Cost Studies of High Strength Bolted Connections

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THE NEW HIGH STRENGTH bolt specification of the Research Council on Riveted and Bolted Structural Joints permits use of both ASTM A325 and ASTM A490 bolts in structural joints. The choice of which of these fasteners to use is essentially an economic decision.

If the time and effort that have gone into the development of the new specification are to be justified, the new rules should lead to more economical joint designs with high strength bolts. This paper is intended to assist the engineer and the fabricator to achieve more economical designs.

Cost comparisons between A325 and A490 joints are presented and discussed. Costs for producing holes and for installing bolts and washers were obtained from fabricators and erectors, and represent a cross section of cost information received. These costs vary from region to region, and even from fabricator to fabricator; however, it is believed that the cost comparisons achieved by the use of these average costs are valid.

COST STUDIES

Table 1 shows the design stress levels for the A490 bolt and the A325 bolt, based upon the Research Council specification. Table 2 summarizes the specification requirements indicating where and when washers should be used in high strength bolted connections. These provisions are the basis for the analyses that follow.

In the following examples, it should be noted that "bolt cost" includes the cost of both the bolt and the appropriate nut. Cost of washers is listed separately when washers are required.

Example 1—Compare the cost of an A325 bearing-type connection with that of an A490 bearing-type connection for the hanger connection shown in Fig. 1. The connected material is A36 steel, and all bolts are to be ¾-in. diameter. The hanger load P is 100 kips.

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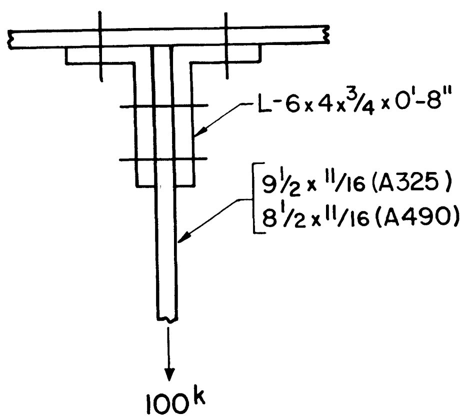

Figure 1

A325

Tension: $N = 100/17.67 = 5.7$, say 6 bolts
Shear: $N = 100/19.44 = 5.2$, say 6 bolts
12 @ 0.26 = \$3.12 (bolts)
12 @ 0.70 = 8.40 (installation)
\$11.52

A490

Tension: $N = 100/26.52 = 3.8$, say 4 bolts
Shear: $N = 100/25 = 4$
8 @ 0.35 = \$2.80 (bolts)
16 @ 0.03 = 0.48 (washers)
\$3.28
8 @ 0.90 = 7.20 (installation)
\$10.48

Note that no allowance has been made in this comparison for the difference in steel requirements. The A490 joint would require slightly less material (8½-in. plate instead of 9½-in.) because of the fewer number of bolts required. In this case the total installation cost for the A490 joint is approximately 10 percent less than that for the A325 joint. This points up the fallacy of a common opinion that A490 bolts are only economical when the connected material is A440 or A514 steel.

Example 2—Compare the cost of A325 and A490 friction-type connections in the truss chord splice shown in Fig. 2. The chord is a 14WF264 of A440 steel. The load on the splice is 1655 kips. Use 1 in. diameter bolts.

A325

$N = 1655/23.56 = 70$ bolts

140 bolts @ 0.85 =	$119.00
Splice plates: 1,185 lb @ 0.15 =	178.00
Total material	**$297.00**
Shop: 140 holes @ 0.25 =	35.00
Field bolting: 140 @ 0.70 =	98.00
Total labor	**$133.00**
Total	**$430.00**

A490

$N = 1655/35.34 = 47$ bolts (for symmetry use 50)

100 bolts @ $1.15 =	$115.00
100 washers @ 0.05 =	5.00
Splice plates: 1020 lb @ 0.15 =	153.00
Total material	**$273.00**
Shop: 100 holes @ 0.25 =	25.00
Field bolting: 100 @ 0.80 =	80.00
Total labor	**$105.00**
Total	**$378.00**

