DESIGN METHODOLOGY FOR HOLE REINFORCEMENT OF COLD-FORMED STEEL BENDING MEMBERS

Summary: The “North American Specification for the Design of Cold-Formed Steel Structural Members” (AISI S100) does not provide guidelines for the reinforcement of holes in cold-formed steel members. This Technical Note provides a methodology for engineering a reinforcement solution.

Disclaimer: Designs cited herein are not intended to preclude the use of other materials, assemblies, structures or designs when these other designs and materials demonstrate equivalent performance for the intended use; CFSEI documents are not intended to exclude the use and implementation of any other design or construction technique.

INTRODUCTION

Cold-formed steel members are sometimes damaged inadvertently and unknowingly during the construction process. An all too common damage is the cutting of holes in either the flange or web elements of the cross section. In situations where the cross section of the cold-formed steel beam has been damaged by the cutting of holes, the member must either be replaced or reinforced to achieve the required bending or shear strength. The following discussion presents a methodology for engineering a reinforcement solution for either the flange element or the web element of a stud or joist.

FLANGE ELEMENTS

Design a flange element reinforcement to transfer the equivalent couple force, \( C = T = M/d \) where \( C \) and \( T \) are the compression and tension forces of the couple, \( M \) is the required bending strength of the cross section and \( d \) is the depth of the cold-formed steel beam. An adequate number of self-drilling screws is to be provided to transfer the \( C \) and \( T \) forces from the beam flange into the reinforcement piece and then back into the flange. This design concept relies on the concept of either a single or double shear connection as employed in hot-rolled steel splice plate design.

WEB ELEMENTS

Web elements with holes may fail by either bending or shear as illustrated by Figure 1. The following design methodology is adapted from the AISC design guide “Steel and Composite Beams with Web Openings” (Darwin, 2003).

Bending. The AISC design guide is based on achieving the plastic moment capacity in the cross section. However, cold-formed steel members typically are unable to achieve the plastic moment. Thus, the methodology proposed herein is based on elastic behavior.

Figure 2 illustrates the definition of the hole, \( h_b \) by \( a_c \) and the eccentricity of the hole, \( e \) (always taken as positive). The length of extension of the reinforcement beyond the edge of the hole, \( l_1 \), is defined as larger of \( a_c/4 \) or \( A_r/\sqrt{2}\pi \) where \( A_r \) is the cross-section area of the web reinforcement.
Above or below the hole and \( t_w \) is the web thickness. The web reinforcement (e.g., angle or U section) should be placed as close to the edge of the hole as possible. Screw attach the top and bottom reinforcement pieces by self-drilling screws spaced not greater than three inches on center. In lieu of screws, welds may be used.

Figure 3 summarizes the design methodology.

To determine the design flexural strength, Section A1.2 of the AISI Specification should be used to define the \( \Omega \) or \( \Phi \) value.

Screw attach the top and bottom reinforcement pieces by self-drilling screws spaced not greater than three inches on center. In lieu of screws, welds may be used.

**Option No. 1:** Provide \( A_r \) in accordance with the above moment methodology. Compute the shear strength using Section C3.2 of the AISI Specification with the “h” equal to the flat portion of the web area above the web opening.

To determine the shear strength Section A1.2 of the Specification should be used to define the \( \Omega \) or \( \Phi \) value.

**Option No. 2:** Screw or weld attach a track section horizontally to the web and design the track section and the screw connections to transfer the required shear strength of the member at the cross section in question. The concept is to use a shallower, thicker track section to develop the shear strength of the deeper, thinner web element being reinforced. The size and number of self-drilling screws is to be determined by using Section E4 of the AISI Specification.

Calculate the moment capacity assuming elastic behavior of the flexural member.

1. \( A_r \) = gross area of reinforcement. Typically the reinforcement is assumed to be a “U” section.
2. As a simplification \( D_1 \) and \( D_2 \) are measured from the neutral axis of the full section. Thus, the measurement is from mid-height of the C-section.
3. As a simplification \( F_1 \) and \( F_2 \) are based on similar triangles assuming the neutral axis is for the full section. Thus, the measurement is from mid-height of the C-section.

The nominal moment strength of the section is based on the nominal moment strength of the C-section with the hole, \( M_{n0} \), alone plus the moment strength contribution from the reinforcement. \[
M_n = (M_{n0} + A_rD_1 + A_rD_2) \leq M_{nwo}
\]

Where,

\( M_{n0} \) = nominal yield moment reduced for the web opening per Section B2.4 the applicable limits are to be ignored.

