AUSTRALIAN STEEL INSTITUTE
(ABN)/ACN (94) 000973 839
www.steel.org.au

ASI Head Office
Level 13, 99 Mount Street
North Sydney NSW 2060
Tel: 02 9931 6666
Email: enquiries@steel.org.au

Author: P.W.KEY

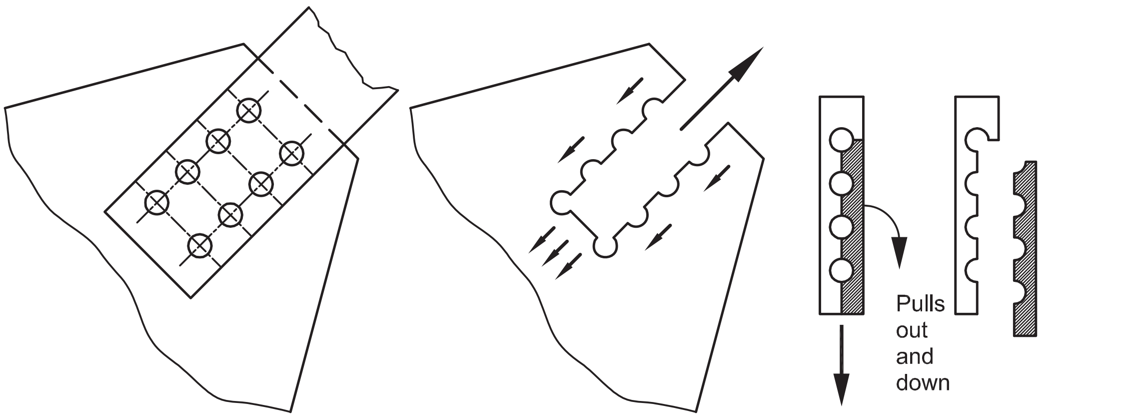
ASI TECHNICAL NOTE TN013 V1

Date: Mar 2015

BLOCK SHEAR CONNECTION DESIGN CHECKS

INTRODUCTION

A connection component may fail when a block of material ruptures as illustrated in Figure 1. Figure 1(a) shows block shear failure of a gusset plate subject to tension while Figure 1(b) shows block shear failure of a cleat component subject to a shear force.



(a) Gusset plate subject to tension

(b) Cleat component subject to shear

FIGURE 1 EXAMPLES OF BLOCK SHEAR FAILURE IN COMPONENTS

AS 4100 has addressed the failure mechanism of rupture due to block shear only relatively recently in the 2012 Amendment (Ref. 1).

This Technical Note is intended to raise industry awareness of the latest provisions in AS 4100 for block shear failure and provide design guidance, in particular for cases outside the scope of application of the AS 4100 implementation.

BACKGROUND

Bolted connections are commonly designed by considering a range of potential failure modes, assessing the capacity for each mode and taking the lowest mode as the failure mode for the connection. This approach has been used in documenting the connection design models in existing ASI connection design guides, including those for simple open section connections (Ref. 2), rigid open section connections (Ref. 3) and most recently, for hollow section connections (Ref. 4). One of the potential failure modes that must be checked is that of block shear failure in components, as illustrated in Figure 1.

The simple and open section connection models were published prior to the 2012 amendment to AS 4100 and contain block shear failure models based on an assessment of research and best industry practice at the time. Whilst drawing from a similar basis as the 2012 amendment, the models in Refs 2 and 3 do not specifically reference the 2012 amendment to AS 4100. The hollow section connections manuals (Ref. 4) do reference the specific block shear provisions in the 2012 amendment to AS 4100.

AS 4100 IMPLEMENTATION OF BLOCK SHEAR

Clause 9.1.9 of AS 4100 now specifies the design capacity in block shear (R_{bs}) as:

$$R_{bs} = 0.6 f_{uc} A_{nv} + k_{bs} f_{uc} A_{nt}$$

$$\leq 0.6 f_{yc} A_{gv} + k_{bs} f_{uc} A_{nt}$$

where

f_{uc} = minimum tensile strength of connection element

f_{yc} = yield stress of connection element

A_{nv} = net area subject to shear at rupture

A_{nt} = net area subject to tension at rupture

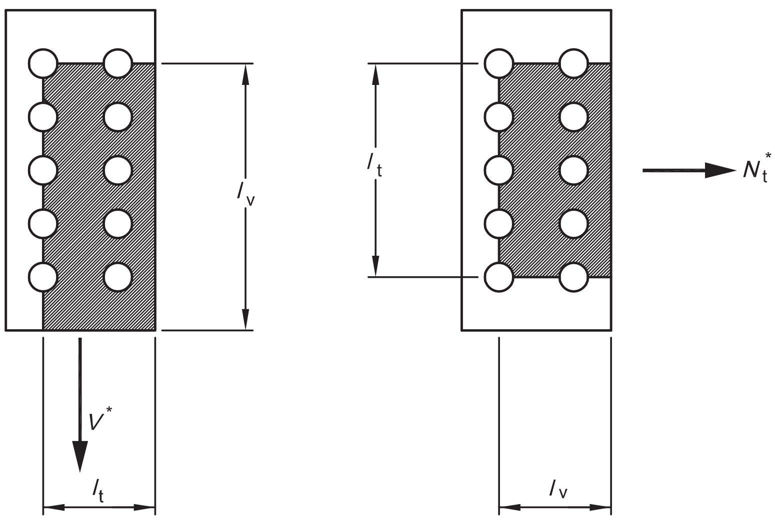
A_{gv} = gross area subject to shear at rupture

k_{bs} = a factor to account for the effect of eccentricity on the block shear capacity

= 1.0 when tension stress is uniform

= 0.5 when tension stress is non-uniform

AS 4100 does not specifically illustrate the definition of the net or gross areas subject to tension or shear at rupture. However, based on the available research that underpinned the AS 4100 provisions, the relevant areas A_{nv}, A_{nt} and A_{gv} are defined as shown in Figure 2.



$A_{nv} = (l_v - (n_h - 0.5)\, d_h)\, t_p$

$A_{nt} = (l_t - 1.5 d_h)\, t_p$

$A_{gv} = l_v\, t_p$

d_h = hole diameter

t_p = thickness of component

$A_{nv} = 2\,(l_v - 1.5\, d_h)\, t_p$

$A_{nt} = (l_t - (n_h - 1)\, d_h)\, t_p$

$A_{gv} = 2\, l_v\, t_p$

n_h = no. of holes on vertical line

FIGURE 2 BLOCK SHEAR AREA IN COMPONENTS

TYPICAL BOLTED CLEAT CONFIGURATIONS

Figure 3 provides specific formulae for A_{nv}, A_{nt} and A_{gv} for typical bolted cleat configurations, divided into the two principal modes of failure, 'Mode A' involving primary tearing along the direction of the force, and 'Mode B' involving a tear out across to one side of the cleat.

'Mode C' is particular to two rows of bolts only ($n_{\mathrm{g}} = 2$). The design capacity in block shear (ϕR_{bs}) is the minimum of the capacity calculated for each of these failure modes.

