DESIGNING HSS CONNECTIONS

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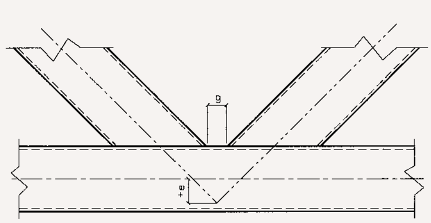
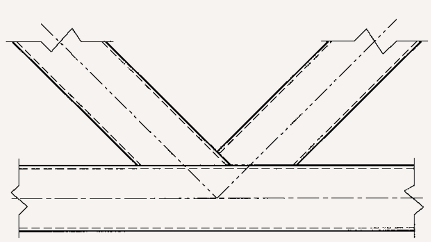
Hollow structural sections (HSS) are being used more and more often in building construction. A synergy between this increased use and the advances in connection design has resulted in new HSS design specifications and connection design aids.

There are two primary reasons to use HSS in building construction: standard structural applications where their use results in cost savings (typical applications are columns or beams that are unbraced and/or bi-axially loaded), and architectural or aesthetic appearance. Both of these applications are primarily the result of the closed shape of the HSS. This closed shape is also what makes HSS connections unique and often challenging to design and fabricate. When HSS are used for architectural applications and appearance becomes a design constraint, it becomes even more challenging to design a connection that is economical to fabricate and erect.

Almost all of the current HSS connection design methods and specifications are based on research done outside of the United States. A group of international HSS producers, CIDECT, gathered information and issued Monograph No. 6 in 1986 giving a state of the art approach to welded HSS connections. The International Institute of Welding (IIW) has been working with CIDECT to develop HSS design knowl-

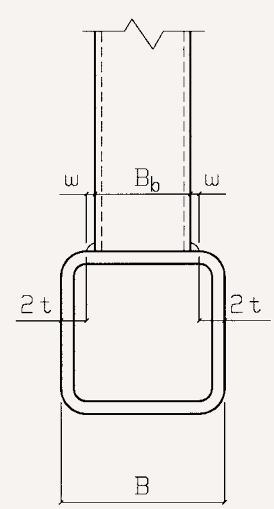


Gapped K Connection



Overlapped K Connection

Figure 1.



Stepped Connection

Figure 2.

edge into a specification format, and their design recommendations form the basis of most specifications. North American research on HSS connections has been lead by Professor J. A. Packer of the University of Toronto. The Canadian Institute of Steel Construction publication, "Hollow Structural Section Connections and Trusses—A Design Guide" by J. A. Packer and J. E. Henderson, is regarded as the primary reference for design information on HSS connections.

Until very recently the only specification for design of HSS connections in the United States was found in the American Welding Society (AWS) D1.1 Structural Welding Code—Steel. The AWS provisions for design of tubular connections are similar to IIW/CIDECT recommendations.

The AISC Specification for The Design of Steel Hollow Structural Sections published in 1997 along with the AISC "Hollow Structural Sections Connection Manual" was a major step towards bringing comprehensive HSS connection design information to engineers in the United States. The AISC HSS Connections Manual provides design procedures and a series of connection design tables for a variety of HSS connections. Included are simple shear connections, moment connections, tension and compression connections, cap and base plate connections along with welded truss connections. HSS cross-section properties in the manual are based on the actual wall thickness being 93% of the nominal thickness per the AISC Specification Section 1.2.2. This reduction in thickness, which is permitted by ASTM A 500, has become standard practice.

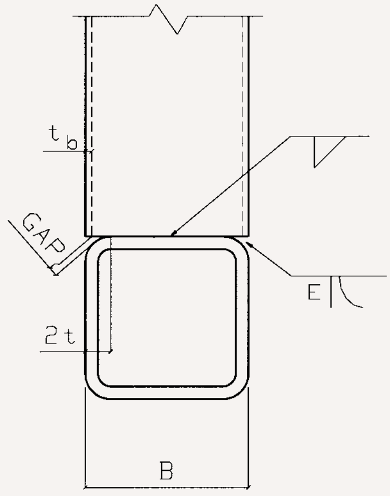
Connections to HSS almost always require some type of welded connection. Even where bolts are used to make the field connection, it is usually necessary to weld some type of detail material to the HSS. The strength of a connection welded to the face of an HSS is primarily a function of the geometric parameters of the connection and cannot be increased by simply increasing the weld strength. However, the weld strength must be adequate to accommodate the highly non-uniform load distribution along the weld length due to the varying stiffness across the wall of the HSS. Unlike open sections, such as wide flange shapes, it is not possible to add a stiffener to the backside of the connection to provide a more uniform load transfer. Instead, the weld must be designed to ensure that yielding and redistribution will occur in the base metal, thereby allowing the weld to develop the required design load before reaching its ultimate breaking strength.

