The University of Sydney
Department of Civil Engineering
Sydney NSW 2006
AUSTRALIA

http://www.civil.usyd.edu.au

Centre for Advanced Structural Engineering
Research Report No. R805

STRENGTH OF FILLET AND FLARE-BEVEL WELDED CONNECTIONS IN 2.5-MM DURAGAL® ANGLE

By

Lip H Teh BE PhD
Gregory J Hancock BSc BE PhD

April 2001

STRENGTH OF FILLET AND FLARE-BEVEL WELDED CONNECTIONS IN 2.5-MM DURAGAL® ANGLE SECTIONS

Research Report No. R805

Lip H Teh, BE PhD
Gregory J. Hancock, BSc BE PhD

The University of Sydney
Department of Civil Engineering
Centre for Advanced Structural Engineering
http://www.civil.usyd.edu.au

ABSTRACT

This report presents the laboratory test results on fillet and flare-bevel welded truss connections in $50\times50\times2.5$ DuraGal® angle sections. The arc welded connections between the DuraGal® sections and 10-mm hot-rolled steel plates were fabricated using the gas metal arc welding (GMAW) process. It was found that failures of the fillet and the flare-bevel welds occurred in both the weld metal and the DuraGal® angle section. The ultimate test loads of the connection specimens were compared with their predicted failure loads and their nominal capacities computed using the equations specified in the cold-formed steel standard AS/NZS 4600:1996 and the steel structures code AS 4100-1998, respectively. It is concluded through a reliability analysis that Clauses 5.2.3.2(a) and 5.2.6.2(3) of AS/NZS 4600 may be used to design fillet and flare-bevel welded connections in 2.5-mm DuraGal® angle sections, respectively. The use of Clause 9.7.3.10 of AS 4100 to compute the nominal capacities of the fillet and the flare-bevel welded connections in 2.5-mm DuraGal® angle sections fabricated in the present work was found to be conservative.

Keywords: angle section, cold-formed steel, design standards, fillet welds, flare-bevel welds, load and resistance factor design, sheet metal, welded connections

Copyright Notice

Department of Civil Engineering, Research Report No. R805
Strength of fillet and flare-bevel welded connections in 2.5-mm DuraGal® angle sections

L.Teh@civil.usyd.edu.au

Published by:
Department of Civil Engineering
The University of Sydney
Sydney, NSW, 2006
AUSTRALIA

http://www.civil.usyd.edu.au

1 Introduction

This report presents the laboratory test results on fillet and flare-bevel welded connections in $50 \times 50 \times 2.5$ DuraGal® angle sections. The aim is to verify the applicability of design equations specified in AS 4100 (SA 1998) and in AS/NZS 4600 (SA/SNZ 1996a) to arc welded connections in DuraGal® angle sections of 2.5 mm nominal thickness. Currently, the design capacities of fillet welds in sections as thick as or thicker than 2.5 mm shall be determined in accordance with AS 4100 based on the weld metal strength and the weld throat thickness, while those of flare-bevel welds in sections thinner than 3.0 mm shall be determined in accordance with AS/NZS 4600 based on the parent steel strength and the section base metal thickness.

Thus the main concern of this report is whether the arc welded connections in the 2.5-mm DuraGal® angle section fail in the weld metal or in the parent material. It is assumed that all welded connections in angle sections are truss connections that are not required to resist moments. Furthermore, all the welded connection specimens tested to failure in the present work were subjected to longitudinal loadings only. It should be noted that this report does not address the shear lag effects in a welded connection of an angle member which may lower the member tensile capacity as specified in Clause 7.3 of AS 4100 (SA 1998) and Clause 3.2.2 of AS/NZS 4600 (SA/SNZ 1996a).

This report complements the findings of Teh & Hancock (2000, 2001) on arc welded connections in 1.5-mm and 3.0-mm G450 sheet steels. Both G450 sheet steels and DuraGal® structural steel sections undergo cold-forming in their manufacture, and thus may encounter some common problems concerning reduced ductility and the weakened heat-affected-zone (HAZ) around a weld.

The DuraGal® angle sections tested in the present work were supplied by OneSteel Market Mills, Pipe & Tube, Newcastle.

