Blindbolt design resistances for use with BS 5950 and BS EN 1993

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Version	Date	Purpose	Author	Reviewer	Approved
01	03/20	Issue to client	DGB		
02	06/20	Updated with final material test results	DGB		
03	06/20	Updated with M8 carbon steel tension results	DGB		
04	10/20	Property class for nuts added	DGB		

EXECUTIVE SUMMARY

In January 2020, comprehensive physical testing of carbon steel and stainless steel Blindbolts was undertaken, supplementing previous testing completed in 2009.

Design resistances in shear and tension have been determined in accordance with BS EN 1990 for use with BS 5950 and BS EN 1993. There is no change to the 2009 guidance that bearing resistance should be calculated in the same way as for ordinary bolts, and that bolts in combined shear and tension should conform to the codified interaction expressions.

Design shear resistances are presented in the following table. In all cases the shear resistance is through the slotted portion of the assembly, with the toggle parallel to the line of the force.

	Shear resistance (kN)			
	Carbon steel		Stainless steel	
Bolt diameter	BS 5950	EC3	BS 5950	EC3
M8	7.9	9.1	6.5	7.8
M10	15.8	19.0	11.1	13.3
M12	22.0	26.4	15.4	18.4
M14	29.0	29.0		
M16	43.0	49.1	30.1	36.1
M20	63.4	76.1		
M24	87.8	105.4		
M30	137.2	164.6		

Design tensile resistances are presented in the following table.

	Tension resistance (kN)			
	Carbon steel		Stainless steel	
Bolt diameter	BS 5950	EC3	BS 5950	EC3
M8	9.8	9.8	5.3	5.3
M10	14.1	14.1	12.7	12.7
M12	22.4	22.4	21.4	22.0
M14	34.8	34.8		
M16	38.8	38.8	42.8	42.9
M20	71.4	71.4		
M24	116.7	116.7		
M30	174.5	174.5		

In combined bending and shear, the interaction expressions presented in BS 5950 and in BS EN 1993-1-8 should be used, substituting the design resistances given in the preceding tables.

The bearing resistance according to BS 5950 should be calculated in the normal way, using an effective diameter equal to the nominal diameter of the Blindbolt, less the width of the slot.

The bearing resistance according to BS EN 1993-1-8 should be calculated in the normal way, using the nominal diameter of the Blindbolt.

Contents

1 Blindbolts

1.1 Product supply

Blindbolts covered by this report are supplied by:

Henry Venables Products Ltd
UK Head Office
The Woodhouse
Hopton Wafers
Kidderminster
Worcester
DY12 0EE
United Kingdom

