Recommended Effective Throat Sizes for Flare Groove Welds to HSS

JEFFREY A. PACKER and GEORGE S. FRATER

Flare groove welds arise when a convex surface makes up the joint preparation in a partial-joint-penetration (PJP) groove weld (see Figure 1). These welds occur when one or both components of a joint consist of a round bar or 90° bend in a formed section, for example a hollow structural section (HSS). The fabrication of HSS structures involves joints where flare bevel (Figure 1a), and to a lesser extent, flare-V (Figure 1c) groove welds are common. The deposition of sound weld metal to the bottom of the flare is very difficult because the welding puddle bridges between the two surfaces and then penetration into the root is inhibited. Hence, the extent of root penetration in flare bevel groove welds is dependent on the angle between the fusion faces, and therefore the outside corner radius or profile of an HSS is a major parameter determining the geometry of the weld. With the quality of the weld being difficult to control, specifications in many cases require the fabricators to demonstrate the effective weld throats being produced by sectioning random sections of production welds for each weld procedure. By performing trial welds and sectioning, larger effective weld sizes can be justified relative to values given in specifications that provide pre-qualified PJPs, thereby allowing higher joint design loads, however extra costs will be incurred in the fabrication stage. In general there is a tendency for flare groove welds to be oversized and "filled flush" (see Figure 2).

In the case of equal-width rectangular HSS welded joints, considerable cost would go into qualifying welds at truss joints. For example, when sections of differing wall thickness are joined the resulting interface between one tube's corner radius (truss chord member) and the wall of the other tube (truss web member) necessitates a costly adjustment of the root gap. Three options are available to the fabricator to close the root of the joint: (i) profile shaping one of the tubes, (ii) building out with weld metal to produce a "backing" weld, and (iii) using a backing steel element (AISC, 1997). If the tubes have equal wall thickness the root gap

will become more favorable for welding, however if the outside corner radius (R) approaches the upper limit (in other words, three times the nominal wall thickness (ASTM, 2001)), then backing would be required and joint welding would become expensive.
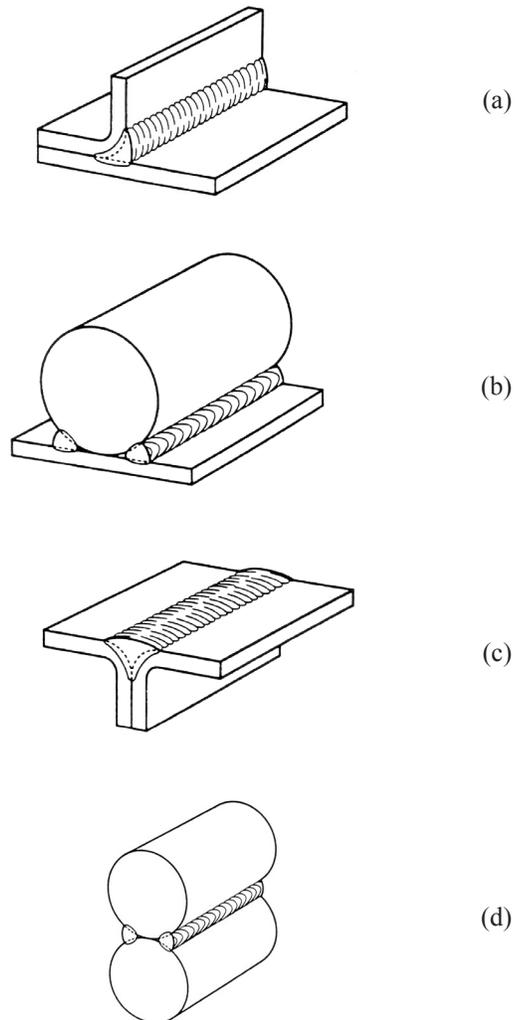

Fig. 1. Flare Groove Welds (CSA, 1989; 2003), (a) Flare Bevel Groove Weld (HSS & Plate), (b) Flare Bevel Groove Weld (Round Bar & Plate), (c) Flare-V Groove Weld (Two HSS), (d) Flare-V Groove Weld (Two Round Bars).

Jeffrey A. Packer is professor, department of civil engineering, University of Toronto, Toronto, Ontario, Canada.

George S. Frater is codes and standards engineer, Canadian Steel Construction Council, Toronto, Ontario, Canada.

**Table 1. Effective Throat Thickness, for Welds Filled Flush, according to
AISC ASD (AISC, 1989) & LRFD (AISC, 1999b), Table J2.2**

Type of Weld	Radius of Bar or Bend (R)	Effective Throat Thickness
Flare bevel groove	All	⁵⁄₁₆ R
Flare V-groove	All	½ R [a]
[a] Use ⅜ R for Gas Metal Arc Welding (except short circuiting transfer process) when R $\geq$ 1 in. (25 mm)		

Three specifications listed below give the following design guidance for flare welds:

AISC ASD (AISC, 1989) and LRFD (AISC, 1999b)

Both AISC design specifications establish the effective throat thickness of a flare groove weld, when the weld is flush (tangent) to the surface of a bar or 90° bend in a formed section (see Figure 3), as a ratio of radius to effective throat, as shown in Table 1.

Further to the table, the specifications state the following:

"Random sections of production welds for each welding procedure, or such test sections as may be required by design documents, shall be used to verify that the effective throat is consistently obtained. Larger effective throat thicknesses than those in Table J2.2 are permitted, provided the fabricator can establish by qualification the consistent production of such larger effective throat thicknesses. Qualification shall consist of sectioning the weld normal to its axis, at mid-length and terminal ends. Such sectioning shall be made on a number of combinations of material sizes representative of the range to be used in the fabrication or as required by the designer."

AWS D1.1/D1.1M:2004

Similar to the AISC specifications, the AWS D1.1 specification in Section 2 under design of welded connections, provides Table 2 for effective weld size, E, of flare groove welds when filled flush to the surface of round bar, a 90° bend in a formed section, or a rectangular tube.

One difference between the AISC and AWS tables is in the ⅜R weld size for the GMAW process which is stated to occur when $R \geq 1$ in. (25 mm) in the AISC specification while in the AWS specification it is shown to occur when R is ½ in. (12 mm) or greater.

