BEAM-COLUMN JOINTS

The function of a beam-column joint in a frame is to transfer the loads and moments at the ends of the beams into the columns. This section gives a brief description of various types of joints and the design of non-seismic joints.

1. Type of Joints:
   a. Corner joints

1. Opening joint: It is angular joints exposed to bending moment causing high tensile stress on the internal joint face and compressive stress on the external joint face (see Fig 1).

   ![Fig.1: Opening joint](image)

   - (a) Stresses on joint area;
   - (b) $\rho_x$ and $\rho_y$ stresses;
   - (c) Cracks;
   - (d) Equilibrium of corner;
   - (e) Strut and tie model for joint

Fig. 2(a) compares the measured efficiency of a series of corner joints reported in. The efficiency is identified as the ratio of the failure moment of the joint to the moment capacity of the members entering the joint.
2. **Closing joint:** It is angular joints exposed to bending moment causing high tensile stress on the external joint face and compressive stress on the internal joint face (see Fig. 3).

![Diagram of joint stresses and cracking](image)

*Fig. 3: Closing joints; (a) Stresses in joint ;(b) Cracking in joint*
(b) T-Joints: occur at exterior column-beam connections (as shown in Fig. 4), at the base of retaining walls, or where roof beams are continuous over columns. The forces acting on such a joint can be idealized as shown in Fig. 5 (a). Two different reinforcement patterns for column-to-roof beam joints are shown in Fig. 5 (b) and (c), and their measured efficiencies are shown in Fig. 6.

Fig. 4: Exterior beam-column joint

Fig. 5: T-joints; (a) Strut-and-tie model of joint; (b) Unsatisfactory detail interior column to roof beam joint; (c) Satisfactory detail interior column to roof beam joint; (d) base of retaining wall
(c) Cross joints (Internal joints): it is anoint between column, and beam, column is surrounded with beams form four fronts whereas beam has more 75% than column distance in each direction.

Fig. 7: Cross joints; (a) Forces due to gravity loads; (b) Forces due to lateral loads
2. Design of reinforcement at joints

The ACI committee 352 report on the design of reinforced concrete beam-column joints (Recommendations for Design of Beam-column Joints in Monolithic Reinforced Concrete Structures) divides joints into two groups depending on the deformation of the joints.

a. Type1 joints: Non-seismic joints, which are joints not subjected to large inelastic deformations and need not to be designed according to ACI chapter 21.

b. Type2 joints: Seismic joints, which are joints designed to sustain large inelastic deformations, according to ACI chapter 21.

The ACI Committee 352 design procedure for Type 1 (non-seismic) joints consists of three main stages:

1. Providing confinement to the joint region by means of beams framing into the sides of the joint, or a combination of confinement from the column bars and ties in the joint region.
2. Limiting the shear in the joint.
3. Limiting the bar size in the beams to a size that can be developed in the joint.

In the following sections design of non-seismic joints is dealt with.

I. Shear forces at the joint

Consider the equilibrium of the upper half of the joint as shown in the Fig. 8. The horizontal shear at the mid height of an exterior beam-column joint $V_{u,j}$ is given by:

$$V_{u,j} = T_n - V_{col}.$$  

Where:

$T_n$ = nominal force in the top steel in the joint = $\alpha A_y f_y$ and $\alpha = 1$

$V_{col}$ = column shear, which can be evaluated from frame analysis or from the free body diagram, assuming that points of inflection are situated at mid height of each story.

For an interior beam-column joint, the horizontal shear at the mid height of the joint $V_{u,j}$ is given by the following equation:

$$V_{u,j} = T_{n1} + C_{n2} - V_{col}.$$  

Where:

$C_{n2}$ = compressive force in concrete to the other side of the joint
II. Shear strength at the joint

The nominal shear strength on a horizontal plane at mid height of the joint is given by the following equation:

\[ V_n = 0.083 \sqrt{f'_c b_j h_{col}}. \]  

(ACI-352R Eq.4.7)

The factored shear force on a horizontal plane at mid height of the joint is to satisfy the following equation:

\[ V_{u,j} \leq \Phi V_n \]

Where:

- \( \gamma \) = constant related to the confinement of the joint given by ACI Committee 532
- \( h_{col} \) = column dimension parallel to the shear force direction
- \( b_j \) = effective width of the joint \( b_b + b_{col} \) or \( b_b + h_{col} \)
- \( b_b \) = width of the beam parallel to the applied force
- \( b_c \) = dimension of the column perpendicular to the applied force

If the previous equation is not satisfied, either the size of the column needs to be increased or the shear force transferred to the joint needs to be decreased.
III. Anchorage requirements at the joint

Beam reinforcement terminating in a non-seismic joint should have 90 deg hooks with
\[ l_{dh} = \frac{f_y d_b}{4.2 \sqrt{f'_c}} \]  
(ACI-352R Eq.4.9)

and \( l_{dh} \) is not less than \( 8d_b \) nor less than \( 150\text{mm} \).

the critical section for developing tension in the beam reinforcement is taken at the face of the joint. If the development length for hooked bars \( l_{dh} \) is not satisfied, either the size of the column will need to be increased or the size of reinforcement be decreased.

IV. Transverse reinforcement at the joint

ACI committee recommends that the non-seismic joints be provided with at least two layers of transverse reinforcement (ties) between the top and bottom levels of longitudinal reinforcement in the deepest beam framing into the joint. For gravity load only maximum spacing is kept to \( 300\text{mm} \) and to \( 150\text{mm} \) for non-seismic lateral loads.