1.2 Product form, dimensions and material

The blind bolts covered by this report have the form shown in Figure 1.1

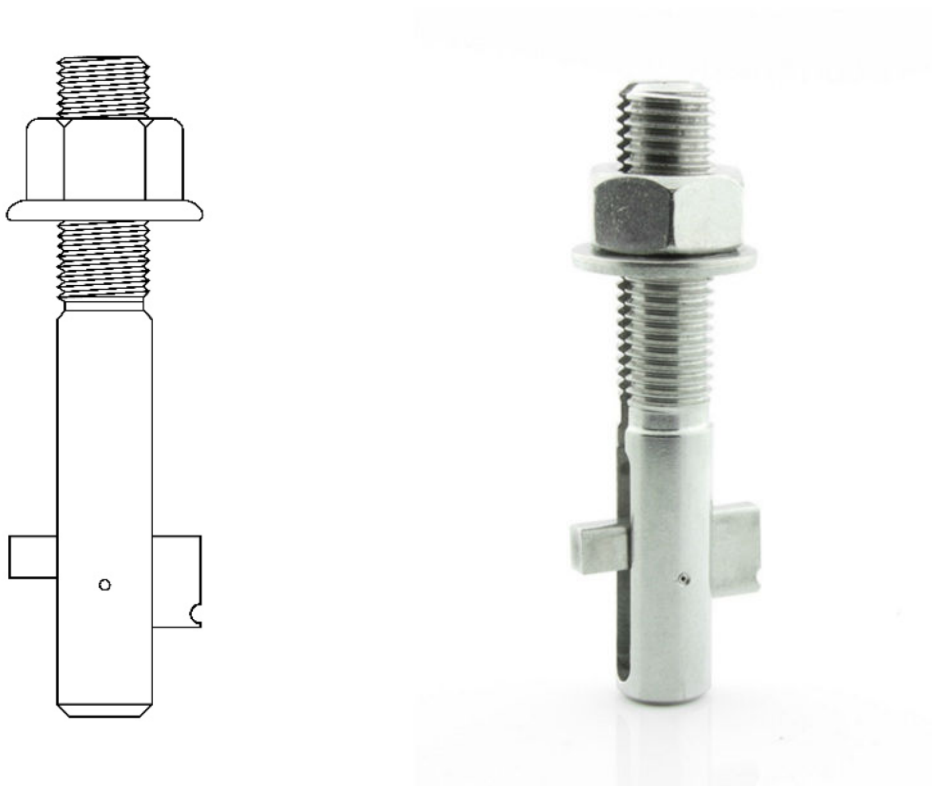

Figure 1.1 Blind bolt

Blind bolts from Henry Venables Products Ltd, UK, are manufactured in property class 10.9 carbon steel (ultimate strength 1000 N/mm^2; yield strength 900 N/mm^2) and in A4-70 stainless steel (ultimate strength 700 N/mm^2; 450 N/mm^2 at 0.2% elongation). For carbon steel bolts property class 8 nuts are used with M8 to M20 and property class 10 nuts with M24 and M30.

The (2020) range of carbon steel blind bolts is presented in Table 1.1.

Table 1.1 Carbon steel blind bolts

Product Code	Diameter (mm)	Length (mm)
BB0850DTASM	8	50
BB1060DTASM	10	60
BB1095DTASM	10	95
BB10130DTASM	10	130
BB1270DTASM	12	70
BB12120DTASM	12	120
BB12180DTASM	12	180
GBB1475DTASM	14	75
GBB14125DTASM	14	125
GBB14185DTASM	14	185
GBB1690DTASM	16	90
GBB16130DTASM	16	130
GBB16180DTASM	16	180
GBB20110DTASM	20	110
GBB20140DTASM	20	140
GBB201800DTASM	20	180
GBB20250DTASM	20	250
GBB24130DTASM	24	130
GBB30140DTASM	30	140

The (2020) range of stainless steel blind bolts is presented in Table 1.2.

Table 1.2 Stainless steel blind bolts

Product Code	Diameter (mm)	Length (mm)
BB0850A4ASM	8	50
BB1060A4ASM	10	60
BB1290A4ASM	12	90
GBB16100A4ASM	16	100

The bolt dimensions and calculated shear and tensile areas are presented in Table 1.3. It should be noted that the pin plays no part in resisting tensile loads – the toggle bears on the end of the machined slot in the blot shank.

Table 1.3 Bolt dimensions and areas

Bolt diameter	Slot width (mm)	Pin diameter (mm)	Shear area (mm^2)	Tensile area (mm^2)
M8 carbon	4	1.0	19.7	15.7
M8 stainless	3.5	1.0	23.2	18.7
M10	4	1.6	39.6	30.1
M12	5	1.6	54.9	43.7
M14	6	1.8	72.6	58.3
M16	6	2.0	107.4	87.4
M20	8	2.0	158.5	134.6
M24	10	2.0	219.5	191.6
M30	12.5	3.2	343.0	287.2

1.3 Physical testing

Physical testing of Blindbolts in carbon steel and stainless steel, as supplied by Henry venables Products Ltd was completed in January and February of 2020, by:

Intertek NDT (Materials Testing)
99 Victory Road
Derby
DE24 8ZF
United Kingdom

Intertek NDT are an ISO/IEC 17025 UKAS accredited metallurgical test laboratory.

2 Shear tests

Four samples of each assembly were tested in a simple lap joint arrangement, as shown in Figure 2.1.

In every case, the thickness of the plates were arranged so that the shear plane was through the slotted region of the bolt.

In every case, the toggle (and slot) were parallel to the applied load.