Section 3 of AWS D1.1, namely Figure 3.3, shows welds that are prequalified and allow a fabricator to avoid the cost associated with qualification procedures required by welding authorities. The flare-bevel groove weld size, E, is expressed as a function of wall thickness, in other words,
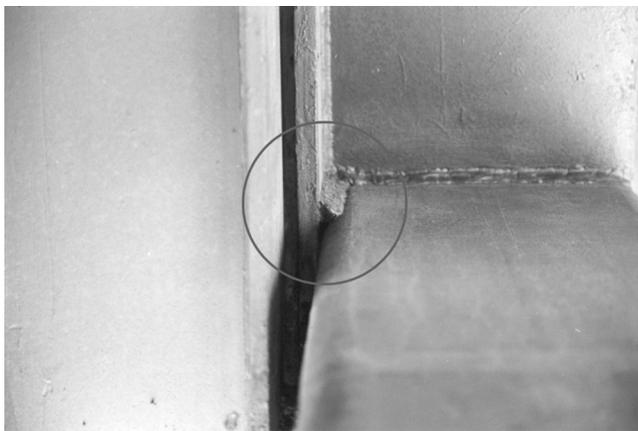

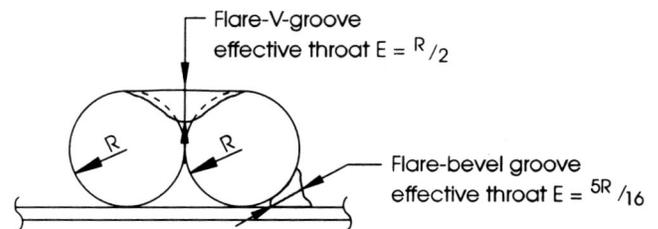*Fig. 2. A Flare Bevel Groove Weld in an HSS Structure.*

Fig. 3. AISC Flare Weld Nomenclature (AISC, 1997; 1999a).

Table 2. Effective Throat Thickness, for Welds Filled Flush, According to AWS D1.1/D1.1M:2004, Table 2.1

Flare-Bevel-Groove Welds	Flare-V-Groove Welds
$^5/_{16}$ R	½ R *
* Use • R for GMAW (except GMAW-S) process when R is ½ in. (12 mm) or greater.	

**Table 3. Effective Throat Thickness, for Welds Filled Flush,
According to CSA W59 (CSA, 1989), Table 4.1**

Flare-Bevel-Groove Welds	Flare-V-Groove Welds
All Diameter Bars	
0.3R	½ R *
Not applicable to GMAW using the short-circuiting transfer mode of metal deposition. * Except 0.4R for GMAW process with bar sizes 25 mm (1 in.) and over. Note: R = radius of bar.	

$E = {}^5/_8 T$ and is equivalent to those in Section 2 of the standard if the nominal relationship holds for the corner radius, in other words, $R = 2T$. That AWS figure includes a "bend radius", C, with a minimum of $(3/2)T$, however it is not limited to this value and has been shown to be as low as $C = T$. This dimension acknowledges the true geometry of cold-formed sections where the corner curvature may not be a 90° quadrant of a circle tangent to the sides, and the corner dimension, C, can be less than the radius of the corner.

CSA W59 (CSA, 1989)

In CSA W59 Section 4.3.1.6, effective throats are prequalified for flare bevel and flare-Vgroove welds on solid bars but not for HSS. For HSS the effective throat thickness of flare-V and flare bevel groove welds needs to be established by the fabricator by means of trial welds and sectioning. The prequalified effective throat thickness for flare groove welds on solid bars is similar to the AISC and AWS specifications and is presented in Table 3.

CSA W59 (CSA, 2003)

A new 8th edition of CSA Standard W59 has recently been published. The section on flare welds has been completely rewritten and expanded significantly to cover flare bevel and flare V-groove welds in butt joints and flare bevel groove welds in T-joints with several configurations of both being taken as prequalified.

The W59 standard defines the flare bevel groove weld in a T-joint as a joint configuration formed between a member with a curved surface and a surface of a planar member (see Figures 4 and 5). The flare-V groove weld in a butt joint results when two curved surfaces make side-by-side longitudinal contact such as the joints formed by side-to-side contact of two round bars or two HSS members, as shown in Figure 6.

The concept of a flare bevel fillet weld is introduced for the first time. For round bars with radii less than or equal to $^3/_8$ in. and for HSS with wall thicknesses less than or equal to $^3/_{16}$ in. (or radii less than or equal to $^3/_8$ in.), T-joint welds may be designed and detailed as flare bevel fillet welds, and this has now been incorporated into the W59 standard. The root of such a fillet weld is assumed to be the intersection of the planar surface and a tangent to the curve of the flare that is perpendicular to the planar surface (see Figure 4).

In the new CSA W59, for T-joints with round bars having radii greater than $^3/_8$ in. and square/rectangular HSS members having radii greater than $^3/_8$ in., a prequalified flare bevel groove weld need not be filled flush to the tangent of the curve of the flare that is perpendicular to the planar surface (see Figure 5). A designer has the option to consider a weld within the flare, flush with it or extended beyond it by means of a fillet. For design purposes, the effective throat shall be indicated by specifying a weld face, W, greater than or equal to a factor of δ times the required effective throat, E, subject to the following criteria:

a. for the SMAW process: factor $\delta = 1.7$ (see Figure 5)

b. for the SAW, FCAW, MCAW and GMAW processes: factor $\delta = 1.5$ (see Figure 5)

**Table 4. Effective Throat Thickness, for Welds Filled Flush,
According to CSA W59 (CSA, 2003), Table 4.1**

Flare-Bevel-Groove Welds	Flare-V-Groove Welds
0.3R	0.5R *
Not applicable to GMAW using the short-circuiting transfer mode of metal deposition.	
* Except 0.375R for GMAW process with R $\geq$ 12 mm (½ in.)	
Note: R = radius of round bar, tubing, or measured corner radius of HSS member.	

c. the effective throat shall be indicated on the welding symbol in brackets to the left of the flare bevel weld symbol and the weld face width (W) noted below the flare bevel symbol (see Figure 5). A detail showing the weld face should be provided on the shop drawing.

For flare bevel groove welds in T-joints using round bars, tubing or HSS members, when filled flush to the surface of the round bars, tubing or HSS members, the effective throats are as shown in Table 4.

CSA S16 (CSA, 2004)

The latest version of the Canadian steel structures design standard for buildings (CSA, 2001) is about to have a supplement issued, S16-04. In this, the effective throat of a flare bevel groove weld is given as 0.5 of the width of the flare bevel groove weld face. This has the effect of rounding up the values of $\delta = 1.7$ or $\delta = 1.5$ (see above and Figure 5) to $\delta = 2.0$. This reduces the effective throat size relative to CSA W59 (CSA, 2003) but is a more conservative approach and is deemed to result in a structural reliability index (β) of 4.0.

Jaxa-Rozen (2001), a member of both the CSA W59 Standard Committee and AWS D1.1 Design Subcommittee, has also presented a variation of this design concept utiliz-

ing the weld face, which is in use as an internal specification at Bombardier Transportation, Canada.

