

Design of Screw Connections in Steel

By

Thomas Sputo, Ph.D., P.E.

PDHLibrary Course No 2020072
1 PDH HOURS

1. INTRODUCTION

Screws are a common method of connecting cold-formed steel elements. Provisions for determining strength of screw connections are found in the AISI S100-16 *North American Specification for Design of Cold-Formed Steel Structural Members*. These provisions were developed for single and multiple screws; however, it is recommended that at least two screws should be used to connect individual elements. This provides redundancy against under-torqueing, over-torqueing, etc., and limits connection distortion of flat unformed members such as straps.

Unlike bolts that are specified by diameter (e.g. ½" diameter A325 bolt), screws are specified by a number designation; Table 1 gives the correlation between the common number designation and the nominal diameter for screws, while Figure 1 defines the nominal diameter.

Table 1. Screw Designation and Diameter

Number Designation	Nominal Diameter, d	
	in.	mm
0	0.060	1.52
1	0.073	1.85
2	0.086	2.18
3	0.099	2.51
4	0.112	2.84
5	0.125	3.18
6	0.138	3.51
7	0.151	3.84
8	0.164	4.17
10	0.190	4.83
12	0.216	5.49
14	0.240	6.10
1/4"	0.250	6.35

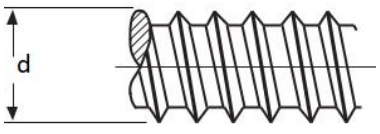


Figure 1. Nominal Diameter for Screws

AISI S100 requirements are applicable to screws with 0.08 in. (2.03 mm) $\leq$ d $\leq$ 0.25 in. (6.35 mm) (#2 through ¼"). The screws can be thread-forming or thread-cutting, with or without a self-drilling point. Screws should be installed and tightened in accordance with the manufacturer's recommendations.

The following notation applies to the AISI S100 equations for determining the resistance of screw connections:

d	=	Nominal screw diameter
d_w	=	Larger of screw head diameter or washer diameter
d'_w	=	Effective pull-over diameter
e	=	Distance measured in line of force from center of a standard hole to nearest end of connected part
F_u	=	Tensile strength of part in which end distance is measured
F_{u1}	=	Tensile strength of member in contact with screw head
F_{u2}	=	Tensile strength of member not in contact with screw head
P_{ns}	=	Nominal shear strength [resistance] per screw
P_{ss}	=	Nominal shear strength [resistance] of screw as reported by manufacturer or determined by independent laboratory testing
P_{nt}	=	Nominal tension strength [resistance] per screw
P_{not}	=	Nominal pull-out strength [resistance] per screw
P_{nov}	=	Nominal pull-over strength [resistance] per screw
P_{ts}	=	Nominal tension strength [resistance] of screw as reported by manufacturer or determined by independent laboratory testing
t	=	Thickness of part in which end distance is measured
t_1	=	Thickness of member in contact with screw head
t_2	=	Thickness of member not in contact with screw head
t_c	=	Lesser of depth of penetration and thickness t_2
t_w	=	Steel washer thickness

The following factor of safety or resistance factors are used for determining the design strength of screw connections.

Table 2. Factor of Safety or Resistance Factor

Ω (ASD)	Φ (LRFD)
3.00	0.50

Spacing, Edge Distance and End Distance Requirements

The AISI S100 provisions are applicable when:

2. The distance between the centers of screws is not be less than 3d.
3. The distance from the center of a screw to the edge of any part is not less than 1.5d.

Screws Loaded in Shear

Connection Shear Limited by Tilting and Bearing

Screw connections loaded in shear can fail in one mode or in combination of several modes. These modes are screw shear, edge tearing, tilting and subsequent pull-out of the screw, and bearing of the joined materials.

These provisions are focused on the tilting and bearing failure modes. Tilting of the screw followed by threads tearing out of the lower sheet reduces the connection shear capacity from that of the typical connection bearing strength (Figure 2).