Direct Welded Connections

The most common direct welded connections are axially loaded truss type members forming joints in a T, Y or K configuration. The connection strength, as noted above depends on the geometric parameters of the members, and therefore it is important that the designer choose member sizes with the connection design as part of the selection criteria. The main member or chord should always be checked to make sure the wall thickness is adequate for all of the connection forces delivered by branch member.

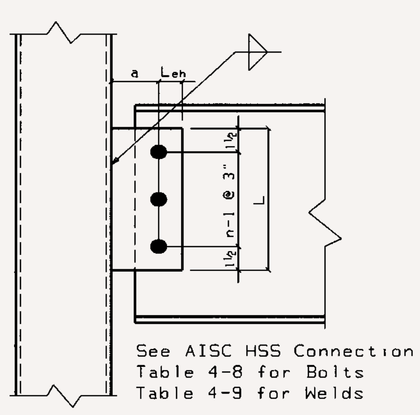
The joint configuration for K type truss connections can be classed as gapped or overlapped and as stepped or matched as shown in Figures 1, 2 & 3. The AISC HSS Specification currently only provides design rules for gapped type connections. Overlapped connections should only be considered where branch loads are so large they require some type of load transfer directly between branches. Gapped connections are more economical to fabricate because they require only a single bevel cut and the gap allows fit up tolerance. The gap also permits the entire truss to be assembled before welding, which helps to reduce cost.

Matched connections require a flare-bevel-groove weld that, depending on the corner radius of the chord, may require some type of steel backing or a special backing weld to close the root of the joint. Flare-bevel-groove welds are relatively inefficient because of the limited effective throats allowed for AWS pre-qualified joints. It is possible to qualify these welds with a much larger effective throat by following the



Matched Connection

Figure 3.



Single-Plate Connection

Figure 4.

procedure qualification provisions of D1.1. Procedure qualification should be considered if the effective throat of the pre-qualified joint is not adequate for the design loads.

Stepped connections are more economical to fabricate than matched connections because they permit the use of fillet welds. The chord and branch member sizes should be selected to allow the fillet welds to be placed on the flat of the chord. The chord width should be approximately the branch width plus four times the chord wall thickness plus two times fillet weld size. If the leg of the fillet weld does extend slightly onto the corner radius, it is still possible to get the required effective throat by modifying the weld profile.

Direct welded HSS connections must have enough strength to provide for the non-uniform distribution of load along the weld length at the required load. This can be accomplished by either providing welds that will develop the yield strength of the branch before rupturing or by sizing welds using the "effective weld length" concept in the AISC HSS Specification section 9.2. The design procedure for developing the branch strength is covered in the AWS D1.1 provisions. The effective weld length procedure is preferred because it is based on actual member loads and results in more economical weld sizes, but it is applicable only to rectangular HSS connections.

The effective weld length formulas were developed by Packer and are based on extensive physical tests of HSS joints. More recent work by Packer indicates that the AISC provisions are conservative because they are based on the rectangular dimensions of the HSS in calculating the effective length instead of the actual weld length. The AISC HSS Specification also does not permit the use of the fillet weld increase in strength due to the direction of the load that is allowed by AISC LRFD Specification Appendix J2.4, while Packer's work again indicates this increase can be used.

The weld strength required is determined by dividing the design load in the member by the effective length calculated per the appropriate formula in Section 9.2. The same strength weld is required around the entire perimeter of the member even though the effective length maybe substantially less. Fillet welds the preferred weld detail to use for these joints. When detailing fillet welds on surfaces that do not intersect at 90 degrees the weld size or joint detail should be modified to provide the required effective throat. Complete joint penetration (CJP) welds should be avoided in these truss type joints. Except for joints subject to cyclic loading, CJP details are not required. Truss type joints because of the geometry do not permit the use of steel backing. CJP welds that are made without backing require special welder qualifications, special fit-up and require special inspection procedures. It is possible to develop the required connection strength for most HSS using fillets welds and/or partial joint penetration welds.

The preferred HSS truss joint is gapped, stepped and fillet welded with the welds sized using the "effective weld length" procedure.

Welded / Bolted Connections

The most important advance in HSS connection economy has been the development of the HSS single plate framing connection by Dr. Donald R Sherman of the University of Wisconsin at Milwaukee. The single plate connection shown in Figure 4 is the most economical way to connect a wide flange beam to HSS columns and beams. The fabrication cost of a single plate connection is less than $^1/_4$ the cost of the old through plate connection and substantially less than a WT or a double angle connection. Single plate connections can be used as long as the wall of the HSS is not classed as a slender element. For A500 Grade B material the b/t ratio must be 35 of less.

