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Carbon Steel Blind Bolt Resistances to AISC 360-10

Report To Blind Bolt
Document: RT 1716
Version: 01
Date: October 2016

SCI, Silwood Park, Ascot,
Berkshire, UK. SL5 7QN
Tel: +44 (0)1344 636525
Fax: +44 (0)1344 636570

Version	Issue	Purpose	Author	Reviewer	Approved
01	Oct 2016	Issue to client	DGB	AXW	

For information on publications, telephone direct: +44 (0) 1344 636505 or Email: publications@steel-sci.com

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EXECUTIVE SUMMARY

This report covers the recalculation of the resistance of carbon steel blind bolts in a form suited to the American market and design completed in accordance with the AISC specification 360-10[1].

Resistances in tension, shear, bearing and combined shear and tension are presented, for both Allowable Stress Design (ASD) and Load and Resistance Factor Design (LRFD).

The recalculation is based on the test program reported in SCI Report RT 1303 of July 2009[2].

A suggested presentation of the resistances is provided in Appendix A.

Contents

1 INTRODUCTION

1.1 Blind Bolts

A blind bolt is illustrated in Figure 1.1. The bolts are used in a horizontal orientation.

The bolt shank has a machined slot, within which a rotating ‘toggle’ is positioned and retained by a pin, about which the toggle can rotate in one direction. The toggle cannot rotate in the opposing direction due to the shape of the toggle and the stepped slot machined in the bolt shank.

After inserting the bolt through the supporting material, the bolt is turned 180°, which allows the toggle to turn through 90° under the action of gravity forming a perpendicular stop inside the supporting structure. A mark on the end of the bolt indicates the orientation of the bolt, and a special tool can be inserted longitudinally through machined slots on the outside of the bolt shank to confirm that the toggle has rotated.

The nut can then be tightened in the normal way. The bolts are not intended to be used as pre-loaded assemblies.

It should be emphasised that due to the special shape of the toggle and machined slot, tension force in the bolt is transferred by bearing between the toggle and the bolt shank. The pivot pin plays no part in transferring load.

Figure 1.1 Blind bolt

Carbon steel blind bolts are supplied in Class 10.9 material with a minimum ultimate tensile strength of 1000 N/mm^2.

Carbon steel blind bolts are available in the following diameters:

M8, M10, M12, M16, M20, M24 which correspond to diameters (in inches) of 0.315, 0.394, 0.472, 0.630, 0.787 and 0.945.

In 2009, an extensive series of tests were undertaken to establish design resistances. The test work, statistical analysis and derivation of design resistances is reported in SCI report RT1303[2].

2 TENSION RESISTANCE

2.1 AISC specification

Tension resistance is covered by clause J3-6, where the resistance of a bolt in tension, R_n is given by:

$R_n = F_n A_b$

where:

F_n is the nominal tensile stress F_{nt} from Table J3.2.
A_b is the nominal unthreaded body area.

From the commentary to the AISC specification[1] (clause J3-6), the nominal tensile strength value, F_{nt} is given by:

$F_{nt} = 0.75F_u$

where:

F_u is the ultimate strength of the bolt.

The 0.75 factor allows for the approximate ratio of the effective area of the threaded portion of the bolt to the area of the unthreaded shank.

Because the tensile resistance of the blind bolt is based on the actual cross sectional area of the assembly, the 0.75 factor is not applied.

According to clause J3-6:

(LRFD) The design resistance is ϕR_n and $\phi = 0.75$.

(ASD) The design resistance is R_n/Ω and $\Omega = 2.00$.

2.2 Characteristic tensile resistance

The characteristic tensile resistance of a blind bolt is therefore given by:

$R_n = 0.537\ F_u A_t$ (see expression 19 of RT 1303).

where:

F_u is the ultimate strength of the bolt (1000 N/mm^2).
A_t is the minimum cross sectional area, at the pin.

The characteristic tension resistance is given in Table 2.1 (From Table 7.2 in RT 1303).

Table 2.1 Characteristic tension resistance

Bolt	Cross section at the pin (mm^2)	R_n Tension resistance (kN)
M8	16.1	8.63
M10	30.1	16.17
M12	43.7	23.49
M16	93.4	50.16
M20	134.6	72.29
M24	191.6	102.89

2.3 Design tension resistances

Design tension resistances are given in Table 2.2.

