CHAPTER

3b

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ANALYSIS OF TENSION MEMBERS

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Part II – Structural Steel Design and Analysis

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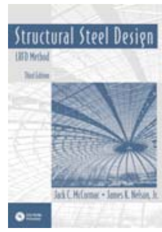

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ENCE 355 - Introduction to Structural Design

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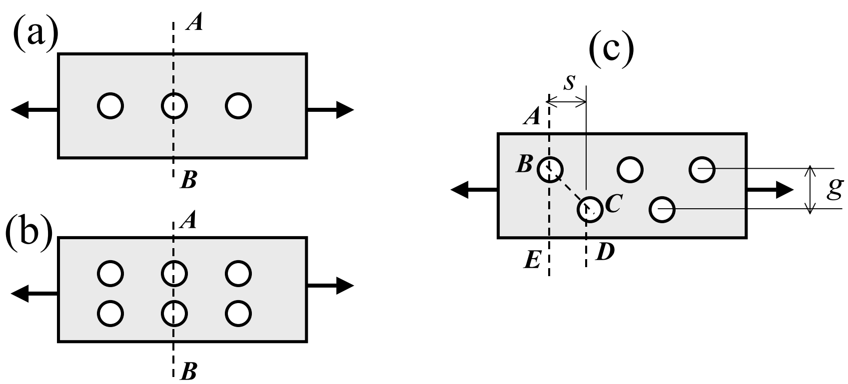
Effect of Staggered Holes

- Whenever there is more than on hole and the holes are not lined up transverse to the loading direction, more than one potential failure line may exist.
- The controlling failure line is that line which gives the minimum net area.
- In the previous examples, tension members were assumed to fail transversely as along line *AB* in Fig. 1a or 1b.

Effect of Staggered Holes

- Figure 1. Possible Failure Sections in Plates



Effect of Staggered Holes

- Fig. 1c shows a member in which a failure other than a transverse one is possible.
- The holes are staggered, and failure along section *ABCD* is possible unless the holes are a large distance apart.
- In Fig. 1b, the failure line is along the section *AB*.

Effect of Staggered Holes

- In Fig. 1c, which is showing two lines of staggered holes, the failure line might be through one hole (section *ABE*) or it might be along a diagonal path *ABCD.*
- At first glance, one might think section *ABE* is critical since the path *ABE* is obviously shorter than path *ABCD*.
- However, from path *ABE*, only one hole would be deducted while two holes would be deducted from path *ABCD.*

Effect of Staggered Holes

- Controlling Section
  - In order to determine the controlling section, both paths *ABE* and *ABCD* must be investigated .
  - Accurate checking of strength along path *ABCD* is very complex.
  - However, a simplified empirical relationship has been proposed by Cochrane and adopted by in the AISC LRFD Manual.

Effect of Staggered Holes

- LRFD Specification
  - The LRFD Specification and other specifications use a very simple method for computing the net width of a tension member along a zigzag section.
  - The method is to take the gross width of the member regardless of the line along which failure might occur, subtract the diameter of the holes along the zigzag section, and for each individual line the quantity given by $s^2/4g$.

Effect of Staggered Holes

- LRFD Specification
  - In determining the critical section among various paths, the one that gives the least value after subtracting the holes, and the quantity

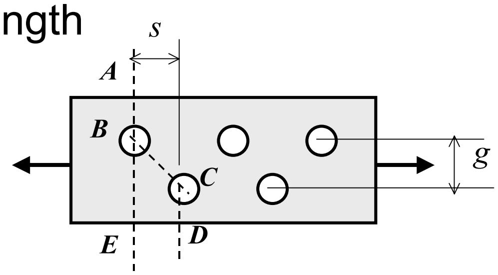
$$\frac{s^2}{4g} \qquad (1)$$

is the critical section.

s = stagger or spacing of adjacent holes parallel to loading direction (see Fig. 2), also called pitch
g = gage distance transverse to the loading (Fig. 2)

Effect of Staggered Holes

- Figure 2. Critical Section and net Length



$$\frac{s^2}{4g}$$

Net length of *ABC* = length of *ABC* – diameter of hole

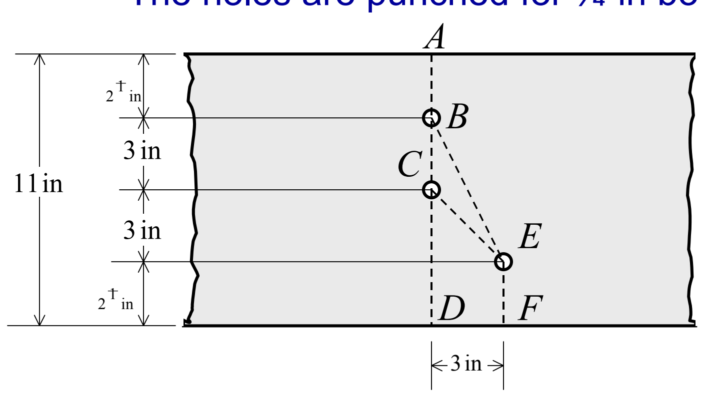
Net length of *ABCD* = length of *ABCD* – 2(diameter of hole) + $\frac{s^2}{4g}$

