Simpler Shear Connections

Design procedures for single-plate shear connections have been expanded in the new *Manual* to incorporate a wider variety of geometric parameters.

BY CHRISTOPHER M. HEWITT

SINGLE-PLATE SHEAR CONNECTIONS, ALSO KNOWN AS SHEAR TABS, HAVE AS SIMPLE A GEOMETRY AS CAN BE HOPED FOR—a single rectangular plate of steel welded to a support on one end and bolted to a supported beam on the other. However, despite their very basic geometry and construction, understanding the actual performance of these connections can be somewhat complex. Unlike many of the other types of connections, shear tabs rely upon inelastic deformation to achieve the required rotation capacity of simple shear connections, making them difficult to model and evaluate accurately.

To assist designers in selecting and evaluating the strength of these connections, the *Steel Construction Manual*, 13th edition, now includes an easy to apply, step-by-step design procedure for single-plate shear connections in both their classic "conventional" form and in an "extended" geometry that was not previously addressed in AISC design procedures.

Like all simple shear connections, single-plate shear connections have some level of restraint and a corresponding eccentricity on the connection. This restraint is largely relieved before the connection reaches its ultimate strength through both elastic deformations, such as flexing of the plate and bending of the supporting member, and inelastic deformations associated with the movement of the bolts as they shift in the holes and then, as the ultimate load is approached, deform the bolt holes in the plate. Bolt plowing is the unique feature that allows shear tabs to function well beyond the rotational requirements of simple shear connection and is critical to understanding the performance of this connection type.

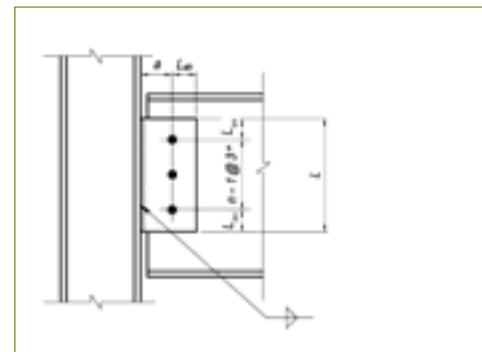### Conventional Single-Plate Shear Connections

The new design procedure for conventional single-plate shear connections is a refinement of methods of the past, and considers work done by Astaneh, Richard, Sherman, Sumner, U.S. Steel, and others. Components of each of these studies were used to develop a simplified procedure that may be applied in the design of single-plate shear connections with a single row of bolts and a distance from the support to the bolt line (a-distance) that is within 2½ to 3½ in.

Changes in the conventional single-plate connection design procedure from the previous *Manual* requirements include a reduction to the requirement for the design of the supporting welds, revised methods for considering connection eccentricity, removal of the distinction between flexible and rigid supports, and more restrictive horizontal edge distance and plate thickness limits to ensure that bolt plowing can occur in a predictable and controlled manner.

Weld Requirements

The *Manual* now recommends that double-sided fillet welds on conventional single-plate shear connections be sized as ⁵⁄₈ times the thickness of the plate—reduced from ¾ times the thickness of the plate as recommended in the previous edition of the *Manual*. In previous *Manuals*, the plate was sized to yield before the welds yielded. However, the AISC Committee on Manuals and Textbooks determined that weld fracture, being a better defined limit state, was more appropriate for this application and the procedure now recommends that the plate be designed to yield before the welds fracture. The adequacy of this liberalization in the design procedure was verified by testing at Virginia Tech.