Table 2.2 Design tension resistances

Bolt Diameter		ASD		LRFD	
(mm)	(inch)	R_n/Ω		ϕR_n	
		kN	Kips	kN	Kips
8	0.315	4.3	0.97	6.5	1.46
10	0.394	8.1	1.82	12.1	2.73
12	0.472	11.7	2.64	17.6	3.96
16	0.63	25.1	5.64	37.6	8.46
20	0.787	36.1	8.12	54.2	12.19
24	0.945	51.4	11.57	77.2	17.35

3 SHEAR RESISTANCE

3.1 AISC Specification

Shear resistance is covered by clause J3-6, where the resistance of a bolt in shear, R_n is given by:

$R_n = F_n A_b$

where:

F_n	is the nominal shear stress F_{nv} from Table J3.2.
A_b	is the nominal unthreaded body area.

From the commentary to the AISC specification (clause J3-6), the nominal shear strength value, F_{nv} is given by:

$F_{nv} = 0.563 F_u$

where:

F_u	is the ultimate strength of the bolt.

The 0.563 factor applies if the shear plane is in the unthreaded shank. A further reduction of 0.8 is applied if the shear plane passes through the threaded portion of the shank (because the calculation still uses the unthreaded area).

Because the shear resistance of the blind bolt is based on the actual cross sectional area of the assembly, the 0.563 factor is applied.

According to clause J3-6:

(LRFD) The design resistance is ϕR_n and $\phi = 0.75$.

(ASD) The design resistance is R_n/Ω and $\Omega = 2.00$.

3.2 Characteristic shear resistance over the slot

The characteristic shear resistance of a blind bolt with the shear plane in the slotted length is therefore given by:

$R_n = 0.563\ F_u A_{slot}$ (compare with expression 26 of RT 1303).

where:

F_u	is the ultimate strength of the bolt (1000 N/mm^2).
A_{slot}	is the cross sectional area, at the slot.

The characteristic shear resistance over the slot is given in Table 3.1.

Table 3.1 Characteristic shear resistance over the slot

Bolt	R_n Shear resistance (kN)
M8	13.1
M10	22.3
M12	30.9
M16	60.5
M20	89.2
M24	123.6

3.3 Design shear resistance over the slot

Design shear resistances over the slot are given in Table 3.2.

Table 3.2 Design shear resistance over slot

Bolt Diameter		ASD		LRFD	
(mm)	(inch)	R_n/Ω		ϕR_n	
		kN	Kips	kN	Kips
8	0.315	6.5	1.47	9.8	2.20
10	0.394	11.1	2.51	16.7	3.76
12	0.472	15.5	3.47	23.2	5.21
16	0.63	30.2	6.8	45.3	10.20
20	0.787	44.6	10.03	66.9	15.05
24	0.945	61.8	13.89	92.7	20.84

3.4 Characteristic shear resistance over the threads

The characteristic shear resistance over the threads is given in Table 3.3.

Table 3.3 Characteristic shear resistance over the threads

Bolt	R_n Shear resistance (kN)
M8	20.4
M10	32.7
M12	47.5
M16	88.2
M20	137.8
M24	198.5

3.5 Design shear resistance over the threads

Design shear resistances over the threads are given in Table 3.4.

Table 3.4 Design shear resistance over threads

Bolt Diameter		ASD		LRFD	
(mm)	(inch)	R_n/Ω		ϕR_n	
		kN	Kips	kN	Kips
8	0.315	10.2	2.30	15.3	3.45
10	0.394	16.3	3.67	24.5	5.51
12	0.472	23.7	5.33	35.6	8.00
16	0.63	44.1	9.92	66.2	14.87
20	0.787	68.9	15.49	103.4	23.24
24	0.945	99.2	22.31	148.8	33.46

3.5.1 Checks against published data

To verify the resistances quoted in Table 3.4, it is noted that the resistances for M20 and M24 should be approximately the same as for ¾” and 1” bolts.

The resistances in Table 3.5 are taken from the AISC Manual.

Table 3.5 Design resistances from AISC Manual

Bolt diameter	Shear Strength (kips)	
	ASD	LRFD
¾”	15.0	22.5
1”	26.7	40.0

The difference can be explained by the variation in diameter and the ultimate strength of the bolt (1040 N/mm^2 in the AISC Manual, compared to 1000 N/mm^2 for the blind bolt).

For M20 bolt (LRFD):

$$\frac{19.05^2}{20^2} \times \frac{1040}{1000} \times 23.4 = 22.1$$ (compares with 22.5 kips, OK).

For M24 bolt (LRFD):

$$\frac{25.4^2}{24^2} \times \frac{1040}{1000} \times 33.46 = 39.0$$ (compares with 40.0 kips, OK).

