Design Loads for Seated-beam in LRFD

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ABSTRACT

For many years, the AISC *Manual of Steel Construction*[1] has provided allowable loads for various types of connections for supporting a simple beam on a column. The most economical of these is the seated-beam connection where the end reaction is supported by an unstiffened angle bolted or welded to the column. When plans were made to develop a new Manual based on the *AISC Load and Resistance Factor Design Specification,* it was necessary to review the methods used to determine the allowable loads in the 1980 Manual. This paper presents a summary of that work to show the basis for the load capacities in both Manuals. It is shown that, for some applications, the economy of the seated-beam connection should be enhanced with the new LRFD Specification.

INTRODUCTION

The seated-beam connection, as its name implies, is used to provide a simple connection between a beam and a column by allowing the beam to "sit" on an angle connected to the flange of the supporting column. To provide stability, an angle connecting the upper portion of the beam to the column is optionally located either on the top flange or on the upper part of the web of the beam. However, the entire load is assumed to be transmitted through the bottom or "seat" angle. A typical seated-beam connection is shown in Fig. 1.1.

As with any connection, the seated-beam connection must provide enough vertical load resistance to safely support the beam. This requires the seat angle to have the required bending strength to transfer the beam's reaction to the bolts or welds and that the bolts or welds connecting the angle to the column have adequate strength to transmit the load to the column. In general, the bolt capacities in such connections are computed based on pure vertical shear, while weld capacities are computed for shear plus additional forces from the eccentric application of the load. This paper only addresses the determination of the allowable (for ASD) and factored (for LRFD) seat-angle load. These angle-load capacities are the same for bolted and welded connections.

In the next section, the assumptions and the logic used to derive the allowable seat angle loads for ASD are discussed. In the third section, the derivation of the ultimate seat angle capacity for LRFD is discussed.

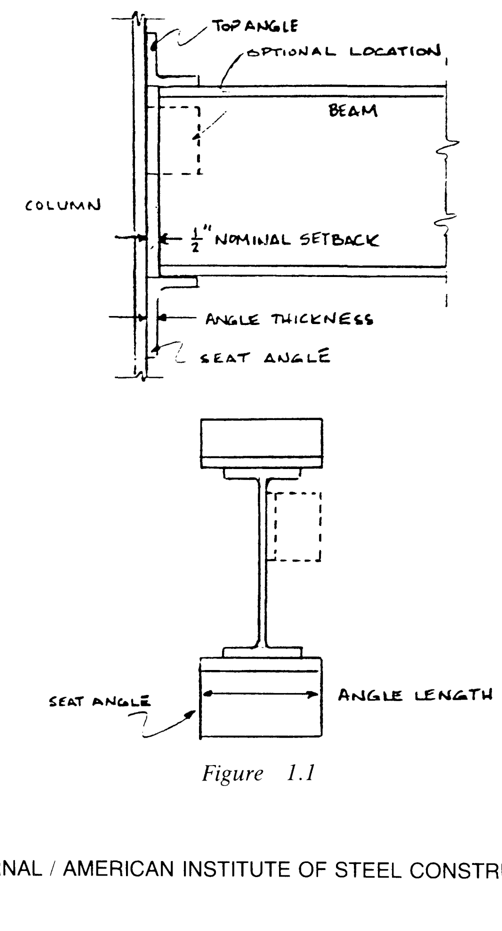

Figure 1.1

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ASD SEATED-BEAM CONNECTIONS

For over 40 years, AISC has included the allowable load capacities for seat angles of seated-beam connections in their *Manual of Steel Construction,* but the details of the procedure used to calculate them has not been generally available. This section describes the assumptions and equation derivations made for allowable angle loads used to generate the allowable load tables for seated-beam connections appearing in the 6th Edition of the Manual.[3]

The allowable angle load is determined by examining two possible conditions: excessive bending stress on the seat angle and web crippling of the supported beam. When computing the allowable load of the angle, it is assumed the governing condition is that which provides the most conservative result. Assuming the critical section is located at the toe of the fillet of the outstanding leg, the expression for the limiting condition of flexure in the angle is

$$F_b = \frac{eR\left(\frac{t_a}{2}\right)}{\left(\frac{1}{12}\right)Lt_a^3} \qquad (1)$$

The expression for the limiting condition of web yielding is

$$F_{cr} = \frac{R}{t_w(N+k)} \qquad (2)$$

where

- R = magnitude of reaction
- e = distance from toe of angle fillet to location of reaction
- t_a = angle thickness
- L = transverse angle length
- t_w = beam-web thickness
- F_b = allowable stress for bending
- F_{cr} = allowable stress for beam web crippling
- k = distance from outer face of flange to web toe of fillet
- N = length of beam in bearing

Three cases will be considered, depending on the relative values of N, k and the angle-leg dimension.