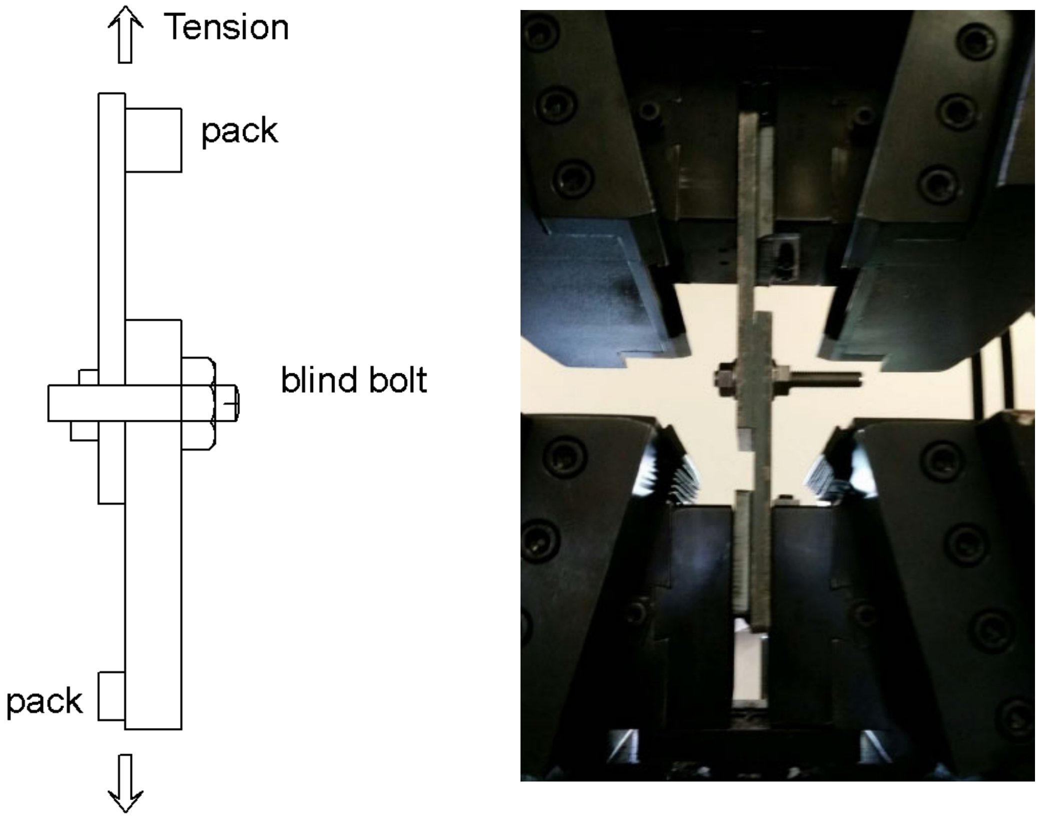

Figure 2.1 Static shear test arrangement

The dimensions of the bolts were verified to an accuracy of 0.01 mm.

For each bolt diameter, material strengths were established by test.

2.1 Carbon steel bolts in shear

Section 2.1.1 presents a fully worked example of the input data and calculation procedure undertaken in accordance with BS EN 1990[1] used to establish the shear resistance.

Section 2.1.4 summarises the results from all bolt diameters. In each case, the same process was used to determine the bolt diameters.

Figure 2.2 shows the plot of load against deformation for a typical carbon steel bolt tested in shear. The specific test was M16, Test 2.