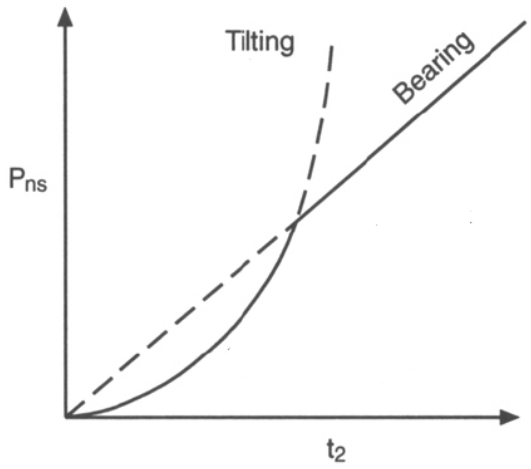
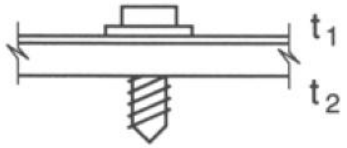


Figure 2. Comparison of Tilting and Bearing

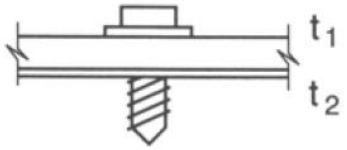
Two cases are given depending on the ratio of thicknesses of the connected members. Normally, the head of the screw will be in contact with the thinner material as shown in Figure 3.



tilting	N/A
bearing	$P_{ns} = 2.7\ t_1 d F_{u1}$ or
bearing	$P_{ns} = 2.7\ t_2 d F_{u2}$

Figure 3. Design Equations for $t_2/t_1 \geq 2.5$

However, when both members are the same thickness, or when the thicker member is in contact with the screw head, tilting must also be considered as shown in Figure 4.



tilting	$P_{ns} = 4.2\ (t_2^3 d)^{1/2} F_{u2}$ or
bearing	$P_{ns} = 2.7\ t_1 d F_{u1}$ or
bearing	$P_{ns} = 2.7\ t_2 d F_{u2}$

Figure 4. Design Equations for $t_2/t_1 \leq 1.0$

It is necessary to determine the lower bearing capacity of the two members based on the product of their respective thicknesses and tensile strengths.

The nominal shear strength [resistance] per screw, P_{ns}, is calculated as follows:

For $t_2/t_1 \leq 1.0$, P_{ns} is the smallest of

$P_{ns} = 4.2\ (t_2^3 d)^{1/2} F_{u2}$ (Eq. 1)

$P_{ns} = 2.7\ t_1\ d\ F_{u1}$ (Eq. 2)

$P_{ns} = 2.7\ t_2\ d\ F_{u2}$ (Eq. 3)

For $t_2/t_1 \geq 2.5$, P_{ns} is the smallest of

$P_{ns} = 2.7\ t_1\ d\ F_{u1}$ (Eq. 4)

$P_{ns} = 2.7\ t_2\ d\ F_{u2}$ (Eq. 5)

For $1.0 < t_2/t_1 < 2.5$, P_{ns} is calculated by linear interpolation between the above two cases.

$$P_{ns} = P_{ns1.0} + \frac{\left(t_2 / t_1 - 1.0 \right)}{1.5} \left[P_{ns2.5} - P_{ns1.0} \right] \qquad \text{(Eq. 6)}$$

Shear in Screws

Shear strength [resistance] of the screw fastener itself should be known and documented from testing. Screw strength should be established and published by the screw manufacturer. In order to avoid the brittle and sudden shear fracture of the screw, AISI S100 limits the shear strength [resistance] to 0.80 times the shear strength of the screw as reported by the manufacturer or determined by independent laboratory testing.

The nominal shear strength [resistance] of the screw shall be taken as P_{ss}.

$$P_{ns} = P_{ss} \qquad \text{(Eq. 7)}$$

Screws Loaded in Tension

Screw connections loaded in tension can fail either by pulling out of the screw from the sheet t_2 (pull-out) or pulling of material, t_1, over the screw head and the washer, if a washer is present, (pull-over) or by tensile fracture of the screw.

There are a variety of washers and head styles in use. For screws which carry tension, the head of the screw or washer, if a washer is provided, must have a diameter d_h or d_w not less than 5/16 in. (7.94 mm).

The nominal washer thickness shall be at least 0.050 in. (1.27 mm) for t_1 greater than 0.027 in. (0.686 mm) and at least 0.024 in. (0.610 mm) for t_1 equal to or less than 0.027 in. (0.686 mm). The washer shall be at least 0.063 in. (1.60 mm) thick when 5/8 in. (15.9 mm) < $d_w \leq$ 3/4 in. (19.1 mm).