When the reaction is larger than what a single plate connection can carry, the next choice is usually a double angle connection shop welded to the HSS. Stiffened seats welded to the wall of the HSS can also be used.

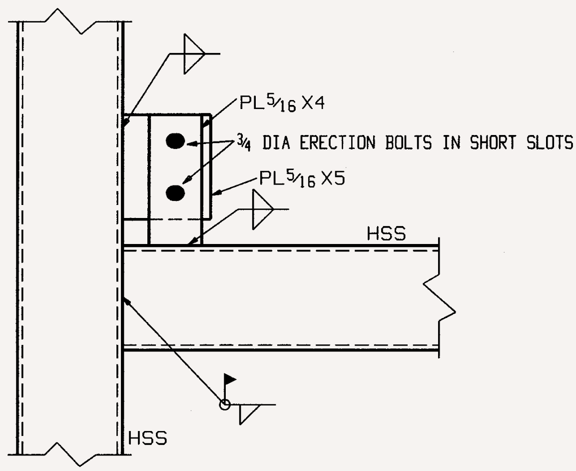
The AISC HSS Connections Manual also gives a procedure for sizing column cap plates supporting beams and joist girders. If the reaction is within the face of the HSS, the load is delivered in direct bearing to the wall of the HSS, and the controlling limit state is either the local yielding or crippling of the wall of the HSS. Increasing the plate thickness will only increase the bearing length slightly and result in only a minimal increase in strength.

Through-bolting of HSS is not very practical. Holes in the HSS have to be manually drilled, the bolt lengths required exceed normal stock lengths and the bolt is difficult to install. When designing through bolts, it is important to remember that the snug tight requirements of the AISC Specification requires all plies in the connection to be in firm contact. This is not possible with an HSS unless some type of interior fill is used. The AISC HSS Specification treats through bolts as pin type connections with reduced bearing values. It is suggested through bolts be used only for erection aids with oversize holes or slots to allow for easier field fit-up.

Architecturally Exposed Connections

When HSS are used for aesthetic or architectural reasons, the connections are often specified to be welded connections. Connections that are field welded usually require some type of temporary bolted erection aid (connection) to locate and support the member until it can be welded. These connections, including the one shown in Figure 5, are the means and methods of construction and not part of the permanent structure. Therefore, the structural engineer does not normally design these connections or may not even indicate they are required. This can lead to possible conflicts when the fabrication and erection is bid separately. The design drawings should at least indicate that erection aids are to be provided as necessary to allow for the erection and field welding. If it is possible to locate these connections so they can remain and be part of the finished structure the structural engineer should show this on the connection details.

Project specifications should reference the Architecturally Exposed Structural Steel (AESS) provisions in the AISC Code of Standard Practice. Often project specifications have provisions that require "all welds to be ground." Grinding welds, especially fillet welds, is expensive and usually does not improve the appearance. The AESS provisions require "reasonably smooth and uniform welds." Where multi-pass fil-



HSS to HSS Erection Connection

Figure 5. Note: Erection connection is only for locating and supporting HSS member. All field welds must be completed before any other load is applied. After field welding HSS, remove plate connection and grind flush.

HSS CONNECTION TIPS

- The single plate connection shown in Figure 4 is the most economical way to connect a wide flange beam to HSS columns and beams.
- The design drawings should at least indicate that erection aids are to be provided as necessary to allow for the erection and field welding.
- Grinding welds, especially fillet welds, is expensive and usually does not improve the appearance.

let welds are used and a special appearance is required, it is more economical to dress the surface with a plastic filler material like those used in auto repair. The use of a joint mockup is often helpful in establishing reasonable appearance standards for exposed welds. The architect should be required to view the mockup from the same distance he or she will see the finished weld in the structure. This same mockup can be sectioned to verify the effective throats of the various weld details.

HSS Connection Design References

There have been significant advances in HSS connection design in recent years that make the design process more user-friendly and the fabrication and erection more economical. The HSS connection manuals published by CISC and AISC can be ordered from their web sites: www.cisc-icca.ca and www.aisc.org. In addition to these key references, structural engineers designing truss type connections m ight find a new computer program by the University of Toronto Tube Group helpful. This Windows-based program covers a wide variety of truss connections in metric or U.S. customary units. For more information, e-mail Professor Jeffrey Packer at packer@ecf.utoronto.ca.

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