Case I—Basic Case ($k \leq N \leq 3.25$ in.)

The location of the reaction R must be the same for both conditions considered, because it is the same reaction. The following equation relating the eccentricity of R and the bearing length is derived by examining the geometry in Fig. 2.1:

$$N/2 + 3/4 = t_a + + 3/8 + e \qquad (3)$$

The following assumptions are inherent in this relationship.

1. The reaction occurs at the center of the bearing length N.
2. The beam setback is 0.75 in., which is 0.25 in. more than the nominal setback to allow for possible mill underrun in beam length. This is a conservative assumption because less setback would reduce e and the corresponding bending stress.
3. The angle's fillet radius is ⅜ in.

Because there are only three unknowns (R, N and e), Eqs. 1-3 can be solved directly as follows:

1. Solving Eq. 2 for N, the following results:

$$N = \frac{R}{F_{cr} \cdot t_w} - k \qquad (4)$$

2. Solving Eq. 3 for N, the following results:

$$N = 2t_a - 3/4 + 2e \qquad (5)$$

3. Equating Eqs. 4 and 5, the following expression for e can be derived:

$$e = \frac{R}{2F_{cr} \cdot t_w} - \frac{k}{2} - t_a + 3/8 \qquad (6)$$

4. Solving Eq. 1 for e, the following results:

$$e = \frac{F_b t_a^2\left(\frac{L}{6}\right)}{R} \qquad (7)$$

5. Equating Eqs. 6 and 7, the following equation eliminating e is derived:

$$\frac{F_b t_a^2\left(\frac{L}{6}\right)}{R} = \frac{R}{2F_{cr} \cdot t_w} - k - t_a + 3/8 \qquad (8)$$

6. Rearranging terms, the following results:

$$\frac{R^2}{2F_{cr}t_w} - R\left(\frac{k}{2} + t_a - 3/8\right) - \frac{F_b}{6} Lt_a^2 = 0 \qquad (9)$$

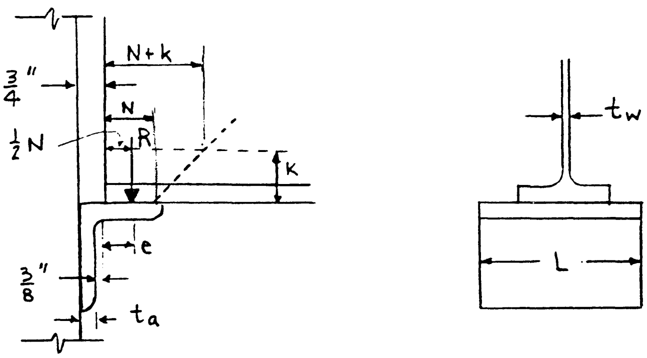

Fig. 2.1. Basic Case I. $k \leq N \leq 3.25$

Eq. 9 can be solved for a positive value of R and then Eq. 4 can be solved for a value of N, which represents the length of beam in bearing when the web is stressed to its maximum crippling stress over a distance $(N + k)$. For simplicity, the following approximations for k are used in solving Eqs. 4 and 9:

$$k = 2.5\ t_w \text{ for } t_w < 5/16 \tag{9a}$$

$$k = 2.75 t_w \text{ for } t_w \geq 5/16 \tag{9b}$$

Also, the following expressions are used in accordance with AISC paragraphs 1.10.10.1 and 1.5.1.4.3,[1] respectively:

$$F_{cr} = 0.75\ F_{y\text{-}beam} \tag{9c}$$

$$F_b = 0.75\ F_{y\text{-}angle} \tag{9d}$$

Three possible cases may result from the evaluation of Eqs. 9 and 4:

1. If N is greater than k and less than 3.25 in., the maximum load capacity has been found and the solution process is complete.
2. If the resulting value of N is less than k, the equations for the more conservative assumption of Case II (described later) must be used to compute the value of R. Note that an actual bearing length less than k would violate the requirement of equation 1.10-9[1] that N be not less than k. However, the N used in the equations is not the actual bearing length, but is the length of the beam in bearing when the web is stressed to its maximum allowable crippling value over a distance $(N + k)$ chosen to produce the maximum allowable bending stress in the outstanding leg of the seat angle.
3. If the resulting value of N is greater than 3.25 in., which is derived by subtracting the assumed beam setback of 0.75 in. from the assumed 4-in. angle-leg width, the equations of Case III must be used to compute the value of R.

Case II—N is less than k

If the value of N resulting from the solution of Eq. 9 is less than k, Eq. 9 produces unrealistic R values as N decreases to 0. Therefore, for this case, the reaction is assumed to be located at one-fourth of the distance $(N + k)$, instead of centered at the center of the distance N, as shown in Fig. 2.2. This is a more conservative assumption.

Of the first three equations, this assumption only affects Eq. 3, which is now rewritten as:

$$\frac{N+k}{4} + 3/4 = t_a + 3/8 + e \tag{10}$$

Resolving the equations in the same order as Case I, but using Eq. 10 instead of Eq. 3, the following quadriatic expression in R results:

$$\frac{R^2}{4F_{cr}t_w} - R\left(t_a - 3/8\right) - \frac{F_b}{6} L t_a^2 \tag{11}$$

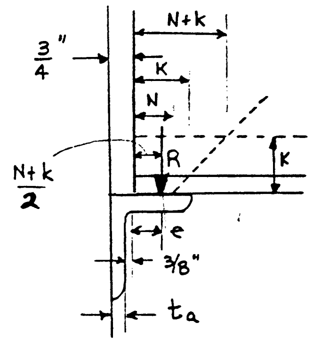

Fig. 2.2. $N < k$

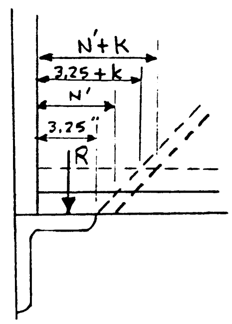

Figure 2.3

Case III—N is greater than 3.25 in.

If the value of N resulting from the solution of Eq. 9 is greater than 3.25 in., which is the maximum possible bearing length (based on an angle with a 4-in. leg and ¾-in. setback), N is assumed to be 3.25 in., as shown in Fig. 2.3. Because the original N was greater than 3.25 in., the bending stress computed using the original N will always be greater than that computed using the new N. Thus, the bending stress in the angle will not be the limit state governing the allowable load. The governing limit state is web crippling and the resulting allowable load is:

$$R = (3.25 + k) t_w F_{cr} \tag{12}$$

Summary of Cases I, II and III

In summary, the allowable load on a seat angle is computed as follows:

1. Assume Case I applies and use Eqs. 9 and 4 to compute values of R and N, respectively;
2. If N is greater than k and less than 3.25 in., the value for R is valid and the solution process can stop;
3. If N is less than k, Case II applies and Eq. 11 should be used to calculate a new value for R; and
4. If N from step 1 is greater than 3.25 in., Case III applies and Eq. 12 should be used to calculate a new value for R.

This algorithm was used to generate the tables found on

p. 4-40 of AISC *Manual of Steel Construction.*[1] Two values for $F_{y\text{-beam}}$ were considered (36 and 50 ksi), two values for L were considered (6 and 8 in.), five values for angle thickness were considered (3/8, 1/2, 5/8, 3/4, 1 in.) and seven values of beam web thickness were considered (3/16, 1/4, 5/16, 3/8, 7/16, 1/2, 9/16 in.). The outstanding leg was maintained as 4 in. The angle was considered to be A36 steel for all cases.