4 COMBINED SHEAR AND TENSION

Rules for combined shear and tension are covered in clause J3-7 if the AISC specification.

The commentary on the specification rearranges the expressions to give:

For design according to LRFD:

$$\left(\frac{f_t}{\phi F_{nt}}\right)+\left(\frac{f_v}{\phi F_{nv}}\right)=1.3 \qquad \text{(expression C-J3-6a)}$$

For design according to ASD:

$$\left(\frac{\Omega f_t}{F_{nt}}\right)+\left(\frac{\Omega f_v}{F_{nv}}\right)=1.3 \qquad \text{(expression C-J3- 6b)}$$

The above expressions are presented in terms of stress, but with appropriate substitution may be presented in terms of resistance, as follows:

For design according to LRFD:

$$\left(\frac{F_{t,Ed}}{\phi R_{nt}}\right)+\left(\frac{F_{v,Ed}}{\phi R_{nv}}\right)\leq 1.3$$

where:

$F_{t,Ed}$ and $F_{v,Ed}$ are the applied tension and shear forces respectively (LRFD values).

ϕR_{nt} is the design tension resistance for LRFD, from Table 2.2.

ϕR_{nv} is the design shear resistance for LRFD, from Table 3.2 (if the shear plane is over the slot) or Table 3.4 if the shear plane is over the threaded shank.

For design according to ASD:

$$\left(\frac{F_{t,Ed}}{R_{nt}/\Omega}\right)+\left(\frac{F_{v,Ed}}{R_{nv}/\Omega}\right)\leq 1.3$$

where:

$F_{t,Ed}$ and $F_{v,Ed}$ are the applied tension and shear forces respectively (ASD values).

R_{nt}/Ω is the design tension resistance for ASD, from Table 2.2.

R_{nv}/Ω is the design shear resistance for ASD, from Table 3.2 (if the shear plane is over the slot) or Table 3.4 if the shear plane is over the threaded shank.

As the interaction limit of 1.3 is more conservative than the equivalent value (1.4) considered appropriate in RT 1303 (see section 5.3), it is recommended that the AISC expressions may be safely adopted, re-expressed as above.

5 BEARING RESISTANCE

The testing reported in RT 1303 demonstrated that the test resistance exceeded the value calculated in accordance with the Eurocode (EN 1993-1-8)[3]. The recommendation was therefore made that the Eurocode expressions be adopted.

In this section, the Eurocode provisions are compared to the AISC requirements with reference to the test results.

5.1 AISC specification

Bearing strength is covered in clause J3-10 of AISC specification 360-10.

When the end distance is not limiting, the design expressions are as follows:

When deformation at service load is a design consideration:

$R_n \leq 2.4dtF_u$

When deformation at service loads is not a consideration:

$R_n \leq 3.0dtF_u$

where:

d is the nominal bolt diameter.
t is the ply thickness.
F_u is the ultimate strength of the plate.

In LRFD design, the available bearing strength is ϕR_n ($\phi = 0.75$).

When deformation at service loads is not a consideration, the bearing strength is therefore given by:

$\phi R_n = 0.75 \times 3.0dtF_u = 2.25dtF_u$

When deformation at service loads is a consideration, the bearing strength is therefore given by:

$\phi R_n = 0.75 \times 2.4dtF_u = 1.8dtF_u$

In ASD design, the available bearing strength is given by R_n/Ω ($\Omega = 2.0$).

5.2 Eurocode design

The (design) bearing resistance of a bolt is given by:

$$F_{\mathrm{b,Rd}} = \frac{k_1 \alpha_\mathrm{b} f_\mathrm{u} dt}{\gamma_{\mathrm{M3}}}$$

where:

k_1	is a factor accounting for the edge distance, with a maximum value of 2.5.
α_b	is a factor primarily accounting for the end distance, with a maximum value of 1.0.
d	is the nominal bolt diameter.
t	is the thickness of the ply.
f_u	is the ultimate strength of the ply material.
γ_{M3}	is a material factor, specified as 1.25.

When the detail is not limited be either edge or end distance, the design resistance is therefore given by:

$$F_{\mathrm{b,Rd}} = \frac{2.5 \times 1.0 f_\mathrm{u} dt}{1.25} = 2 f_\mathrm{u} dt$$

The UK National Annex to BS EN 1993-1-8[4] notes that if deformation at serviceability limit state (SLS) might control, a value of $\gamma_{\mathrm{M3}} = 1.5$ would be more appropriate.