Note: for standard bolts, add 1/8 in. to hole diameter,

Effect of Staggered Holes

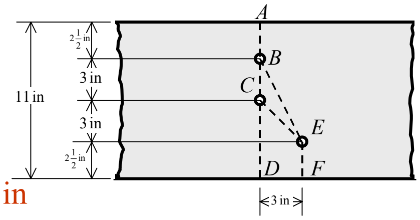
- Example 1

  Determine the critical net area of the ½ -in plate shown using the LRFD Specification. The holes are punched for ¾-in bolts.



Effect of Staggered Holes

- Example 1 (cont'd)



From the figure,

s = 3 in, and $g = 3$ in and 6 in

The critical section could be possibly be

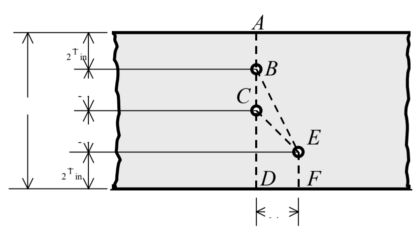
ABCD, ABCEF, or *ABEF*

$$\text{net length of } ABCD = \text{length of } ABCD - 2(\text{hole dia.} + \frac{1}{8}\text{ in})$$

$$\text{net length of } ABCD = 11 - 2\left(\frac{3}{4} + \frac{1}{8}\right) = 9.25 \text{ in}$$

Effect of Staggered Holes

- Example 1 (cont'd)

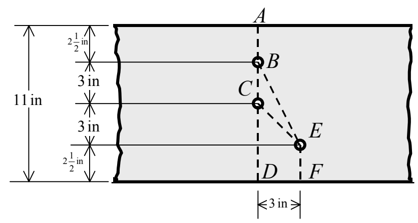


$$\text{net length of } ABCEF = \text{length of } ABCEF - 3(\text{hole dia.} + \frac{1}{8}\text{ in}) + \frac{s^2}{4g}$$

$$\text{net length of } ABCEF = 11 - 3\left(\frac{3}{4} + \frac{1}{8}\right) + \frac{(3)^2}{4(3)} = 9.125 \text{ in} \quad \text{(controls)}$$

Effect of Staggered Holes

- Example 1 (cont'd)



$$\text{net length of } ABEF = \text{length of } ABEF - 2(\text{hole dia.} + \frac{1}{8}\text{in}) + \frac{s^2}{4g}$$

$$\text{net length of } ABEF = 11 - 2\left(\frac{3}{4} + \frac{1}{8}\right) + \frac{(3)^2}{4(6)} = 9.625 \text{ in}$$

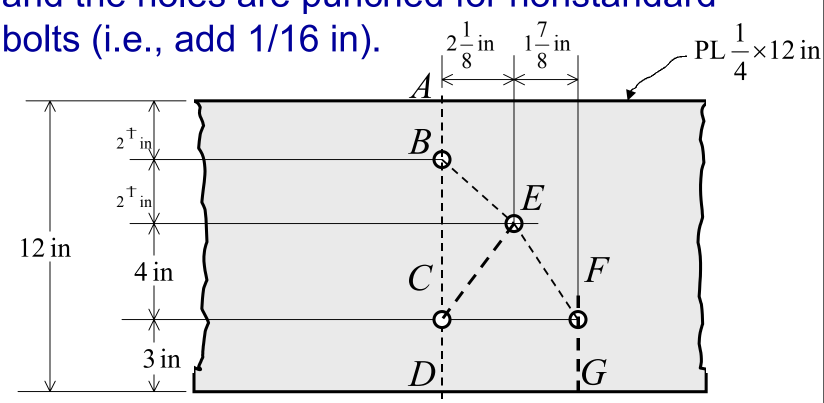
Therefore,

$$\text{The neat area } A_n = 9.125\left(\frac{1}{2}\right) = 4.56 \text{ in}^2$$

Effect of Staggered Holes

- Example 2

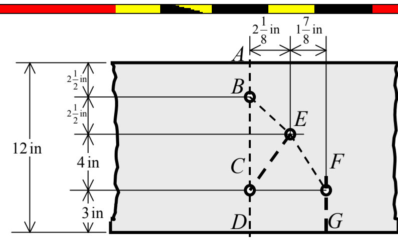
Determine the minimum net area of the plate shown assuming 15/16-in diameter holes, and the holes are punched for nonstandard bolts (i.e., add 1/16 in).



