Design of Non-seismic Beam-Column Joints According To ACI 352-02

ACI committee 352R-02 "Recommendations for Design of Beam-Column Connections in Monolithic Reinforced Concrete Structures) classifies structural connections into two categories; Type 1 and Type 2—based on the loading conditions for the connection and the anticipated deformations of the connected frame members when resisting lateral loads. 

**Type 1** is a moment-resisting connection designed on the basis of strength in accordance with ACI 318-14, excluding Chapter 18. 

**Type 2** is a connection that has members that are required to dissipate energy through reversals of deformation into the inelastic range. Connections in moment-resisting frames designed according to section 18.8 of ACI 318-14 are of this category.

In the following section, design of Type 1 (non-seismic joint) is to be dealt with.

**Shear Forces at the Joint:**

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

$$V_{u,\text{joint}} = T_n - V_{col.}$$

where:

$T_n = \text{normal force in the top steel in the joint} = \alpha A_f f_y \text{ and } \alpha = 1.0$
$V_{\text{col.}}$ = column shear, which can be evaluated from frame analysis or from the free body diagram assuming the points of inflection at mid-height of each story. For an interior beam-column joint, the horizontal shear at mid-height of the joint $V_{u, \text{joint}}$ is given by

$$V_{u, \text{joint}} = T_{n1} + C_{n2} - V_{\text{col.}}$$

Where:

$T_{n1}$ = normal force in the top steel in the joint = $\alpha A_s f_y$ and $\alpha = 1.0$

$C_{n2}$ = compressive force in concrete to the other side of the joint

Shear Strength of the Joint:

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

$$V_n = 0.265 \gamma \sqrt{f'_c b_j h_c}$$

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

$$V_u = \phi V_n$$

where:

$\gamma$ = constant related to the confinement of the joint

$h_c$ = column dimension parallel to the shear force direction

$b_j$ = effective width of the joint
\[ \frac{b_b + b_c}{2} \leq b_b + h_c \]

- \( b_b \) = width of the beam parallel to the applied force
- \( b_c \) = dimension of the column perpendicular to the applied force
- \( \phi \) = strength reduction factor for shear = 0.75

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.

**Width of Joint, \( b_j \)**
Values of $\gamma$ for Type-I joints,

**Detailing of Joints:**

- ACI 15.4 requires that in a beam-column joint, an area of transverse reinforcement calculated in accordance with 15.4.2 shall be distributed within a column height not less than the deepest beam framing into the column. For beam-column joints, the spacing of the transverse reinforcement $S$ shall not exceed one-half the depth of the shallowest beam.

- ACI Code 15.4.2 requires that the minimum area of shear reinforcement, $A_{v,min}$ shall be at least the greater of (a) and (b):

(a) $A_{v,min} = 0.2 \sqrt{f_c^e} \frac{b_w S}{f_{yt}}$

(b) $A_{v,min} = 3.5 \frac{b_w S}{f_{yt}}$
ACI 15.2.4 states that a beam-column joint shall be considered to be "restrained" if the joint is laterally supported on four sides by beams of approximately equal depth.

Development of longitudinal reinforcement terminating in the joint shall be in accordance with 25.4.

Beam reinforcement terminating in a non-seismic joint should have 90-deg hooks with $l_{dh} = \frac{318 d_b}{\sqrt{f_c'}}$ where $l_{dh}$ is not to be less than $8d_b$ nor less than 15 cm.

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 amount of shear being transferred to the joint will need to be decreased.

**Transverse Reinforcement at the Joint:**

ACI committee 352 recommends that 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 30 cm and to 15 cm for non-seismic lateral loads. This requirement is to be ignored if the joint is considered "restrained" as defined in ACI 15.2.4.
Example (10):
Check the adequacy of the joint shown in the figure, in terms of shear resistance.
Note that story height is 3.0 m, $f'_c = 300 \text{Kg/cm}^2$ and $f_y = 4200 \text{Kg/cm}^2$.