\( M_{nwo} \) = nominal yield moment for the C-section without a web hole.

**FIGURE 2: HOLE CONFIGURATIONS (a) UNREINFORCED HOLE (b) REINFORCED HOLE (DARWIN, 2003)**

Shear. Typically cold-formed beams are over-designed for shear. Therefore, developing the full nominal design strength of the web element is typically not necessary. Thus, the following two design options are proposed:

- **Option No. 1:** Provide \( A_r \) in accordance with the above moment methodology. Compute the shear strength using Section C3.2 of the AISI Specification with the “h” equal to the flat portion of the web area above the web opening.

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- **Option No. 2:** Screw or weld attach a track section horizontally to the web and design the track section and the screw connections to transfer the required shear strength of the member at the cross section in question. The concept is to use a shallower, thicker track section to develop the shear strength of the deeper, thinner web element being reinforced. The size and number of self-drilling screws is to be determined by using Section E4 of the AISI Specification.

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**FIGURE 3: MOMENT DESIGN METHODOLOGY**
Example Problem

Given:

1400S162-68
Based on the nomenclature, the member depth is 14”, the flange width is 1-5/8”, and the 68 mil thickness indicates its design thickness = 0.0713”, and its inside bend radius = 0.1070”. For this problem, the yield strength of this member \( F_y \), is 50 ksi.

A hole has been cut into the web for a plumbing pipe, and this member is being used as a floor joist. Assume that the member without the hole is adequate for its intended use, and has appropriate bracing and stiffeners. There is no concentrated load or support within 1.5 h of the hole. The cut hole is of irregular yet smooth shape: no corner of the hole has a radius of less than twice the joist thickness. The hole is centered between the top and bottom of the joist.

d\(_h\) = 9.5 inches (\( d_h \) is the web hole depth in the AISI Specification)

\( h \) = the flat portion of the web measured along the plane of the web. To calculate \( h \), subtract twice the member thickness and twice the bend radius from the overall member depth. Thus, \( h = 14'' - 2 \times (0.0713 + 0.1070) = 13.64 \) inches.

Nominal Bending Strength:

Use a 150U50-54 (33 ksi) as the reinforcement member: one along the top of the hole, and one along the bottom of the hole. From manufacturers data, the cross sectional area of this member, \( A_r = 0.129 \) in.\(^2\).

Since the hole is centered vertically in the joist, \( D_1 = D_2 \). Since the hole depth is 9.5 inches, and the 150U50-54 has a depth of 1.5 inches, \( D_1 = D_2 = \frac{9.5}{2} + \frac{1.5}{2} = 5.5 \) inches.

Assuming the neutral axis is at mid-depth of the member, the distance from the neutral axis to the top of the joist is 14”/2 = 7”. Using similar triangles,

\[ F_1 = F_2 = 50 \text{ ksi} \cdot \left(\frac{5.5}{7}\right) = 39.3 \text{ ksi}. \]

However, \( F_y = 33 \text{ ksi} \) for the 150U50-54. Therefore, use \( F_1 = F_2 = 33 \text{ ksi} \).

\[ M_n = M_{no} + A_r F_1 D_1 + A_r F_2 D_2 \]

Using computer software, \( M_{no} = 139.8 \) in.-kips (for the C-section at the 9.5” deep hole).

\[ M_n = \frac{139.8 \text{ in.-kips} + (0.129 \text{ in.}^2 \times 5.5 \text{ in} \times 33 \text{ ksi}) \times 2 = 186.6 \text{ in.-kips}}{156.9 \text{ in.-kips}} \]

However, \( M_n = 156.9 \text{ in.-kips} \) for the unpunched C-section. Thus, the design nominal moment capacity is limited to 156.9 in.-kips.

\[ M_a = M_n / \Omega, \text{ where } \Omega = 2.0 \text{ in accordance with AISI Section A1.2} \]

Nominal Shear Strength:

Option No. 1: Shear Strength with No Reinforcement

\[ c = h/2 - d_h/2 \quad (\text{Eq. C3.2.2-3 from the AISI Specification}) \]

\[ c = 13.64''/2 - 9.5''/2 = 2.070'' \]

\[ c/t = 2.070''/0.0713'' = 29.03 \]

