Design of Single Plate Framing Connections with A307 Bolts

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The analysis and design of single plate framing connections using A325 and A490 high-strength bolts was presented in Ref. 1 and design aids for this connection with these high strength bolts was presented in Ref. 2. Recent research completed at the University of Arizona has shown that A307 bolts may also be used in single plate framing connections if slotted holes are provided either in the beam web or the framing plate. The use of these bolts may result in a more economical connection design because field inspection is not required and, additionally, significantly less connection moment is developed.

A307 SINGLE BOLT SINGLE SHEAR TESTS

Using the test fixture designed for the high-strength bolt tests, which was described in Ref. 1, the test schedule shown in Table 1 was made to establish bolt-diameter-to-plate-thickness ratios (D/t) to circumvent bolt shear, and edge-distance-to-bolt-diameter ratios (e/D) to circumvent plate tension tearing. Just as with the high-strength bolts, if these two modes of failure are avoided, the ductile bearing mode of deformation results as desired.

The modes of failure for the test schedule of Table 1 are shown in Table 2. From these results, as summarized in Table 3, it is apparent that a D/t ratio of about 4 is required to prevent the bolt shear mode of failure for A307 bolts in A36 steel plates. For example, a 1-in. dia. A307 bolt would be required for a $1/4$-in. framing plate if standard holes are used. In view of these results, it is recommended that the A307 bolt be used only in slotted holes where the D/t ratio requirement does not apply.

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Table 1. Test Schedule for A307 Bolts in A36 Steel Plates

Plates		A307 Bolts*					
Material	Thickness	3/4	7/8	1	1 1/8	1 1/4	1 1/2
A36 Steel	1/4	X	X	X			
	5/16			X	X	X	
	3/8						X

*X = Tests (3 each)

Table 2. Failure Mode for A307 Bolts in Single Shear

Bolt Diameter, in.	Plate Thickness, in.	D/t	Failure Mode Test Number* 1	2	3
3/4	1/4	3.0	S	S	S
7/8	1/4	3.5	B	S	B
1	1/4	4.0	B	B	B-S
1	5/16	3.2	S	S	S
1 1/8	5/16	3.6	B	B	B
1 1/4	5/16	4.0	B	B	B
1 1/2	3/8	4.0	B	B	B

*B = Bearing Failure
S = Shear Failure

Table 3. Recommended D/t Ratios for A307 Bolts

Bolt Size, in.	Web or Plate Thickness, in. 1/4	5/16	3/8	7/16
1	4.0	3.2	2.7	2.3
1 1/8	4.5	3.6	3.0	2.6
1 1/4	5.0	4.0	3.3	2.9
1 1/2	6.0	4.8	4.0	3.4

From these studies it is recommended that the A307 bolt be limited to wide-flange sections up to and including W24 shapes. This limits the number of bolts used to 7 and a bolt depth pattern, h, of 18 in. For a W24 section that has a 30-ft span and is uniformly loaded to 1.5 times its service load, the end rotation is approximately

$$\phi_{simple} \approx \frac{2}{3}\frac{F_y L}{Ed} = \frac{2(36)(30 \times 12)}{3(30 \times 10^3)24} = 0.012 \text{ rad}$$

so that the deflection of the top bolt is

$$\Delta_{top\ bolt} \approx \phi_{simple}(h/2) = 0.012 \times (18/2) = 0.108 \text{ in.}$$

Therefore, short slotted holes, in general, would be adequate for designs using A307 bolts.

FULL SCALE BEAM TESTS AND RESULTS

The proposed use of A307 bolts in single plate framing connections with slotted holes was evaluated using the test apparatus shown in Fig. 1. This is the same test configuration used to evaluate and develop the design criteria for A325 and A490 bolts which was reported in Ref. 1.

A total of 15 tests were made using 7/8-in. dia. A307 bolts. Standard punched holes 15/16-in. in diameter were made in the beam, and standard long slots were made in the framing plate which was welded to a rigid support structure shown in Fig. 1. Tests were conducted with the bolts installed under normal field erection procedures, i.e., tightened to a snug fit with a spud wrench. Tests were also made, for comparative purposes, with the bolts simply finger tight (no wrench used).

Two different l/d ratios for the beam, 16 and 10, were used to assess end rotation effects on the eccentricity generated by this connection when the beam was loaded to 1.5 times its service load.

