2. Steel Anchors in Composite Beams

The length of steel headed stud anchors shall not be less than four stud diameters from the base of the steel headed stud anchor to the top of the stud head after installation.

2a. Strength of Steel Headed Stud Anchors

The nominal shear strength of one steel headed stud anchor embedded in a solid concrete slab or in a composite slab with decking shall be determined as follows:

$$Q_n = 0.5 A_{sa} \sqrt{f_c' E_c} \le R_g R_p A_{sa} F_u \tag{I8-1}$$

where

A_{sa} = cross-sectional area of steel headed stud anchor, in.^{2} (mm^2)

E_c = modulus of elasticity of concrete

= $w_c^{1.5}\sqrt{f_c'}$, ksi $\left(0.043 w_c^{1.5}\sqrt{f_c'}, \text{ MPa}\right)$

F_u = specified minimum tensile strength of a steel headed stud anchor, ksi (MPa)

R_g = 1.0 for:

(a) One steel headed stud anchor welded in a steel deck rib with the deck oriented perpendicular to the steel shape

(b) Any number of steel headed stud anchors welded in a row directly to the steel shape

(c) Any number of steel headed stud anchors welded in a row through steel deck with the deck oriented parallel to the steel shape and the ratio of the average rib width to rib depth ≥ 1.5

= 0.85 for:

(a) Two steel headed stud anchors welded in a steel deck rib with the deck oriented perpendicular to the steel shape

(b) One steel headed stud anchor welded through steel deck with the deck oriented parallel to the steel shape and the ratio of the average rib width to rib depth < 1.5

= 0.7 for three or more steel headed stud anchors welded in a steel deck rib with the deck oriented perpendicular to the steel shape

R_p = 0.75 for:

(a) Steel headed stud anchors welded directly to the steel shape

(b) Steel headed stud anchors welded in a composite slab with the deck oriented perpendicular to the beam and $e_{mid\text{-}ht} \ge 2$ in. (50 mm)

(c) Steel headed stud anchors welded through steel deck, or steel sheet used as girder filler material, and embedded in a composite slab with the deck oriented parallel to the beam

= 0.6 for steel headed stud anchors welded in a composite slab with deck oriented perpendicular to the beam and $e_{mid\text{-}ht} < 2$ in. (50 mm)

$e_{mid\text{-}ht}$ = distance from the edge of steel headed stud anchor shank to the steel deck web, measured at mid-height of the deck rib, and in the load bearing direction of the steel headed stud anchor (in other words, in the direction of maximum moment for a simply supported beam), in. (mm)

User Note: The table below presents values for R_g and R_p for several cases. Available strengths for steel headed stud anchors can be found in the AISC *Steel Construction Manual*.

Condition	R_g	R_p
No decking	1.0	0.75
Decking oriented parallel to the steel shape		
$\dfrac{w_r}{h_r} \geq 1.5$	1.0	0.75
$\dfrac{w_r}{h_r} < 1.5$	0.85[a]	0.75
Decking oriented perpendicular to the steel shape Number of steel headed stud anchors occupying the same decking rib:		
1	1.0	0.6[b]
2	0.85	0.6[b]
3 or more	0.7	0.6[b]

h_r = nominal rib height, in. (mm)
w_r = average width of concrete rib or haunch (as defined in Section I3.2c), in. (mm)
[a] For a single steel headed stud anchor
[b] This value may be increased to 0.75 when $e_{mid\text{-}ht} \geq 2$ in. (50 mm).

2b. Strength of Steel Channel Anchors

The nominal shear strength of one hot-rolled channel anchor embedded in a solid concrete slab shall be determined as:

$$Q_n = 0.3(t_f + 0.5t_w)l_a\sqrt{f_c'E_c} \tag{I8-2}$$

where

l_a = length of channel anchor, in. (mm)
t_f = thickness of flange of channel anchor, in. (mm)
t_w = thickness of channel anchor web, in. (mm)

The strength of the channel anchor shall be developed by welding the channel to the beam flange for a force equal to Q_n, considering eccentricity on the anchor.