2 Laboratory tests

The specimen configuration used in the laboratory tests is depicted in Fig. 1. As shown in the figure, each angle has fillet welds at the toe and flare-bevel welds at the heel. It is not possible to test the fillet welds (in the *intact* angle section) separately from the flare-bevel welds without experiencing the shear lag effects which cause premature fracture of the angle section. Welded (truss) connections in an angle section should ideally have a balanced combination of fillet and flare-bevel welds. Nevertheless, in the present work, fillet and flare-bevel welds of different length ratios were tested and the ultimate test loads were compared with the predicted failure loads computed as the algebraic sums of the fillet and flare-bevel weld capacities. The connection specimen depicted in Fig. 1, which is clamped at the ends of the hot-rolled plates during the tension test, is not subjected to eccentric loading.

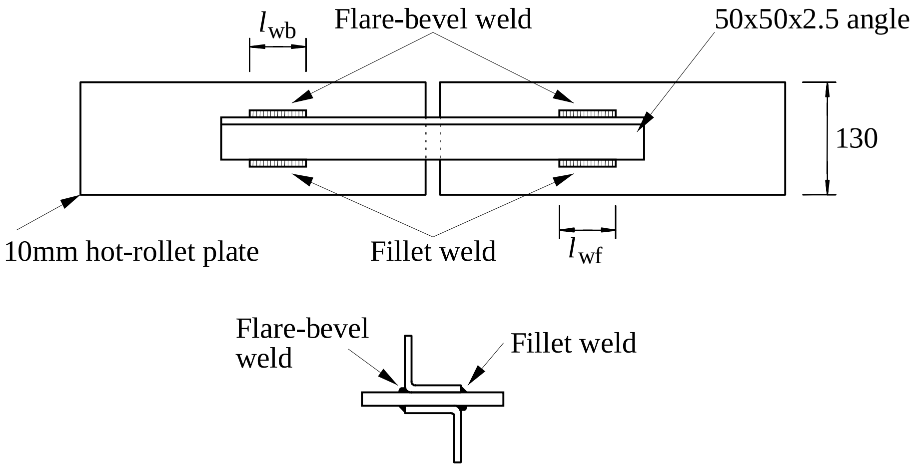

Fig. 1 Specimen configuration

The welding procedures for fillet and flare-bevel welded connections between the 2.5-mm DuraGal® angle section and the 10-mm hot-rolled steel plate of Grade 450, the latter manufactured to AS/NZS 3678 (SA/SNZ 1996b), are given in Appendix I. The electrode, which was manufactured to AS/NZS 2717.1 (SA/SNZ 1996c), is a pre-qualified welding consumable for gas metal-arc welding of grade C350L0 steels such as the 50×50×2.5 DuraGal® angle section according to Clause 4.5.1 of AS/NZS 1554.1 (SA/SNZ 1998a).

It was found that for both fillet and flare-bevel welds, failure may occur either in the weld metal or in the DuraGal® section itself. Figure 2 shows an intact fillet weld with some material torn from the DuraGal® angle section attached to it. It is noteworthy that fracture took place at some distance away from the boundary between the fillet weld and the DuraGal® section. Figure 3, on the other hand, shows the shear failure of a fillet weld at the toe of the DuraGal® angle section on the other side of the same double-lap connection specimen.