Solution:
Shear force at centreline of joint

$$V_u = T_n - V_{col}.$$ 

Where $T_n = \alpha A_s f_y$ and $\alpha = 1.0$ for non-seismic joints

$$T_n = \frac{1.0(31.41)(4200)}{1000} = 131.922 \text{ tons}$$

From equilibrium of forces, $C_n = T_n$ and

$$0.85(300)(a)(40) = 131.922 \times 1000 \text{ and } a = 12.93 \text{ cm}.$$
d = 80 - 4 - 1 - 2 - 1.25 = 71.75 cm

\[ M_n = A_s f_y (d - a/2) = \frac{(31.41)(4200)}{10^5} \left[ 71.75 - 12.93/2 \right] = 86.125 \text{t.m} \]

\[ V_{\text{col}} \cdot (l_{pc}) = M_n \quad \text{and} \quad V_{\text{col}} = \frac{M_n}{3} = 28.708 \text{tons} \]

\[ V_a = 131.922 - 28.708 = 103.214 \text{tons} \]

\[ b_j = \frac{40 + 40}{2} = 40 \text{cm} \leq (40 + 60) \text{cm} \quad \text{O.K} \]

\[ V_n = 0.265 \gamma \sqrt{f_c' b_j h_c} = \frac{0.265(20)\sqrt{300(40)(60)}}{1000} = 220.32 \text{tons} \]

\( \Phi V_n = 0.75(220.32) = 165.24 \text{tons} \quad > 103.214 \text{tons} \)

i.e., joint is adequate in terms of resisting shear

Two ties, as a minimum, are to be provided at the joint, where

\[ A_{\text{min}} = \frac{3.5 b_w S}{f_y} \]

For \( \phi 10 \text{mm} \) bars (3-legged)

\[ S = \frac{3(0.785)(4200)}{3.5(40)} = 70.65 \text{cm} \]

Provide two sets of \( \phi 10 \text{mm} \) ties (3-legged) spaced at 30 cm \((S_{\text{max}} = 30 \text{ cm})\)
Anchorage of top reinforcement in girder:

\[ l_{dh} = \frac{318 d_p}{\sqrt{f'_c}} = \frac{318 (2)}{\sqrt{300}} = 36.72 \text{cm} \]

Available development length = 60 - 4 - 1 - 2 - 2.5 = 50.50 cm > 36.72 cm O.K
Joints of Special Moment Frames

The overall integrity of a structure is dependent on the behavior of the beam-column joint. Degradation of the joint can result in large lateral deformations which can cause excessive damage or even failure.

Requirements of ACI 18.8 are applicable for joints of special moment frames.

1- Scope:
- This section shall apply to beam-column joints of special moment frames forming part of the seismic-force resisting system.

2- General:
- Forces in longitudinal beam reinforcement at the joint face shall be calculated assuming that the stress in the flexural tensile reinforcement is $1.25 f_y$.
- Beam longitudinal reinforcement terminated in a column shall extend to the far face of the confined column core and shall be developed in tension in accordance with 18.8.5 (to be covered in the next sections) and in compression in accordance with 25.4.9.
- Where longitudinal beam reinforcement extends through a beam-column joint, the column dimension parallel to the beam reinforcement shall be at least 20 times the diameter of the largest longitudinal beam bar for normal-weight concrete, or 26 times the largest longitudinal bar for light-weight concrete.
- Depth $h$ of the joint, as defined in Fig. R18.8.4, shall not be less than one-half of the depth $h$ of any beam framing into the joint and generating joint shear as part of the seismic-force resisting system. Joints having depth less than half the beam depth require a steep diagonal compression strut across the joint, which may be less effective in resisting joint shear.
3- Transverse Reinforcement:

The transverse reinforcement in a beam-column joint is intended to provide adequate confinement of the concrete to ensure its ductile behavior and to allow it to maintain its vertical load-carrying capacity even after spalling of the outer shell.