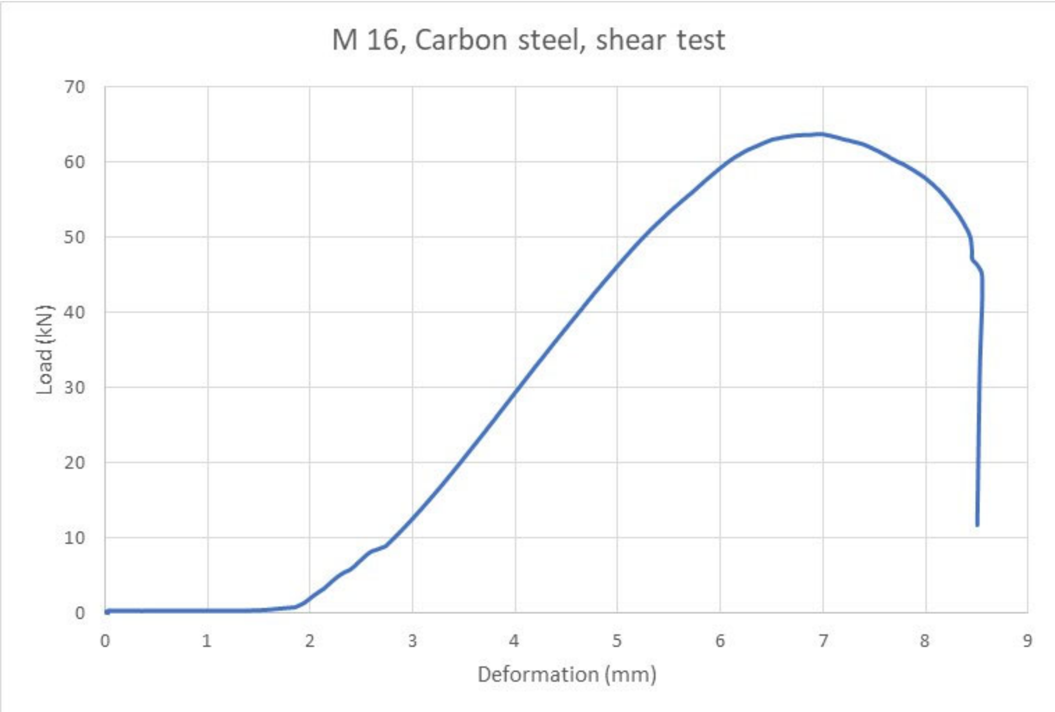

Figure 2.2 Typical carbon steel shear test (M16, test 2)

Figure 2.3 shows the plot of load against deformation for a typical stainless steel bolt tested in shear. The specific test was M12, Test 2.

Figure 2.3 Typical stainless steel shear test (M12, test 2)

2.1.1 M20 carbon steel blind bolt in shear

2.1.1.1 Material strength

The ultimate strength determined by test is shown in Table 2.1.

Table 2.1 M20 material strength

	Ultimate strength (N/mm^2)
	1125
	1072
	1077
Average	1091

2.1.1.2 Bolt diameter

Measured diameters are shown in Table 2.2.

Table 2.2 M20 measured bolt diameters

Diameter (mm)	Diameter (mm)
19.92	19.98
19.97	19.99
20.02	20.02
19.98	19.99
19.97	20.03
20.00	20.01
Average	19.99

2.1.1.3 Shear resistance

Failure loads are recorded in Table 2.3.

Table 2.3 M20 measured shear resistance

Test	Test resistance (kN)
1	107.73
2	102.23
3	103.21
4	100.55

2.1.1.4 Tested capacity adjustment

The tested capacity has been normalised to allow for the measured material strength and measured diameter by the following factor:

$$\alpha_{\mathrm{v}} = \frac{[df_{\mathrm{u}}]_{\mathrm{Specified}}}{[df_{\mathrm{u}}]_{\mathrm{Measured}}} = \frac{20\times1000}{19.99\times1091} = 0.917$$

2.1.1.5 Normalised test resistance

The normalised resistances are shown in Table 2.4.

Table 2.4 M20 normalised shear resistance

Test	Normalised shear resistance (kN)
1	98.76
2	93.80
3	94.62
4	92.18
Mean	94.84
Standard deviation	2.80
Coefficient of variation	3.0%

2.1.1.6 Ultimate resistance to BS EN 1990

The ultimate design shear resistance has been calculated in accordance with BS EN 1990, Annex D.

Previous tests have established the anticipated coefficient of variation, so $k_{d,n}$ is taken from Table D2 for "V_x known", for 32 tests (value taken for 30), as 3.13.

Therefore:

Design shear resistance = 94.84 – 3.13 × 2.8 = 86.1 kN

2.1.2 Resistance calculations in accordance with BS 5950[2]

The design shear resistance should not more than that calculated in accordance with clause 6.3.2.1, where:

$P_s = p_s A_s$ where p_s = 400 N/mm^2 from Table 30 of BS 5950.

From Table 1.3, A_s = 158.5 mm^2 for an M20 Blindbolt.

Therefore:

$P_s = 400 \times 158.5 \times 10^{-3} = 63.4$ kN

2.1.3 Resistance calculations in accordance with BS EN 1993-1-8[3]

The design shear resistance should not more than that calculated in accordance with Table 3.4, where:

$F_{v,Rd} = \frac{0.6 f_{ub} A}{\gamma_{M2}}$, where f_{ub} = 1000 N/mm^2 for property class 10.9 bolts and γ_{M2} = 1.25

From Table 1.3, A_s = 158.5 mm^2 for an M20 Blindbolt.