Effect of Staggered Holes

- Example 2 (cont'd)

From the figure,



$s = 2\frac{1}{8}\text{ in and } 1\frac{7}{8}\text{ in,}$ and $g = 2.5$ in, and 4 in

The critical section could be possibly be *ABCD, ABECD,* or *ABEFG*

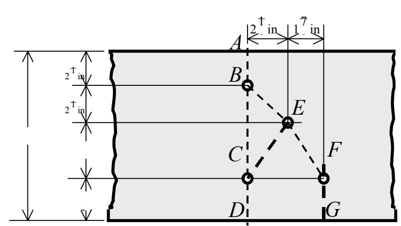
$$\text{net length of } ABCD = \text{length of } ABCD - 2(\text{hole dia.} + \frac{1}{16}\text{in})$$

$$\text{net length of } ABCD = 12 - 2\left(\frac{15}{16} + \frac{1}{16}\right) = 10.00\text{ in}$$

Effect of Staggered Holes

- Example 2 (cont'd)

$$2\frac{1}{8} = 2.125\text{ in, and } 1\frac{7}{8} = 1.875\text{ in}$$



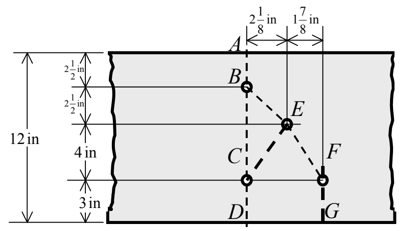
$$\text{net length of } ABECD = \text{length of } ABECD - 3(\text{hole dia.} + \frac{1}{16}\text{in}) + \sum_{i=1}^{2}\frac{s^2}{4g}$$

$$\text{net length of } ABECD = 12 - 3\left(\frac{15}{16} + \frac{1}{16}\right) + \frac{(2.125)^2}{4(2.5)} + \frac{(2.125)^2}{4(4)}$$

$$= 9.734\text{ in}$$

Effect of Staggered Holes

■ Example 2 (cont'd)



$$\text{net length of } ABEFG = \text{length of } ABEFG - 3(\text{hole dia.} + \frac{1}{16}\text{ in}) + \sum_{i=1}^{2}\frac{s^2}{4g}$$

$$\text{net length of } ABEFG = 12 - 3\left(\frac{15}{16}+\frac{1}{16}\right) + \frac{(2.125)^2}{4(2.5)} + \frac{(1.875)^2}{4(4)} = 9.671\text{ in}$$

↑ controls

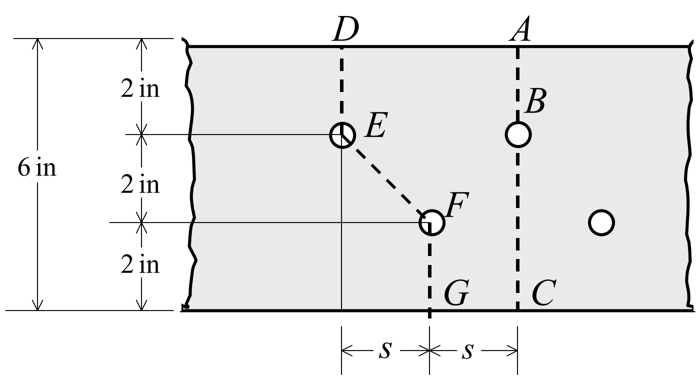
Therefore,

$$\text{The neat area } A_n = 9.671\left(\frac{1}{4}\right) = 2.42\text{ in}^2$$

Effect of Staggered Holes

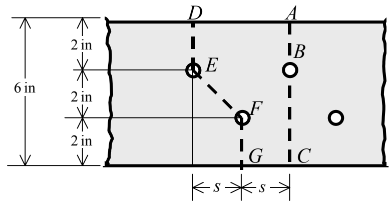
■ Example 3

For the two lines of bolt holes shown, determine the pitch s that will give a net area *DEFG* equal to the one along *ABC*.



