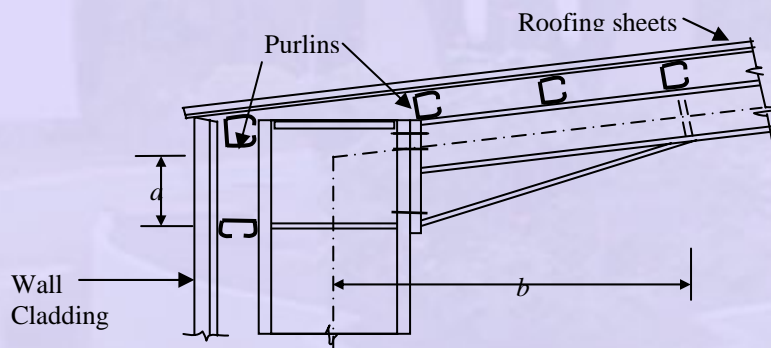


## 2.6 Portal frames

Portal frames are the most commonly used structural forms for single-storey industrial structures. They are constructed mainly using hot-rolled sections, supporting the roofing and side cladding via cold-formed purlins and sheeting rails. They may also be composed of tapered stanchions and rafters fabricated from plate elements. Portal frames of lattice members made of angles or tubes are also common, especially in the case of longer spans.



(a) Elevation



(b) Eaves detail

Fig. 2.24 Haunched gable portal frame

The slopes of rafters in the gable portal frames (Fig.2.24) vary in the range of 1 in 10 to 1 in 3. Generally, the centre-to-centre distance between frames is of the order 6 to 7.5 m, with eaves height ranging from 6 -15 m. Normally, larger spacing of frames is used in the case of taller buildings, from the point of economy. Moment-resisting connections are to be provided at the eaves and crown to resist lateral and gravity loadings. The stanchion bases may behave as either pinned or fixed, depending upon

rotational restraint provided by the foundation and the connection detail between the stanchion and foundations. The foundation restraint depends on the type of foundation and modulus of the sub-grade. Frames with pinned bases are heavier than those having fixity at the bases. However, frames with fixed base may require a more expensive foundation.

For the design of portal frames, plastic methods of analysis are mainly used, which allows the engineer to analyse frames easily and design it economically. The basis of the plastic analysis method is the need to determine the load that can be applied to the frame so that the failure of the frame occurs as a mechanism by the formation of a number of plastic hinges within the frame. The various methods of plastic analysis are discussed later.

The most common form of portal frame used in the construction industry is the pinned-base frame with different rafter and column member size and with haunches at both the eaves and apex connections (Fig.2.24).

Due to transportation requirements, field joints are introduced at suitable positions. As a result, connections are usually located at positions of high moment, i.e. at the interface of the column and rafter members (at the eaves) and also between the rafter members at the apex (ridge) (See Fig.2.24). It is very difficult to develop sufficient moment capacity at these connections by providing 'tension' bolts located solely within the small depth of the rafter section. Therefore the lever arm of the bolt group is usually increased by haunching the rafter members at the joints. This addition increases the section strength.

### 2.6.1 General design procedure

The steps in the plastic design of portals, according to SP: 6(6) – 1972, are given below:

- a) Determine possible loading conditions.
- b) Compute the factored design load combination(s).
- c) Estimate the plastic moment ratios of frame members.
- d) Analyse the frame for each loading condition and calculate the maximum required plastic moment capacity,  $M_p$
- e) Select the section, and
- f) Check the design for other secondary modes of failure (IS: 800-1984).

The design commences with determination of possible loading conditions, in which decisions such as, whether to treat the distributed loads as such or to consider them as equivalent concentrated loads, are to be made. It is often convenient to deal with equivalent concentrated loads in computer aided and plastic analysis methods.

In step (b), the loads determined in (a) are multiplied by the appropriate load factors to assure the needed margin of safety. This load factor is selected in such a way that the real factor of safety for any structure is at least as great as that decided upon by the designer. The load factors to be used for various load combinations are presented in an earlier chapter on Limit states method.

The step (c) is to make an assumption regarding the ratio of the plastic moment capacities of the column and rafter, the frame members. Optimum plastic design methods present a direct way of arriving at these ratios, so as to obtain an optimum value of this ratio. The following simpler procedure may be adopted for arriving at the ratio.

- (i) Determine the absolute plastic moment value for separate loading conditions.

(Assume that all joints are fixed against rotation, but the frame is free to sway). For beams, solve the beam mechanism equation and for columns, solve the panel (sway) mechanism equation. These are done for all loading combinations. The moments thus obtained are the absolute minimum plastic moment values. The actual section moment will be greater than or at least equal to these values.

- (ii) Now select plastic moment ratios using the following guidelines.

- At joints establish equilibrium.
- For beams use the ratio determined in step (i)
- For columns use the corner connection moments  $M_p (Col) = M_p (beam)$

In the step (d) each loading condition is analysed by a plastic analysis method for arriving at the minimum required  $M_p$ . Based on this moment, select the appropriate sections in step (e). The step (f) is to check the design according to secondary design considerations discussed in the following sections (IS: 800-1984).