EXPERIMENTAL WORK

The objective of the research project was to examine flare groove weld geometries more closely and see from the deposited welds the relationship among three different variables: HSS wall thickness/corner geometries, different weld processes and welding position. From the research results,
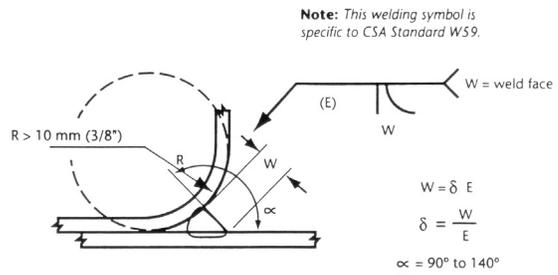

Fig. 5. CSA W59 (2003), Figure 4.5, Partial Joint Penetration Flare Bevel Groove Weld in a T-Joint (CSA, 2003).
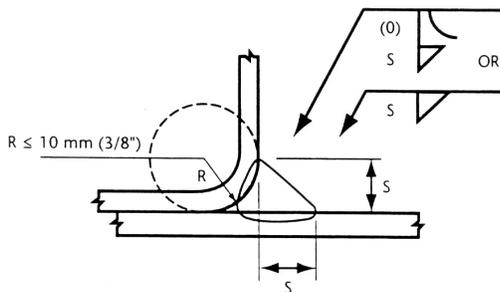

Fig. 4. CSA W59 (2003), Figure 4.4, Flare Bevel Fillet Weld in a T-Joint (CSA, 2003).
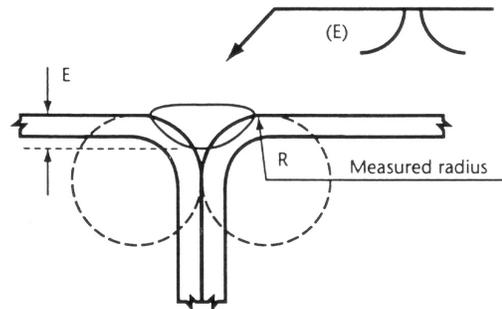

Fig. 6. CSA W59 (2003), Figure 4.6, Partial Joint Penetration Flare-V Groove Weld in a Butt Joint (CSA, 2003).

Table 5: Test Specimen Summary for HSS 4 x 4 x ³⁄₁₆

HSS Size (in.)	Weld Process	Specimen No.	Weld Type	Weld Position	Weld No.	No. of Weld Cross-sections
4 x 4 x ³⁄₁₆	FCAW-G	1	FB	H	1	3
			FB	V	2	3
			FV	F	3	2
			FV	V	4	2
		2	FB	OH	5	3
			FV	OH	6	2
	FCAW-S	3	FB	H	7	3
			FB	V	8	3
			FV	F	9	2
			FV	V	10	2
		4	FB	OH	11	3
			FV	OH	12	2
	GMAW	5	FB	H	13	3
			FB	V	14	3
			FV	F	15	2
			FV	V	16	2
		6	FB	OH	17	3
			FV	OH	18	2
	SMAW	7	FB	H	19	3
			FB	V	20	3
			FV	F	21	2
			FV	V	22	2
		8	FB	OH	23	3
			FV	OH	24	2
TOTALS	4	8	2	4	24	60

the aim of the study was to quantify the weld effective throat size (or *Z* loss dimension) by joint variables for specific welding situations, thereby allowing prequalified joints having a larger limit on effective throats.

The HSS sizes for the study consisted of three sections representing a range of corner geometries due to varying corner profile (see Tables 5 to 7). The acquisition of material was from two Canadian HSS producers and STI member companies. Material for the study was cold-formed, square HSS to ASTM A500 Grade C (F_y = 50 ksi nominal). Pre-fabrication of 24 tacked specimens was done at the University of Toronto laboratories. Specimens were one foot in length for welds produced in the flat, horizontal and vertical positions and one-and-a-half feet in length for welds produced in the overhead position. For the HSS-to-HSS-to-plate assemblies a ½ in. thick plate was used on one side of the HSS. After the specimens were tacked, test weld numbers as shown in Tables 5 to 7 were punched in multiple locations along HSS walls adjacent to the flare bevel or flare-V groove joint.

Four weld processes, namely FCAW-G (with shielding gas), FCAW-S (without shielding gas), GMAW (spray mode) and SMAW were used to make the test welds, using just single pass welds. These processes are the predominant processes used in the welding of such joints by fabrication shops. Welding parameters, or Welding Procedure Specifications (WPSs) associated with each particular process (see Tables 8a and b) were prescribed to reflect prevalent shop practices, and were the result of considerable consultation amongst the project Oversight Committee. The final WPSs were targeted to be "somewhat below the median" (in other words, conservative) for a typical fabrication shop. In summary, each HSS size was used to produce eight flare bevel and flare-V groove welded specimens made by four different weld processes and four different welding positions (horizontal (H), flat (F), vertical, up or down (V) and overhead (OH)).

Final welding of the HSS-to-HSS-to-plate assemblies, for the study of flare bevel and flare-V groove welds was carried out by Walters Inc., a fabricator certified to CSA

Table 6: Test Specimen Summary for HSS 4 x 4 x ¼

HSS Size (in.)	Weld Process	Specimen No.	Weld Type	Weld Position	Weld No.	No. of Weld Cross-sections
4 x 4 x ¼	FCAW-G	9	FB	H	25	3
			FB	V	26	3
			FV	F	27	2
			FV	V	28	2
		10	FB	OH	29	3
			FV	OH	30	2
	FCAW-S	11	FB	H	31	3
			FB	V	32	3
			FV	F	33	2
			FV	V	34	2
		12	FB	OH	35	3
			FV	OH	36	2
	GMAW	13	FB	H	37	3
			FB	V	38	3
			FV	F	39	2
			FV	V	40	2
		14	FB	OH	41	3
			FV	OH	42	2
	SMAW	15	FB	H	43	3
			FB	V	44	3
			FV	F	45	2
			FV	V	46	2
		16	FB	OH	47	3
			FV	OH	48	2
TOTALS	4	8	2	4	24	60

W47.1-92 (CSA, 1992). During the study, the Authors supervised the production of all test welds. All welds were made by a certified welder and visually inspected by a certified inspector. Prior to depositing a particular test weld the welding engineer and welder performed trial welds to verify the welding parameters. Over each particular weld length, the travel speed was noted. The complete documentation for each test weld is available in the form of 72 Procedure Qualification Record (PQR) sheets, which are a part of the Final Report on this project (Packer and Frater, 2003). As an aid to collecting welding parameters, the welding engineer supplied a computerized data acquisition system. Figure 7 shows the welding of a particular specimen in the overhead position.