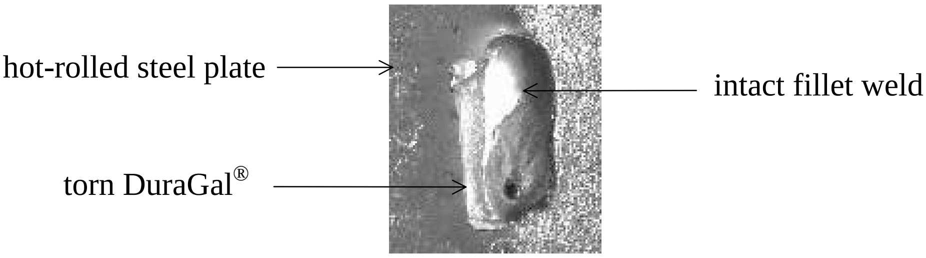

Fig. 2 Failure of DuraGal® parent material around a fillet weld

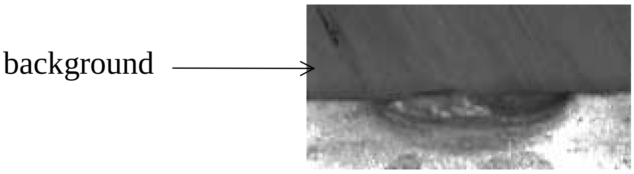

Fig. 3 Shear failure of a fillet weld at the toe of DuraGal® angle

Figure 4 shows the tearing of the parent material around a longitudinal flare-bevel weld at the heel of a DuraGal® angle section, which started from the tension end (the right-hand side). It can also be seen in the figure that some weld failure took place in the left half of the longitudinal flare-bevel weld. Conversely, Figure 5 shows the complete shear failure of the other flare-bevel weld in the same connection specimen. It may be noted that for this specimen, both fillet welds at the toes of the angle sections failed in the weld metal.

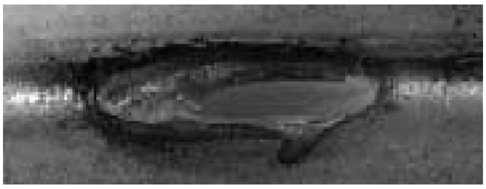

Fig. 4 Tearing of parent material around a flare-bevel weld

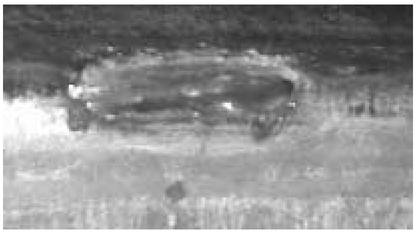

Fig. 5 Complete shear failure of a flare-bevel weld

3 Comparisons with design equations

In order to check whether a common standard, either AS/NZS 4600 (SA/SNZ 1996a) or AS 4100 (SA 1998), can be used to determine the nominal capacities of both fillet and flare-bevel welded connections in the 2.5-mm DuraGal® angle section, the ultimate test loads P_t of the specimens are compared against the predicted (P_p) and the nominal (P_n) capacities so determined.

Using AS/NZS 4600 (SA/SNZ 1996a) first, the failure loads P_{p4600} of the test specimens were predicted using the equation

$$V_{wf} = (1 - 0.01 l_{wf} / t) l_{wf} \, t \, f_u \text{ ; } \phi = 0.60 \tag{1}$$

adapted from Clause 5.2.3.2(a) of the standard for the nominal capacity of a longitudinal fillet weld, and equation

$$V_{wb} = 1.5 l_{wb} \, t \, f_u \text{ ; } \phi = 0.55 \tag{2}$$

adapted from Clause 5.2.6.2(3) of the same standard for the nominal capacity of a longitudinal flare-bevel weld. The variable l_{wf} is the fillet weld length, l_{wb} is the flare-bevel weld length, t is the base metal thickness of the connected steel and f_u is the tensile strength of the parent steel.

The average base metal thickness t of the 2.5-mm DuraGal® angle sections tested in the present work was found to be 2.39 mm, and the average tensile strength f_u of the 2.5-mm DuraGal® section was found to be 505 MPa. These values were substituted into Equations (1) and (2) to predict the failure loads P_{p4600} shown in Table 1, which are the sums of the predicted failure loads P_{pf} of the fillet welds and P_{pb} of the flare-bevel welds. Since the welded connections are double lap, P_{pf} and P_{pb} are twice V_{wf} and V_{wb} in Equations (1) and (2), respectively. The weld lengths l_{wf} and l_{wb} shown in Table 1 are the average values for the failed welds.

