The Economic Impact of Overspecifying Simple Connections

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INTRODUCTION

An accurate and complete design will result in an economical and safe connection. Yet it is entirely common for the engineer of record to withhold, either intentionally or unintentionally, the information necessary to the fabricator or detailer to perform a design which is both accurate and complete. Specifically, actual reactions are seldom shown on the contract drawings from which the connections must be designed.[1]

AISC states, "For economical connections, beam reactions should be shown on the contract drawings. If these reactions are not shown, connections must be selected to support one-half the total uniform load capacity...for the given beam, span, and grade of steel specified."[2,3] No quantification is given, however, of the actual difference in economy between the two cases. In fact, this difference is somewhat elusive as it may vary greatly among specific examples. For the general case, however, it is possible to determine a reasonable estimate of the economic sacrifice incurred when a larger connection than required is used. The focus of this paper, then, is this economic sacrifice. For simplicity, a standard configuration[4] of the double angle connection will be considered in which only n, the number of bolt rows (and consequently, the length of the angles), varies. Based on values of n from 2 to 10, the cost of these standard connections will be estimated. Ranges of n compatible with each beam size group will be identified and the percent increase in cost which results when a larger connection than required is used will then be determined over these ranges.

Note that the practices which routinely result in uneconomical connection designs are not specifically addressed in this paper. For a discussion of these practices, the reader is referred to "Eliminating the Guesswork in Connection Design—Communication of Design Requirements Between Fabricator and Engineer is Crucial for a Safe and Economic Structure" by W.A. Thornton, in the June 1992 issue of *Modern Steel Construction*. Also not addressed is the effect of standardization on the detailing costs, ease of fabrication, and overall quality of the constructed product. While in general, standardization will reduce detailing costs, increase the ease of fabrication, and lead to improvements in quality because of decreased variability, these considerations are more project related than connection specific. Thus, it would not be feasible to consider their effect in this paper.

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THE STANDARD CONFIGURATION

The standard parameters of the double angle connection to be considered are as follows. The shop and field bolts will be ¾-in. diameter A325-N at 3-in. spacing with 1¼-in. edge distance. The holes will be short-slotted in the outstanding angle legs (those connected to the supporting member) and standard otherwise. The angles will be 2L 4×3½×⁵⁄₁₆ (SLBB). This standard configuration produces nine connections with the number of bolts rows n ranging from 2 to 10. While these connections will not satisfy every case, they will be adequate for the typical case and, therefore, will be used in this cost comparison.

CONNECTION COSTS

The costs which will be considered in this paper can be divided into three categories: material, shop labor, and field labor. The material costs include the cost of the bolts, washers and nuts, and the framing angles. The shop labor cost includes shearing and punching the angles, punching the supported and supporting members, and installing the shop bolts. The field labor cost is comprised of installing the field bolts. While material costs are readily available, labor costs are seldom a matter of public knowledge. Furthermore, labor costs will vary from fabricator to fabricator and from region to region. Consequently, those presented in this paper should be regarded as an average estimate and should by no means be construed to be universal. The fabricators' costs which will be used in this paper are as follows:

A325 tension control (TC) bolts	\$90.00 per 100 lbs.
L4×3½×⁵⁄₁₆	\$14.75 per 100 lbs.
Shop Labor	\$20.00 per hour
Field Labor	\$30.00 per hour

These are base costs; selling costs, which would include overhead and profit, would be higher.

The material and labor costs for double angle connections

Table 1. Material, Shop Labor, Field Labor, and Total Cost Estimates of Double Angle Connections in Standard Configuration								
n	L	Bolt Material Cost	Angle Material Cost	Shop Labor Time	Shop Labor Cost	Field Labor Time	Field Labor Cost	Rounded Total Cost
10	29½-in.	$22.50	$5.61	0.65	$13.00	2.65	$79.50	$121
9	26½-in.	$20.25	$5.04	0.60	$12.00	2.40	$72.00	$109
8	23½-in.	$18.00	$4.47	0.55	$11.00	2.15	$64.50	$ 98
7	20½-in.	$15.75	$3.90	0.50	$10.00	1.90	$57.00	$ 87
6	17½-in.	$13.50	$3.33	0.45	$9.00	1.60	$48.00	$ 74
5	14½-in.	$11.25	$2.76	0.40	$8.00	1.35	$40.50	$ 63
4	11½-in.	$9.00	$2.19	0.35	$7.00	1.05	$31.50	$ 50
3	8½-in.	$6.75	$1.62	0.30	$6.00	0.80	$24.00	$ 38
2	5½-in.	$4.50	$1.05	0.25	$5.00	0.55	$16.50	$ 27

in the standard configuration are summarized in Table 1. The bolt material cost is based on a bolt length of 3-in. with one washer and nut each; about 83 pounds per 100 count. The angle material cost is based on an angle size of 4×3½×5⁄16 which weighs 7.7 pounds per foot. The labor costs are based on the labor time estimates[4] summarized in the same table. Note that, in each row of bolts, there are three bolts: one shop bolt and two field bolts. Total costs have been rounded to the nearest whole dollar.