LRFD SEATED-BEAM CONNECTIONS

In 1985, when the LRFD *Manual of Steel Construction*[2] was being compiled, the seated-beam connection tables were in need of translation from ASD into LRFD. The tables cannot be generated by multiplying the ASD tables by a factor, because the expressions for web crippling have been changed, based on further research. Thus, the LRFD load capacities must be derived in the same way the ASD tables were derived, using the LRFD equations.

As with ASD, the two possible limit states are: (1) the excessive bending stress on the seat angle and (2) web crippling of the supported beam. Again, in order to compute the load capacity of the angle, both limit states must be considered at the same time: The plastic moment of the angle's outstanding leg is defined as follows:

$$M_p = \frac{F_{y\text{-angle}} L t_a^2}{4} \qquad (13)$$

Based on a resistance factor of 0.9, the flexural design strength is:

$$\phi_b M_n = 0.9 M_p = 0.225 F_{y\text{-angle}} L t_a^2 \qquad (14)$$

This design strength can be expressed in terms of the reaction:

$$\phi_b M_n = \phi_b (ek) \qquad (15)$$

Thus, the equation for the limit state of flexure is:

$$\phi_b R = \frac{0.225\, F_{y\text{-angle}} L t_a^2}{e} \qquad (16)$$

The LRFD Specification addresses the limit states of both "local web yielding" and "web crippling." The latter is based on stability considerations and is a less critical condition when considering the maximum loads that can be imposed on the seat angle. The condition of local web yielding is similar to that previously (ASD) termed web crippling, except a longer bearing length is used ($N + 2.5k$) vs. ($N + k$). The equation for the limit state of local web yielding is:

$$F_{y\text{-beam}} \geq \frac{\phi_b R}{t_w (N + 2.5k)} \qquad (17)$$

where

$\phi_b R$ = the magnitude of the reaction corresponding to the design flexural strength of the angle
e = distance from toe of angle fillet to location of reaction
t_a = angle thickness
L = transverse angle length
t_w = beam web thickness
$F_{y\text{-angle}}$ = yield stress for angle
$F_{y\text{-beam}}$ = yield stress for beam
k = distance from outer face of flange to web toe of fillet
N = length of beam in bearing

Case I—Basic Case (2.5*k* ≤ *N* ≤ 3.25 in.)

As with ASD, another equation is available because of the requirement that the location of the reaction be the same for both limit states. Thus, the following equation is again applicable, based on the same assumptions previously stated:

$$\frac{N}{2} + 3/4 = t_a = 3/8 + e \qquad (18)$$

Like ASD, there are three equations (16, 17 and 18) and three unknowns ($\phi_b R$, N and e), which can be solved as follows:

1. Solving Eq. 17 for N, the following results:

$$N = \frac{\phi_b R}{t_w F_{y\text{-beam}}} - 2.5k \qquad (19)$$

2. Substituting Eq. 19 into Eq. 18, the following results:

$$\left(\frac{\phi_b R}{2 t_w F_{y\text{-beam}}} \frac{5}{4} k \right) + 3/4 = t_a + 3/8 + e \qquad (20)$$

3. Solving Eq. 20 for e, results in:

$$e = (3/8 - t_a - 5/4\, k) + \frac{\phi_b R}{2 t_w F_{y\text{-beam}}} \qquad (21)$$

4. Substituting Eq. 21 into Eq. 16, the following results:

$$\phi_b R = \frac{0.225\,(F_{y\text{-angle}} L t_a^2)}{(3/8 - t_a - 5/4\, k) + \dfrac{\phi_b R}{2 t_w F_{y\text{-beam}}}} \qquad (22)$$

5. Rewriting Eq. 22 as a quadratic, the following in $\phi_b R$ results:

$$\frac{(\phi_b R)^2}{2 t_w F_{y\text{-beam}}} + \phi_b R (3/8 - t_a - 5/4\, k) - 0.225 F_{y\text{-angle}} L t_a^2 = 0 \qquad (23)$$

Eq. 23 can be solved for a positive value of $\phi_b R$ and then Eq. 19 can be solved for a value of N.

Like the ASD derivation, three possible cases may result from the evaluation of Eqs. 23 and 19:

1. If N is greater than $2.5k$ and less than 3.25 in., the maximum load capacity has been found and the solution process is complete.