Table 1 Results of using Equations (1) and (2) specified in AS/NZS 4600

Spec No.	l_{wf} **(mm)**	l_{wb} **(mm)**	P_t **(kN)**	P_{pf} **(kN)**	P_{pb} **(kN)**	P_{p4600} **(kN)**	P_t/P_{p4600}
1	15	13	66.0	33.9	47.1	81.0	0.81
2	17	16	66.5	38.1	57.9	96.0	0.69
3	22	22	132.0	48.2	79.7	127.9	1.03
4	22	28	137.0	48.2	101.4	149.6	0.92
5	25	23	108.5	54.0	83.3	137.3	0.79
6	24	33	159.5	52.1	119.5	171.6	0.93
7	25	37	152.0	54.0	134.0	188.0	0.81
8	36	25	138.0	73.8	90.5	164.3	0.84

It can be seen from the ratios of ultimate test load to predicted failure load P_t/P_{p4600} that in many cases the design equations specified in AS 4600 (SA/SNZ 1996) overestimate the capacity of the welded connection specimens tested in the present work. This is due to the fact that the equations implicitly assume that the welds are strong enough to cause failure in the parent materials, but all of the tested specimens except for Specimen 3 failed in at least some of the welds. In fact, all the (failed) fillet and flare-bevel welds of Specimen 2 failed in the weld metal. Nevertheless, it is noted that capacity factors of 0.60 and 0.55 are specified in Clauses 5.2.3.2(a) and 5.2.6.2(3), respectively. Furthermore, the nominal tensile strength of the $50 \times 50 \times 2.5$ DuraGal® angle section as used in design is 400 MPa, which is significantly lower than the value of 505 MPa used in predicting the failure loads P_{p4600} shown in Table 1.

In order to formally assess the applicability of Clauses 5.2.3.2(a) and 5.2.6.2(3) specified in AS/NZS 4600 (SA/SNZ 1996a) to arc welded connections in 2.5-mm DuraGal® angle sections, a reliability analysis must be carried out (Zhao & Hancock

1993, Teh & Hancock 2000). Brief description of the reliability analysis based on the First Order Second Order Moment method is given in Appendix II. The statistical parameters required for the present reliability analysis are given in Table 2. The mean ratio of actual tensile strength to nominal tensile strength M_m of the $50 \times 50 \times 2.5$ DuraGal® angle section was based on 78 tests conducted from December 1999 to January 2001 at the Newcastle steel plant of OneSteel, Market Mills, Pipe & Tube.

Table 2. Statistical parameters

M_m	1.26
V_m	0.05
F_m	0.98
V_m	0.01
P_m	0.85
V_P	0.10
R_m/ R_n	1.05
V_R	0.12

M_m = mean ratio of actual tensile strength to nominal tensile strength

F_m = mean ratio of actual thickness to nominal thickness

P_m = mean ratio of test loads to predicted failure loads

R_m/ R_n = ratio of mean resistance to nominal resistance

V's are the coefficients of variation of the corresponding quantities.

It was found that when a uniform capacity factor of 0.55 is used for the fillet as well as the flare-bevel welds, the safety indices vary between 3.8 and 5.9. Using a higher uniform capacity factor of 0.60 results in safety indices that vary between 3.5 and 5.3. All these safety indices are equal to or greater than the target index of 3.5 recommended for connections in cold-formed steels (SA/SNZ 1998b). (Note that strictly speaking, all the safety indices are greater than 3.5 as Clause 5.2.6.2(3) specifies a capacity factor of 0.55 rather than 0.60.) Therefore, Clauses 5.2.3.2(a) and 5.2.6.2(3) specified in AS/NZS 4600 (SA/SNZ 1996a) may be used to design longitudinal fillet and flare-bevel welded connections in 2.5-mm DuraGal® angle sections, *provided the weld quality is comparable to that produced in the present work.*

Table 3 compares the ultimate test loads P_t with the nominal capacities P_{n4100} computed using the equation

$$V_w = 0.6 l_w t_w f_{uw} \tag{3}$$

adapted from Clause 9.7.3.10 of AS 4100 (SA 1998) for determining the shear capacity of a fillet or flare-bevel weld. The variable t_w is the weld throat thickness and f_{uw} is the weld metal strength. In computing P_{n4600} shown in Table 3, the nominal weld throat thickness and the nominal weld metal strength are used.