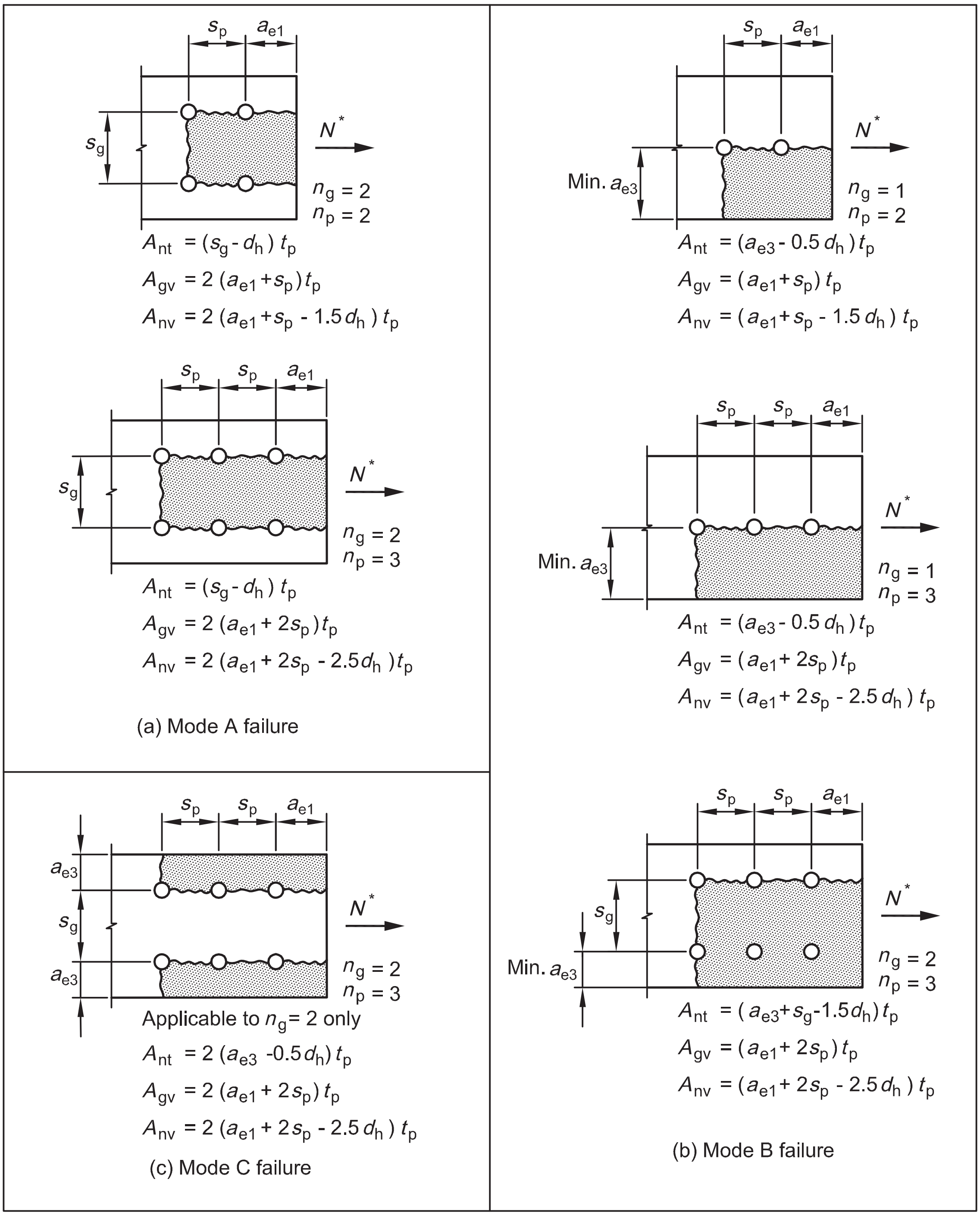


FIGURE 3 END PLATE BLOCK SHEAR AREAS IN CONNECTION COMPONENT

Whilst the calculation of block shear areas shown in Figure 3 do not cover all scenarios of connections, they do cover the majority of common connections and can be used for assessment of connection capacity for the block shear failure mode.

It is important to stress that the approach to ascertaining block shear failure paths is not prescriptive. Whilst Figure 3 has shown a number of logical failure paths, it is possible that alternate paths with lower failure loads exist. In the general case, all potential failure paths should be checked. A case in point is the possibility of inclined failure planes as described in the next section.