2c. Required Number of Steel Anchors

The number of anchors required between the section of maximum bending moment, positive or negative, and the adjacent section of zero moment shall be equal to the horizontal shear as determined in Sections I3.2d.1 and I3.2d.2 divided by the nominal shear strength of one steel anchor as determined from Section I8.2a or Section I8.2b. The number of steel anchors required between any concentrated load and the nearest point of zero moment shall be sufficient to develop the maximum moment required at the concentrated load point.

2d. Detailing Requirements

Steel anchors in composite beams shall meet the following requirements:

(a) Steel anchors required on each side of the point of maximum bending moment, positive or negative, shall be distributed uniformly between that point and the adjacent points of zero moment, unless specified otherwise on the contract documents.

(b) Steel anchors shall have at least 1 in. (25 mm) of lateral concrete cover in the direction perpendicular to the shear force, except for anchors installed in the ribs of formed steel decks.

(c) The minimum distance from the center of a steel anchor to a free edge in the direction of the shear force shall be 8 in. (200 mm) if normal weight concrete is used and 10 in. (250 mm) if lightweight concrete is used. The provisions of ACI 318 Chapter 17 are permitted to be used in lieu of these values.

(d) Minimum center-to-center spacing of steel headed stud anchors shall be four diameters in any direction. For composite beams that do not contain anchors located within formed steel deck oriented perpendicular to the beam span, an additional minimum spacing limit of six diameters along the longitudinal axis of the beam shall apply.

(e) The maximum center-to-center spacing of steel anchors shall not exceed eight times the total slab thickness or 36 in. (900 mm).

3. Steel Anchors in Composite Components

This section shall apply to the design of cast-in-place steel headed stud anchors and steel channel anchors in composite components.

The provisions of the applicable building code or ACI 318 Chapter 17 are permitted to be used in lieu of the provisions in this section.

User Note: The steel headed stud anchor strength provisions in this section are applicable to anchors located primarily in the load transfer (connection) region of composite columns and beam-columns, concrete-encased and filled composite beams, composite coupling beams, and composite walls, where the steel and concrete are working compositely within a member. They are not intended for hybrid construction where the steel and concrete are not working compositely, such as with embed plates.

Section I8.2 specifies the strength of steel anchors embedded in a solid concrete slab or in a concrete slab with formed steel deck in a composite beam.

Limit states for the steel shank of the anchor and for concrete breakout in shear are covered directly in this Section. Additionally, the spacing and dimensional limitations provided in these provisions preclude the limit states of concrete pry-out for anchors loaded in shear and concrete breakout for anchors loaded in tension as defined by ACI 318 Chapter 17.

For normal weight concrete: Steel headed stud anchors subjected to shear only shall not be less than five stud diameters in length from the base of the steel headed stud to the top of the stud head after installation. Steel headed stud anchors subjected to tension or interaction of shear and tension shall not be less than eight stud diameters in length from the base of the stud to the top of the stud head after installation.

For lightweight concrete: Steel headed stud anchors subjected to shear only shall not be less than seven stud diameters in length from the base of the steel headed stud to the top of the stud head after installation. Steel headed stud anchors subjected to tension shall not be less than ten stud diameters in length from the base of the stud to the top of the stud head after installation. The nominal strength of steel headed stud anchors subjected to interaction of shear and tension for lightweight concrete shall be determined as stipulated by the applicable building code or ACI 318 Chapter 17.

Steel headed stud anchors subjected to tension or interaction of shear and tension shall have a diameter of the head greater than or equal to 1.6 times the diameter of the shank.

User Note: The following table presents values of minimum steel headed stud anchor h/d ratios for each condition covered in this Specification.