2. If the resulting value of N is less than $2.5k$, the equations of Case II must be used to compute the value for $\phi_b R$. This limitation is not present in LRFD, but was assumed for the same reason that N must be greater than k in ASD.
3. If the resulting value of N is greater than 3.25 in., which is the assumed standard seat angle's leg width minus the 0.75 in. assumed setback, the equations of Case III must be used to compute the value of $\phi_b R$.

Case II—N is less than $2.5k$

If the value of N resulting from the solution of Eq. 23 is less than $2.5k$, the reaction is assumed to be located at the center of the distance $(N + 2.5k)$.

Of the first three equations, this assumption only affects Eq. 18, now rewritten as:

$$\frac{N+2.5k}{4} + 3/4 = t_a + 3/8 + e \quad (24)$$

Resolving the equations in the same order as the Case I, but using Eq. 24 instead of Eq. 18, the following quadratic in $\phi_b R$ results:

$$\frac{(\phi_b R)^2}{4 t_w F_{y\text{-beam}}} + \phi_b R(3/8 - t_a) - 0.225 F_{y\text{-angle}} L t_a^2 = 0 \quad (25)$$

Case III—N is greater than 3.25 in.

If the value of N resulting from the solution of Eq. 19 is greater than 3.25 in., which is the maximum possible bearing length for a 4-in. angle, N is assumed to be 3.25 in. Because the original N was greater than 3.25 in., the bending stress computed using the original N will always be greater than that computed using the new N. Thus, the bending stress in the angle will not be the limit state governing the maximum load capacity. The governing limit state is web crippling and the resulting maximum load capacity is:

$$\phi_b R = (3.25 + 2.5k) t_w F_{y\text{-beam}} \quad (26)$$

Summary of Cases I, II and III

In summary, the maximum load capacity on a seat angle is computed as follows:

1. Assume Case I applies, and use Eq. 23 and Eq. 19 to compute values of $\phi_b R$ and N, respectively;
2. If N is greater than $2.5k$ and less than 3.25 in., the value for $\phi_b R$ is valid and the solution process can stop;
3. If N is less than $2.5k$, Case II applies and Eq. 25 should be used to calculate a new value for $\phi_b R$; and
4. If N from Step 1 is greater than 3.25 in., Case III applies and Eq. 26 should be used to calculate a new value for $\phi_b R$.

This algorithm was used to generate the tables to be found in AISC's *LRFD Manual of Steel Construction*[2] with the same range of variables as for the ASD tables. This resulted in 70 cases for each beam yield point. The majority of these (75%) were controlled by Case II ($N < 2.5k$). Case III ($N >$ 3.25 in.) controlled in only a few cases (6 %) when a 1-in. angle was used for beam web thicknesses of about ¼ in. and less—an unlikely condition. Case I ($2.5k < N <$ 3.25 in.) controlled in transition cases (19 %) also involving the combination of heavy angles and thin beam webs. Cases II and III produce more conservative results than Case I.

SUMMARY

The basis for the load capacity of the seat angle in seated-beam connections has been reviewed. A comparison of the factored values to be found in the LRFD Manual to the allowable values in the ASD Manual range from about 1.5 to 1.8. The ratio of 1.5 reflects identical design conditions for a live load to dead load ratio of 3, as discussed in Ref. 4. The higher ratios, which tend to occur with the smaller beam-web thicknesses and heavier angles, reflect the effect of the more realistic multiplier for k in calculating the bearing length by the LRFD Specification ($N + 2.5k$ instead of $N + k$). Thus, the economy of the seated-beam connection should be enhanced in some applications. □

REFERENCES

1. *American Institute of Steel Construction, Inc.* Manual of Steel Construction *8th Ed., 1980, Chicago, Ill.*
2. *American Institute of Steel Construction, Inc.* Proposed Load and Resistance Factor Design Specification for Structural Steel Buildings *1985, Chicago, Ill.*
3. *American Institute of Steel Construction, Inc.* Manual of Steel Construction *6th Ed., 1969, Chicago, Ill.*
4. *Edinger, J. A.* Introduction to Proposed AISC Load and Resistance Factor Design Specification *AISC Engineering Journal, 1st Qtr., 1984, Chicago, Ill. (pp. 62).*

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