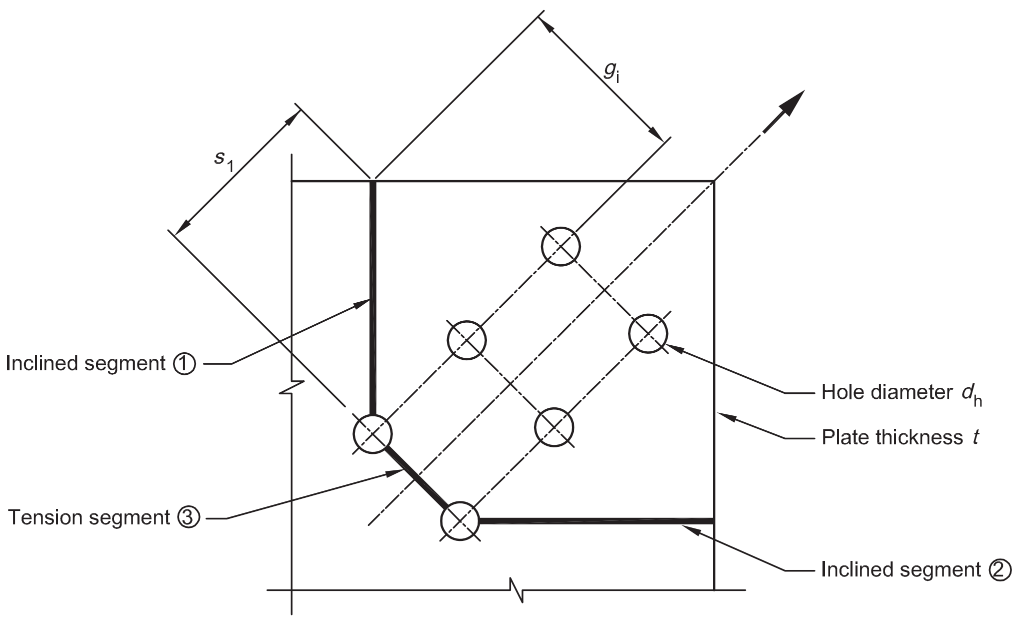
INCLINED FAILURE PLANES IN BLOCK SHEAR FAILURE MODES

The case of failure planes inclined to the direction of the applied load, such as illustrated in Figure 4, is not specifically covered in AS 4100 (2012). Guidance on an appropriate approach has been given in Ref. 5, which adopts the $s^2/4g$ rule commonly used for net section fracture paths. A similar rule is used in AS 4100 (Ref. 1) Clause 9.1.10.3 to assess the area to be deducted from a failure path allowing for staggered holes.

In the approach described in Ref. 5, and referring to Figure 4, each inclined segment is converted into an equivalent net area subject to tension, A_{nte}, and these equivalent areas summed with A_{nt} in the expression for the design capacity in block shear (R_{bs}) given previously. Hence, inclined segments are converted into the equivalent net tension areas and the expression for the design capacity in block shear becomes:

$$R_{\text{bs}} = 0.6 f_{\text{uc}} A_{\text{nv}} + k_{\text{bs}} f_{\text{uc}} (\Sigma A_{\text{nt}} + \Sigma A_{\text{nte}})$$

$$\leq 0.6 f_{\text{yc}} A_{\text{gv}} + k_{\text{bs}} f_{\text{uc}} (\Sigma A_{\text{nt}} + \Sigma A_{\text{nte}})$$



For typical inclined segment ①:

$$A_{\text{nt},1} = (g_i - 0.5 d_h)\, t$$

$$A_{\text{nte},1} = A_{\text{nt},1} + \frac{s_1^2}{4 g_i} t$$

$A_{\text{nte},1}$ = equivalent net area subject to tension at rupture for inclined segment ①

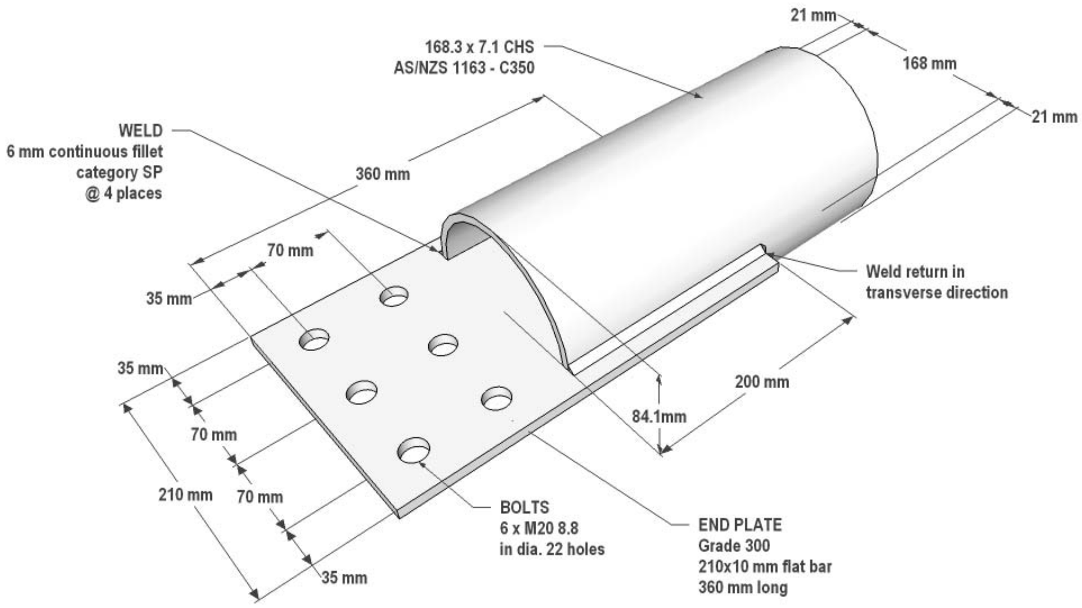
$$A_{\text{nt}} = A_{\text{nte},1} + A_{\text{nt},2} + A_{\text{nte},3}$$