After the production of fully-welded test specimens, each was ready for saw-cuts and this was carried out by Walters Inc. at the fabrication plant. Tables 5 to 7 summarize the total number of weld cross sections for measurement (180). Subsequent to the welding phase, all test specimen material was returned to the University of Toronto laboratories where all 180 test weld cross sections were ground and pol-

ished with an industrial die grinder then macro-etched using an etchant referred to as 10 percent Nital (made using proportions of 180 ml ethyl alcohol and 20 ml nitric acid). The
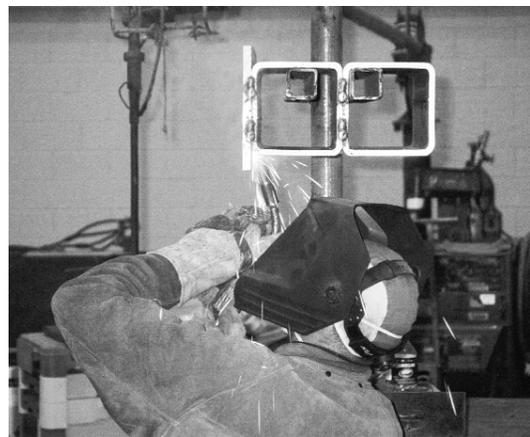

Fig. 7. Overhead Welding of a Test Specimen at Walters Inc.

Table 7. Test Specimen Summary for HSS 6 x 6 x ⅜

HSS Size (in.)	Weld Process	Specimen No.	Weld Type	Weld Position	Weld No.	No. of Weld Cross-sections
6 x 6 x ⅜	FCAW-G	17	FB	H	49	3
			FB	V	50	3
			FV	F	51	2
			FV	V	52	2
		18	FB	OH	53	3
			FV	OH	54	2
	FCAW-S	19	FB	H	55	3
			FB	V	56	3
			FV	F	57	2
			FV	V	58	2
		20	FB	OH	59	3
			FV	OH	60	2
	GMAW	21	FB	H	61	3
			FB	V	62	3
			FV	F	63	2
			FV	V	64	2
		22	FB	OH	65	3
			FV	OH	66	2
	SMAW	23	FB	H	67	3
			FB	V	68	3
			FV	F	69	2
			FV	V	70	2
		24	FB	OH	71	3
			FV	OH	72	2
TOTALS	4	8	2	4	24	60

welding engineer provided technical advice on these two procedures.

All cross sections, prior to etching, received a punched test weld number adjacent to the weld itself to carry on the permanent record of test weld numbers within the photographic image that was used in the measurement phase. This photographic digital image was created by setting the actual HSS-to-HSS-to-plate saw-cut test pieces (after polishing and etching the weld measurement area) directly on a scanning machine. Figures 8 and 9 show two scanned images for test weld numbers 17C and 59C; in other words, flare bevel groove welds made on HSS 4×4×³/₁₆ and HSS 6×6×³/₈ test specimens, respectively. It is noteworthy to mention the large difference in the Z-loss factor between the two test welds. The Z value is quite large for test weld number 59C, made by the FCAW-S process in the overhead position, and for test weld number 17C, a small Z dimension is evident, also made in the overhead position, however utilizing the GMAW process. The letters A, B and C distinguish between the three different cross sections for each particular test weld made in the 12 in. or 18 in. long joints.

The etched cross sections, as shown in Figures 8 and 9, allow one to examine the degree of root penetration and the heat-affected zone (HAZ).

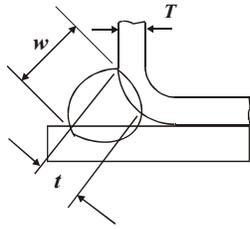*Fig. 8. Scanned Image of Test Weld No. 17 Cross-section.*

Table 8a. WPS for Flare Bevel Groove Welds (Tee Joints) before Trial Welding

Weld Process	Position	Electrode Diameter (in.)	WFS (in./min.)	Current (Amps)	CTTWD[a] (in.)	Voltage (Volts)
FCAW-G Lincoln 71M (E71T-9 with CO_2)	H (2G)	1/16	225	250	¾	26-28
	V (3G) - Up	1/16	150	200	¾	22-24
	OH (4G)	1/16	225	250	¾	26-28
FCAW-S Lincoln NR232	H (2G)	0.072	200	275	¾	20-23
	V (3G) - Up	0.072	170	250	¾	20-21
	OH (4G)	0.072	170	250	3/4	20-23
GMAW (ER70S-6 with C-10)	H (2G)	0.045	325	250	1/2	26-28
	V (3G) – Down	0.045	325	250	1/2	26-28
	OH (4G)	0.045	325	250	1/2	26-28
SMAW (E7018)	H (2G)	1/8	N/A	125	N/A	N/A
	V (3G) - Up	1/8	N/A	125	N/A	N/A
	OH (4G)	1/8	N/A	125	N/A	N/A

[a] Contact Tube to Work Distance

The next phase of the project involved the measurement of weld profile dimensions and angles from 180 photographic scanned images. As indicated in Tables 5 to 7 the flare bevel test welds had three cross-sections, and flare-V test welds had two cross sections, from which a small statistical evaluation of weld dimensions along a length of weld could be made. Weld and HSS dimensions were measured using AutoCAD 2000 drafting software. Using the digitized ruler within each scanned image as a reference length, a scaling factor was applied to the image to regenerate the image into its actual size. A "spline" command was used to contour the corner profile of the HSS. This involved drawing a part circle by specifying three points along the HSS corner arc. A series of trials were needed before the best-fit circle could be obtained, from which the corner geometry could be established; in other words, the corner radius R, and the *Bend* angle (angle of corner circular arc between two HSS straight faces).

The weld profile data measured can be summarized as follows:

Z = Z loss factor (in.)
E = effective throat (in.)
R = HSS corner radius (in.)
T = HSS wall thickness (in.)
W = dimension of weld face (in.)
Bend = angle of HSS corner between two flat sides of an HSS (degrees)

For flare bevel welds only, an additional two measurements were reported, as follows:

Alpha = angle between weld face and plate (degrees)
S = leg dimension of weld along plate (in.)

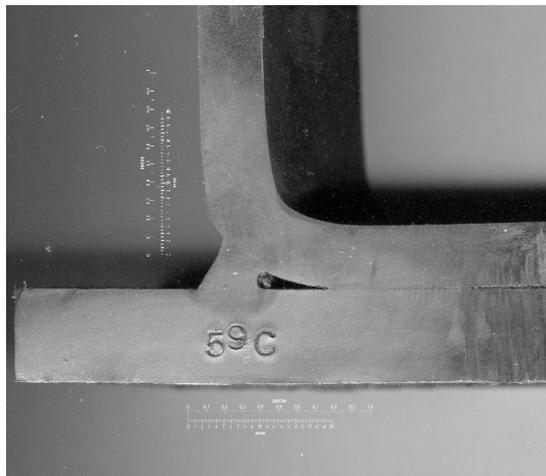A typical example for the above dimensions is shown for a flare bevel weld in Figure 10.