Pull-Out

For the limit state of pull-out of the fastener from material t_2, AISI S100 uses the following equation for calculating the nominal pull-out strength [resistance], P_{not}.

$$P_{not} = 0.85\, t_c\, d\, F_{u2} \qquad \text{(Eq. 8)}$$

Pull-Over

For the limit state of pull-over of material t_1, AISI S100 uses the following equation for calculating the nominal pull-over strength [resistance], P_{nov}.

$$P_{nov} = 1.5\, t_1\, d'_w\, F_{u1} \qquad \text{(Eq. 9)}$$

Where:

d'_w is determined as follows:

1. For a round head, a hex head (Figure 5(1)), pancake screw washer head (Figure 5(2)), or hex washer head (Figure 5(3)) screw with an independent and solid steel washer beneath the screw head:
   $d'_w = d_h + 2t_w + t_1 \leq d_w$ (Eq. 10)
2. For a round head, a hex head, or a hex washer head screw without an independent washer beneath the screw head:
   $d'_w = d_h$, but not larger than 3/4 in. (19.1 mm)
3. For a domed (non-solid and either independent or integral) washer beneath the screw head (Figure 5(4)), it is permitted to use d'_w as calculated in Eq. 10, where t_w is the thickness of the domed washer. In the equation, d'_w shall not exceed 3/4 in. (19.1 mm).