Effect of Staggered Holes

- Example 3 (cont'd)



$$\text{net length of } ABC = 6 - (1)\left[\frac{3}{4} + \frac{1}{8}\right] = 5.125 \text{ in}$$

$$\text{net length of } DEFG = 6 - (2)\left[\frac{3}{4} + \frac{1}{8}\right] + \frac{s^2}{4(2)} = 4.25 + \frac{s^2}{8}$$

$$\text{Requirement : net length of } ABC = \text{net length of } DEFG$$

$$5.125 = 4.25 + \frac{s^2}{8}$$

$$\therefore s = 2.65 \text{ in.}$$

Effect of Staggered Holes

- LRFD Manual Provisions for Angles
  - Holes for bolts and rivets are usually drilled or punched in steel angles at certain standard locations.
  - These locations or gages are dependent on the angle-leg widths and on the number of lines of holes.
  - Table1 (Table 3.1, Text), which is taken from Fig. 10.6 of the LRFD Manual, shows these gages.

CHAPTER 3b. ANALYSIS OF TENSION MEMBERS

Slide No. 20

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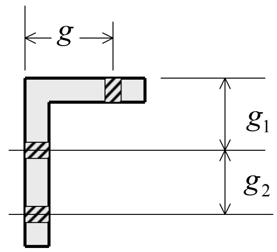
Effect of Staggered Holes

- LRFD Manual Provisions for Angles

Table 1. Usual Gages for Angles, in Inches (AISC Manual)

Leg	8	7	6	5	4	3 1/2	3	2 1/2	2	1 3/4	1 1/2	1 3/8	1 1/4	1
g	4 1/2	4	3 1/2	3	2 1/2	2	1 3/4	1 3/8	1 1/8	1	7/8	7/8	3/4	5/8
g_1	3	2 1/2	2 1/4	2										
g_2	3	3	2 1/2	1 3/4										



CHAPTER 3b. ANALYSIS OF TENSION MEMBERS

Slide No. 21

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Effect of Staggered Holes

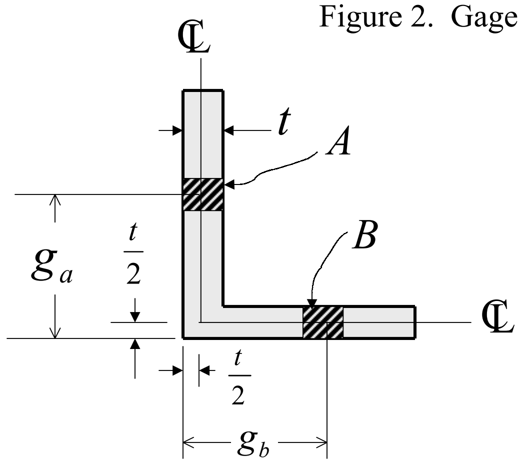
- LRFD Manual Provisions for Angles
  - When holes are staggered on two legs of an angle, the gage length g for use in $s^2/4g$ expression is obtained by using a length between the centers of the holes measured along the centerline of the angle thickness, i.e., the distance *AB* in Fig. 2.
  - Thus the gage distance g is given by

$$g = g_a - \frac{t}{2} + g_b - \frac{t}{2} = g_a + g_b - t \qquad (2)$$

Effect of Staggered Holes

- LRFD Manual Provisions for Angles

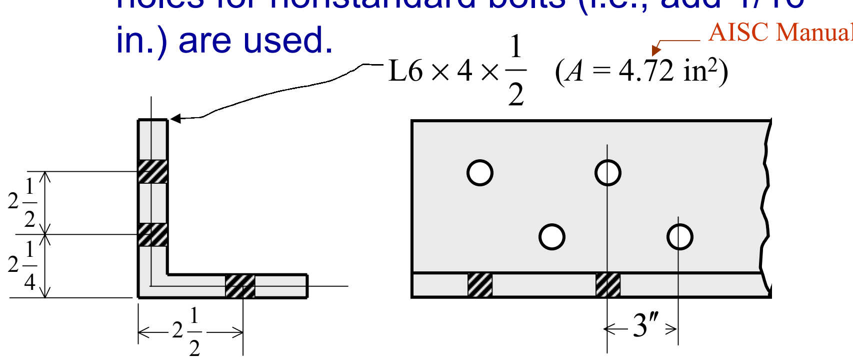
Figure 2. Gage Distances for an Angle



Effect of Staggered Holes

- Example 4

Determine the net area A_n for the angle given in the figure if 15/16-in diameter holes for nonstandard bolts (i.e., add 1/16 in.) are used.



Effect of Staggered Holes

- Example 4 (cont'd)

For the net area calculations the angle may be visualized as being flattened into a plate as shown in Fig. 3.

$$A_n = A_g - Dt + \frac{s^2}{4g}t$$

Where D is the width to be deducted for the hole.