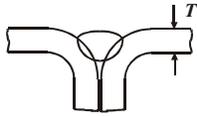*Fig. 9. Scanned Image of Test Weld No. 59 Cross-section.*

Table 8b: WPS for Flare-V Groove Welds (Butt Joints) before Trial Welding

Weld Process	Position	Electrode Diameter (in.)	WFS (in./min.)	Current (Amps)	CTTWD[a] (in.)	Voltage (Volts)
FCAW-G Lincoln 71M (E71T-9 with CO_2)	F (1G)	1/16	225	250	3/4	26-28
	V (3G) - Up	1/16	150	200	3/4	22-24
	OH (4G)	1/16	225	250	3/4	26-28
FCAW-S Lincoln NR232	F (1G)	0.072	200	275	3/4	20-23
	V (3G)- Up	0.072	170	250	3/4	20-21
	OH (4G)	0.072	170	250	3/4	20-23
GMAW (ER70S-6 with C-10)	F (1G)	0.045	325	250	1/2	26-28
	V (3G) - Down	0.045	325	250	1/2	26-28
	OH (4G)	0.045	325	250	1/2	26-28
SMAW (E7018)	F (1G)	1/8	N/A	125	N/A	N/A
	V (3G) - Up	1/8	N/A	125	N/A	N/A
	OH (4G)	1/8	N/A	125	N/A	N/A

[a] Contact Tube to Work Distance

PROCESS	TYPE	POSITION	HSS SIZE	SECTION	UNIT	T_{avg}
FCAW-G	FB	HORIZONTAL	4x4x1/4	25A	INCH	0.240
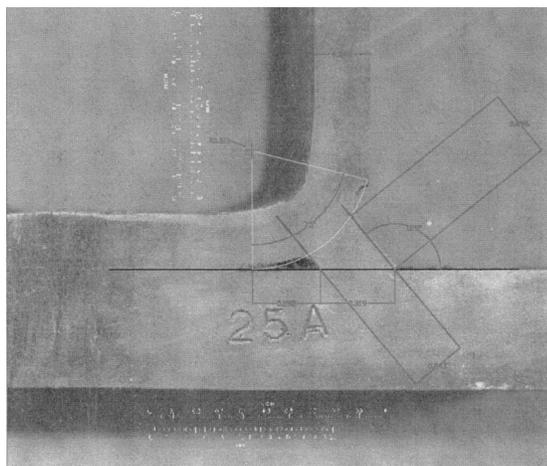
Z	S	R	BEND	E	W	ALPHA
0.292	0.319	0.511	75	0.247	0.296	129

Fig. 10. Typical Data Sheet for Measured Weld Dimensions of a Flare Bevel Weld .

EXPERIMENTAL RESULTS

HSS geometric properties, namely *T, R, Bend* and *R/T* ratio for the three HSS sections used in the test program are given in Table 9. Statistical values for average and standard deviation were determined from a population size of 60 for *T* and 84 for both the *R* and *Bend* values. Additional data for *R* and Bend angles was due to having two measurements taken from each flare-V cross section; in other words, from two HSS on either side of a flare-V weld.

It can be seen in Table 9 that the measured wall thickness, *T*, for these three HSS, in all cases exceeds the $0.93T$ "design thickness," prescribed by AISC (AISC, 1997). The corner or *Bend* angle was, on average, 72.7°, which is considerably less than the popularly assumed corner radius of 90°. Thus, the corner radius in modern HSS does not meet the flat of the section at a tangent. The corner radius-to-thickness ratio shown in Table 9 varies considerably, but one company produced the HSS 4×4×^{3}/$_{16}$, whereas a different company produced the other two.

Values of *Z, S, W* and *E* recorded for flare bevel welds are averages from three measurements, while the *Z, W* and *E* values recorded for flare-V welds are averages from two measurements. The 36 values of *Z* for flare bevel welds, and the 36 values of *Z* for flare-V welds, are presented in histogram format in Figure 11. The histograms are shaded to identify the particular HSS. The *Z* values in the flare-V

Table 9. HSS Geometric Properties

HSS Size (in.)		4 x 4 x ³⁄₁₆	4 x 4 x ¼	6 x 6 x ⅜
Thickness – T	Average (in.)	0.183	0.241	0.372
(n=60)	Std. Dev. (in.)	0.001	0.001	0.001
Radius – R	Average (in.)	0.445	0.466	0.716
(n=84)	Std. Dev. (in.)	0.022	0.028	0.048
Bend (HSS corner)	Average (deg.)	76.2	72.3	69.5
(n=84)	Std. Dev. (deg.)	2.1	2.2	1.3
Bend Angle – average (degrees)		72.7		
T/T $_{nominal}$		0.976T	0.964T	0.992T
R/T		2.43	1.93	1.92

histogram show the majority (10 of 12) of the *Z* values measured on HSS 4×4×¼ welds to be all greater than those measured on the other two HSS. This has occurred because the HSS 4×4×¼ was found to have a bowed or convex side-wall and this exacerbates the *Z*-dimension. Histograms of *E*, for the 36 flare bevel and 36 flare-V welds, are shown in Figure 12 and are again shaded to identify the three HSS sizes.

ANALYSIS OF RESULTS

For the purpose of making a direct comparison of test data to AWS rules, for flare bevel and flare-V effective throats filled flush to the HSS face, a predicted AWS value for *Z* can be back-calculated from the AWS effective throat formulas, which are:

- for Flare Bevel Welds: $E = {}^5/_{16} R$, for all HSS

- for Flare-V Welds: $E = \frac{1}{2} R$, for HSS 4×4×³⁄₁₆ and HSS 4×4×¼ (see Table 9 for average *R*)

- for Flare-V Welds: $E = {}^3/_8 R$, for HSS 6×6×³⁄₈ with GMAW (see Table 9 for average *R*)

If one considers the summation of *Z* and *E* to be equal to the corner radius, for welds "filled flush", and assuming a 90° corner radius, the following predicted *Z* can be determined:

- for Flare Bevel Welds: *Z* (predicted) or $Z_{AWS} = {}^{11}/_{16}$ R, for all HSS

- for Flare-V Welds: *Z* (predicted) or $Z_{AWS} = \frac{1}{2}$ R, for HSS 4×4×³⁄₁₆ and HSS 4×4×¼ (see Table 9 for average *R*)

- for Flare-V Welds: *Z* (predicted) or $Z_{AWS} = {}^5/_8 R$, for HSS 6×6×³⁄₈ with GMAW (see Table 9 for average *R*)