ACI 18.8.3 requires transverse reinforcement in a joint regardless of the magnitude of the calculated shear force.

- Transverse reinforcement in a joint shall satisfy 18.7.5.2, 18.7.5.3, 18.7.5.4, and 18.7.5.7, except as permitted in 18.8.3.2
- ACI 18.8.3.2 states that where beams frame into all four sides of the joint and where each beam width is at least three-fourths the column width, the amount of reinforcement required by 18.7.5.4 shall be permitted to be reduced by one-half, and the spacing required by 18.7.5.3 shall be permitted to be increased to 15 cm within the overall depth $h$ of the shallowest framing beam.
- Longitudinal beam reinforcement outside the column core shall be confined by transverse reinforcement passing through the column that satisfies spacing requirements of 18.6.4.4, and requirements of 18.6.4.2, and 18.6.4.3, if such confinement is not provided by a beam framing into the joint.
• Where beam negative moment reinforcement is provided by headed deformed bars that terminate in the joint, the column shall extend above the top of the joint a distance at least the depth $h$ of the joint. Alternatively, the beam reinforcement shall be enclosed by additional vertical joint reinforcement providing equivalent confinement to the top face of the joint.

*Fig. 4.2—Vertical transverse reinforcement in connections with discontinuous columns.*
4- **Shear Strength:**

- The nominal shear strength of the joint, $V_n$, is calculated as shown below:
  - For joints confined on all four sides $ 5.3\lambda \sqrt{f'_c} A_j$
  - For joints confined on three faces or on two opposite faces $ 4\lambda \sqrt{f'_c} A_j$
  - For other cases $ 3.2\lambda \sqrt{f'_c} A_j$

- A joint face is considered to be confined by a beam if the beam width is at least $\frac{3}{4}$ of the effective joint width. Extensions of beams at least one overall beam depth $h$ beyond the joint face are considered adequate for confining that joint face. Extensions of beams shall satisfy 18.6.2.1(b), 18.6.3.1, 18.6.4.2, 18.6.4.3, and 18.6.4.4.

- Effective cross-sectional area within a joint, $A_j$, shall be calculated from joint depth times effective joint width. Joint depth shall be the overall depth of the column, $h$. Effective joint width shall be the overall width of the column, except where a beam frames into a wider column, effective joint width shall not exceed the lesser of (a) and (b):
  (a) Beam width plus joint depth
  (b) Twice the smaller perpendicular distance from longitudinal axis of beam to column side.

![Diagram of shear strength calculation](image)
Effective area of joint

Horizontal shear in beam-column connection

5- Development length of bars in tension:

- The development length $l_{dh}$ for a bar with a standard hook shall not be less than the largest of $8d_p$, 15 cm, and the length required by the following equation which is applicable to bar diameters ranging from 10 mm to 36 mm.

$$l_{dh} = \frac{f_y d_p}{17 \lambda \sqrt{f'_c}}$$

The hook shall be located within the confined core of a column, with the hook bent into the joint.

- For bar diameters 10 mm through 36 mm, the development length $l_d$ for a straight bar be at least the greater of (a) and (b):
  (a) 2.5 times the length required by the previous equation if the depth of the concrete cast in one lift beneath the bar does not exceed 30 cm, and
  (b) 3.5 times the length provided by the same equation if the depth of the concrete cast in one lift beneath the bar exceeds 30 cm.
- Straight bars terminated at a joint shall pass through the confined core of a column. Any portion of $l_d$ not within the confined core shall be increased by a factor of 1.6.
Example (11):
Determine the transverse reinforcement and shear strength requirements for the interior beam-column connection shown in Example (9).

Solution:

A- ACI 18.8 "General Requirements"
Based on ACI 18.8.2, forces in longitudinal beam reinforcement at the joint face shall be calculated assuming that the stress in the flexural tensile reinforcement is $1.25f_y$.