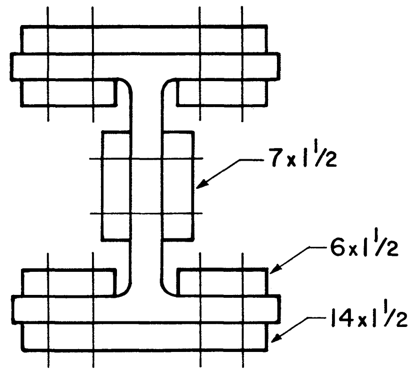

Figure 2

Note that there is relatively little difference in the actual cost of bolts. However, there is a marked difference in the cost of the splice plate steel required, again because less splice material is required with fewer bolts.

The unit cost for field bolting is estimated at $0.70 per bolt for the A325 and $0.80 per bolt for the A490, because one more washer is used with the A490 bolts. This relative cost is considered realistic. The total cost of all material and labor indicates a saving of approximately 12 percent when this splice is designed with A490 bolts instead of A325 bolts.

Table 1. Allowable working Stresses for Fasteners[a,b]

Loading Conditions	ASTM A325 Bolts		ASTM A490 Bolts	
	Bridges	Buildings	Bridges	Buildings
1. Applied tension, psi	36,000	40,000	54,000[c]	60,000[c]
2. Shear, psi				
(A) Friction-type connections	13,500	15,000	20,000	22,500
(B) Bearing-type connections shear plane through threads	13,500	15,000	20,000	22,500
(C) Bearing-type connections threads excluded from shear plane	20,000	22,000	29,000	32,000
3. Bearing, psi[d]	$1.22F_y$	$1.35F_y$	$1.22F_y$	$1.35F_y$

[a] The tabulated stresses, except for bearing stress, apply to bolts used in any grades of steel.
[b] There are certain variables and allowables for AREA and AASHO.
[c] Static loading only.
[d] F_y = specified minimum yield point of the lowest strength connected part. The bearing stress shall not be more than the specified minimum tensile strength of the lowest strength of connected material.

Table 2. Requirements for Washers

Strength of Steel Specified minimum yield point	A325 Bolt		A490 Bolt	
	Turn-of-nut	Cal. Wrench	Turn-of-nut	Cal. Wrench
Less than 40,000 psi	No washer	1 washer	2 washers	2 washers
Greater than 40,000 psi	No washer	1 washer	1 washer	1 washer

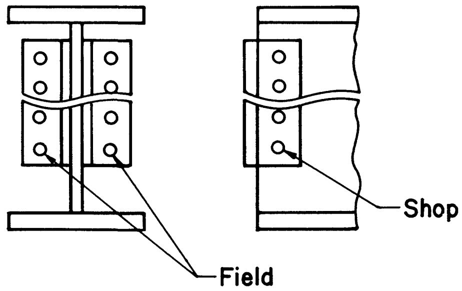

Figure 3

Example 3—Compare the cost of A325 and A490 connections, both friction-type and bearing-type, for the framed beam connection shown in Fig. 3. The beam is 36WF300 and is of A36 steel. The end reaction is 177 kips. Use ⅞-in. diameter bolts, installed by the turn-of-nut method.

A325 (No Washers)—⅞-in. dia. x 3 in.

	Friction	Bearing
N =	10	7
3N bolts @ 0.40	$12.00	$ 8.40
Washers	—	—
Angles* @ 0.10	4.48	3.11
Total material	**$16.48**	**$11.51**
N bolts shop @ 0.35	$ 3.50	$ 2.45
2N bolts field @ 0.70	14.00	9.80
Total labor	**$17.50**	**$12.25**
Total	**$33.98**	**$23.76**

A490 (2 Washers)—⅞-in. dia. x 3¼ in.