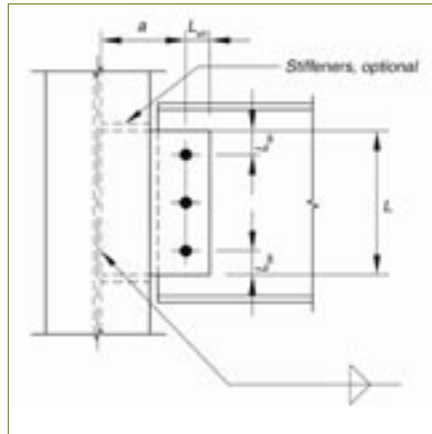### Horizontal Edge Distance and Plate Thickness Limits

The plate must be capable of withstanding the bolts plowing through the plate at ultimate load to ensure that adequate ductility remains after the connection reaches its elastic capacity. To ensure this is the case, either the plate or the beam web must be thin enough to deform before the ultimate shear strength of the bolts is reached and there must be sufficient edge distance for the deformation of the plate to occur. To satisfy both of these requirements, the plate thickness is limited to half the diameter of the bolt plus ¹⁄₁₆ in., and the edge distance from the center of the hole

to the edge of the plate must be at least two times the diameter of the bolt. Both of these detailing limitations will ensure that the bolt holes will have adequate deformation capacity. The mechanism of this deformation capacity will usually be a combination of hole elongation and arching of the plate material. Note that these deformations also tend to relieve the eccentricity of the connection.

Connection Eccentricity

The AISC *Specification* explains in Commentary Section C-J3.6 that the nominal shear strength of bolts includes a 20 percent reduction on the bolt shear strength, to account for the differential strain in long, end-loaded connections. This is done in the *Specification* to allow the bolts in connections less than 50 in. in length to be selected without explicit consideration of the length of the connection in evaluating bolt strength. While this simplifying assumption of the *Specification* is very useful to typical design practice, the reduction is not necessary for the case of shear connections, which are not end-loaded. Therefore, and based upon actual testing of single-plate connections, this 20 percent reduction can be removed when evaluating the ability of shear tab connections to reach their inelastically deformed state.

With 125 percent of the shear strength of the bolts used when considering the eccentricity of shear load, one can establish a range within which the effects of the eccentricity of the end reaction will not control the strength of the connection. The limitation on this eccentricity is reflected in the *Manual* design procedure by restricting the number of bolts in a single row. These limitations ensure that the empirically derived limits of eccentricity, found in the work of Astaneh and Sumner, can be accommodated. Outside of these limitations, connection eccentricity must still be considered, as outlined in the design

procedure found in Part 10 of the *Manual*, though use of the increased shear strength of the bolts discussed above is permitted. A significant simplification of the *Manual* procedure results.

Support Rigidity

Previous editions of the *Manual* presented different equations for the location of the eccentric force based on the rigidity of the support. Further investigation of these equations determined that the eccentricity equations included conservatism to account for the serviceable rotation of the connection, and that the support condition did not effect the connection strength. Therefore, in the new design procedure, the strength of the connection is based on a single method for any support type and the serviceability of the connection is to be considered by the engineer as it would be for any other type of simple shear connection.

Extended Single-Plate Shear Connections

New to the *Manual* is a general design procedure for extended single-plate shear connections. The design procedure may be used for any geometry of single-plate shear connection that does not meet the geometrical restrictions of the "conventional" single-plate shear connection design pro-

cedure, such as connections with multiple rows of bolts and/or longer distances from the support to the bolt line than would be permitted with the conventional procedure. The procedure is one of many design methods that have been developed for this connection type and was chosen for publication in the *Manual* because of its broad applicability to current design practice. Other methods of designing extended single-plate shear connections are permitted when justified by rational analysis.

Designers of extended single-plate shear connections have always been primarily concerned that the rigidity of the connection may allow a substantial unanticipated moment to be developed in the connection and transmitted to the supporting member. The new design procedure provides a conservative method of design for these connections, when simple shear performance is required.

Unique features of this design procedure include simplifying assumptions when some of the detailing requirements of conventional single-plate shear connections can be accommodated to relieve eccentricity, limits on the size of the plate to ensure that the eccentricity is relieved, a plate buckling check, a check for bending and shear interaction on the plate, and consideration of support rotation.

