rafters
— Same Temperature

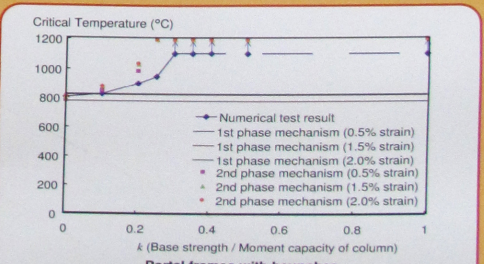
As a result, an iterative procedure illustrated by the following flowchart is required.



VALIDATIONS



Portal frames without haunches



Portal frames with haunches

CONCLUSION

- A new design method based on two most common failure mechanisms of pitched portal frames under fire conditions has been developed to predict the critical temperature of the frame.
- The critical temperatures predicted by the new design method on the basis of the first-phase failure mechanism show very good agreement with the numerical results at which a typical frame initially loses stability in fire.
- Very reasonable predictions about the re-stabilised position and the final collapse temperatures of the frames were achieved using the new method.
- It is evident from this study that the initial collapse of the frame due to the first failure mechanism is often a temporary instability, and that after this the frame can experience a second-phase mechanism with a higher critical temperature, which depends on the base strength and the loading conditions of the frame.