

specwise

A TALE OF TEAROUTS

BY LARRY MUIR, PE

The strength of bolt groups or the *shear* delight of *bearing* change without *tearing* out your hair.

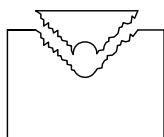
SECTION J3.10 of the 2016 *Specification for Structural Steel Buildings* (ANSI/AISC 360-16) introduces a new limit state: tearout.

Actually, that's only half the story. More accurately, the section splits what had been presented in the 2010 *Specification* as a single check into two separate checks: bearing and tearout. There has been some confusion and controversy related to the proper application of this check that we'll attempt to clear up here. (*Note: For the sake of brevity, we have listed the bolt grades but not the full ASTM designation of F3125 Grades A325 and A490 throughout the text.*)

What is Tearout?

The limit state of bolt edge tearout was introduced in the 1999 *Specification* as part of the bolt bearing checks. Tearout is a limit state provided in Section J3.10 of the *Specification*. It is described in the Commentary as a bolt-by-bolt block shear rupture of the material upon which the bolt bears—a failure of the material in front of the bolt in the direction of the force. Though not a theoretically correct model, bolt tearout may be easier to understand if you think about a bolt tearing through the material (as shown in Figure 1). There are two shear planes. Assuming the planes shown, the strength is calculated as:

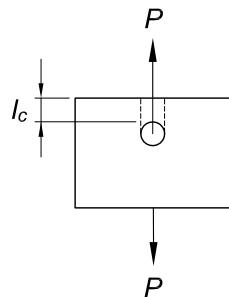
$$R_n = 2(0.6)l_c t F_u = 1.2l_c t F_u$$



▲ Figure 2

Though this is a simple and useful model, it does not reflect the actual behavior. If the bolt tears from the material, the phenomenon looks more similar to Figure 2. The model does, however, produce *Specification* Equation J3-6c, the nominal tearout strength when deformation at the bolt hole is a design consideration. The

fact that the model is not precise is reflected by the fact that the *Specification* also presents a limit state for conditions when deformation at the bolt hole is not a design consideration with Equation J3-6d, $R_n = 1.5l_c t F_u$, which predicts a strength 25% higher than the Figure 1 model.



▲ Figure 1

As described in the Commentary, when deformation at the bolt hole is a design consideration, the strength is limited such that hole elongation will not exceed ¼ in. when high tensile stress occurs on the net section. At this stress level, the bolt may not tear from the joint—but for simplicity, the limit state is still referred to as tearout.

Tearout can occur between a bolt and any edge, whether the edge occurs at the end of the material or at an adjacent bolt hole.

The Change

The change to the 2016 *Specification* is minor. Equation J3-6a in the 2010 *Specification* has been broken into two separate Equations, J3-6a and J3-6c, in the 2016 *Specification* (see Table 1). A similar change has been made to Equations J3-6b and J3-6d. This is intended to be an editorial change. The 2016 Commentary was also revised to provide further information and guidance.

Table 1. Comparison Between 2010 and 2016 *Specification* Tearout Provisions

2010 <i>Specification</i>	2016 <i>Specification</i>
$R_n = 1.2l_c t F_u \leq 2.4dt F_u$ (J3-6a)	$R_n = 2.4dt F_u$ (J3-6a) $R_n = 1.2l_c t F_u$ (J3-6a)

Lower Bound Method

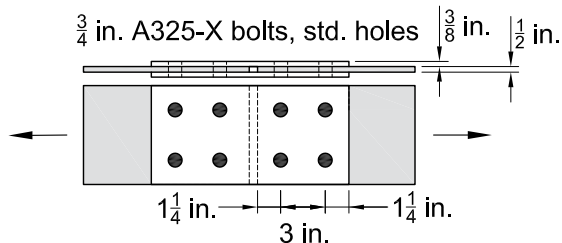
As stated previously, there has been some confusion related to the proper application of this check. There are multiple approaches possible. However, the User Note in Section J3.6 of

Larry Muir (muir@aisc.org)

is AISC's director of technical assistance.