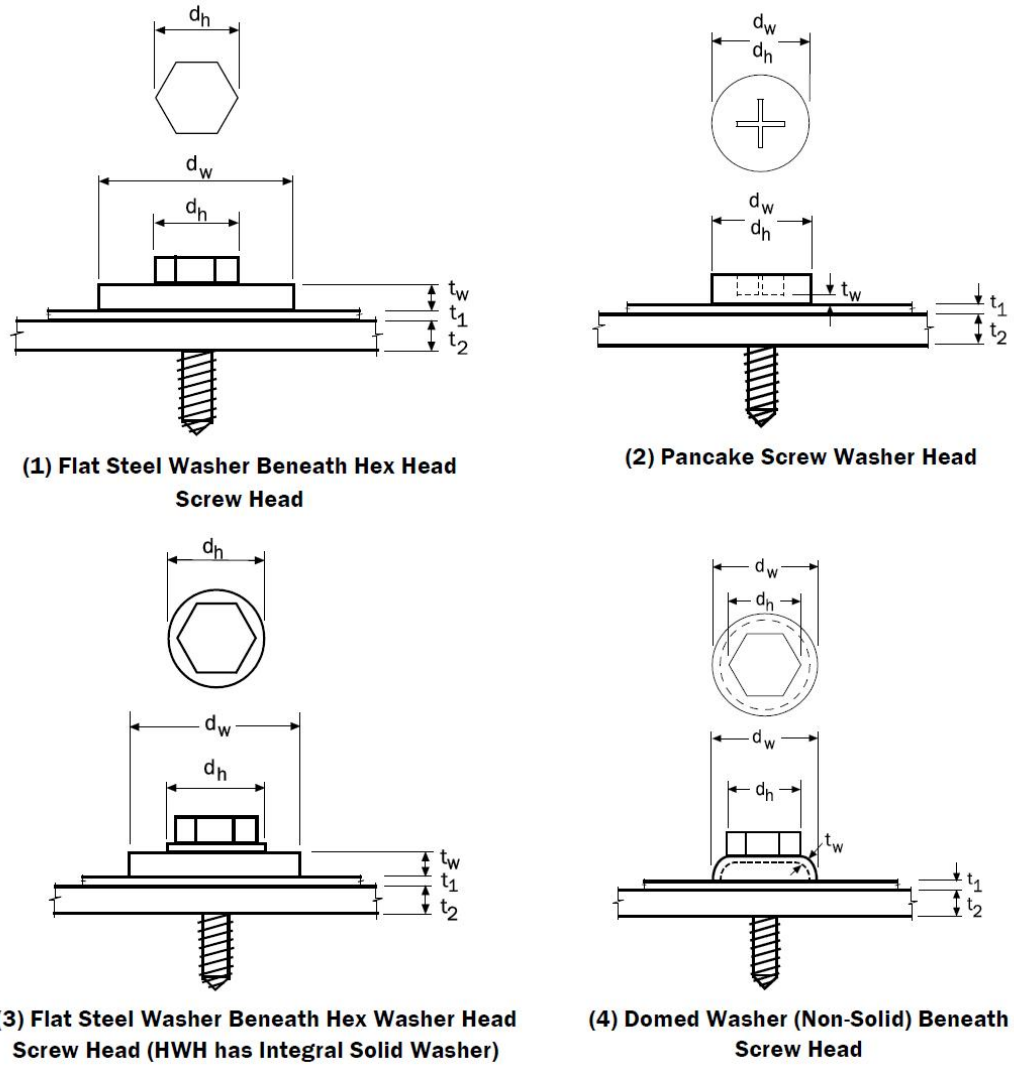


Figure 5. Effective Washer Diameter for Pull-over

Tension in Screws

Tensile strength [resistance] of the screw fastener itself should be known and documented from testing. Screw strength [resistance] should be established and published by the manufacturer. The nominal tension strength [resistance] of the screw shall be taken as P_{nt}.

Example 1. Shear

Shear Strength of Self Drilling Screws in Cold-Formed Steel			
t1 =	0.0400	inches	Thickness of sheet in contact with screw head
t2 =	0.0600	inches	Thickness of sheet NOT in contact with screw head
Fu1 =	65	ksi	Tensile strength of sheet in contact with screw head
Fu2 =	45	ksi	Tensile strength of sheet in NOT contact with screw head
d =	0.190	inches	Screw Diameter
Omega =	3.00		
Phi =	0.50		
t2 / t1 =	1.50		
			if (t2 / t1) <= 1.0
Pns1 =	1210.8	pounds	
Pns2 =	1333.8	pounds	
Pns3 =	1385.1	pounds	
Pns =	**1210.8**	**pounds**	
			if (t2 / t1) >= 2.5
Pns2 =	1333.8	pounds	
Pns3 =	1385.1	pounds	
Pns =	**1333.8**	**pounds**	
			if 1.0 < (t2 / t1) < 2.5
Pns =	**1251.8**	**pounds**	**Controls**
Pns =	**1251.8**	**pounds**	
P allow =	**417.3**	**pounds**	**ASD**
Phi Pn =	**625.9**	**pounds**	**LRFD**

Example 2. Tension

Tension Strength of Self Drilling Screws in Cold-Formed Steel				
t1 =	0.0400	inches	Thickness of sheet in contact with screw head	
t2 =	0.0600	inches	Thickness of sheet NOT in contact with screw head	
Fu1 =	65	ksi	Tensile strength of sheet in contact with screw head	
Fu2 =	45	ksi	Tensile strength of sheet in NOT contact with screw head	
d =	0.190	inches	Screw Diameter	
Omega =	3.00			
Phi =	0.50			
t2 / t1 =	1.50			
Pullout				
Pnot =	436.1	pounds		
Pullover				
d'w =	0.400	inches	Effective Washer Diameter	
Pnov =	1560.0	pounds		
Pn =	**436.1**	**pounds**	**Pullout Controls**	
P allow =	**145.4**	**pounds**	**ASD**	
Phi Pn =	**218.0**	**pounds**	**LRFD**	

Design of Screw Connections in Steel - Quiz

Updated: 6/019/2020

1. The AISI S100 provisions are applicable when the distance between the centers of screws is not less than _____.

a. 1d
b. 2d
c. 3d
d. 4d

2. Limit states for screw connections in tension include.

a. Pull-over and Pull-out
b. Tilting
c. Bearing
d. Screw shear

3. Tilting and bearing are limit states for screws loaded in shear.

a. True
b. False

4. In order to avoid the brittle and sudden shear fracture of the screw, AISI S100 limits the shear strength [resistance] to _____ times the shear strength of the screw as reported by the manufacturer or determined by independent laboratory testing.

a. 0.50
b. 0.60
c. 0.75
d. 0.80

5. For a round head, a hex head, or a hex washer head screw without an
independent washer beneath the screw head, d'_w may not exceed:

a. 0.50 in.
b. 0.375 in.
c. 0.75 in.
d. 1.00 in