The results of these tests are summarized in Table 4. From these results, it is apparent that some eccentricity is developed and should be accounted for in the design of the plate weldment and its support. These tests result in a simple design aid, wherein the eccentricity for uniformly loaded beams may be calculated using the formula

$$e = \frac{nh}{384}\frac{l}{d}$$

where e is the eccentricity as measured from the bolt line to the point of inflection in the beam (as shown in Fig. 2), n is the number of bolts used, h is the height of the bolt pattern, l is the length of the beam and d is the depth of the beam. Test results indicate the formula is valid for a bolt pitch up to 6 in. For concentrated loads, the eccentricity coefficients presented in Ref. 1, Appendix A, should be applied.

It is noted that the moment generated by this connection is primarily a result of the clamping force between the connection plate and the beam web, since this moment is zero or very near zero for all the cases where the bolts were installed only finger tight. This observation is also consistent with the much higher moment that is developed by the torqued high-strength A325 and A490 bolts as reported in our earlier research studies.[1,3]

Since the moment is due to the clamping force and A307 bolts are tightened using a spud wrench, the above design formula should be valid for 3/4-in. dia. and 1-in. dia. A307 bolts, since the torque applied to these bolts would be about the same as that for the 7/8-in. dia. bolts used in the tests to derive this formula. Thus, this design formula may also be used for untorqued A325 and A490 bolts in slotted holes.

RECOMMENDED DESIGN PROCEDURE

Following is a detailed design procedure that is based upon the results of the experimental research study on single plate framing connections with A307 bolts.

1. Select plate thickness of supported beam web thickness ± 1/16-in.
2. Compute number of bolts required, based upon allowable beam shear and allowable bolt loads. Insure connection ductility by providing slotted holes with standard edge distances (AISC Specification Table 1.16.5.1).
3. Compute e, for which the uniform load case is

$$e = \frac{nh}{384}\frac{l}{d}$$

where

n = number of bolts
h = depth of bolt pattern
l = length of beam
d = depth of beam

4. Compute the moment at the weldment:

$$M = V(e + a)$$

where

V = beam shear force
e = eccentricity from Step 3
a = distance from the bolt line to the weldment, as shown in Fig. 2.

Table 4. Test Results

Test No.	No. of Bolts	l/d	$\frac{nh}{192}(l/d)$*	Experimental e_1	e_2	e_3
1	7	16	10.5	12.5	8.1	1.3
2	6		7.5	—	8.5	0.0
3	5		5.0	5.0	5.0	—
4	4		3.0	2.5	3.0	0.0
5	3		1.5	2.0	2.1	—
6	3 @ 6″		3.0	—	4.4	0.0
7	7	10	6.6	—	5.2	0.0
8	6		4.7	—	3.7	
9	5		3.1	—	1.7	
10	4		1.9	—	0.0	

Note: Results are for A307 bolts at 3″ pitch (except where noted). Tests e_1 and e_2 are with normally torqued bolts. Test e_3 is for finger-tight bolts.

*Coefficient (1/192) is applicable to mid-span concentrated load applied in the tests. The equivalent factor for a uniformly distributed load is (1/192) × (1/2) = (1/384) according to the eccentricity coefficients presented in Ref. 1, Appendix A.