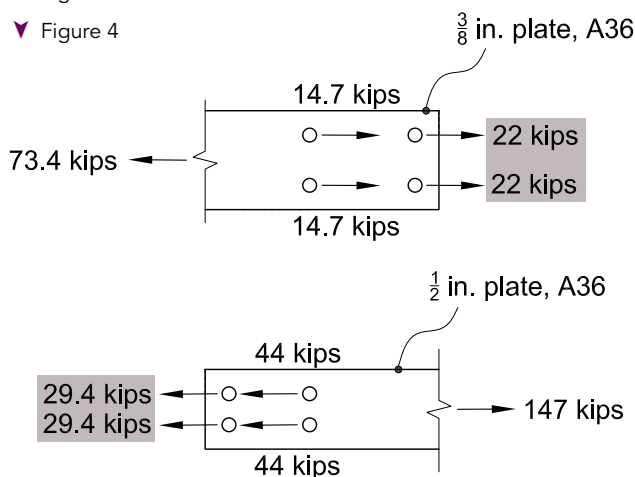


the 2016 *Specification* describes the preferred procedure. This same User Note appeared in Section J3.6 of the 2010 *Specification* as well. To illustrate, consider the connection with a top and bottom $\frac{3}{8}$ -in.-thick plate and a center $\frac{1}{2}$ -in.-thick plate as shown in Figure 3.



▲ Figure 3

▼ Figure 4



To save you from tearing your hair out, let's start with the outcome that tearout on the edges in both plates simultaneously controls—i.e., two bolts tear out of the loaded edge of the $\frac{1}{2}$ -in. plate and the other two bolts tear out of the loaded edges of the $\frac{3}{8}$ -in. plates. The associated applicable nominal strengths are shown in the free body diagram in Figure 4. A free-body diagram showing the nominal strengths applicable, based on the User Note, is shown in Figure 4 (note that the governing forces are highlighted). To explain where this came from, there are five limit states to be checked for each bolt:

1. The nominal single shear strength for a $\frac{3}{4}$ -in.-diameter A325 bolt with the threads excluded from the shear plane is 30.1 kips/bolt.
2. The nominal bearing strength on the $\frac{1}{2}$ in. plate is 52.2 kips/bolt.
3. The nominal bearing strength on each of the a in. plates can be found by prorating the strength of the $\frac{1}{2}$ in. plate:

$$52.2 \text{ kips/bolt} \left(\frac{0.375 \text{ in.}}{0.5 \text{ in.}} \right) = 39.2 \text{ kips/bolt/plate} \text{ or } 78.4 \text{ kips/bolt}$$

4. The nominal tearout strength at the edge for the $\frac{1}{2}$ in. plate is 29.4 kips/bolt.
5. The nominal tearout strength at the edge on each of the a in. plates can be found by prorating the strength of the $\frac{1}{2}$ in. plate:

$$29.4 \text{ kips/bolt} \left(\frac{0.375 \text{ in.}}{0.5 \text{ in.}} \right) = 22.0 \text{ kips/bolt/plate} \text{ or } 44.0 \text{ kips/bolt}$$

As is typical, the tearout strength between the bolts does not govern, though for unusual conditions it could.

The strength of the bolts at the inner bolt line is governed by the tearout strength at the edge for the $\frac{1}{2}$ -in. plate $2(29.4 \text{ kips}) = 58.8 \text{ kips}$. Note this is less than the double shear value of $2(30.1 \text{ kips/bolt}) = 60.2 \text{ kips}$ and the bearing strength of $2(52.2 \text{ kips/bolt}) = 104.4 \text{ kips}$.

The strength of the bolts at the outer bolt line is governed by the tearout strength at the edge for the $\frac{3}{8}$ -in. plate $2(22.0 \text{ kips}) = 44.0 \text{ kips}$ per shear plane. Note the tearout strength, $22 \text{ kips/bolt/plate}$, is less than the single shear value of 30.1 kips and the bearing strength of $39.2 \text{ kips/bolt/plate}$.

The total strength of the connection is $58.8 \text{ kips} + 44.0 \text{ kips}$ (2 shear planes) = 147 kips.