Table 3 Results of using Equation (3) specified in AS 4100

Spec No.	l_{wf} (mm)	l_{wb} (mm)	P_t (kN)	P_{nf} (kN)	P_{nb} (kN)	P_{n4100} (kN)	P_t/P_{n4100}
1	15	13	66.0	21.7	28.7	50.4	1.31
2	17	16	66.5	24.6	35.3	59.9	1.11
3	22	22	132.0	31.9	48.5	80.4	1.64
4	22	28	137.0	31.9	61.7	93.6	1.46
5	25	23	108.5	36.2	50.7	86.9	1.25
6	24	33	159.5	34.8	72.8	107.5	1.48
7	25	37	152.0	36.2	81.6	117.8	1.29
8	36	25	138.0	52.2	55.1	107.3	1.29

The statistical data for the mean ratio of the actual weld metal strength to the nominal weld metal strength of the electrode used in the present work is not available to the authors. This is also the situation with the mean ratio of the actual weld length to the nominal weld length. (In the previous reliability analysis, this ratio is assumed to be unity.) Although some data is available for the mean ratio of the actual weld throat thickness to the nominal weld throat thickness of fillet welds in tubular sections of a similar thickness (Zhao & Hancock 1993), this data is not appropriate for the fillet weld at the toe of an angle section. The mean ratio F_m for the fillet weld between a rectangular hollow section and an end plate was found to be approximately 1.5 (Zhao & Hancock 1993), but the critical thickness of a fillet weld at the toe of a 2.5-mm angle section is limited by the section thickness. For the DuraGal® angle sections tested in the present work, the operator had little control over the weld throat thickness and the resulting critical weld thicknesses were about the same as the thickness of the angle section, i.e. 2.5 mm. To the authors' knowledge, no statistical data is available for flare-bevel welds either.

As a reliability analysis cannot be carried out for Equation (3) in the case of arc welded connections in 2.5-mm DuraGal® angle sections due to the lack of statistical data, the nominal capacities P_{n4100} shown in Table 3 were computed using nominal throat thicknesses of 2.3 mm for the fillet welds and 3.5 mm for the flare-bevel welds, which are the average values as determined in accordance with Clauses E2.4 and E2.5 of the Specification for the Design of Cold-Formed Steel Structural Members (AISI 1996), as illustrated in Figs. 6 and 7. The nominal tensile strength of the weld metal, which is 525 MPa for the electrode used in the present work (CIGWELD 1993), is substituted into Equation (3) to compute the nominal capacities P_{n4100} shown in Table 3. Thus with regard to the design equation specified in AS 4100 (SA 1998), this report merely illustrates the consequence of using Equation (3) to compute the nominal capacities of the arc welded connections in $50 \times 50 \times 2.5$ DuraGal® angle sections fabricated in the Civil Engineering workshop at the University of Sydney.

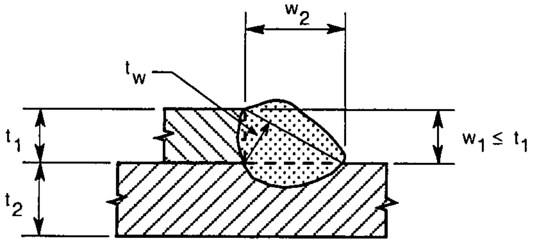

Fig. 6 Throat thickness t_w of a fillet weld

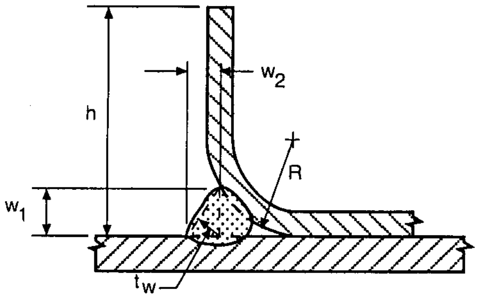

Fig. 7 Throat thickness t_w of a flare-bevel weld

It is evident from the ratios of ultimate test load to nominal capacity P_t/P_{n4100} shown in Table 3 that the design equations specified in AS 4100 (SA 1998) underestimates the capacities of all welded connections tested in the present work. This is largely due to the fact that the actual throat thickness of a flare-bevel weld as produced in the present work is larger than the nominal value determined in accordance with Fig. 7. This situation is in fact well-illustrated in Fig. 7.