The *Z* values measured in this test program can now be compared to a predicted *Z* value based on an AWS rule. The rule was found to be a safe predictor of *Z* for both the
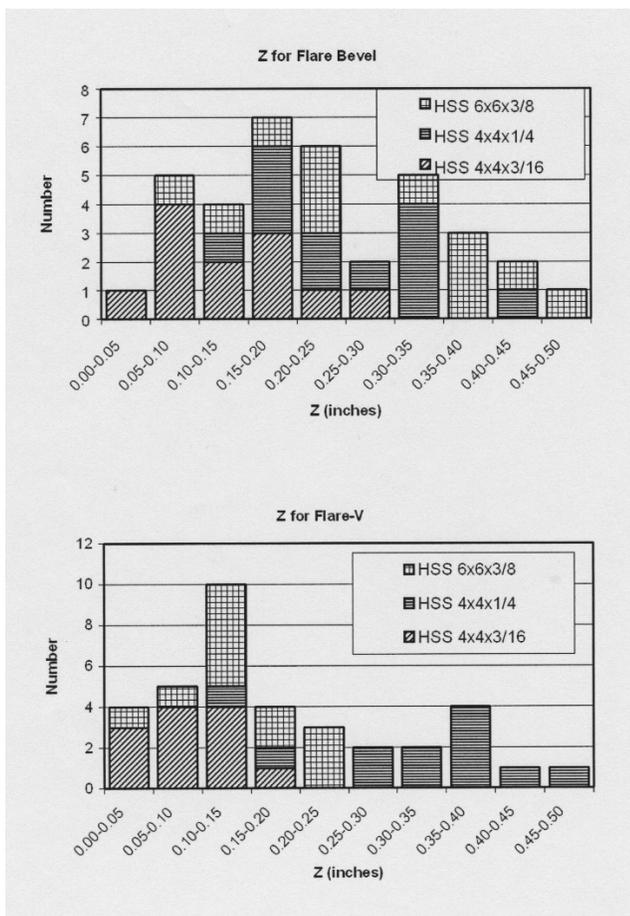

Fig. 11. Z for Flare Bevel and Flare-V Test Welds.

HSS 4×4×³/₁₆ and HSS 6×6×³/₈ test welds, however for HSS 4×4×¼ there are some unsafe predictions especially in the flare-V welds where 10 out of 12 welds have Z greater than the predicted Z. For the HSS 4×4×¼ flare bevel welds, 2 out of 12 welds show unsafe Z value predictions. As mentioned previously, the convex shape of the HSS 4×4×¼ face has had the effect of increasing all the measured values of Z. This illustrates the problem of trying to define effective throat by measuring the Z loss dimension. Furthermore, this method of effective throat and Z prediction seems to be historically related to the habit of cross-sectioning flare groove welds for qualification.

Flare groove welds are frequently not filled flush to the face (or faces) of the HSS, and in such circumstances it would be particularly advantageous if the weld effective throat could be related to the size or location of the weld face. This is even more imperative if the existing weld

effective throat rules are to be relaxed, and smaller flare groove welds consequently used. The weld face size or location is also the only dimension that can be determined by external measurement and also verified by an inspector. Thus, the weld effective throat, as a fraction of the weld face dimension, in other words, E/W, is plotted as a histogram in Figure 13 (for flare bevel welds) and in Figure 14 (for flare-V welds). Also on these two figures are the mean of the (E/W) ratio and the mean minus two standard deviations of this ratio. The mean minus two standard deviations level is a commonly-accepted level of structural reliability, rather than the absolute lowest bound from any test data point. In Figure 11 it could be seen that anomalously high values for Z were obtained for the HSS 4×4×¼, because the flats of this section were slightly convex, but analyzing the results in terms of E and W (Figures 13 and 14) has taken care of this manufacturing problem.
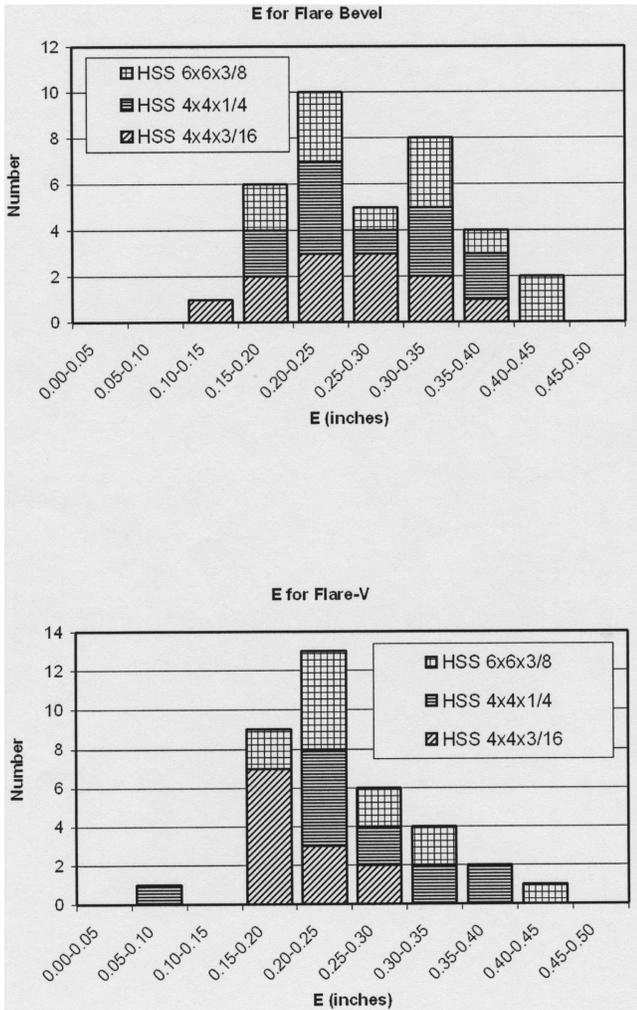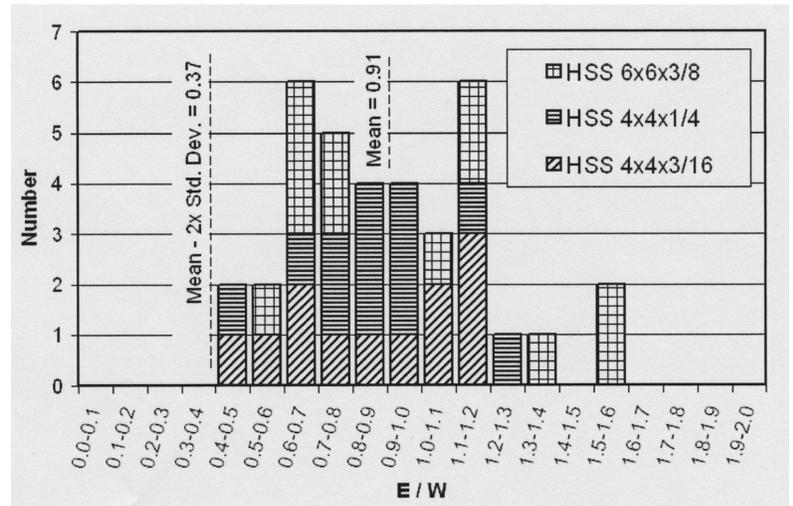