	Friction	Bearing
N =	7	5
3N bolts @ 0.55	$11.55	$ 8.25
Washers @ 0.04	1.68	1.20
Angles* @ 0.10	3.11	2.56
Total material	**$16.34**	**$12.01**
N bolts shop @ 0.45	$ 3.15	$ 2.25
2N bolts field @ 0.90	12.60	9.00
Total labor	**$15.75**	**$11.25**
Total	**$32.09**	**$23.26**

There is very little difference indicated in the overall cost of the finished connection when comparing either friction-type joints or bearing-type joints.

*N	A36 Steel	Weight
10	2 angles—4 x 3½ x ⅜ x 2 ft-5½ in.	44.8 lbs
7	2 angles—4 x 3½ x ⅜ x 1 ft-8½ in.	31.1 lbs
5	2 angles—4 x 3½ x 7/16 x 1 ft-2½ in.	25.6 lbs—

(*t* increased for shear)

Example 4—Make the same comparison as in Example 3, except that the beam is A440 steel instead of A36 steel, and the end reaction is 269 kips.

A325 (No Washers)—⅞-in. dia. x 3 in.

	Friction	Bearing
N =	16	10
3N Bolts @ 0.40	$19.20	$12.00
Washers	—	—
Angles* @ 0.15	11.01	6.72
Total material	**$30.21**	**$18.72**
N bolts shop @ 0.35	$ 5.60	$ 3.50
2N bolts field @ 0.70	22.40	14.00
Total labor	**$28.00**	**$17.50**
Total	**$58.21**	**$36.22**

A490 (1 Washer)—⅞-in. dia. x 3 in.

	Friction	Bearing
N =	10	7
3N bolts @ 0.54	$16.20	$11.34
Washers @ 0.04	1.20	84
Angles** @ 0.15	6.72	4.66
Total material	**$24.12**	**$16.84**
N bolts shop @ 0.40	$ 4.00	$ 2.80
2N bolts field @ 0.80	16.00	11.20
Total labor	**$20.00**	**$14.00**
Total	**$44.12**	**$30.84**

In this case there is an appreciable difference in total cost of the connection. In the friction-type connection with A325 bolts the total cost is $58.21 against $44.12 for the equivalent A490 connection. Similarly in the bearing-type connection the cost is $36.22 using A325 bolts, and $30.84 for the A490 connection.

Example 5—Consider a framed beam connection with a 12B22 of A36 steel and an end reaction of 37 kips. Use ¾-in. diameter bolts in a friction-type connection, installed by the turn-of-nut method.

A325 (3 Rows)

9—2 in. bolts @ 0.22	=	$1.98
2 angles—10.9 lbs @ 0.10	=	1.09
Total material	=	**$3.07**
3 bolts shop @ 0.35	=	$1.05
6 bolts field @ 0.70	=	4.20
Total labor	=	**$5.25**
Total	=	**$8.32**

**N	A440 Steel	Weight
16	2 angles—6 x 6 x ⅜ x 2 ft-5½ in.	7.34 lbs
10	2 angles—4 x 3½ x ⅜ x 2 ft-5½ in.	44.8 lbs
7	2 angles—4 x 3½ x ⅜ x 1 ft-8½ in.	31.1 lbs

A490 (2 Rows)

6—2 ¼ in. bolts @ 0.30	=	$1.80
12 washers @ 0.03	=	0.36
2 angles—7.1 lbs.		
@ 0.10	=	0.71
Total material	=	**$2.87**
2 bolts shop @ 0.45	=	$0.90
4 bolts field @ 0.90	=	3.60
Total labor	=	**$4.50**
Total	=	**$7.37**

The comparison indicates a small saving with A490 bolts.

Example 6—Many of the previous examples have been selected to show how A490 bolts can be used advantageously. However, the A490 bolt is not a panacea for all types of connections, it merely has its place along with A325 bolts, and each connection must be evaluated to determine which type of bolt is most suitable.

Consider a framed beam connection using a 10B17 of A440 steel, having an end reaction of 24 kips, and a two row friction-type connection, installed by the turn-of-nut method.