As implied in the introduction, at present the design capacity of a fillet weld in the 2.5-mm DuraGal® angle section shall be determined in accordance with AS 4100 (SA 1998), while that of a flare-bevel weld in the same section shall be determined in accordance with AS/NZS 4600 (SA/SNZ 1996a). Table 4 shows the results of following this requirement. For the sake of consistency with the fillet welds, a nominal tensile strength of 400 MPa and a nominal base thickness of 2.4 mm for the $50\times50\times2.5$ DuraGal® angle section (BHP 1999) are used in computing the nominal capacities P_{nb} of the flare-bevel welds. These can be compared with the predicted failure loads P_{pb} shown in Table 1 which are considerably higher.

Table 4 Results of using Equations (3) and (2), as required by Clause 5.2.1 of AS/NZS 4600

Spec No.	l_{wf} **(mm)**	l_{wb} **(mm)**	P_t **(kN)**	P_{nf} **(kN)**	P_{nb} **(kN)**	P_n **(kN)**	P_t/P_n
1	15	13	66.0	21.7	37.4	59.1	1.12
2	17	16	66.5	24.6	46.1	70.7	0.94
3	22	22	132.0	31.9	63.4	95.3	1.39
4	22	28	137.0	31.9	80.6	112.5	1.22
5	25	23	108.5	36.2	66.2	102.5	1.06
6	24	33	159.5	34.8	95.0	129.8	1.23
7	25	37	152.0	36.2	106.6	142.8	1.06
8	36	25	138.0	52.2	72.0	124.2	1.11

It can be seen from the ratio P_t/P_n of Specimen 2 that the current specifications may overestimate the capacity of an arc welded connection in 2.5-mm DuraGal® angle section. Apparently this is due to the fact that the flare-bevel welds of Specimen 2 failed in the weld metal, as mentioned previously. However, in practice this overestimation is likely to be offset by the capacity factor of 0.55 specified in Clause 5.2.6.2(3) of AS/NZS 4600 (SA/SNZ 1996a). Overall, the current specifications appear to be conservative as far as the specimens tested in the present work are concerned.

4 Conclusions

Fillet and flare-bevel welded connections in $50\times 50\times 2.5$ DuraGal® angle sections have been fabricated and tested to failure. It was found that failure of the specimens occurred in both the weld metal and the DuraGal® section.

The use of Clauses 5.2.3.2(a) and 5.2.6.2(3) specified in AS/NZS 4600 to compute the design capacities of the fillet and the flare-bevel welded connections, respectively, results in safety indices greater than the target index of 3.5.

Although no formal reliability analysis is carried out with respect to the design equation specified in Clause 9.7.3.10 of AS 4100, it was found to give conservative estimates for the nominal shear capacities of the fillet and the flare-bevel welds produced in the present work. This conservatism is largely due to the use of nominal weld throat thicknesses which are significantly smaller than the actual throat thicknesses.

Using Clause 9.7.3.10 of AS 4100 to compute the nominal capacities of the fillet welds and Clause 5.2.6.2(3) of AS/NZS 4600 to compute the nominal capacities of the flare-bevel welds appears to be conservative.

The above conclusions are valid for fillet and flare-bevel welded connections in $50\times 50\times 2.5$ DuraGal® angle sections as fabricated in the present work.

Acknowledgments

The work reported herein was undertaken as part of a Research Project of the Cooperative Research Centre for Welded Structures (CRC-WS). The CRC-WS was established and is supported under the Australian Government's Cooperative Research Centres Program. The DuraGal® angle sections used in the test specimens were provided by OneSteel Limited, Newcastle. All the welded connections were fabricated by Grant Holgate in the Civil Engineering workshop at the University of Sydney. The WeldPrint monitoring equipment was provided by Steve Simpson of the School of Electrical and Information Engineering at the University of Sydney. Thanks are extended to Kim Rasmussen for providing the laptop computer used in conjunction with the WeldPrint monitor. The tensile tests were conducted in the J. W. Roderick Laboratory for Structures and Materials at the University of Sydney.