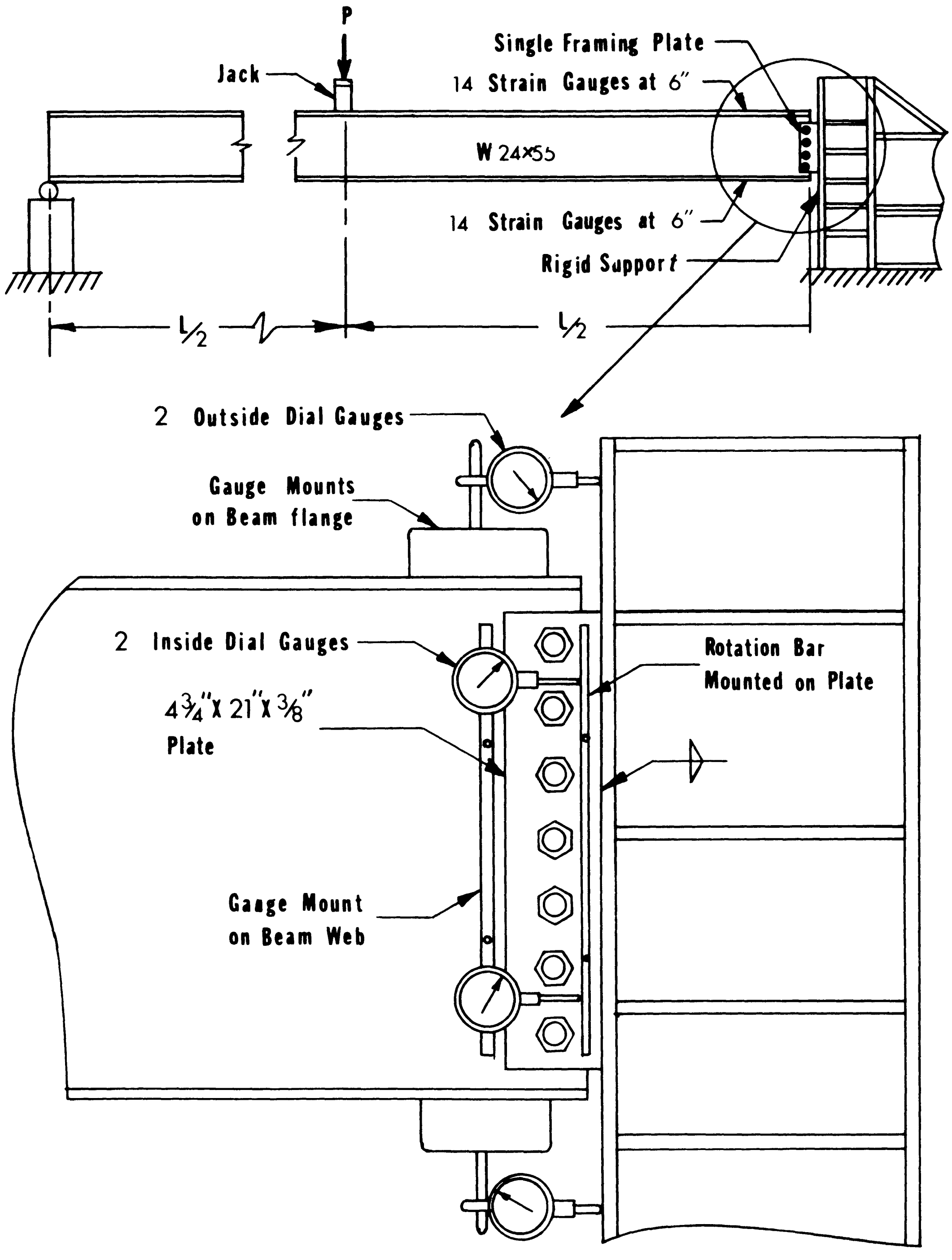

Fig. 1. Full scale beam test apparatus

5. Check the plate normal and shear stresses:

$$f_b = 6M/tb^2$$

$$f_v = V/bt$$

where t and b are the plate thickness and depth, respectively.