Poison Bolt Method

An alternate method, sometimes referred to as the poison bolt method, simply multiplies the least strength of any of the bolts by the total number of bolts. In this case the poison bolt method yields:

$$R_n = (4 \text{ bolts})(29.4 \text{ kips/bolt}) = 118 \text{ kips}$$

This is obviously significantly less work, but it results in about a 20% reduction in the predicted strength in this case. The underestimation of strength can be greater for some connections. This approach is not recommended.

Commentary Method

The Commentary to the 2016 *Specification* suggests a simplification for typical connections, such as those shown in the AISC *Steel Construction Manual*. The shear, bearing and tearout limit states for each bolt in the same connected part are determined and the lowest value summed to determine the strength of the group. This ignores the potential for interaction of these limit states among multiple connected parts, but the impact is small in common connection details. The key is that a “reasonable” connection is being considered, such as the example being considered here. There is some parity between the bolts chosen and the plates, and the edge distances are typical of those historically used and recommended in the *Specification*. The *Specification* does not prohibit the use of 1-in.-diameter A490-X bolts to connect $\frac{1}{4}$ -in. material, but such an arrangement does not make a lot of sense, may not be economical and will present more of an issue relative to tearout and interaction between connected elements.

The Commentary simplification can be applied to the example. The strength based on bolt shear remains unchanged, $8(30.1 \text{ kips/bolt}) = 241 \text{ kips}$. The bearing and edge bolt tearout strengths of the $\frac{1}{2}$ -in. plate was determined previously as 52.2 kips/bolt and 29.4 kips/bolt, respectively. The tearout strength between the bolts is 76.2 kips, and as is common in typical connections, it does not govern. By inspection, the limits states for the $\frac{3}{8}$ -in. plates do not govern. Therefore, the strength of the connection is:

$$(2 \text{ bolts})(52.2 \text{ kips/bolt}) + (2 \text{ bolts})(29.4 \text{ kips/bolt}) = 163 \text{ kips}$$

The predicted strength, 163 kips, is higher than the 147 kips predicted by the User Note model but only by about 11%. We knew it would be higher, because it starts by assuming a failure mechanism instead of a force distribution; it is an upper-bound solution. As described in the 2016 Commentary, we have bounded the actual strength of the connection. A comparison of the various methods is presented in Table 2.

Table 2. Comparison of Methods

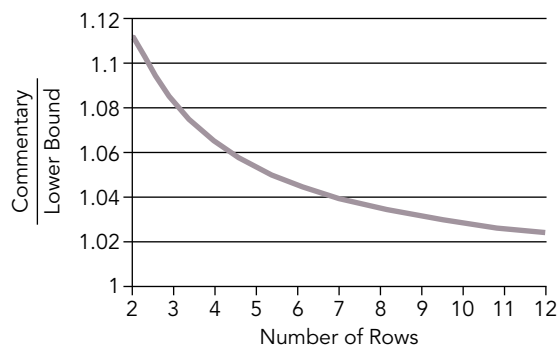
	Pre-1999	Poison Bolt	Lower Bound*	2016 Commentary
Values (kips)	209	118	147	163
% of Lower Bound	142	80	100	111

*Per User Note in Section J3.6 in the 2010 and 2016 *Specification*.

Adding Bolt Rows

As is probably already clear, it is the way in which the tearout at the edge bolts is handled that is causing the difference between the various models. The effect of adding rows of bolts can be seen in Figure 5. The discrepancy between the methods drops off quickly as rows of bolts are added. This is consistent with assumptions, made as far back as at least 1936, that edge tearout is less of a concern for connections with multiple rows of bolts in the direction of the force.

▼ Figure 5: Effect of number of rows.



Tearout Between Holes

Common connections typically provide for $\frac{3}{4}$ -in. or $\frac{7}{8}$ -in. bolts spaced at 3 in. on center. Fortunately, for this common configuration, tearout is not a concern between the rows of bolts. For bolts larger than $\frac{7}{8}$ in. in diameter, bolt shear, not tearout, will govern if the plate is made significantly thick. Table 3 presents the minimum thickness required to ensure that bolt shear (and not tearout) governs. The values assume either 3 in. spacing or the minimum allowed by the *Specification*: $2\frac{2}{3}$ times the nominal diameter per Section J3.3. Single shear is also assumed.