Therefore:

$$F_{v,Rd} = \frac{0.6 \times 1000 \times 158.5}{1.25} \times 10^{-3} = 76.1 \text{ kN}$$

In this example, the resistance is set by the calculated results in accordance with the design standard. The final design resistances are:

BS 5950: 63.4 kN

BS EN 1993-1-9: 76.1 kN

2.1.4 Carbon bolt shear resistance summary

Table 2.5 presents the shear resistances for carbon steel blind bolts, following the process shown in the preceding sections. Calculations for each bolt diameter are presented in Appendix A.

Table 2.5 Carbon steel Blindbolt shear resistance

Bolt Diameter	Shear resistance (kN)	
	BS 5950	BS EN 1993-1-8
M8	7.9	9.1
M10	15.8	19.0
M12	22.0	26.4
M14	29.0	34.8
M16	43.0	49.1
M20	63.4	76.1
M24	87.8	105.4
M30	137.2	164.6

2.2 Stainless steel bolts in shear

Section 2.2.1 presents a fully worked example of the input data and calculation procedure undertaken in accordance with BS 5950 and BS EN 1993-1-8. There is no modification given in BS EN 1993-1-4[4] for stainless steel.

Section 2.2.2 summarises the results from all bolt diameters. In each case, the same process was used to determine the bolt diameters.

2.2.1 M12 stainless steel blind bolt in shear

2.2.1.1 Material strength

The ultimate strength determined by test is shown in Table 2.6.

Table 2.6 M12 material strength

	Ultimate strength (N/mm^2)
	775
	776
	792
Average	781

2.2.1.2 Bolt diameter

Measured diameters are shown in Table 2.7.

Table 2.7 M12 measured bolt diameters

Diameter (mm)	Diameter (mm)
11.98	11.92
11.96	11.94
11.93	11.94
11.94	11.94
11.95	11.95
11.95	11.95
Average	11.95

2.2.1.3 Shear resistance

Failure loads are recorded in Table 2.8.

Table 2.8 M12 measured shear resistance

Test	Test resistance (kN)
1	34.40
2	34.22
3	33.80
4	33.92

2.2.1.4 Tested capacity adjustment

The tested capacity has been normalised to allow for the measured material strength and measured diameter by the following factor:

$$\alpha_{\mathrm{v}} = \frac{[d f_{\mathrm{u}}]_{\mathrm{Specified}}}{[d f_{\mathrm{u}}]_{\mathrm{Measured}}} = \frac{12 \times 700}{11.95 \times 781} = 0.900$$

2.2.1.5 Normalised test resistance

The normalised resistances are shown in Table 2.9.

Table 2.9 M12 normalised shear resistance

Test	Normalised shear resistance (kN)
1	30.97
2	30.81
3	30.43
4	30.54
Mean	30.69
Standard deviation	0.25
Coefficient of variation	0.8%

2.2.1.6 Ultimate resistance to BS EN 1990

The ultimate design shear resistance has been calculated in accordance with BS EN 1990, Annex D.

Previous tests have established the anticipated coefficient of variation, so $k_{d,n}$ is taken from Table D2 for "V_x known", for 16 tests (value taken for 10), as 3.23

Therefore:

Design shear resistance = 30.69 – 3.23 × 0.25 = 29.9 kN

2.2.2 Resistance calculations in accordance with BS 5950

The design shear resistance should not more than that calculated in accordance with clause 6.3.2.1, where:

$P_s = p_s A_s$ where $p_s = 0.4 f_u$ and $f_u = 700$ N/mm^2.

From Table 1.3, $A_s = 54.9$ mm^2 for an M12 Blindbolt.

Therefore:

$P_s = 0.4 \times 700 \times 54.9 \times 10^{-3} = 15.4$ kN

2.2.3 Resistance calculations in accordance with BS EN 1993-1-8

The design shear resistance should not more than that calculated in accordance with Table 3.4, where:

$F_{v,Rd} = \frac{0.6 f_{ub} A}{\gamma_{M2}}$, where $f_{ub} = 700$ N/mm^2 for property class 70 bolts and $\gamma_{M2} = 1.25$

From Table 1.3, $A_s = 54.9$ mm^2 for an M12 Blindbolt.