Loading Condition	Normal Weight Concrete	Lightweight Concrete
Shear	$h/d_{sa} \geq 5$	$h/d_{sa} \geq 7$
Tension	$h/d_{sa} \geq 8$	$h/d_{sa} \geq 10$
Shear and Tension	$h/d_{sa} \geq 8$	N/A[a]

h/d_{sa} = ratio of steel headed stud anchor shank length to the top of the stud head, to shank diameter.

[a] Refer to ACI 318 Chapter 17 for the calculation of interaction effects of anchors embedded in lightweight concrete.

3a. Shear Strength of Steel Headed Stud Anchors in Composite Components

Where concrete breakout strength in shear is not an applicable limit state, the design shear strength, $\phi_v Q_{nv}$, and allowable shear strength, Q_{nv}/Ω_v, of one steel headed stud anchor shall be determined as:

$$Q_{nv} = F_u A_{sa} \tag{I8-3}$$

$$\phi_v = 0.65 \text{ (LRFD)} \qquad \Omega_v = 2.31 \text{ (ASD)}$$

where

A_{sa} = cross-sectional area of a steel headed stud anchor, in.^{2} (mm^2)

F_u = specified minimum tensile strength of a steel headed stud anchor, ksi (MPa)

Q_{nv} = nominal shear strength of a steel headed stud anchor, kips (N)

Where concrete breakout strength in shear is an applicable limit state, the available shear strength of one steel headed stud anchor shall be determined by one of the following:

(a) Where anchor reinforcement is developed in accordance with ACI 318 on both sides of the concrete breakout surface for the steel headed stud anchor, the minimum of the steel nominal shear strength from Equation I8-3 and the nominal strength of the anchor reinforcement shall be used for the nominal shear strength, Q_{nv}, of the steel headed stud anchor.

(b) As stipulated by the applicable building code or ACI 318 Chapter 17.

User Note: If concrete breakout strength in shear is an applicable limit state (for example, where the breakout prism is not restrained by an adjacent steel plate, flange or web), appropriate anchor reinforcement is required for the provisions of this Section to be used. Alternatively, the provisions of the applicable building code or ACI 318 Chapter 17 may be used.

3b. Tensile Strength of Steel Headed Stud Anchors in Composite Components

Where the distance from the center of an anchor to a free edge of concrete in the direction perpendicular to the height of the steel headed stud anchor is greater than or equal to 1.5 times the height of the steel headed stud anchor measured to the top of the stud head, and where the center-to-center spacing of steel headed stud anchors is greater than or equal to three times the height of the steel headed stud anchor measured to the top of the stud head, the available tensile strength of one steel headed stud anchor shall be determined as:

$$Q_{nt} = F_u A_{sa} \tag{I8-4}$$

$$\phi_t = 0.75 \text{ (LRFD)} \qquad \Omega_t = 2.00 \text{ (ASD)}$$

where

Q_{nt} = nominal tensile strength of steel headed stud anchor, kips (N)

Where the distance from the center of an anchor to a free edge of concrete in the direction perpendicular to the height of the steel headed stud anchor is less than 1.5 times the height of the steel headed stud anchor measured to the top of the stud head, or where the center-to-center spacing of steel headed stud anchors is less than three times the height of the steel headed stud anchor measured to the top of the stud head, the nominal tensile strength of one steel headed stud anchor shall be determined by one of the following:

(a) Where anchor reinforcement is developed in accordance with ACI 318 on both sides of the concrete breakout surface for the steel headed stud anchor, the minimum of the steel nominal tensile strength from Equation I8-4 and the nominal strength of the anchor reinforcement shall be used for the nominal tensile strength, Q_{nt}, of the steel headed stud anchor.

(b) As stipulated by the applicable building code or ACI 318 Chapter 17.

User Note: Supplemental confining reinforcement is recommended around the anchors for steel headed stud anchors subjected to tension or interaction of shear and tension to avoid edge effects or effects from closely spaced anchors. See the Commentary and ACI 318 for guidelines.

