CONNECTIONS

Beams are connected to main beams or to the columns. Design of these connections is more important since failure of connection is more catastrophic than the failure of the beam section.

1. Types of Connections

According to the degree of rotation permitted in the connection, beam-to-beam and beam-to-column connections are classified as:

• Flexi**ble connection**: In this type of connections, no restraint is imposed for rotation. The connection is designed to transfer the end shear only.
• Moment resistant or Rigid connection: In this type of connection, the joint is designed to resist end shear as well as moment. Such supports may be treated as fixed ends, since they do not permit any rotation at the ends.
• Semi-rigid connection: In this type of connection, the rotation of end is partially restrained. The connections are designed to transfer shear and part of fixed end moments.

Flexible connections are further classified as,
(i) Framed connections (Fig. 1 and Fig. 2): When end shear to be transferred is less, it is possible to connect the beam to main beam or to the column using cleat angles.
(ii) Unstiffened seated connection (Fig. 3): When shear force is larger the depth of cleat angle required for framed connection may be more than that can be provided in the available space. In such cases, seat angles are connected to the column over which the beam rests. At top the cleat angles are connected to the column over which the beam rests. At top the cleat angles are provided to prevent the lateral displacement of the beam after positioning it over the seat angle.
(iii) Stiffened seated connection (Fig. 4): If shear force to be transferred in the beam is still large, the seat angle may fail. To strengthen it a stiffener angle may be provided. Such connections are known as stiffened seated connection.

Moment resistant connections may be further classified as,
(i) Clip-angle or split beam connection (Fig. 5): This type of connection can be used at the end, if the moment to be transferred in the end is small.
(ii) Bracket connection (Fig. 6): If the moment to be transferred through the connection is large, such connections are used.

2. Framed Connections

2.1 Bolted Connections

The bolts connecting web of the beam to cleat angles are in double shear. The number of bolts required to transfer end shear should be determined. They may be accommodated in a single or double row depending upon the availability of web depth. The bolts connecting cleat angle to the main beam or columns are under single shear. They are to be designed to resist end shear. The size of cleat angle depends upon the number of rows of bolts provided. Minimum edge distances and spacing decide the size. Thickness of cleat angle should be so selected that the strength of cleat angle per pitch width is more than the strength of the bolt.
2.2 Welded Connections

(i) **Double plated framed connection** (Fig. 11)

50 mm wide two plates of depth ½ to 2/3 of beam, with thickness 1.5 mm more than that of web of the beam are used. To allow rotation at the end of the beam it is necessary to limit the depth of plate to 2/3 of the beam. One plate is shop welded to the beam and other plate is shop welded to column/supporting beam. Beam is kept on erection seat and then field welding is done to complete the connection. Sometimes instead of providing erection seat, erection bolts are provided to temporarily support the beam for field welding. Weld B is kept about 4/5th of web of beam in size. The welds are returned by about 12 mm. The depth ‘h’ of the weld B is kept such that it can resist shear V and moment V x a safely, where, a is the width of connecting plate usually of 50 mm. Weld A of depth d is designed to resist shear V only.

(ii) **Double angle framed connection** (Fig. 12)

- Two angles may be used instead of two plates for connecting beam and the supporting member to get more flexibility in the connection. The angles are connected to the web of the beam by shop welding. The length of the leg of an angle used for this is usually 60 mm. These welds (weld B) are provided on all three sides of the leg of angle. Depth of the angle used is kept ½ to 2/3 the depth of the beam to achieve required flexibility in the connection. The leg of the angle to be connected to supporting member is kept 80 to 90 mm. They are connected to the supporting structure by field welding. To facilitate the fillet welding, erection bolts are provided in the position as low as possible. Thickness of connecting angles should be 4/3 x size of weld used in the beam, so that the required size of the weld is provided along the rounded edge of the angle.