Therefore:

$$F_{\mathrm{v,Rd}} = \frac{0.6 \times 700 \times 54.9}{1.25} \times 10^{-3} = 18.5 \ \text{kN}$$

In this example, the resistance is set by the calculated results in accordance with the design standard. The final design resistances are:

BS 5950: 15.4 kN

BS EN 1993-1-8: 18.5 kN

2.2.4 Stainless steel bolt shear resistance summary

Table 2.10 presents the design shear resistances for stainless steel blind bolts following the process shown in the preceding sections. Calculations for each bolt diameter are presented in Appendix B.

Table 2.10 Stainless steel Blindbolt shear resistance

Bolt Diameter	Shear resistance (kN)	
	BS 5950	BS EN 1993-1-8
M8	6.5	7.8
M10	11.1	13.3
M12	15.4	18.4
M16	30.1	36.1

3 Tension tests

Testing was completed using the test apparatus shown in Figure 3.1. Tension in the bolts is produced by applying compression to the interlocking fabricated assemblies.

Figure 3.1 Static tension test arrangement

The dimensions of the bolts were verified to an accuracy of 0.01 mm.

For each bolt diameter, material strengths were established by test.

Figure 3.2 shows the plot of load against deformation for a typical carbon steel bolt tested in tension. The specific test was M16, Test 2.

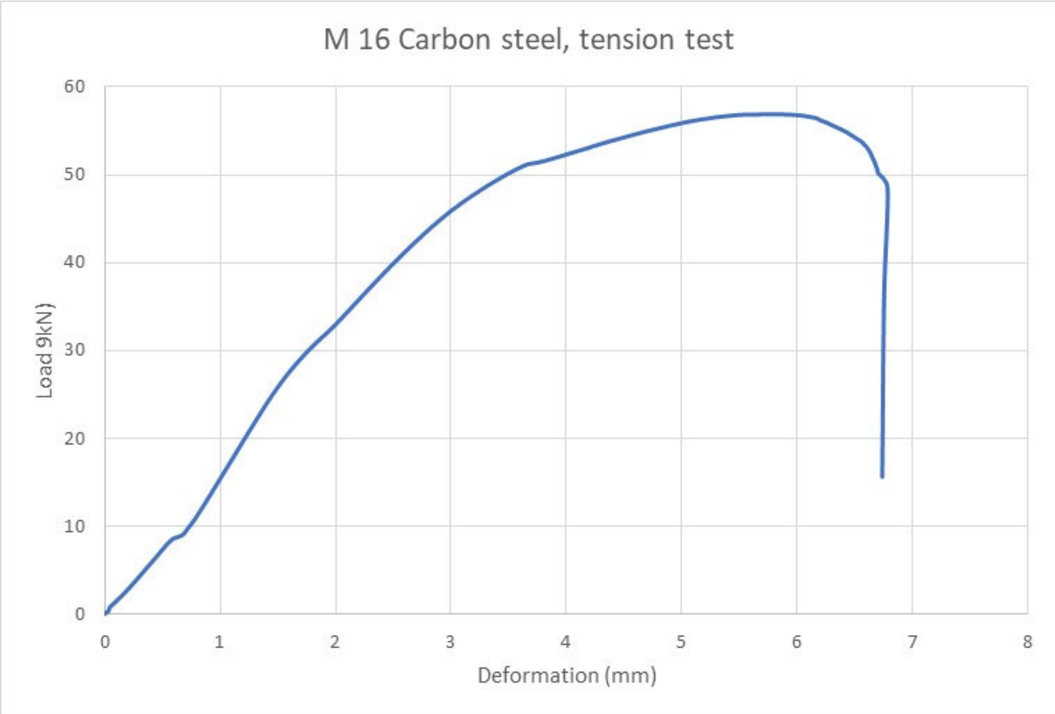

Figure 3.2 Typical carbon steel tension test (M16, test 2)

Figure 3.3 shows the plot of load against deformation for a typical stainless steel bolt tested in tension. The specific test was M12, Test 2.