The following strength evaluation is in accordance with AISI Section C3.2.1 and Section C3.2.2

\[ k_v = 5.34 \]

\[ \sqrt{E k_v / F_y} = \sqrt{29,500 \text{ ksi} \times 5.34/50 \text{ ksi}} = 56.134 \]

\[ c/t < 5, \text{ therefore AISI Eq. C3.2.2.2.-1 governs the shear stress} \]

\[ q_s = (c/t)/54 = 29.03/54 = 0.54 \]

\[ F_v = 0.6 \times F_y = 6.0 \times (50 \text{ ksi}) = 30 \text{ ksi} \quad (\text{Eq. C3.2.1-2}) \]

\[ A_w = 2 \times (c \times t) = 2 \times (2.070'' \times 0.0713'') = 0.295 \text{ in.}^2 \]

\[ V_n = q_s F_v A_w = 0.54 \times 30 \text{ ksi \times 0.295 in.}^2 = 4.78 \text{ kips} \]
\[ V_a = \frac{V_n}{\Omega}, \text{ where } \Omega = 2.0 \text{ in accordance with AISI Section A1.1} \]

Therefore, \( V_a = 4.78 \text{ kips} / 2 = 2.39 \text{ kips} \). Compare this to the largest shear demand at the hole location, to ensure the member is adequate.

**Option No. 2**

Use a 150U50-54 as the reinforcement member with the following properties: \( F_y = 33 \text{ ksi} \), design thickness = 0.0566”, inside bend radii = 0.0849”.

\[ h \text{ of reinforcement member} = 1.5" - 2 (0.0849" + 0.0566") = 1.2170" \]

\[ \frac{h}{t} = \frac{1.2170}{0.0566} = 21.50 \]

\[ \sqrt{k_r F_v} = \sqrt{29,500 \text{ ksi} \times 5.34/33 \text{ ksi}} = 69 \]

\( h/t < 69 \), therefore AISI Eq. C3.2.1-1 governs the shear stress

\[ F_v = 0.6 F_y = 0.6 (33 \text{ ksi}) = 19.8 \text{ ksi} \]

\[ A_w = h \times t = 1.2170" \times 0.0566" = 0.0689 \text{ in.}^2 \]

\[ V_n = F_v A_w = 19.8 \text{ ksi} \times 0.0689 \text{ in.}^2 = 1.36 \text{ kips} \]

\[ V_a = \frac{V_n}{\Omega}, \text{ where } \Omega = 2.0 \text{ in accordance with AISI Section A1.1} \]

Determine the screw pattern to be used to connect the 150U50-54 to the web of the C-section. Use a No. 10 self-drilling screw.

The shear flow to be transferred from the C-section web to the 150U50-54 is computed from strength of materials as \( VQ/I \).

Based on the loading of the joist, assume the worst-case shear force as the center of the hole is 780 lbs. (0.78 kips).

\( Q \) is the first moment of the full area above the location where the shear stress is computed. The shear stress is computed at the top of the hole, therefore the applicable area is the edge stiffener (0.50”), the flange width (1.625”) and the remaining web material (\( c = 2.070" \)). \( A = 0.2929 \text{ in.}^2 \).

\[ Q = 0.2929 \text{ in.}^2 (7" - 0.658") = 1.858 \text{ in.}^3 \] (0.658” is the location of the centroid of the area with respect to the top fibers.)

\( I \) is taken as the full moment of inertia of the C-section (excluding the hole). \( I = 28.954 \text{ in.}^4 \) (calculated from the member geometry).

\[ \text{Shear flow} = \frac{VQ}{I} = \frac{(0.78 \text{ kips} \times 1.858 \text{ in.}^3)}{28.954 \text{ in.}^4} = 0.0500 \text{ kips/in.} \]

The nominal strength of the screw, \( P_{ns} = 1.39 \text{ kips} \) computed in accordance with AISI Section E4.3. \( P_a = P_{ns} / \Omega = 1.39 \text{ kips} / 3.0 = 0.46 \text{ kips} \)

Required screw spacing = 0.46 kips / 0.0450 kips/in. = 9.2 inches.

Although the computed screw spacing is 9.5 inches, based on engineering judgment, it is recommended that screws be spaced no greater than 3 inches on center.

**References**


Primary Author of this Technical Note: 
Roger LaBoube, Ph.D., P.E., Wei-Wen Yu Center for Cold-Formed Steel Structures 
Reviewer: 
Don Allen, P.E., Super Stud Building Products, Inc.

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