Appendix I. Welding procedures

The welding procedures for the fillet and flare-bevel welds of Specimen No. 8 are given below. The settings of the GMAW machine were never changed during the production of all fillet and flare-bevel welds in the present work.

Material:	2.5-mm DuraGal® angle to 10-mm Grade 450 plate
Joint Type:	Fillet and Flare-Bevel Welds
Welding Position:	Flat (1F)
Welding Process:	GMAW, short-arc transfer
Welding Machine:	CIG Transmig 330 transformer; Transmig 2Rse feeder
Polarity:	DCEP
Stick-out:	15 mm
Electrode Trade Name:	CIG Weld Autocraft
Gas Trade Name:	Argoshield 52
Gas Composition:	23% CO_2, 77% Ar
Gas Flow Rate (L/min):	20

Weld	Electrode Classification	Wire Speed mm/min	V	A	Welding Speed mm/min	Arc Energy kJ/mm
Fillet 1	0.8 mm ES6-GC/M-W503AH	11000	21	205	740	0.35
Fillet 2				210	720	0.37
Fillet 3				210	620	0.43
Fillet 4				215	615	0.44
Bevel 1				210	600	0.44
Bevel 2				200	430	0.59
Bevel 3				215	600	0.45
Bevel 4				210	500	0.53

Appendix II. Reliability analysis based on FOSM method

The reliability analyses performed in this paper are based on the First Order Second Moment (FOSM) method described by Ravindra & Galambos (1978). The method assumes a log-normal distribution for the resistance *R* and the load *Q*, so that the safety index β is computed from

$$\beta = \frac{\ln\left(R_m / Q_m \right)}{\sqrt{V_R{}^2 + V_Q{}^2}} \qquad \text{(II.1)}$$

in which R_m is the mean resistance, Q_m is the mean load, V_R is the coefficient of variation of the resistance *R*, and V_Q is the coefficient of variation of the load *Q*.

The ratio of the mean resistance R_m to the mean load Q_m may be computed from (Zhao & Hancock 1993)

$$\frac{R_m}{Q_m} = \frac{\gamma_D \left(D_n / L_n \right) + \gamma_L}{\left(D_m / D_n \right)\left(D_n / L_n \right) + \left(L_m / L_n \right)} \frac{R_m}{R_n} \frac{1}{\phi} \qquad \text{(II.2)}$$

in which γ_D is the dead load factor, D_n is the nominal dead load, L_n is the nominal live load, γ_L is the live load factor, D_m is the mean dead load, L_m is the mean live load, R_n is the nominal resistance, and ϕ is the capacity factor applied to the nominal resistance. In this paper, the ratio of the mean resistance to the mean load, R_m/Q_m, is computed as a function of the ratio D_n/L_n, so all other quantities in Equation (II.2) are constant for a particular type of connection.

In accordance with AS 1170.1 (SA 1993), the dead load factor γ_D used in this paper is equal to 1.25, and the live load factor γ_L is equal to 1.50. The ratios D_m/D_n and L_m/L_n are quoted from Ellingwood et al. (1980), which are 1.05 and 1.00, respectively. The ratio R_m/R_n is equal to

$$R_m / R_n = M_m F_m P_m \qquad \text{(II.3)}$$

in which M_m is the mean ratio of the actual material strength to the nominal material strength, F_m is the mean ratio of the actual geometric property to the nominal geometric property, and P_m is the mean ratio of the ultimate test loads P_t to the predicted failure loads P_p.

In this report, the value of F_m is assumed to be determined solely by the ratio of the actual section thickness to the nominal section thickness. The uncertainty in weld length is ignored as the values of F_m for fillet and for flare-bevel welds are not available to the authors. It is not appropriate to determine this value from the specimens fabricated for the present work as the workmanship is not necessarily representative of that at large.

The coefficient of variation V_R shown in Equation (II.1) is

$$V_R = \sqrt{V_M{}^2 + V_F{}^2 + V_P{}^2} \tag{II.4}$$

in which V_P is the coefficient of variation corresponding to P_m, computed for each type of connection from the ratios of ultimate test loads to predicted failure loads.