COMPATIBILITY WITH BEAM SHAPES

The deepest compatible standard connection must fit within the *T*-dimension of the beam as listed in Part 1 of the ASD and LRFD Manuals. As recommended in Part 4 of the ASD Manual and Part 5 of the LRFD Manual, the depth of the minimum standard connection should be greater than *T*/2. Given these limits, the compatibility of the nine standard connections with W-shapes is summarized in Table 2. Note that limitations such as coping, which may further restrict the maximum value of *n* are not considered.

PERCENT INCREASE IN CONNECTION COST

Given the allowable variations in *n* of Table 2, percent increases in connection cost per unnecessary row of bolts provided are listed in Figure 1. Cells below the heavy line fall outside the spacially permissible variations in *n* given in Table 2. As an example of the use of Figure 1, consider a W18×50 and assume an end reaction which would require four rows of bolts. Using five rows of bolts instead, the largest *n* possible given the *T*-dimension of a W18, would increase the connection cost by 26 percent. Similarly, using six rows of bolts in a W21×44 requiring only five rows would result in a cost increase of 17 percent.

Table 2. Compatibility of W-shape Beams and Standard Connection Depths			
Shape	Weight	n_{min}	n_{max}
W36	359-230 256-135	6 6	10 10
W33	354-118	6	10
W30	235-99	5	9
W27	217-84	5	8
W24	176-55	4	7
W21	166-44	4	6
W18	143-35	3	5
W16	100-26	3	4
W14	132-90 82-43 38-22	3 2 2	3 3 4
W12	87-40 35-14	2 2	3 3
W10	112-33 30-12	2 2	2 3
W8	67-24 21-10	2 2	2 2

Some general observations may be made from Figure 1. The predicted range of economic sacrifice when all beams and ranges of n are considered is from 11 percent to 85 percent. As the size of the beam being connected decreases, the percent change in cost increases. Additionally, and obviously, as the number of unneccesary bolt rows increases, so does the percent change in cost increase.

Focusing on the range of typical simple beam sizes, the variation in percent change can be narrowed. First, do not consider beams larger than a W24; from Table 2, this would eliminate the 8, 9, and 10 row connections. Additionally, consider only uniformly loaded cases, the designs of which are usually controlled by moment. The actual end reactions will likely be close to, but still less than, the end reactions calculated from the Design Uniform Load Tables.[4] Thus, in most cases, the number of unnecessary rows of bolts will be one. Accordingly, the cost increase given these limitations is between 13 percent and 41 percent.

It should not be forgotten, however, that there are many cases which cannot be classified as typical. Shorter span beams, often sized for convenience or for similarity to other beams, and in-fill beams, which may serve no other purpose than to reduce the unbraced length of another member, may sustain actual reactions which are significantly lower than one-half the the total uniform load capacity of the beam. A similar situation is found in beams controlled by deflection considerations. In these cases, the percent increase in economy can be much higher than the range identified as typical.

CONCLUSIONS

A generalized and simplified approach has been taken to estimate the added cost of providing more rows of bolts in a simple connection than were necessary. This approach was intended to estimate the possible economic implications when the engineer of record does not indicate the actual reactions for which the connections must be designed on the contract drawings. While this approach centered on the shop and field bolted double angle connection, this information is likely similar to that which might be obtained when other types of simple shear connections are considered. Given the potential for unnecessary increase in connection cost, the engineer of record should always indicate the actual reactions on the contract drawings. In this manner, the best opportunity for safe and economical connections will be realized.

REFERENCES

1. Thornton, W. A., "Eliminating the Guesswork in Connection Design—Communication of Design Requirements Between Fabricator and Engineer is Crucial for a Safe and Economic Structure," *Modern Steel Construction*, June 1992, p. 27.
2. American Institute of Steel Construction, *Manual of Steel Construction, Allowable Stress Design*, 9th Ed., Chicago, IL, 1989, pp. 4–9.
3. American Institute of Steel Construction, *Manual of Steel Construction, Load and Resistance Factor Design*, 1st Ed., Chicago, IL, 1986, pp. 5–15.
4. Carter, Charles J., "Standardizing Simple Shear Connections in Steel", *Master of Science Thesis*, Pennsylvania State University, University Park, PA, 1991.

Number of Bolts Rows Required \ Number of Bolt Rows Provided	10	9	8	7	6	5	4	3
9	11%							
8	23%	11%						
7	39%	25%	13%					
6	64%	47%	32%	18%				
5		73%	56%	38%	17%			
4				74%	48%	26%		
3						66%	32%	
2							85%	41%

Fig. 1. Percent increase in connection cost.