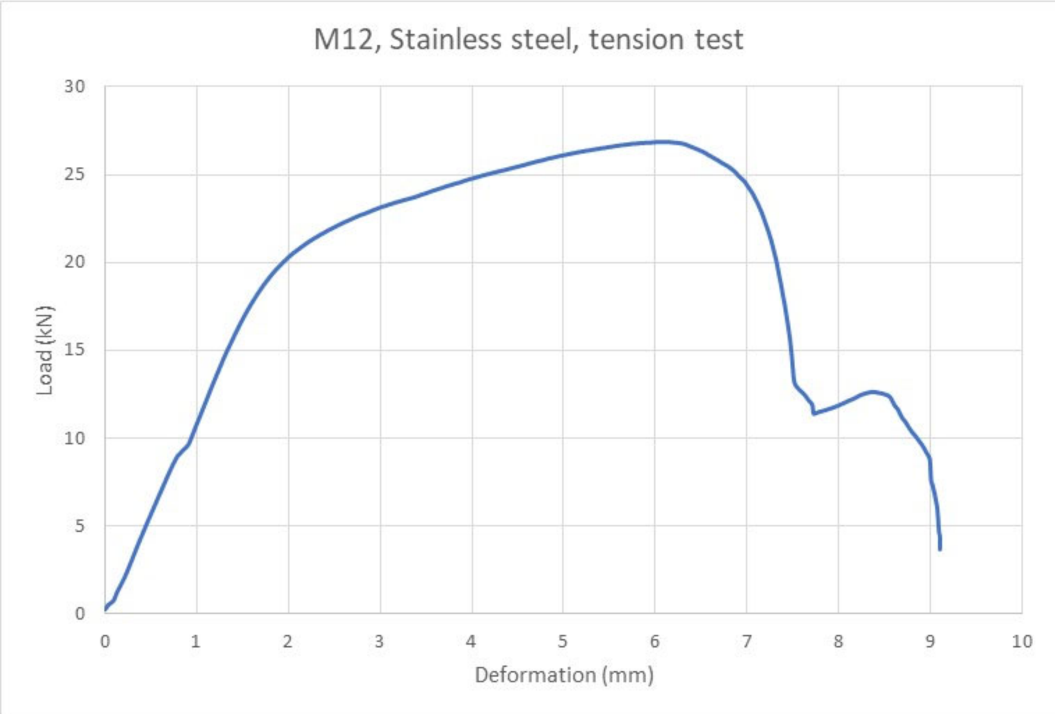

Figure 3.3 Typical stainless steel tension test (M12, test 2)

3.1 Carbon steel bolts in tension

Section 3.1.1 presents a fully worked example of the input data and calculation procedure undertaken in accordance BS EN 1990.

Section 3.1.4 summarises the results from all bolt diameters. In each case, the same process was used to determine the bolt diameters.

3.1.1 M20 carbon steel blind bolt in tension

3.1.1.1 Material strength

The ultimate strength determined by test is shown in Table 3.1.

Table 3.1 M20 material strength

	Ultimate strength (N/mm^2)
	1125
	1072
	1077
Average	1091

3.1.1.2 Bolt diameter

Measured diameters are shown in Table 3.2.

Table 3.2 M20 measured bolt diameters

Diameter (mm)	Diameter (mm)
19.92	19.98
19.97	19.99
20.02	20.02
19.98	19.99
19.97	20.03
20.00	20.01
Average	19.99

3.1.1.3 Tension resistance

Failure loads are recorded in Table 3.3.

Table 3.3 M20 measured tension resistance

Test	Test resistance (kN)
1	82.22
2	83.29
3	79.78
4	80.78
5	82.44
6	82.02

3.1.1.4 Tested capacity adjustment

The tested capacity has been normalised to allow for the measured material strength and measured diameter by the following factor:

$$\alpha_{\mathrm{t}} = \frac{[d^2 f_{\mathrm{u}}]_{\mathrm{Specified}}}{[d^2 f_{\mathrm{u}}]_{\mathrm{Actual}}} = \frac{20^2 \times 1000}{19.99^2 \times 1091} = 0.918$$

3.1.1.5 Normalised test resistance

The normalised resistances are shown in Table 3.4.

Table 3.4 M20 normalised tensile resistance

Test	Normalised tensile resistance (kN)
1	75.41
2	76.40
3	73.18
4	74.09
5	75.62
6	75.23
Mean	74.99
Standard deviation	1.16
Coefficient of variation	1.5%

3.1.1.6 Ultimate resistance to BS EN 1990

The ultimate design tension resistance has been calculated in accordance with BS EN 1990, Annex D.

Previous tests have established the anticipated coefficient of variation, so $k_{d,n}$ is taken from Table D2 for "V_x known", for 48 tests (taken as 30), as 3.13

Therefore:

Design tensile resistance = 74.99 – 3.13 × 1.16 = 71.4 kN

3.1.2 Resistance calculations in accordance with BS 5950

The design tensile resistance should not more than that calculated in accordance with clause 6.3.4.3, where:

$P_t = p_t A_t$ where p_t= 700 N/mm^2 from Table 34 of BS 5950

From Table 1.3, A_s = 134.6 mm^2 for an M20 Blindbolt.