Table 3. Minimum Thickness (inches) to Ensure Tearout Does not Govern Between Holes

Bolt Diameter (inches)	A36			Grade 50		
	F3125 Grade			F3125 Grade		
	A325-N	A325-X or A490-N	A490-X	A325-N	A325-X or A490-N	A490-X
1	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{9}{16}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{1}{2}$
1 $\frac{1}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{16}$	$\frac{9}{16}$	$\frac{5}{8}$
1 $\frac{1}{4}$ *	$\frac{1}{2}$	$\frac{5}{8}$	$1\frac{3}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$1\frac{1}{16}$
1 $\frac{3}{8}$ *	$\frac{9}{16}$	$1\frac{1}{16}$	$\frac{7}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$1\frac{3}{16}$
1 $\frac{1}{2}$ *	$\frac{5}{8}$	$\frac{3}{4}$	$1\frac{5}{16}$	$\frac{9}{16}$	$1\frac{1}{16}$	$\frac{7}{8}$

*Spacing is $2\frac{2}{3}$ times the nominal diameter.

A similar analysis can be performed to find the minimum thickness such that tearout does not govern given edge distances of $1\frac{1}{4}$ in. and $1\frac{1}{2}$ in. The results are presented in Table 4.

Table 4. Minimum Thickness (inches) to Ensure Tearout Does not Govern at Edge

Bolt Diameter (inches)	$l_e = 1.25 \text{ in.}$			$l_e = 1.5 \text{ in.}$		
	F3125 Grade			F3125 Grade		
	A325-N	A325-X or A490-N	A490-X	A325-N	A325-X or A490-N	A490-X
$\frac{1}{2}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{1}{4}$
$\frac{5}{8}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$
$\frac{3}{4}$	$\frac{7}{16}$	$\frac{9}{16}$	$1\frac{1}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$
$\frac{7}{8}$	$\frac{5}{8}$	$1\frac{3}{16}$	1	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$
1	$1\frac{5}{16}$	$1\frac{3}{16}$	$1\frac{7}{16}$	$1\frac{1}{16}$	$\frac{7}{8}$	$1\frac{1}{16}$

What About the Manual?

The most widespread change to AISC's *Steel Construction Manual* (www.aisc.org/publications) involved simply adding the term tearout in the text to reflect the breaking up of the tearout and bearing limit states.

The most substantial change was made to Table 10-1, which included a tabulation of beam web available strength per inch of thickness. Due to the format of the table, neither the lower bound nor the 2016 Commentary alternative approach is pos-

sible. It was therefore decided that the best option was to simply remove these values. This leaves the designer the task of evaluating tearout. *Manual* Table 7-5 can aid in this task. Tables 3 and 4 in this article can also be used to determine when tearout will and will not be an issue.

Rules of Thumb and Helpful Hints

Keep these tips in mind when considering tearout:

- ▶ Tearout will not govern between the bolts for many common connections
 - ▶ Tearout will not govern the strength of shear connections to uncoped beams with $\frac{7}{8}$ -in.- or 1-in.-diameter bolts and the edge distance, l_e , is equal to 1.25 in. or 1.5 in.
 - ▶ Edge tearout will generally not govern if the thickness of the plies is equal to the bolt diameter
 - ▶ Bolt grades and diameters should be well-matched to the strength of the plies
 - ▶ Edge distance must be considered, though often tearout can be deemed okay by inspection
- ▶ In the 2016 *Specification*, the hole clearance increased to $\frac{1}{8}$ in. for bolts 1 in. and larger in diameter. This will affect the clear distance and therefore the tearout strength
 - ▶ The five-limit-state approach described in a User Note is the recommended design approach and is the one reflected in many AISC Design Examples and more recent AISC Design Guides
 - ▶ The poison bolt model is conservative and might be sufficient in some instances but may not result in the most economical design
 - ▶ The mechanism-based approach, as described in the Commentary, though tending to overestimate the strength may be sufficient for many common conditions

Additional information, including a history of edge distance checks in the AISC *Specification*, more detailed calculations related to the example problem, references and other information about bolt tearout can be found at www.aisc.org/tearout. And you can view and download the current version of the *Specification* at www.aisc.org/specifications. ■