14 FIRE BOUNDARY CONDITION

14.1 Outline

If the building is constructed close to the site boundary, the external wall of the building will require a degree of fire resistance. It is generally accepted that the structural members that support these wall will also require fire resistance to ensure that the walls remain stable for a reasonable period during fire.


The requirement for external walls to have fire resistance has resulted in portal framed building being treated as a special case. The argument put forward by building authorities was that columns and rafters of portal frames are designed as a single continuous element thus; this means that the whole elements of the portal frames requires same level if fire resistance. As a result of providing this fire protection to rafter and columns as well, represented a significant increase in the cost and therefore an alternative solutions where investigated to keep portal frames building economical.

14.3 Alternative approaches to boundary fire (Newman, Technical Report P313)

Following a study (Constrado 1979) of portal frames behavior in actual fire it was concluded that the most viable alternative to fire protecting rafters is to ensure that, even if the roof collapsed, the stability of the external walls would be maintained. Guidance on how to achieve this conclusion was initially published in 1979 by Constrado. The guide was later published by SCI, as a second edition the behavior of steel portal frames in boundary conditions (P087). That publication has been referenced in Approved documents B for a number of years. The designing of boundary walls to resist the forces and moments as recommended in SCI P087, is generally a more economical solution than fire protecting the whole portal frame. This engineering solution is considered to meet the “reasonableness” test of the Building Regulations.
14.4 *Effects of fire on Portal frames*

In the early stages of fire, the portal rafter starts to heat up and expands which results in a small outward deflection of the eaves and small upward deflection of the apex. As fire continues to burn, the rafter temperature continues to raise the deflection and moments due to thermal expansion increase. The bending moments induced by thermal expansion are shown in figure 20.

![Figure 20](image)

**Figure 20- Bending moment diagram for uniform temperature rise (Newman, Technical Report P313)**

The temperature raising causes a reduction in the yield strength of the steel and although the loading is constant, the reduction in moment capacity causes the formation of plastic hinge at a high temperature. Plastic hinges starts to form at in the rafter where the term ‘fire hinge’ is used to distinguish this type of plastic hinge from plastic hinges which can form at normal temperatures. The moment resistance of fire hinge is slightly less corresponding value at normal temperature, so the fire hinges tends to forms at the end of hunches and near to the ridge see figure below.

![Figure 21](image)

**Figure 21- Probable positions of fire hinges in portal frame (Newman, Technical Report P313)**
At this stage, the frame maintains its basic shape where the loading on the frame is its self-weight and purlins but with only proportion of the weight of cladding. The rafter continues to collapse and falls to the eaves level but remains reasonably straight between fire hinges. Torsion stability may occur as the purlins lose their strength. The rafter is acting partially as centenary, creating a tension load, which pulls on the top of the column. The columns are still upright and shows sign of distress.

The rafter continues to collapse as it loses stiffness and the section may rotate so that it sags with the web horizontal. The moment at the end of the hunch still withstand an applicable value. As the rafter further losses strength; it continue to sag to below eaves level and begin to pull inward the tops of columns.

![Figure 22- Rafter collapse to eaves level (Newman, Technical Report P313)](image)

The mathematical model of the rafter collapse mechanism at this stage is given in Appendix. It is the forces and moments at this stage that are used to determine the overturning moment.


A full mathematical model of the collapse mechanism for symmetrical pitched portal frames has been developed and presented in Appendix. The use of the full model is tedious to hand calculations. Thus a more simplified version was recommended in SCI P087 which applies to symmetrical pitched rafter of single or multi-bay. Also the columns on the boundary should be adequately restrained in longitudinal direction. The requirement is for fire protection of columns and requirement to resist the calculated forces and moments on the column bases are applicable only to columns that support protected area of boundary wall. Columns which do not support protected areas will not require fire protection or moment resisting column bases.
So the foundations, columns and column beams base should be designed to resist the following moments and reactions.

- **Vertical Reaction**
  
  \[ V_R = \frac{1}{2} \, w_f \times S \times L + W_D \]

- **Horizontal Reaction**
  
  \[ H_R = K \left( w_f S G A - \frac{C}{G} M_p \right) \text{ but not less than } \frac{M_c}{10Y} \]

- **Overturning moment**:
  
  \[ OTM = K \left( w_f S G Y \left( A + \frac{B}{Y} \right) - M_p \left( \frac{Cy}{G} - 0.065 \right) \right) \text{ but not less than } \frac{M_c}{10} \]

In which

- \( B = \frac{t^2 - G^2}{8G} \)

Where

- \( W_f \) is the load at the time of collapse (KN/m²) given in table 7 in appendix.
- \( W_D \) is the dead load of the wall cladding (KN).
- \( S \) is the distance between frame centers (m).
- \( G \) is the distance between ends of hunches (m).
- \( Y \) is the vertical height of the end of hunch (m).
- \( M_p \) is the plastic moment of resistance of the rafter (KNm).
- \( M_c \) is the plastic moment of resistance of column (KNm).
- \( K = 1 \) for single bay frames or is taken from table 5
- \( L \) is the span (m).
- \( A \) and \( C \) are the frame geometry parameters, given in appendix table 6.