FIGURE 4 BLOCK SHEAR FAILURE PLANES INCLINED TO THE DIRECTION OF THE APPLIED LOAD

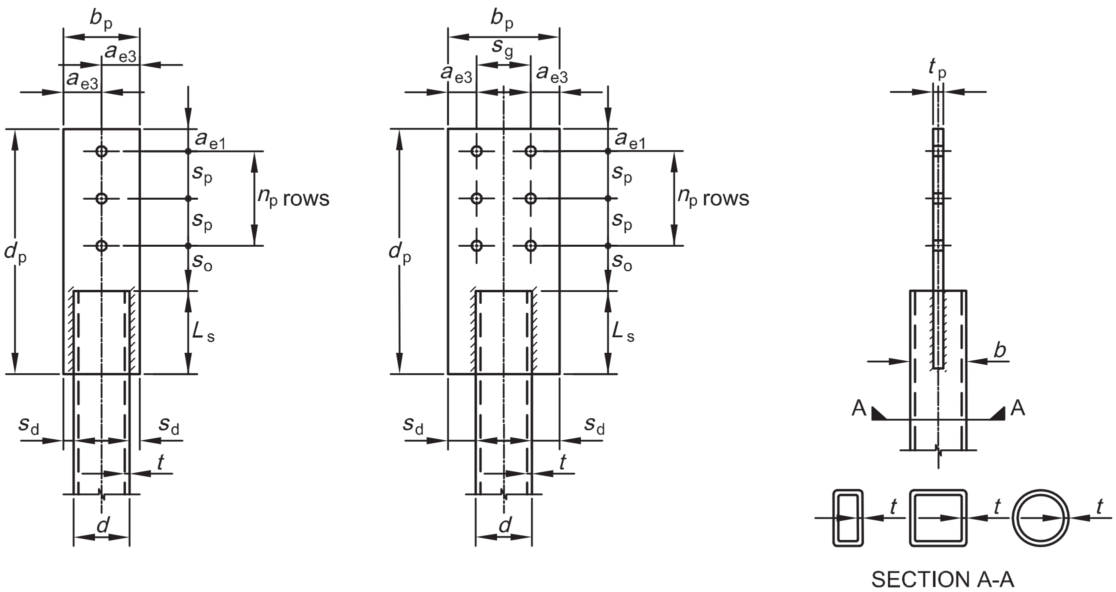
ASI RECOMMENDATIONS

The requirement to check block shear failure modes is now included in the 2012 amendment to AS 4100. Checking of all applicable connection types should now include block shear. Attention needs to be paid to the assumed failure paths to ensure that the full range of representative potential failure paths is checked. These should include potential failure paths with inclined planes where appropriate. AS 4100 does not specifically address the case of inclined failure planes. A suggested approach to include inclined failure planes is outlined in the current Technical Note.

DESIGN EXAMPLE



(a) Design example connection configuration



(b) Standard connection notation

FIGURE 5 DESIGN EXAMPLE CONFIGURATION AND STANDARD NOTATION

Design parameters

Design philosophy: check block shear capacity for applied tension

Design actions:

$N_t^* = 400\ \text{kN}$

Element details:

CHS member: CHS 168.3 x 7.1 Grade 350 to AS/NZS 1163

$d = 168.3\ \text{mm}$ $t = 7.1\ \text{mm}$ $A_g = 3600\ \text{mm}^2$

$f_y = 350\ \text{MPa}$ $f_u = 430\ \text{MPa}$

Cleat: 210 x 360 long square edge flat bar; Grade 300

$d_p = 360\ \text{mm}$ $b_p = 210\ \text{mm}$ $t_p = 10\ \text{mm}$

$f_{yp} = 320\ \text{MPa}$ $\text{f}_{up} = 440\ \text{MPa}$

Bolts: 6 x M20 bolts; 8.8/S category; threads included in shear plane

$d_f = 20\ \text{mm}$ $\phi V_{fn} = 92.6\ \text{kN}$ $k_r = 1.0$

Holes: $d_h = 22\ \text{mm}$ $s_p = 70\ \text{mm}$ $n_p = 2$

$s_g = 70\ \text{mm}$ $n_g = 3$

$a_{e1} = 35\ \text{mm}$ $a_{e3} = 35\ \text{mm}$

Welds: 6 mm continuous fillet weld both sides of cleat; weld category SP

$L_w = 200\ \text{mm}$ $\text{f}_{uw} = 490\ \text{MPa}$ $\phi v_w = 0.998\ \text{kN/mm}$

