Discussion

Design of Bolts or Rivets Subject to Combined Shear and Tension

Paper presented by ALFRED ZWEIG (April, 1966, issue)

Discussion by **W. BERTWELL**

MUCH HAS BEEN WRITTEN on the subject of structural steel brackets, the latest being the paper by Mr. Zweig in the April, 1966 *Engineering Journal*. Unfortunately, the basic assumption of his development—that the neutral axis of the connection is at the centroid of the fasteners—is disputable, to say the least. One of the best treatments of this subject was presented by Professor J. E. Lothers, in ASCE Paper No. 2347, Vol. 116 of *Transactions*. Professor Lothers found the neutral axis to be about 0.94 of the length of the angles from their top.

In view of the many variables, it is doubtful that great accuracy is warranted. Therefore, it has been the writer's practice to take the neutral axis at the bottom of the angles. The calculations required are then extremely simple. The total tension in all the bolts is the moment divided by ⅔ the height of the connection, and the maximum bolt tension is twice the average, plus a correction described below. It seems evident that the comparatively great flexibility of the angle legs in "flat" bending justifies this procedure.

The most critical items in such connections are usually the bending stress in the angle legs carrying the bolts which are in tension, and the corresponding stress in the element of the member to which the bracket is attached. In the case of the angle, using Professor Lothers' terminology, the stress in the upper inch of each angle is

$$s = 4.5M\frac{(g - 0.6R)}{t^2h^2}$$

in which

s = Unit stress in the angle
M = Total moment on the connection
g = Gage of angle less its thickness
h = Height of connection (length of angle)
R = Radius of angle fillet
t = Thickness of angle

The radius of the fillet is taken into account above in a somewhat different way from that of Professor Lothers, but the result is almost identical. It may be omitted altogether for greater simplicity but a greater value of t will then be required.

A further obvious safety measure is to use, as a limiting stress, the bending stress on the net section of the angle leg, thus:

$$\text{Max. } s = \left[\frac{4.5M(g - 0.6R)}{t^2h^2}\right]\left(\frac{h - e}{h}\right)\left(\frac{0.5p + e}{0.5p + e - d}\right)$$

where

e = End distance beyond most highly stressed bolt
d = Diameter of hole
p = Pitch of the bolts

The computations for bending, as noted before, must be repeated for the column flanges, or the appropriate supporting part. In some cases a stress combination at the bracket might be serious.

To obtain the addition to the bolt tension mentioned above, the "prying action" described in the commentary to the AISC specification must be approximated. Referring to L. E. Grinter's "Design of Modern Steel Structures", this is

$$\left(\frac{M}{\tfrac{2}{3}h}\,\frac{2}{N}\right) \times \left(\frac{\tfrac{3}{4}g - 0.6R}{q}\right)$$

where

N = The total number of bolts
q = The distance from center of bolts to toe of angle

Finally, Example 4 of Mr. Zweig's paper is erroneous in assigning equal effectiveness to all the rivets. Those in the outer rows will provide little or no tensile resistance, and should be disregarded except in shear. The pattern of bolts in Example 3 is also objectionable, for similar reasons.

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Discussion by **ALFRED ZWEIG**

MR. BERTWELL's criticism can be summarized in three statements:

1. The neutral axis should be placed at the bottom of the clip angles rather than at the center of the fastener group.
2. The additional force in the bolts resulting from the "prying action" should be considered.
3 In clip angles with two gage lines, bolts or rivets in the outer row should be disregarded in tension.

It was, of course, known and stated so in the paper under discussion that the neutral axis is below the center-line and it was no oversight to assume it at the center of the fastener group. This was done deliberately to conform to common practice, as demonstrated in the example on page 4-51 of the latest Manual of Steel Construction.

The assumption is obviously on the safe side and it might therefore be criticized as causing undue waste, since it assumes tensile forces in the extreme connectors which are up to and more than twice as much as those obtained from the location of a neutral axis proposed by Mr. Bertwell.

This problem should be reviewed, however, in its whole context which brings us to the second point of Mr. Bertwell, that of the omission of the "prying action". For those who are not familiar with this expression it might be well to explain that Mr. Bertwell has thereby made reference to the additional tension in the bolt as a consequence of the end restraint occurring in the clip angles. This end restraint permits us to design these angles for bending moments of half the magnitude compared to those occurring in unrestrained connections as shown in the design example on page 4-67 of the AISC Manual.

To assure this end restraint, however, considerable force is induced into the connector. Grinter has shown in the reference cited by Mr. Bertwell that this additional force is likely to almost double the basic bolt stress, depending upon size and thickness of the clip angle.

If we now combine the two apparent errors mentioned by Mr. Bertwell, that resulting from a lower location of the neutral axis and that resulting from neglecting the so called "prying action", we find that in most cases these errors will more or less offset or completely cancel each other. It, therefore, becomes evident that the commonly used assumption of placing the neutral axis in the center of the fastener group is well justified as it permits not only a very simple solution to the problem but it also results in answers which are very close to those obtained by the more circuitous approach suggested by Mr. Bertwell.

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Now finally a few words about the third objection raised by Mr. Bertwell, that is his summarily stated assertion that connectors in the outer row will provide little or no tensile resistance and should be disregarded except in shear.

It is obvious that his statement is based on the assumption that tensile forces in the outer row will overstress the clip angle to such an extent that these connectors will become practically ineffective in tension and should therefore be disregarded.