3c. Strength of Steel Headed Stud Anchors for Interaction of Shear and Tension in Composite Components

Where concrete breakout strength in shear is not a governing limit state, and where the distance from the center of an anchor to a free edge of concrete in the direction perpendicular to the height of the steel headed stud anchor is greater than or equal to 1.5 times the height of the steel headed stud anchor measured to the top of the stud head, and where the center-to-center spacing of steel headed stud anchors is greater than or equal to three times the height of the steel headed stud anchor measured to the top of the stud head, the nominal strength for interaction of shear and tension of one steel headed stud anchor shall be determined as:

$$\left(\frac{Q_{rt}}{Q_{ct}}\right)^{5/3} + \left(\frac{Q_{rv}}{Q_{cv}}\right)^{5/3} \leq 1.0 \qquad \text{(I8-5)}$$

where

Q_{ct} = available tensile strength, kips (N)

Q_{rt} = required tensile strength, kips (N)

Q_{cv} = available shear strength, kips (N)

Q_{rv} = required shear strength, kips (N)

For design in accordance with Section B3.3 (LRFD):

Q_{rt} = required tensile strength using LRFD load combinations, kips (N)
Q_{ct} = $\phi_t Q_{nt}$ = design tensile strength, determined in accordance with Section I8.3b, kips (N)
Q_{rv} = required shear strength using LRFD load combinations, kips (N)
Q_{cv} = $\phi_v Q_{nv}$ = design shear strength, determined in accordance with Section I8.3a, kips (N)
ϕ_t = resistance factor for tension = 0.75
ϕ_v = resistance factor for shear = 0.65

For design in accordance with Section B3.4 (ASD):

Q_{rt} = required tensile strength using ASD load combinations, kips (N)
Q_{ct} = Q_{nt}/Ω_t = allowable tensile strength, determined in accordance with Section I8.3b, kips (N)
Q_{rv} = required shear strength using ASD load combinations, kips (N)
Q_{cv} = Q_{nv}/Ω_v = allowable shear strength, determined in accordance with Section I8.3a, kips (N)
Ω_t = safety factor for tension = 2.00
Ω_v = safety factor for shear = 2.31

Where concrete breakout strength in shear is a governing limit state, or where the distance from the center of an anchor to a free edge of concrete in the direction perpendicular to the height of the steel headed stud anchor is less than 1.5 times the height of the steel headed stud anchor measured to the top of the stud head, or where the center-to-center spacing of steel headed stud anchors is less than three times the height of the steel headed stud anchor measured to the top of the stud head, the nominal strength for interaction of shear and tension of one steel headed stud anchor shall be determined by one of the following:

(a) Where anchor reinforcement is developed in accordance with ACI 318 on both sides of the concrete breakout surface for the steel headed stud anchor, the minimum of the steel nominal shear strength from Equation I8-3 and the nominal strength of the anchor reinforcement shall be used for the nominal shear strength, Q_{nv}, of the steel headed stud anchor, and the minimum of the steel nominal tensile strength from Equation I8-4 and the nominal strength of the anchor reinforcement shall be used for the nominal tensile strength, Q_{nt}, of the steel headed stud anchor for use in Equation I8-5.

(b) As stipulated by the applicable building code or ACI 318 Chapter 17.

3d. Shear Strength of Steel Channel Anchors in Composite Components

The available shear strength of steel channel anchors shall be based on the provisions of Section I8.2b with the following resistance factor and safety factor:

$$\phi_t = 0.75 \text{ (LRFD)} \qquad \Omega_t = 2.00 \text{ (ASD)}$$

3e. Detailing Requirements in Composite Components

Steel anchors in composite components shall meet the following requirements:

(a) Minimum concrete cover to steel anchors shall be in accordance with ACI 318 provisions for concrete protection of headed shear stud reinforcement.

(b) Minimum center-to-center spacing of steel headed stud anchors shall be four diameters in any direction.