A325 (¾ in. dia., R = 26.5 kips)

6—2 in. bolts @ 0.22	=	$1.32
Total material	=	**$1.32**
2 shop bolts @ 0.35	=	0.70
4 field bolts @ 0.70	=	2.80
Total labor	=	**$3.50**
Total	=	**$4.82**

A490 (⅝ in. dia., R = 27.6 kips)

6—2 in. bolts @ 0.20	=	$1.20
6-washers @ 0.025	=	0.15
Total material	=	**$1.35**
2 shop bolts @ 0.40	=	0.80
4 field bolts @ 0.80	=	3.20
Total labor	=	**$4.00**
Total	=	**$5.35**

In this case ¾-in. diameter bolts were used for A325 and ⅝-in. diameter bolts were used for A490, and the A490 connection cost approximately 10 percent more than the A325 connection.

Example 7—Consider a plate girder splice of A36 steel, with a web of 70 in. x ½ in. and a flange 24 in. x 1⅛ in. Using ⅞-in. diameter bolts in a friction-type connection, compare the cost of an A325 connection with that of an A490 connection.

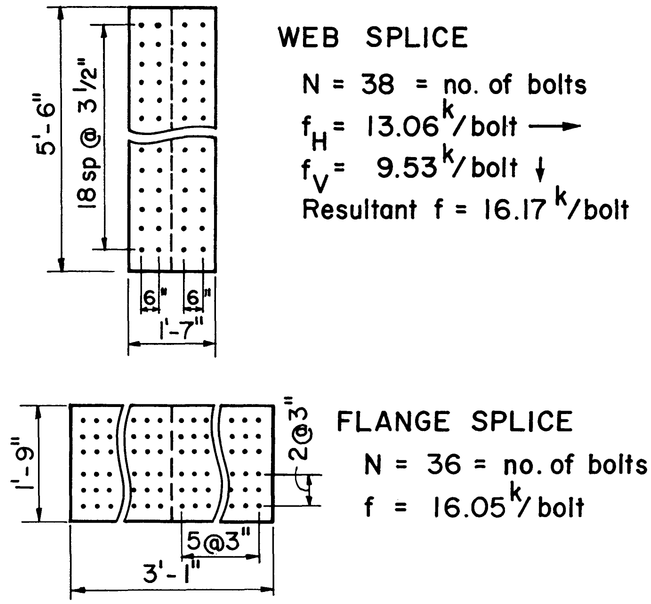

Figure 4

A325 (⅞-in. dia.) (see Fig. 4)

Design stress = 16.24 kips/bolt (13,500 psi—bridges)
Design stress = 18.04 kips/bolt (15,000 psi—buildings)

76—⅞ in. dia. x 2½ in. @ 0.38		=	$28.88
144—⅞ in. dia. x 4 in. @ 0.43		=	61.92
2 plates—19 x ⅜ x 5 ft-6	266 lbs		
2 plates—21 x ¾ x 3 ft-1	330 lbs		
4 plates— 9 x ⅞ x 3 ft-1	330 lbs		
0.15/lb x	926 lbs	=	138.90
Total material		=	**$229.70**
Shop: 220 holes @ 0.25		=	$ 55.00
Field bolting: 220 @ 0.70		=	154.00
Total labor		=	**$209.00**
Total			**$438.70**

A490 (⅞-in. dia.) (see Fig. 5)

Design stress = 24.05 kips/bolt (20,000 psi—bridges)
Design stress = 27.00 kips/bolt (22,500 psi—buildings)

52—⅞ in. dia. x 2¾ in. @ 0.52		=	$ 27.04
96—⅞ in. dia. x 4¼ in. @ 0.61		=	58.56
296 washers @ 0.04		=	11.84
2 plates—19 x ⅜ x 5 ft-6	266 lbs		
2 plates—21 x ¾ x 2 ft-1	224 lbs		
4 plates— 9 x ⅞ x 2 ft-1	224 lbs		
0.15/lb x	714 lbs	=	107.10
Total material		=	**$204.54**
Shop: 148 holes @ 0.25		=	$ 37.00
Field bolting: 148 @ 0.90		=	133.20
Total labor		=	**$170.20**
Total		=	**$374.74**