The coefficient of variation V_Q shown in Equation (II.1) is computed from

$$V_Q = \frac{\sqrt{\left({}^{D_m}\!/_{D_n}\right)^2 V_D{}^2 \left({}^{D_n}\!/_{L_n}\right)^2 + \left({}^{L_m}\!/_{L_n}\right)^2 V_L{}^2}}{\left({}^{D_m}\!/_{D_n}\right)\left({}^{D_n}\!/_{L_n}\right) + \left({}^{L_m}\!/_{L_n}\right)} \tag{II.5}$$

in which the coefficients of variation in the dead load V_D and in the live load V_L are 0.10 and 0.25, respectively (Ellingwood et al. 1980). As with the ratio of the mean resistance to the mean load, R_m/Q_m, the coefficient of variation V_Q is computed as a function of the ratio D_n/L_n.

The safety indices β of a particular type of connection can therefore be computed for cases ranging from “dead load only” to “live load only”. A “live load only” case corresponds to a zero value of D_n/L_n, and a “dead load only” case corresponds to an infinite value of D_n/L_n. The latter case does not present a mathematical difficulty in computing the safety index as a very large value of D_n/L_n (say, 10^4) can be used with little loss in numerical accuracy. However, the safety indices are normally plotted against $D_n/(D_n + L_n)$, which range from zero for the “live load only” case to unity for the “dead load only” case.

References

AISI (1996). Specification for the Design of Cold-Formed Steel Structural Members, American Iron and Steel Institute, Washington.

BHP (1999). Effective Section Properties, DuraGal$^{(R)}$ Angle Sections Grade C350L0, BHP Structural & Pipeline Products, Newcastle, Australia.

CIGWELD (1993). Welding Consumables Guide, Cornweld Group, Preston, Victoria.

Cornell, C. A. (1969) “A probability based structural code.” *Journal of the American Concrete Institute*, 66, 974-985.

Ellingwood, B., Galambos, T. V., MacGregor, J. G., and Cornell, C. A. (1980). Development of a Probability Based Load Criterion for American National Standard A58, National Bureau of Standards, Gaithersburg, Maryland.

Ravindra, M. K., and Galambos, T. V. (1978) “Load and resistance factor design for steel.” *Journal of the Structural Division*, ASCE, 104, 1337-1353.

SA (1993). Minimum Design Loads on Structures. Part 1: Dead and Live Loads and Load Combinations, Amendment No. 1 to SA 1170.1-1989, Standards Australia.

SA (1998). Steel Structures, AS 4100-1998, Standards Australia.

SA/SNZ (1996a). Cold-Formed Steel Structures, AS/NZS 4600:1996, Standards Australia/Standards New Zealand.

SA/SNZ (1996b). Structural Plates – Hot-rolled Plates and Slabs, AS/NZS 3678:1996, Standards Australia/Standards New Zealand.

SA/SNZ (1996c). Welding – Electrodes - Gas Metal Arc - Ferritic Steel Electrodes, AS/NZS 2717.1:1996, Standards Australia/Standards New Zealand.

SA/SNZ (1998a). Structural Steel Welding - Welding of Steel Structures, Amendment No. 1 to AS/NZS 1554.1:1995, Standards Australia/Standards New Zealand.

SA/SNZ (1998b). Cold-Formed Steel Structures—Commentary, Supplement to AS/NZS 4600:1996, Standards Australia/Standards New Zealand.

Teh, L. H., and Hancock, G. J. (2000) “Strength of fillet welded connections in G450 sheet steels,” *Research Report No. R802,* Department of Civil Engineering, University of Sydney, Australia.

Teh, L. H., and Hancock, G. J. (2001) “Strength of flare-bevel and flare-vee welded connections in G450 sheet steels,” *Research Report R806,* Department of Civil Engineering, University of Sydney, Australia.

Welding Technology Institute Pty. Ltd. (2000). WeldPrint, Build 2.70EN, University of Sydney, Australia.

Zhao, X. L., and Hancock, G. J. (1993) "Tests and design of butt welds and transverse fillet welds in thin cold-formed RHS members," *Research Report No. R681*, School of Civil & Mining Engineering, University of Sydney, Sydney.