- **Design of shop welds B** (Fig. 13)
  
  Assume 10mm gap between the edge of the beam and face of the column. Since there is one such weld on each face of web of the beam, reaction resisted by each weld is R/2. As end on the face of the column is assumed simple support, the weld is subjected to a torsional moment R/2 x e₂ also, where e₂ is the eccentricity of the c.g. of the weld. These shop welds are designed to resist a vertical shear of R/2 and moment R/2 x e₂.

- **Design of field welds A** (Fig. 14)

  The welds transfer vertical shear force of R/2 at an eccentricity of e₁ from the face of web of the beam. In the compression zone entire contact area of angle resist the force while in tensile zone only weld has to resist the force. Hence, neutral axis is very close to compression edge. This distance may be assumed as h/6, if h is the depth of weld. The horizontal shear in the weld A may be calculates as, q₉ₜ = (9Re₁) / (5th²)  

  The resultant shear stress q = √ (q₉ₜ² + qᵥ²) ≤ the permissible value in field weld. From this condition, thickness of weld and hence size of the weld is found. To provide the required size of weld at the edge of angle, the angle should have thickness 4s/3.
3. Unstiffened Seated Connections

3.1 Bolted Connections (Fig. 7)

The seat angle over which the beam rests is bolted to the column in shop and cleat angles are bolted in the field. Following steps are to be followed in the design.

- End reaction \( F \) is considered uniformly distributed on the outstanding leg of seat angle over a length \( b \). The length \( b \) is such that web crippling of beam does not occur. This length may be calculated as,
  \[
  b = B - \sqrt{3} h_2 \]
  subject to a minimum of \( B/2 \), where \( B = \frac{F}{f_p t_w} \) where,
  \[
  f_p = \text{permissible bearing stress in the member} = 0.75 f_y
  h_2 = \text{depth of root of fillet from extreme fibre of flange} = t_f + r_1
  \]

- Select a trial section for seat angle

- Provide a clearance of 10 mm between the beam and the column. Compute the distance of end reaction from the critical section which is at the end of root of fillet from extreme fibre of flange. Calculate the bending moment \( M \) at the critical section \( xx \).

- Assume the length of seating angle to be equal to the width of the flange of the beam. Compute the moment of resistance of the seating angle, which should be greater than the bending moment.

- The seating angle is connected to the stanchion in the workshop. Compute the number of bolts required.

- Connect a cleat angle at the top by two bolts in either leg. The diameter of bolts should be equal to the diameter of the bolts used to connect the seating angle.

3.2 Welded Connections

When the end reaction to be transferred is low, welded unstiffened seat connection may be used. The beam is placed over a seat angle and welded. To prevent lateral displacement, a cleat angle ISA 100x100x6 mm may be placed and welded with 6 mm welds. The bearing length of beam may be taken same as used for bolted connection. Thus the bearing length \( b = (B - \sqrt{3} h_2) \geq B/2 \), where \( B = \frac{F I_f t_w}{f_p} \), \( f_b = 185 \text{ MPa for E250 steel} \).

A clearance of 10 mm is provided between the end of beam and column. Assuming reaction is distributed uniformly over bearing length \( b \), the position of centroid of reaction is found. The thickness of angle is determined from the required bending strength of angle at the root of the angle. The moment at the weld is found at the critical section of the weld. The resultant shear stress in the weld of size \( t \) due to vertical shear and horizontal shear is found and equated to strength of the weld in shear to get required throat thickness of the weld.

4. Stiffened Seated Connections

4.1 Bolted Connections

If end reaction to be transferred is more, the thickness of seat angle required will be larger than the available thickness or the number of bolts required in the vertical leg may be too many to be accommodated in the available width. Hence, it is not possible to provide unstiffened seated connection. In such situation, the seat angle needs stiffening from below by one or two angles. In this case, the bearing length \( b \) is measured from the end of the
stiffening leg. The stiffening leg should have sufficient bearing area. Its thickness may be kept not less than the web thickness of the supported beam. To avoid local buckling, the ratio of outstanding leg length to its thickness should be less than 16. The bolts in the column should be checked for direct shear and stress arising due to moment.