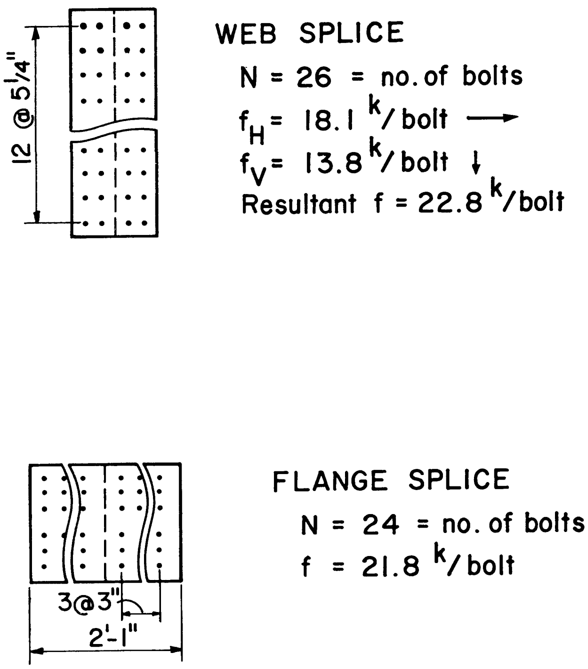

Figure 5

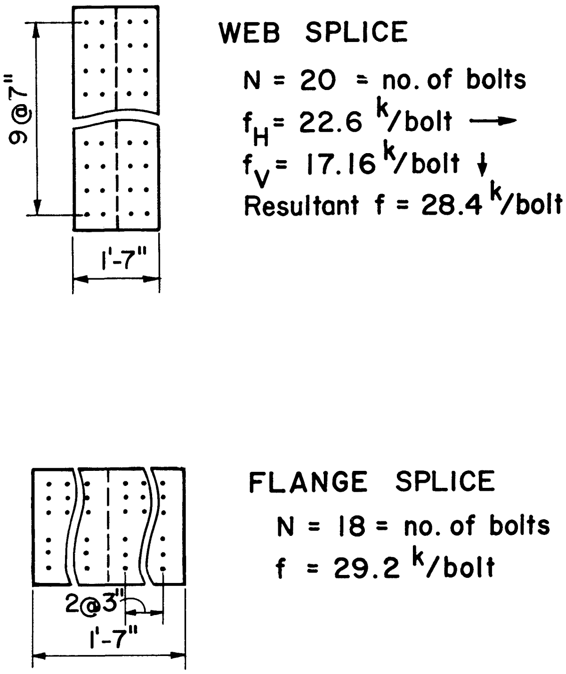

Figure 6

This example points out once again that the A490 bolt can be economical with A36 steel, despite frequently heard opinions to the contrary. Total cost with A490 bolts is $385.64, a saving of approximately $53.00 as compared to the total cost of the splice using A325 bolts.

Example 8—Consider the same splice as in Example 7, except that 1-in. diameter A490 bolts are used instead of ⅞-in. diameter A490 bolts.

A490 (1 in. dia.) (see Fig. 6)

Design stress = 31.40 kips/bolt (20,000 psi—bridges)
Design stress = 35.34 kips/bolt (22,500 psi—buildings)

40—1 in. dia. x 3 in. @ 0.76		= $ 30.40
72—1 in. dia. x 4½ in. @ 0.88		= 63.36
224 washers @ 0.05		= 11.20
2 plates—19 x ⅜ x 5 ft-6	266 lbs	
2 plates—21 x ¾ x 1 ft-7	170 lbs	
4 plates— 9 x ⅞ x 1 ft-7	170 lbs	
0.15/lb x	606 lbs	= $ 90.90
Total material		= **$195.86**
Shop: 112 holes @ 0.25		= $ 28.00
Field bolting: 112 @ 0.90		= 100.80
Total labor		= **$128.80**
Total		= **$324.66**