6 mm fillet weld both sides of cleat; weld category SP

Assembly: $s_d = 21\ \text{mm}$ $L_s = 200\ \text{mm}$ $b_s = 10\ \text{mm}$

$w = (\pi d_o/2) - b_s$

= (π x 168.3/2) – 10

= 254 mm

DESIGN CHECK: Design capacity of cleat plate in block shear

A_{nv} = $2\left[a_{e1} + (n_p - 1)s_p - (n_p - 0.5)d_h\right]t_p$ for Mode A failure

= 2 x [35 + (2 - 1) x 70 - (2 - 0.5) x 22] x 10

= 1440 mm^2

A_{nv} = $\left[a_{e1} + (n_p - 1)s_p - (n_p - 0.5)d_h\right]t_p$ for Mode B failure

= [35 + (2 - 1) x 70 – (2 - 0.5) x 22] x 10

= 720 mm^2

A_{nv} = not applicable, as $n_g \neq 2$ for Mode C failure

A_{nt} = $\left[(n_g - 1)s_g - (n_g - 1)d_h\right]t_p$ for Mode A failure

= [(3 - 1) x 70 – (3 - 1) x 22] x 10

= 960 mm^2

A_{nt} = $\left[(n_g - 1)s_g + a_{e3} - (n_g - 0.5)d_h\right]t_p$ for Mode B failure

= [(3 - 1) x 70 + 35 – (3 - 0.5) x 22] x 10

= 1200 mm^2

A_{nt} = not applicable for Mode C failure

A_{gv}	=	$2[a_{e1} + (n_p - 1)s_p]t_p$	for Mode A failure
	=	2 x [35 + (2 - 1) x 70] x 10	
	=	2100 mm^2	
A_{gv}	=	$[a_{e1} + (n_p - 1)s_p]t_p$	for Mode B failure
	=	[35 + (2 – 1)x 70] x 10	
	=	1050 mm^2	
A_{gv}	=	not applicable	for Mode C failure
R_{bs1}	=	$0.6\mathrm{f}_{up}A_{nv} + k_{bs}\mathrm{f}_{up}A_{nt}$	
	=	$(0.6 \times 440 \times 1440 + 1.0 \times 440 \times 960)/10^3$	for Mode A failure
	=	803 kN	
	=	$(0.6 \times 440 \times 720 + 1.0 \times 440 \times 1200)/10^3$	for Mode B failure
	=	718 kN	
R_{bs2}	=	$0.6f_{yp}A_{gv} + k_{bs}f_{up}A_{nt}$	
	=	$(0.6 \times 320 \times 2100 + 1.0 \times 440 \times 960)/10^3$	for Mode A failure
	=	826 kN	
	=	$(0.6 \times 320 \times 1050 + 1.0 \times 440 \times 1200)/10^3$	for Mode B failure
	=	730 kN	
R_{bs}	=	$[R_{bs1}; R_{bs2}]_{min}$ (minimum for Mode A, B or C failure as per Figure 3)	
	=	718 kN	
ϕR_{bs}	=	0.75 x 718	
	=	**539 kN**	≥ 400 kN Satisfactory

REFERENCES

1. Standards Australia, AS 4100-1998 '*Steel structures*' (includes Amendment 1, 2012).
2. Australian Steel Institute, '*Structural steel connections series: Simple connections – Open sections*', 2007.
3. Australian Steel Institute, '*Structural steel connections series: Rigid connections – Open sections*', 2009.
4. Australian Steel Institute, '*Structural steel tubular connections series*', 2014.
5. Packer, J.A. and Henderson, J.E., '*Hollow structural section connections and trusses. A design guide*', 2nd edition, Canadian Institute of Steel Construction, 1997.