It should be stated, first, that it was the intent of the tables printed in the April issue solely to simplify the design of the fasteners of bracket connections in the light of the new specifications pertaining to combined shear and tension and nothing else. Neither the tables nor the examples were intended to be used in the design of the clip angles. It is, of course, assumed that the clip angles must be strong enough to resist the forces induced by the fasteners and it is also known that frequently the size of the clip angles rather than that of the fasteners will determine the strength of the bracket connection.

As this specific cautionary statement was omitted in the original paper, Mr. Bertwell's warning would be completely justified and valid if it were not worded in such general terms.

The effectiveness of the connector in the outside row depends upon the bending stress in the clip angle, which in turn is a function of the tensile force in the connector and of the angle thickness. In extreme cases it was found necessary to weld horizontal diaphragms into the clip angles when the angle thickness was inadequate to resist the bending stresses therein.

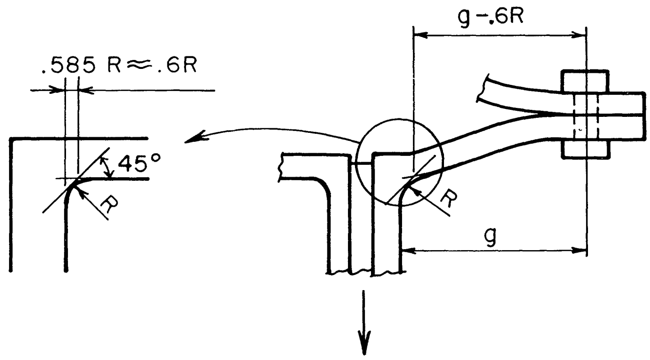
The function of such a horizontal diaphragm can be replaced by the top plate of the bracket. If the top plates of the brackets shown in Figs. 2 to 5 in the April issue are welded to the clip angles they will be strong enough to resist the horizontal pull, and for this reason the fasteners in the outside row can be assumed to resist the full tensile force as the horizontal force at the bracket top is transferred to the vertical plate through the horizontal plate rather than the weak angle legs.

In the light of these observations exception must be taken to Mr. Bertwell's statement that "Example 4 is erroneous . . . and Example 3 is also objectionable."

While it is thus shown that Mr. Bertwell's comments did not invalidate the tables presented in the April issue, his observations are welcome and of great value inasmuch as they brought again before the profession the background for the design of steel brackets and especially the necessity to investigate not only the strength of the fasteners but also the structural adequacy of the clip angles.*

**Mr. Zweig, who submitted this discussion, also suggested that further comments by Mr. Bertwell might be helpful to the reader. Accordingly, here are the supplementary remarks by Mr. Bertwell:*

1. Amplification of expression for stress in connection angle. The distance $(g - 0.6R)$ is illustrated in the sketch below. The effective span between points of fixity of angle leg is assumed to be $(g - 0.6R)$. This gives the strengthening effect of the fillet about the same as calculated by Professor Lothers.



The connection is made up of two angles. The maximum force per inch at the top of one angle is

$$A = \left(\frac{M}{2/3 h} \times 1/2\right)\frac{2}{h} = \frac{3}{2}\frac{M}{h^2}$$

Moment in angle leg at center of bolt is

$$A\left(\frac{g - 0.6R}{2}\right) = \frac{3M}{4h^2}(g - 0.6R)$$

Then

$$S = \frac{6}{t^2}\left[\frac{3M}{4}\frac{(g - 0.6R)}{h^2}\right] = \frac{4.5M(g - 0.6R)}{t^2h^2}$$

In order to take account, roughly and on the safe side, of the bolt hole in the angle, the above stress may be multiplied by two ratios:

$$\frac{\text{distance from N.A. to ℄ end bolt}}{h} = \frac{h - e}{h}$$

$$\frac{\text{gross angle length assigned to end bolt}}{\text{net angle length assigned to end bolt}} = \frac{0.5p + e}{0.5p + e - d}$$

2. The "prying action" is that referred to in the third paragraph of Section 1.5.2.1, Commentary on the AISC Specification. This additional tension is part of the total permissible bolt tension. It has, however, no effect on the bending stress computed in the angle.

In order to avoid further misunderstanding, amplification of the expression for the added bolt tension, or "prying" force, follows:

The basic or primary part of the pull in the top bolt is derived from the moment on the connection. This "primary" pull is

$$\frac{M}{2/3 h}\frac{2}{N}$$

The moment in the angle leg at the center of bolt resulting from this part of the bolt pull is

$$\left(\frac{M}{2/3 h}\frac{2}{N}\right)\left(\frac{g - 0.6R}{2}\right)$$

This moment is also the result of the reaction of the "prying" force, C. Taking the variation of pressure between the angle and supporting member as triangular, as assumed by Professor L. E. Grinter (paragraph 35, pp. 53–54 of his book), this moment is

$$C\left(\frac{2}{3}q\right)$$

Equating these two expressions for the moment in the angle

$$C\left(\frac{2}{3}q\right) = \left(\frac{M}{2/3 h}\frac{2}{N}\right)\left(\frac{g - 0.6R}{2}\right)$$

Then

$$C = \left(\frac{3M}{Nh}\right)\left[\frac{3}{4}\frac{(g - 0.6R)}{q}\right]$$

and

$$\text{total bolt pull} = \frac{3M}{Nh} + C = \frac{3M}{Nh}\left[1 + \frac{3}{4}\left(\frac{g - 0.6R}{q}\right)\right]$$