Most engineers think of the substitution of the A490 bolt for the A325 bolt in the sense that either a fewer number of the same diameter bolts or the same number of bolts of a smaller diameter will be required. Comparing Example 8 with Example 7, however, note that 112—1-in. dia. A490 bolts are compared with 220—A325 ⅞-in. dia. bolts and 148—⅞-in. dia. A490 bolts. The results are interesting and worthy of serious consideration. The cost for the 1-in. dia. A490 bolt and washer material ($104.96) is considerably higher than the bolt costs in the other splices. However, the splice material is considerably lower than that required with A325 bolts because, once again, the reduced number of bolts reduces the amount of necessary splice material. In turn, labor costs are decreased by reducing the number of holes that must be punched or drilled in the shop, as well as the number of holes that have to be filled in the field.

Assuming that this plate girder splice in A36 steel had originally been designed with ⅞-in. dia. A325 bolts, and one examined only the difference in *bolt costs*, it would seem that the use of either ⅞-in. dia. A490 bolts or 1-in. dia. A490 bolts would cost more. In fact, the use of 1-in. dia. A490 bolts would result in a bolt material *cost increase* of approximately 16 percent.

If, however, a more complete analysis of all material and labor involved in bolting this splice was undertaken, it would be found, as shown in these examples, that the switch from ⅞-in. dia. A325 bolts to 1-in. dia. A490 bolts would result in an *overall cost reduction* of 26 percent. The latter is the correct approach to the proper utilization of higher strength properties inherent in the A490 specification.

If, in addition, one were to compare the cost of the labor involved in preparing holes in the shop and bolting these connections in the field, it would be found that the use of fewer 1-in. dia. A490 bolts reduced labor cost by some 38 percent. Inasmuch as labor cost is closely related to time, it is apparent that there would be a direct money saving by using the higher strength bolts, and in addition, there would be time saving in the field which could significantly influence the total time required for the completion of the job.

One of the inherent advantages of steel construction is that in most cases it enables an income-producing structure to be completed sooner than a comparable concrete structure. Any reduction in time such as indicated above through the use of A490 bolts certainly would tend to compound this advantage.

CONCLUSION

The author believes that the figures presented in this paper show quite conclusively that it pays to take advantage of the time and money that have gone into the development of the new A490 Specification. The use of this high strength heat treated alloy structural bolt should not be construed as a panacea; however, careful analysis of *all* the cost factors involved in various connections will certainly indicate that in many cases the use of A490 bolts will lead to overall cost reduction.

Space Forms in Steel—A New Lecture Series

Unusual and dramatic roof structures are becoming increasingly popular as an architectural expression. In the belief that engineers and architects would like a review of the various structural design procedures, AISC is preparing a lecture series for presentation in major cities throughout the United States. This series, which is expected to begin in early 1966, will consist of five lectures:

Three Dimensional Roof Systems—A slide presentation depicting examples of various roof structures and an explanation of their basic design philosophies.

Two-Way Truss Systems—Simple grid systems will be solved by finite-difference and consistent-deflection analyses. The design of a simple two-way system will be included, utilizing the results of the analytical procedures.

Folded Plates—Simple procedures will be developed for the analysis of single- and multiple-bay, single span folded plate structures. Design theories for both membrane and truss-type folded plate elements will be developed and a design example of each type included as an application of the theory.

Hyperbolic Paraboloids—Analytical procedures for membrane and orthogonal grid hyperbolic paraboloid shapes will be reviewed. A design problem utilizing a light-gage deck membrane will be given. A design solution of a structural steel h-p grid problem will also be included.

Steel-Framed Domes—Several dome types will be surveyed. Design procedures will be suggested for Schwedler and Ribbed Domes, including practical design examples.