5.3 Recommendations for bearing strength (LRFD)

Report RT 1303 concluded that adopting the Eurocode rule (effectively $2 f_\mathrm{u} dt$ as explained in Section 5.2) was conservative compared to the test results.

Reviewing Table 5.11 of RT 1303, the lowest characteristic correction factor is 1.12. This means that the design rule could safely have been proposed as:

$F_{\mathrm{b,Rd}} = 1.12 \times 2 f_\mathrm{u} dt = 2.24 f_\mathrm{u} dt$

This may be compared to the AISC design resistance of $2.25 dtF_u$ presented in Section 5.1.

It is therefore recommended that the AISC rule can be safely adopted when deformation at the bolt hole at service loads is not a design consideration.

Based on the guidance in the UK National Annex, the design resistance when deformation at SLS might control is given by:

$$F_{\mathrm{b,Rd}} = \frac{2.5 \times 1.0 f_\mathrm{u} dt}{1.5} = 1.7 f_\mathrm{u} dt$$

It is considered that this is sufficiently close to the AISC resistance ($1.8 dtF_u$ as given in Section 5.1) that the AISC rules can be adopted without modification.

5.4 Recommendations for bearing strength (ASD)

Section 5.3 demonstrated that the rules for LRFD design as given in the AISC specification are appropriate without modification for blind bolts.

Because the calculation of the nominal bearing strength is identical in both LRFD and ASD methods, the AISC rules for the resistance may be adopted.

REFERENCES

1 Specification for structural steel buildings
ANSI/AISC 360-10
American Institute of Steel Construction
2010

2 Design resistances of blind bolts
RT 1301
Steel construction Institute
2009

3 Eurocode 3: Design of steel structures – Part1-8: Design of joints
BSI, 2010

4 UK National Annex to Eurocode 3: Design of steel structure Part 1-8: Design of joints
BSI, 2008

APPENDIX A. PRESENTATION OF RESULTS

It is suggested that the resistances in this report be presented in the following form. Key features are:

- Both LRFD and ASD resistances should be presented.
- In the AISC Manual, ASD is presented in the left hand column, on a bright green background. The LRFD is presented on the right, as blue text on a white background.
- The headers confirm the design approach (R_n/Ω and ϕR_n), following the format in AISC tables.
- The AISC nomenclature presents both the variable and the subscript in italics.
- Resistances are presented as kips.
- Dimensions in inches, but SI units in brackets.
- Standard terms are “Shear strength of bolts” and “Tensile strength of bolts”.

Carbon steel Blind Bolt – Design to AISC 360-10

Diameter, in (mm)	Tensile strength (kips)		Shear strength over slot (kips)		Shear strength over threads (kips)	
	R_n/Ω	ϕR_n	R_n/Ω	ϕR_n	R_n/Ω	ϕR_n
	ASD	LRFD	ASD	LRFD	ASD	LRFD
0.345 (8)	0.97	1.46	1.47	2.20	2.30	3.45
0.394 (10)	1.82	2.73	2.51	3.76	3.67	5.51
0.472 (12)	2.64	3.96	3.47	5.21	5.33	8.00
0.630 (16)	5.64	8.46	6.8	10.20	9.92	14.87
0.787 (20)	8.12	12.19	10.03	15.05	15.49	23.24
0.945 (24)	11.57	17.35	13.89	20.84	22.31	33.46

In bearing, the resistance of a blind bolt should satisfy the requirements of AISC specification 360-10 clause J3-10, expressions J3-6a or J3-6b as required, using the nominal diameter *d,* of the bolt. No reduction in diameter to allow for the slot is required.

In combined tension and shear, blind bolts should satisfy the following expressions:

LRFD: $$\left(\frac{F_{t,Ed}}{\phi R_{nt}}\right)+\left(\frac{F_{v,Ed}}{\phi R_{nv}}\right)\leq 1.3$$

ASD: $$\left(\frac{F_{t,Ed}}{R_{nt}/\Omega}\right)+\left(\frac{F_{v,Ed}}{R_{nv}/\Omega}\right)\leq 1.3$$

where:

$F_{t,Ed}$ and $F_{v,Ed}$ are the applied tension and shear forces respectively (LRFD or ASD values)

ϕR_{nt} and R_{nt}/Ω are the design tension resistance (LRFD or ASD), from the above table.

ϕR_{nv} and R_{nv}/Ω are the design shear resistance (LRFD or ASD) from the above table.

The above resistances and interaction criteria make no allowance for the deformation or yield of the connected part.