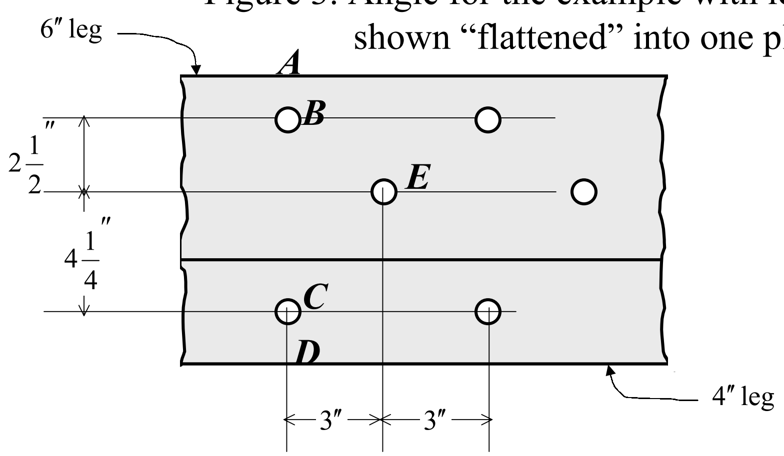
Path *ABCD:*

$$4.72 - 2\left[\frac{15}{16} + \frac{1}{16}\right] \times \frac{1}{2} = 3.72 \text{ in}^2$$ ⟵ Governs

Effect of Staggered Holes

- Example 4 (cont'd)

Figure 3. Angle for the example with legs shown "flattened" into one plane.



Effect of Staggered Holes

- Example 4 (cont'd)

  Using Eq. 2:

$$g = g + g_1 - t = 2\frac{1}{2} + 2\frac{1}{4} - \frac{1}{2} = 4\frac{1}{4}\ \text{in},$$

  Path *ABECD*:

$$4.72 - 3\left[\frac{15}{16} + \frac{1}{16}\right] \times \frac{1}{2} + \left[\frac{(3)^2}{4(2.5)} + \frac{(3)^2}{4(4.25)}\right] \times \frac{1}{2} = 3.94\ \text{in}^2$$

  Hence, A_n = 3.72 in^2.

Effective Net Areas

- The net area as computed previously gives the reduced section that resist but still may not correctly reflect the strength.
- This particularly true when the tension member has a profile consisting of elements not in common plane and where the tensile load is transmitted at the end of the member by connection to some but not all of the elements.

Effective Net Areas

- An angle section having connection to one leg only is an example of such a such a case.
- For such situations, the tensile force is not uniformly distributed over the net area.
- To account for nonuniformity, the AISC Specification provide for an "***effective net area*** A_e" equal to UA_n.

Effective Net Areas

- AISC LRFD Provisions for Effective Net Area

The AISC LRFD Specification provide that the effective net area is to be computed as

$$A_e = UA_n \qquad (3)$$

Where

U = reduction coefficient

A_n = net area

Effective Net Areas

- AISC LRFD Provisions for Effective Net Area
  - The above equation (Eq. 3) logically applies for both fastener connections having holes and for welded connections.
  - For welded connections, the net area equal the gross area A_g since there are no holes.
  - Whenever the tensile load is transmitted by bolts, rivets, or welds through some but not all of the cross-sectional elements of the members, the load carrying efficiency is reduced and *U* will be less than unity.

Effective Net Areas

- AISC LRFD Provisions for Effective Net Area

  The following equation can be used to estimate the reduction coefficient U:

$$U = 1 - \frac{\bar{x}}{L} \leq 0.9 \qquad (4)$$

Where

$\bar{x}$ = distance from centroid of element being connected eccentrically to plane of load transfer

L = length between first and last bolts in line.

Effective Net Areas

■ AISC LRFD Provisions for Effective Net Area

Table 1. Permissible U Values for Bolted Connections

a. *W, M,* or *S* shapes with flange widths not less than two-thirds the depth, and structural tees cut from these shapes, provided the connection is to the flanges and has no fewer than three fasteners per line in the dircetion of stress, $U = 0.90$.
b. *W, M,* or *S* shapes not meeting the conditions of subparagraph **a**, structural tees cut from these shapes, and all other shapes including built-up cross sections, provided the connection has no fewer than three fasteners per line in the direction of stress, $U = 0.85$.
c. All members having only two fasteners per line in the direction of stress, $U = 0.75$.

Effective Net Areas

■ AISC LRFD Provisions for Effective Net Area

Figure 4