6. Design the weldment based upon the resultant of the normal and shear stresses from Step 5:

$$f_r = (f_b{}^2 + f_v{}^2)^{0.5}$$

7. Design support bracket including moment from Step 4 (see Fig. 3).

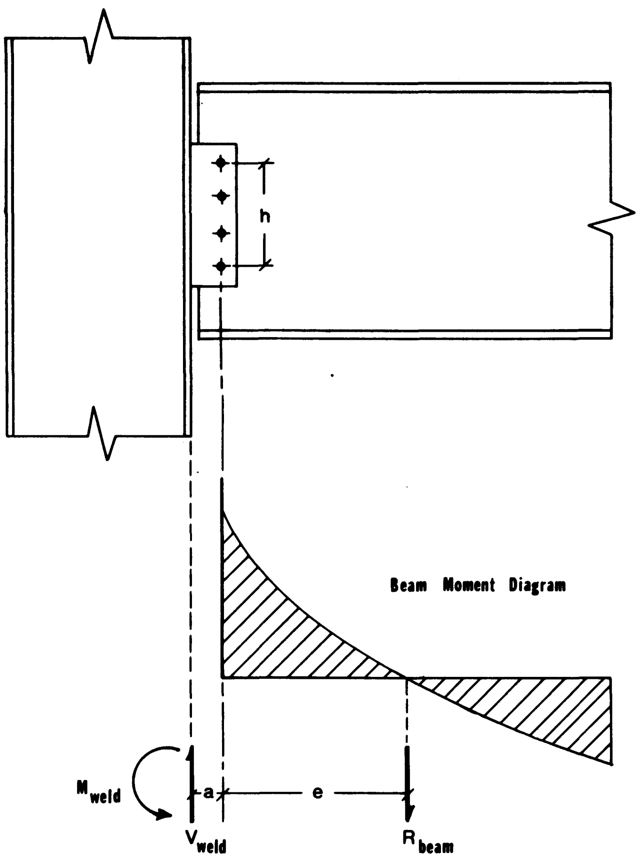

Fig. 2. Beam moment diagram

REMARKS ON THE DESIGN PROCEDURE

1. If according to Steps 2 and 6 a thinner plate will be adequate, such plate may be selected. Use A36 material.

2. The number of bolts computed here assumes equal shear in each bolt. This research has shown that this is not exactly true; however, by designing ductility into the connection through the prevention of bolt shear by means of slotted holes, adequate redistribution of the shear in the bolt pattern results in satisfactory connection performance at the bolt line. This design procedure is not applicable to single plate framing connections with A307 bolts in standard holes.

3. The design formula is independent of the bolt pitch up to 6 in. For concentrated loads, use the eccentricity coefficients of Ref. 1, Appendix A.

4. The distance from the bolt line to the weldment line, denoted here as a (see Fig. 2) is usually about 3 in.

5. Unlike the nearly uniform high-strength bolt force blocks evident in these types of connections, A307 bolts in slotted holes produce a relatively linear force

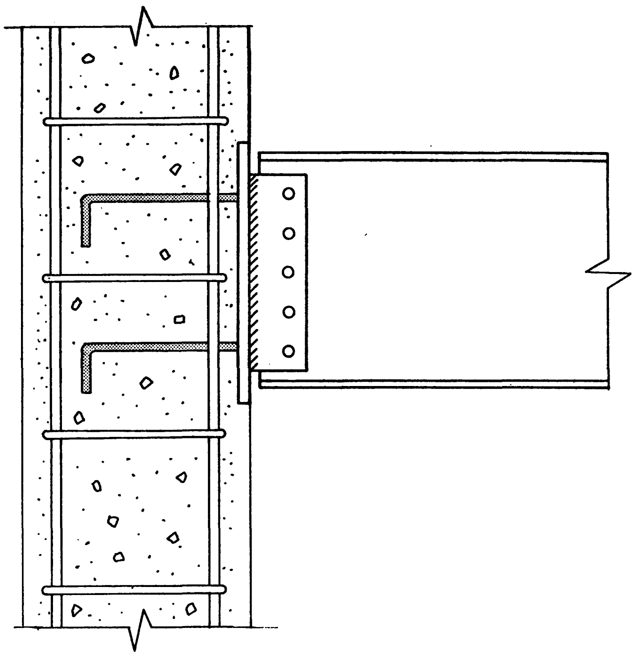
Fig. 3. Single plate application in mixed construction

distribution through the plate depth, due to the reduced clamping action. Thus, the elastic section modulus is appropriate for the latter case in the computation of the plate bending stress.

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APPENDIX A

Design Example

Given: W18 x 35, A36 steel
Span: 18 ft, laterally supported
Loading: Uniform with total load $W = 51$ kip

Solution:

1. Select $t_{plate} = 5/16$-in. ($t_{web} = 0.298$ in.)

2. Try $7/8$-in. A307 bolts, $R = 51/2 = 25.5$ kips

   $N_{req} = 25.5$ kips/6.0 kips = 5 bolts

3. For 3-in. pitch, $h = 12$ in.

   $$e = \left(\frac{5 \times 12}{384}\right)\left(\frac{18 \times 12}{18}\right) = 1.88 \text{ in.}$$

4. For $a = 3$ in., $V = R = 25.5$ kips

   $M = 25.5 \times (1.88 + 3) = 124$ kip-in.

5. $$f_b = \frac{6 \times 124}{0.312 \times 15^2} = 10.6 < 24 \text{ ksi}$$

   $$f_v = \frac{25.5}{0.312 \times 15} = 5.45 \text{ ksi}$$

6. $f_r = (10.6^2 + 5.45^2)^{1/2} = 11.9$ ksi

   $$\text{70XX weld req'd} = \frac{11.9 \times 0.312}{0.93}$$

   $$= 3.99 \text{ sixteenths}$$

   Use $1/8$-in. fillets each side.

7. Connection support bracket design should include consideration of connection moment, as illustrated in the mixed construction sketch shown in Fig. 3.