(c) The maximum center-to-center spacing of steel headed stud anchors shall not exceed 32 times the shank diameter.

(d) The maximum center-to-center spacing of steel channel anchors shall be 24 in. (600 mm).

User Note: Detailing requirements provided in this section are absolute limits. See Sections I8.3a, I8.3b and I8.3c for additional limitations required to preclude edge and group effect considerations.

CHAPTER J

DESIGN OF CONNECTIONS

This chapter addresses connecting elements, connectors and the affected elements of connected members not subject to fatigue loads.

The chapter is organized as follows:

J1. General Provisions
J2. Welds
J3. Bolts and Threaded Parts
J4. Affected Elements of Members and Connecting Elements
J5. Fillers
J6. Splices
J7. Bearing Strength
J8. Column Bases and Bearing on Concrete
J9. Anchor Rods and Embedments
J10. Flanges and Webs with Concentrated Forces

User Note: For cases not included in this chapter, the following sections apply:
- Chapter K Additional Requirements for HSS and Box-Section Connections
- Appendix 3 Fatigue

J1. GENERAL PROVISIONS

1. Design Basis

The design strength, ϕR_n, and the allowable strength, R_n/Ω, of connections shall be determined in accordance with the provisions of this chapter and the provisions of Chapter B.

The required strength of the connections shall be determined by structural analysis for the specified design loads, consistent with the type of construction specified, or shall be a proportion of the required strength of the connected members when so specified herein.

Where the gravity axes of intersecting axially loaded members do not intersect at one point, the effects of eccentricity shall be considered.

2. Simple Connections

Simple connections of beams, girders and trusses shall be designed as flexible and are permitted to be proportioned for the reaction shears only, except as otherwise indicated in the design documents. Flexible beam connections shall accommodate end rotations of simple beams. Some inelastic but self-limiting deformation in the connection is permitted to accommodate the end rotation of a simple beam.

3. Moment Connections

End connections of restrained beams, girders and trusses shall be designed for the combined effect of forces resulting from moment and shear induced by the rigidity of the connections. Response criteria for moment connections are provided in Section B3.4b.

User Note: See Chapter C and Appendix 7 for analysis requirements to establish the required strength for the design of connections.

4. Compression Members with Bearing Joints

Compression members relying on bearing for load transfer shall meet the following requirements:

(a) For columns bearing on bearing plates or finished to bear at splices, there shall be sufficient connectors to hold all parts in place.

(b) For compression members other than columns finished to bear, the splice material and its connectors shall be arranged to hold all parts in line and their required strength shall be the lesser of:

  (1) An axial tensile force equal to 50% of the required compressive strength of the member; or

  (2) The moment and shear resulting from a transverse load equal to 2% of the required compressive strength of the member. The transverse load shall be applied at the location of the splice exclusive of other loads that act on the member. The member shall be taken as pinned for the determination of the shears and moments at the splice.

User Note: All compression joints should also be proportioned to resist any tension developed by the load combinations stipulated in Section B2.

5. Splices in Heavy Sections

When tensile forces due to applied tension or flexure are to be transmitted through splices in heavy sections, as defined in Sections A3.1c and A3.1d, by complete-joint-penetration (CJP) groove welds, the following provisions apply: (a) material notch-toughness requirements as given in Sections A3.1c and A3.1d; (b) weld access hole details as given in Section J1.6; (c) filler metal requirements as given in Section J2.6; and (d) thermal cut surface preparation and inspection requirements as given in Section M2.2. The foregoing provision is not applicable to splices of elements of built-up shapes that are welded prior to assembling the shape.

User Note: CJP groove welded splices of heavy sections can exhibit detrimental effects of weld shrinkage. Members that are sized for compression that are also subject to tensile forces may be less susceptible to damage from shrinkage if they are spliced using partial-joint-penetration (PJP) groove welds on the flanges and fillet-welded web plates, or using bolts for some or all of the splice.