4.2 Welded Connections (Fig. 15)

The seat used may be a split I beam or two plates forming a T-section. The seat plate thickness is not less than the thickness of flange of beam and the thickness of stiffening plate is not less than the thickness of the web of beam. Seat plate and stiffening plate are welded (Fig. 15(a)). The width of seat plate is kept equal to the width of flange of beam. The same size plate may be used as stiffening plate. Weld looks like a T-section (Fig. 15(b)). The bearing length ‘b’ is calculated as explained for unstiffened connection, but is measured from outer end of seat plate. 10 mm clearance is provided between the end of the beam and the flange of the column. The size of weld is so selected that it can resist combined vertical and horizontal shear. ISA 100 x 100 x 6 mm is used as clip angle at the top. It is welded with 6 mm size weld.

5. Moment Resisting Connections

5.1 Small Moment Resisting Bolted Connections

If the moment to be transferred is small, clip angles may be provided to transfer moment and web angles to transfer shear (Fig. 8). Hence the design consists of:

(a) Design of clip angle connection

• Force at clip angle (1-1), \( p = \frac{M d}{l} \). Bolts should be capable of resisting this force in tension
• Moment in the leg of clip angle (Fig. 8(b))
  \[ M = 0.6 p \left( g - t \right), \] assuming point of contraflexure at 0.6 \( g - t \) from bolt, length of clip angle \( l = \) width of flange of beam connected
  Design moment of angle \( M_d = \frac{l Z_p f_y}{1.1} \), which should be more than \( M \)
  If thickness required is more than available, the thickness is to be built-up with addition of plates or split I-sections may be used. (Fig. 9)
  □ Design of connection between clip angle and beam (2-2)
  The bolts are subjected to shear force of \( V = M / h \)
  Connection is to be designed to resist this shear force.

(b) Design of web angle connections

It is same as design of bolted framed connections. (Fig. 2)

5.2 Large Small Moment Resisting Bolted Connections

If end moment to be transferred from beam to column is large, clip angles are not sufficient enough. In such cases, bracket type moment resisting connections are used (Fig. 10). In this type, a bracket plate, which have thickness equal to that of web of the beam is connected to flange of the beam and to the flange of the column using horizontal and vertical angles. If exact thickness of plate is readily not available, slightly larger plate is taken and machined to the size of web. Design of such connection includes design of the following:
• Vertical angle to resist moment \( M = 0.6p (g - t) \)
• Bolts A-A to resist direct shear and tension
• Bolts B-B to resist vertical shear and horizontal force due to moment
• The bracket plate
• Horizontal angle
• Bolts C-C to resist shear and tension
• Bolts D-D to resist vertical shear and horizontal force due to bending

5.3 Moment Resisting Welded Connections

To transfer moment a tension plate connected top of flange of beam to the supporting structure. Near the support, for the usual vertical downward loads, beam is in tension at the top and is in compression at bottom. The bottom flange of beam is connected to the supporting member by butt weld. The tension plate provided over top flange is connected to the supporting structure by full penetration butt weld. It needs a minimum gap of 4 to 5 mm between the plate and the column. A backing plate may be installed for welding efficiently. The width of tension plate is kept smaller than the flange width of beam so that welding on 3 sides is possible over the beam. The plate is kept sufficiently long so that a length of plate equal to its width is not welded. It helps in preventing failure of the joint before the failure of plate, which gives sufficient warning in the case of failure. A stiffener plate is welded in the supporting member to safeguard against web failure.
Fig. 2  Framed connection if flanges are at the same level.

Fig. 3  Unstiffened seated connection.
Fig. 4: Stiffened scated connection.

(a) Clip angle connection

(b) Split beam connection

Fig. 5: Moment Resisting connections

Fig. 6: Bracket connection.
Fig. 15  Stiffener welded seat connections

Fig. 16  Moment resistant welded connections