### 2.6.2 Secondary design considerations

The 'simple plastic theory' neglects the effects of axial force, shear and buckling on the member strength. So checks must be carried out for the following factors.

- a) Reductions in the plastic moment due to the effect of axial force and shear force.
- b) Instability due to local buckling, lateral buckling and column buckling.
- c) Brittle fracture.
- d) Deflection at service loads.

In addition, proper design of connections is needed in order that the plastic moments can be developed at the plastic hinge locations.

## Connections

In a portal frame, points of maximum moments usually occur at connections. Further, at corners the connections must accomplish the direction of forces change. Therefore, the design of connections must assure that they are capable of developing and maintaining the required moment until the frame fails by forming a mechanism.

There are four principal requirements, in design of a connection

- a) *Strength* - The connection should be designed in such a way that the plastic moment ( $M_p$ ) of the members (or the weaker of the two members) will be developed. For straight connections the critical or 'hinge' section is assumed at point  $H$  in Fig. 6 (a). For haunched connections, the critical sections are assumed at  $R_1$  and  $R_2$ , [Fig. 6 (b)].
- b) *Stiffness* - Average unit rotation of the connecting region should not exceed that of an equivalent length of the beam being joined. The equivalent length is the length of the connection or haunch measured along the frame line. Thus in Fig. 6(a).

$$\Delta L = r_1 + r_2$$

This requirement reduces to the following

$$\theta_h \leq \frac{M_p}{EI} \cdot \Delta L \quad (2.33)$$

Where  $\theta_h$  is the joint rotation.

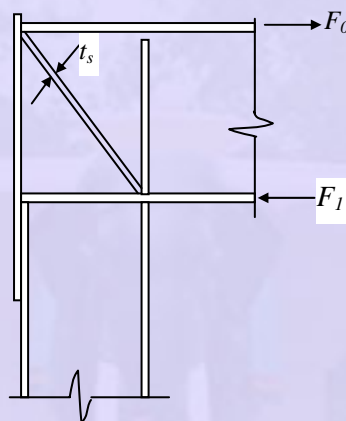
Eq. 12 states that the change in angle between sections  $R_1$  and  $R_2$  as computed shall not be greater than the curvature (rotation per unit of length) times the equivalent length of the knee.

- c) *Rotation Capacity* – The plastic rotation capacity at the connection hinge is adequate to assure that all necessary plastic hinges will form in the structure to enable failure

mechanism and hence all connections should be proportioned to develop adequate rotation at plastic hinges.

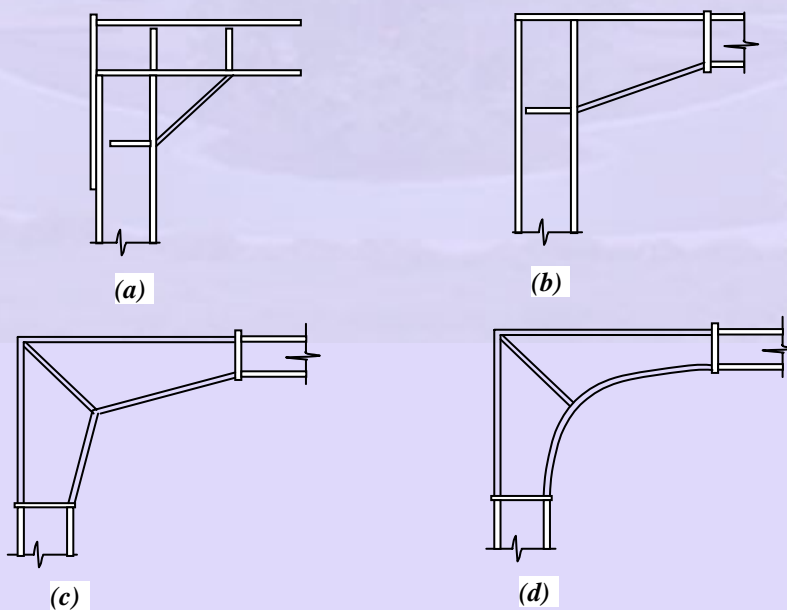
- d) *Economy* - Extra connecting materials and labour required to achieve the connection should be kept to a minimum.

If the knee web is deficient in resisting the shear force, a diagonal stiffener may be used. (Fig. 2.25)



**Fig. 2.25 Stiffened corner joint**

### Haunched connections



**Fig. 2.26 Haunched connection types**

Some of the typical haunched connections are shown in Fig. 2.26. Haunched connections are to be proportioned to develop plastic moment at the junction between the rolled steel section and the haunch. In order to force formation of hinge at the end of a tapered haunch (Fig. 2.26), make the flange thickness in the haunch, to be 50 percent greater than that of section joined. Check the shear resistance of the web to ensure  $M_p$  governs the strength.