- Based on ACI 18.8.2.3, where longitudinal beam reinforcement extends through a beam-column joint, the column dimension parallel to the beam reinforcement shall not be less than 20 times the diameter of the larger longitudinal bar.
  
  \[
  20d_b = 20(2.5) = 50 \text{ cm} < 70 \text{ cm} \quad \text{(O.K)}
  \]

B- ACI 18.8.3 "Transverse Reinforcement":
Based on ACI 18.8.3.1, transverse reinforcement shall be provided within the joint.
In the short direction, $A_{sh} = 5.43 \text{ cm}^2$
In the long direction, \( A_{sh} = 3.24 \text{ cm}^2 \)

C- ACI 18.8.4 "Shear Strength":

\[
V_{\text{col}} = \frac{72.69 + 50.77}{4.6} = 26.84 \text{ tons}
\]

\[
V_{u, \text{joint}} = T_1 + C_2 - V_{\text{col}}.
\]

\[
= 154.61 + 103.06 - 26.84 = 230.83 \text{ tons}
\]

\[
b_j = b_b + 2x = 45 \text{ cm} \leq (45 + 70) \text{ cm}
\]

\[
A_j = b_j h_c = (70)(45) = 3150 \text{ cm}^2
\]

\[
V_n = 4\sqrt{300(3150)/1000} = 218.24 \text{ tons}
\]

\[
\Phi V_n = 0.75(218.24) = 163.68 \text{ tons}
\]

\[V_u > \Phi V_n\] and column dimension in the direction of shear force needs to be increased.

For \( V_u = \Phi V_n \), \( 0.75(4)\sqrt{300(45)(h_{\text{col}})/1000} = 230.83 \text{ tons} \) and \( h_{\text{col}} = 98.72 \)

Increase column cross sectional dimension to 45 cm x 100 cm.
Requirements For Foundations

This section shall apply to foundations resisting earthquake-induced forces or transferring earthquake-induced forces between structure and ground in structures assigned to SDC D, E, or F. The requirements for foundations are given in ACI 18.13, presented below.

- Longitudinal reinforcement of columns and structural walls resisting forces induced by earthquake effects shall extend into the footing, mat, or pile cap, and shall be developed for tension at the interface.

- Columns designed assuming fixed-end conditions at the foundation, and if hooks are required, longitudinal reinforcement resisting flexure shall have 90-degree hooks near the bottom of the foundation with the free end of the bars oriented toward the center of the column.

- Columns or boundary elements of special structural walls that have an edge within one-half the footing depth from the edge of the footing shall have transverse reinforcement in accordance with 18.7.5.2 through 18.7.5.4 provided below the top of the footing. This reinforcement shall extend into the footing, mat, or pile cap a length equal to the development length calculated for \( f_y \) in tension, of the column or boundary element longitudinal reinforcement.

- Where earthquake effects create uplift forces in boundary elements of special structural walls or columns, flexural reinforcement shall be provided in the top of the footing, mat, or pile cap to resist actions resulting from the factored load combination, and shall be at least that required by 7.6.1 or 9.6.1.

- Grade beams designed to act as horizontal ties between pile caps or footings shall have continuous longitudinal reinforcement that shall be developed within or beyond the supported column or anchored within the pile cap or footing at all discontinuities.

- Grade beams designed to act as horizontal ties between pile caps or footings shall be sized such that the smallest cross-sectional dimension shall be at least equal to the clear spacing between connected columns divided by 20, but need not exceed 45 cm. Closed ties shall be provided at a spacing not to exceed the lesser of one-half the smallest orthogonal cross-sectional dimension and 30 cm.

- Grade beams and beams that are part of a mat foundation subjected to flexure from columns that are part of the seismic-force-resisting system shall be in accordance with 18.6 (beams of special moment frames).
- Piles, piers, or caissons resisting tension loads shall have continuous longitudinal reinforcement over the length resisting design tension forces. The longitudinal reinforcement shall be detailed to transfer tension forces within the pile cap to supported structural members.