Fig. 13. E/W *Ratios for all 36 Flare Bevel Welds.*

Fig. 12. E *for Flare Bevel and Flare-V Test Welds.*

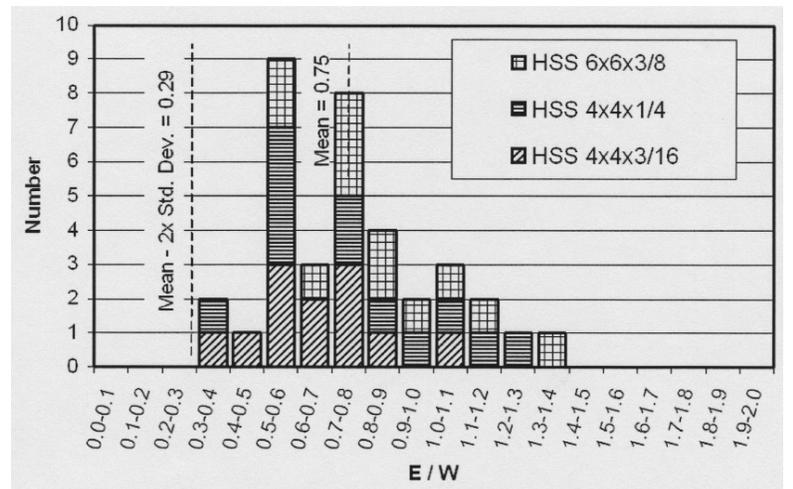

Fig. 14. E/W *Ratios for all 36 Flare-V Welds.*

Table 10. Effective Throat Size to Weld Face Size Ratio, for All Test Data

Weld Type	E/W
Flare Bevel	Average = 0.91
(n=36)	Std. Dev. = 0.27
Flare-V	Average = 0.75
(n=36)	Std. Dev. = 0.23

Based on the statistical parameters for E/W test data one can now make a direct comparison to the AWS effective throat rule, for welds filled flush to the HSS face(s). Figure 15 shows theoretical weld face dimensions for flare bevel and flare-V welds using the average measured bend angle of the three HSS used in the test program. Using a 72.7° bend angle (Table 9) and setting $D_f = 0$ in Figure 15, the weld face dimension, W, is as follows:

- for Flare Bevel Welds:

$$W = R (\cos 8.65° - \sin 8.65°) = 0.838R \qquad (1)$$

- for Flare-V Welds:

$$W = 2R (\cos 8.65° - \sin 8.65°) = 1.677R \qquad (2)$$

The E/W mean and standard deviation for all test data ($n=72$) are given in Table 10.

One should also bear in mind that each flare bevel data point is itself the average of three measurements, and each flare-V data point is itself the average of two measurements. Thus, the statistical base is actually a total of 180 flare weld cross sections.

Expressing an effective throat rule in the form of $E = $ constant $\times W$, and using a constant developed from test data, in other words, Mean $E/W - 2 \times$ S.D., the general expression for effective throat, with R and test data combined, is as follows:

- for Flare Bevel Welds:

$$
\begin{aligned}
E &= \text{constant} \times W \\
E &= (\text{Mean } E/W - 2 \times \text{S.D.}) \times (0.838R) \\
E &= (0.91 - 2 \times 0.27) \times (0.838R) \\
E &= 0.31R \qquad (3)
\end{aligned}
$$

Note that this E is almost identical to the E predicted by AWS; in other words, $E = {}^5/_{16} R = 0.3125R$.

- for Flare-V Welds:

$$
\begin{aligned}
E &= \text{constant} \times W \\
E &= (\text{Mean } E/W - 2 \times \text{S.D.}) \times (1.677R) \\
E &= (0.75 - 2 \times 0.23) \times (1.677R) \\
E &= 0.49R \qquad (4)
\end{aligned}
$$

Note that this E is again very similar to the E predicted by AWS; in other words, $E = 0.50R$ in general, or $E = 0.375R$ for GMAW with $R \geq \frac{1}{2}$ in.
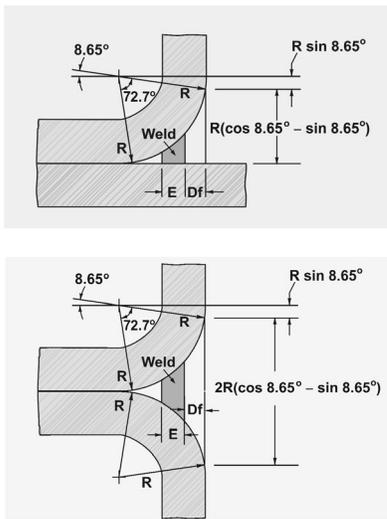
Screening and Grouping of Data

The procedure outlined above was also done for each set of nine test welds made with each of the four weld processes. It was also decided to exclude data that pertained to non-prequalified welding procedures. Six of the 72 test welds (3 GMAW flare bevel welds and 3 GMAW flare-V welds) were done in the "vertical down" position; a weld progression that is not prequalified to AWS D1.1. These welds were made in this manner because:

a. It was actually recommended by the Oversight Committee, and

b. According to the project's professional welding engineer GMAW can not be done "vertical up" with the kind of equipment available in a typical structural fabrication shop.

Fig. 15. Flare Bevel and Flare-V Weld Faces Related to HSS Radius.

Table 11. Effective Throat Size to Weld Face Size Ratio, for Screened and Grouped Test Data

Weld Types		FCAW-G (n=9)	GMAW (n=6)	SMAW (n=9)	FCAW-S (n=9)	GMAW & FCAW-G (n=15)	SMAW & FCAW-S (n=18)
Flare Bevel	Mean (E/W)	1.12	1.19	0.83	0.61	1.15	0.72
	S.D. (E/W)	0.19	0.20	0.17	0.10	0.19	0.18
	Mean-2xS.D.	0.75	0.79	0.49	0.41	0.76	0.37
	E	0.63R	0.66R	0.41R	0.34R	0.64R	0.31R
Flare-V	Mean (E/W)	0.90	0.90	0.70	0.58	0.90	0.64
	S.D. (E/W)	0.26	0.19	0.11	0.13	0.23	0.14
	Mean-2xS.D.	0.38	0.52	0.47	0.32	0.43	0.37
	E	0.64R	0.88R	0.79R	0.53R	0.73R	0.61R

Nevertheless, to derive recommendations in conformance with AWS D1.1 prequalified welding procedures, the GMAW "vertical down" data was omitted.

Based on this analysis, the weld processes that had the highest E/W mean were grouped together and another calculation was made of an E/W mean, this time with a grouping of 15 or 18 test welds from two processes. For both the flare bevel and flare-V weld types the processes with the highest E/W means were FCAW-G and GMAW. The summary of this data is given in Table 11.