Plate Thickness Limits

In the extended configuration, to ensure that bolt fracture under eccentric load is not a controlling limit state, the strength of the bolt group in shear is kept greater than the moment strength of the plate. This is achieved by limiting the thickness of the plate to

$$t_{min} = \frac{6M_{min}}{F_y d^2}$$
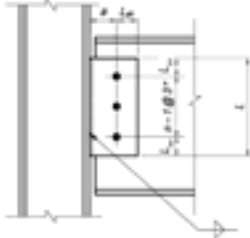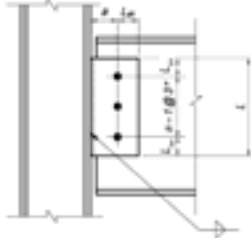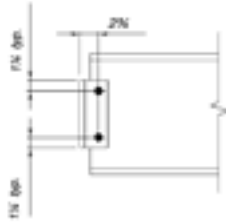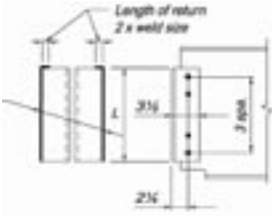
where

$$M_{max} = 1.25 F_v A_b C'$$

The factor C' is a coefficient that represents the moment-only case for the instan-

Comparison of Simple Shear Connection Design Strengths

It is interesting to note that single-plate shear connections, while considerably stronger in the *Manual*, 13th edition, than permitted by the previous edition, are now very close in their predicted strength to bolted/welded single angle connections for shallow connection geometries. Here is a snapshot of some similar simple shear connections and their relative LRFD design strengths.

Assumptions
→ ¾ in. A325-N bolts in standard holes and with conventional gages.
→ ASTM A36 connection material for connections with angles.

Conventional Single-Plate Shear Connection *Steel Construction Manual*, 13th edition		Conventional Single-Plate Shear Connection *LRFD Manual*, third edition		Bolted/Welded Single Angle Connection		Bolted/Welded Double Angle Connection, Case II	
$^5/_{16}$ in. plate, weld size = $^5/_8 t_p$ = ¼ in.		$^5/_{16}$ in. plate, weld size = $^3/_4 t_p$ = ¼ in.		L4×3×$^3/_8$, ¼ in. welds		$^5/_{16}$ in. angle thickness, ¼ in. welds	
3 rows of bolts	47.7 k	3 rows of bolts	27.8 k	3 rows of bolts	47.7 k	3 rows of bolts	48.1 k
7 rows of bolts	111 k	7 rows of bolts	96.4 k	7 rows of bolts	111 k	7 rows of bolts	187 k
12 rows of bolts	178 k	12 rows of bolts	165 k	12 rows of bolts	191 k	12 rows of bolts	366 k

taneous center of rotation of the bolt group. This factor may be found in the vertical load (θ = 0) cases of instantaneous center of rotation tables in Part 7 of the *Manual*. By limiting the plate to this thickness, plate yielding is accommodated before the fracture of the bolt group would occur under any location of load eccentricity.

Plate Buckling, Force Interaction, and Support Rotation

The buckling strength, force interaction, and support rotation of extended single-plate connections are all checked using general connection design techniques, as outlined in Part 9 of the *Manual* and reiterated in the design procedure for these connections in Part 10. The plate buckling check is the general plate bucking approach adopted into the new edition of the *Manual*. The interaction check is a simple von Mises force interaction check, and support rotation, while an important design consideration for long connections such as this one when a support is loaded on a single side, must be considered as it would be for any other kind of simple shear connection. When designing using this procedure, support rotation is a serviceability concern, rather than a strength limit.

The design procedures for conventional and extended single-plate shear connections discussed in this article are presented in their entirety in the new *Manual*, beginning on page 10-101. The design procedures reflect substantial effort by the AISC Committee on Manuals and Textbooks to evaluate all known previous design methods and tests conducted on these connections since the 1960s and reduce them into a single, simplified method. The study resulted in the new refined design method of the *Manual*, which is both technically rigorous and simple to apply in engineering practice. **MSC**

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