Thus, it would seem possible to recommend design rules, as follows, for flare groove welds filled flush to the HSS face and made with prequalified welding procedures:

- for Flare Bevel Welds:
  $E = 0.64R$ for GMAW and FCAW-G   (5)
  or $E = 0.31R$ for SMAW and FCAW-S   (6)

- for Flare-V Welds:
  $E = 0.73R$ for GMAW and FCAW-G   (7)
  or $E = 0.61R$ for SMAW and FCAW-S   (8)

In the case of flare bevel welds, predictions for E by individual welding process are all as high or higher than the AWS rule ($E = 0.3125R$). For flare-V welds, predictions for E by individual welding process are also higher than the AWS rule ($E = 0.5R$) for FCAW-G, SMAW and FCAW-S weld processes. In the case of GMAW the prediction for E is considerably greater than the AWS rule ($E = \frac{3}{8}R$ or $E = \frac{1}{2}R$, depending on R).

Using test data to establish an effective throat rule for welds _not filled flush to the HSS face(s)_, the externally measured weld face size (W) can be related to the E value by a constant developed from E/W test data ratios, but excluding "vertical down" welds, as follows:

- for Flare Bevel Welds:
  $E = \text{constant} \times W$
  $E = (\text{Mean } E/W - 2 \times \text{S.D.}) \times W$
  $E = (0.91 - 2 \times 0.28) \times W$
  $E = 0.35W$ (9)

- for Flare-V Welds:
  $E = \text{constant} \times W$

$E = (\text{Mean } E/W - 2 \text{ x S.D.}) \text{ x } W$
$E = (0.76 - 2 \text{ x } 0.23) \text{ x } W$
$E = 0.30W$ (10)

As discussed previously, this is a similar procedure to that now adopted in the new CSA W59 welding standard (CSA, 2003), to account for flare bevel welds "not filled flush." Equations 9 and 10 require an inspector to measure the weld face dimension, W, which clearly will vary considerably with the angle of inclination of the weld face. Another similar alternative would be to use Equations 5, 6, 7 and 8 but to reduce the effective throat size E by the distance D_f that the weld face is set back from the "filled flush line." This requires a weld gage measurement and one could conservatively take the largest D_f distance measured, if the weld face was inclined. This approach is deemed more practical than measuring the weld face dimension, W, as advocated by CSA methods, because the weld face is often a concave curve and hence W can be very difficult to determine.

CONCLUSIONS

The experimental results of this test program have been used to make direct comparison to existing AWS D1.1 rules for flare groove welds.

- **For flare bevel groove welds, filled flush to the face of the HSS,** test data confirms that, after inclusion of a suitable safety margin, the following effective throat sizes (E) can be justified, in terms of the HSS outside corner radius (R), for flat, horizontal, vertical up and overhead welding positions, depending on the welding process:

  $E = 0.64R$ for GMAW (spray) and FCAW-G   (5)
  or $E = 0.31R$ for SMAW and FCAW-S   (6)

- **For flare-V groove welds, filled flush to the faces of the HSS**, test data confirms that, after inclusion of a suitable safety margin, the following effective throat sizes (E) can be justified, in terms of the HSS outside corner radius (R), for flat, horizontal, vertical up and

overhead welding positions, depending on the welding process:

$$E = 0.73R \text{ for GMAW (spray) and FCAW-G} \qquad (7)$$
$$\text{or } E = 0.61R \text{ for SMAW and FCAW-S} \qquad (8)$$

- **For flare bevel groove welds, not filled flush to the face of the HSS**, Equations 5 and 6 above can be re-written in the following form, using a dimension D_f (which must be measured), where D_f is the distance from the outer wall of the HSS to the face of the weld (see Figure 15):

$$E = 0.64R - D_f \text{ for GMAW (spray) and FCAW-G} \quad (11)$$
$$\text{or } E = 0.31R - D_f \text{ for SMAW and FCAW-S} \qquad (12)$$

- **For flare-V groove welds, not filled flush to the faces of the HSS**, Equations 7 and 8 above can be re-written in the following form, using a dimension D_f (which must be measured), where D_f is the distance from the outer walls of the HSS to the face of the weld (see Figure 15):

$$E = 0.73R - D_f \text{ for GMAW (spray) and FCAW-G} \quad (13)$$
$$\text{or } E = 0.61R - D_f \text{ for SMAW and FCAW-S} \qquad (14)$$

Equations 5 to 8 and 11 to 14 above all entail a knowledge of the square or rectangular HSS outside corner radius, R. For ASTM A500 hollow sections, an outside corner radius of $R = 2T_{actual}$ can be assumed. The tube wall thickness, T_{actual}, can either be measured or a "design value" of $0.93T_{nominal}$ may be assumed, as specified by AISC (1997).

The HSS used in this study had a C dimension (see AWS D1.1, 2004, Figure 3.3) averaging $1.68T_{actual}$, so a limit of applicability of $C \geq 1.5T_{actual}$ would be reasonable for these recommendations.

ACKNOWLEDGMENTS

REFERENCES

AISC (1989), *Allowable Stress Design Manual of Steel Construction,* 9th ed., American Institute of Steel Construction, Inc., Chicago.

AISC (1997), *Hollow Structural Sections Connections Manual*, American Institute of Steel Construction / Steel Tube Institute of North America / American Iron and Steel Institute, Chicago.

AISC (1999a), *Load and Resistance Factor Design Manual of Steel Construction, Volume II: Connections*, Metric conversion of 2nd ed., American Institute of Steel Construction, Chicago.

AISC (1999b), *Load and Resistance Factor Design Specification for Structural Steel Buildings*, American Institute of Steel Construction, Chicago.

ASTM (2001), *Standard Specification for Cold-Formed Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes*, ASTM A500-01, ASTM International, West Conshohocken, PA.

AWS (2004), *Structural Welding Code—Steel*, 19th ed., ANSI/AWS D1.1/D1.1M:2004, American Welding Society, Miami.

CSA (1989), *Welded Steel Construction (Metal Arc Welding)*, W59-M1989, Canadian Standards Association, Toronto, Ontario.

CSA (1992), *Certification of Companies for Fusion Welding of Steel Structures*, W47.1-92, Canadian Standards Association, Toronto, Ontario.

CSA (2001), *Limit States Design of Steel Structures*, S16-01, Canadian Standards Association, Toronto, Ontario.

CSA (2003), *Welded Steel Construction (Metal Arc Welding)*, W59-03, Canadian Standards Association, Toronto, Ontario.

CSA (2004), *Supplement to: Limit States Design of Steel Structures*, S16-04 (draft), Canadian Standards Association, Toronto, Ontario.

Jaxa-Rozen, W. (2001), "Flare Bevel Weld Configurations and Representations," Bombardier Transportation, Canada.

Packer, J.A. and Frater, G.S. (2003), "Effective Throat for Flare Bevel and Flare-V Groove Welds," Final Report to AISC and STI, Department of Civil Engineering, University of Toronto, Toronto, Ontario.