Therefore:

$P_t = 700 \times 134.6 \times 10^{-3} = 94.2$ kN

3.1.3 Resistance calculations in accordance with BS EN 1993-1-8

The design tensile resistance should not more than that calculated in accordance with Table 3.4, where:

$F_{t,Rd} = \frac{0.9 f_{ub} A_s}{\gamma_{M2}}$, where f_{ub} = 1000 N/mm^2 for property class 10.9 bolts and γ_{M2} = 1.25

From Table 1.3, A_s is the tensile area, = 134.6 mm^2 for an M20 Blindbolt.

Therefore:

$$F_{t,Rd} = \frac{0.9\times1000\times134.6}{1.25} \times 10^{-3} = 96.9 \text{ kN}$$

In this example, the resistance is set by the tested resistance calculated in accordance with BS EN 1990. The final design resistances are:

BS 5950: 71.3 kN

BS EN 1993-1-8: 71.3 kN

3.1.4 Carbon bolt tensile resistance summary

Table 3.5 presents the design tensile resistances for carbon steel blind bolts following the process shown in the preceding sections. Calculations for each bolt diameter are presented in Appendix C.

Table 3.5 Carbon steel Blindbolt tensile resistance

Bolt Diameter	Tensile resistance (kN)	
	BS 5950	BS EN 1993-1-8
M8	9.8	9.8
M10	14.1	14.1
M12	22.4	22.4
M14	34.8	34.8
M16	38.8	38.8
M20	71.4	71.4
M24	116.7	116.7
M30	174.5	174.5

3.2 Stainless steel bolts in tension

Section 3.2.1 presents a fully worked example of the input data and calculation procedure undertaken in accordance with BS EN 1990.

Section 3.2.4 summarises the results from all bolt diameters. In each case, the same process was used to determine the bolt diameters.

3.2.1 M12 stainless steel blind bolt in tension

3.2.1.1 Material strength

The ultimate strength determined by test is shown in Table 3.6.

Table 3.6 M12 material strength

	Ultimate strength (N/mm^2)
	775
	776
	792
Average	781

3.2.1.2 Bolt diameter

Measured diameters are shown in Table 3.7.

Table 3.7 M12 measured bolt diameters

Diameter (mm)	Diameter (mm)
11.98	11.92
11.96	11.94
11.93	11.94
11.94	11.94
11.95	11.95
11.95	11.95
Average	11.95

3.2.1.3 Tension resistance

Failure loads are recorded in Table 3.8.

Table 3.8 M12 measured tension resistance

Test	Test resistance (kN)
1	26.61
2	26.87
3	25.91
4	27.36
5	25.89
6	25.73

3.2.1.4 Tested capacity adjustment

The tested capacity has been normalised to allow for the measured material strength and measured diameter by the following factor:

$$\alpha_t = \frac{[d^2 f_u]_{Specified}}{[d^2 f_u]_{Actual}} = \frac{12^2 \times 700}{11.95^2 \times 1781} = 0.904$$

3.2.1.5 Normalised test resistance

The normalised resistances are shown in Table 3.9.

Table 3.9 M12 normalised tensile resistance

Test	Normalised tensile resistance (kN)
1	24.07
2	24.30
3	23.43
4	24.75
5	23.42
6	23.27
Mean	23.87
Standard deviation	0.59
Coefficient of variation	2.5%

3.2.1.6 Ultimate resistance to BS EN 1990

The ultimate design tension resistance has been calculated in accordance with BS EN 1990, Annex D.

Previous tests have established the anticipated coefficient of variation, so $k_{d,n}$ is taken from Table D2 for "V_x known", for 24 tests (value taken as 20), as 3.16

Therefore:

Design tensile resistance = 23.87 – 3.16 × 0.59 = 22.0 kN

3.2.2 Resistance calculations in accordance with BS 5950

The design tensile resistance should not more than that calculated in accordance with clause 6.3.4.3, where:

$P_t = p_t A_t$ where $p_t = 0.7 U_b$, where U_b = 700 N/mm^2 for a property class 70 bolt.

From Table 1.3, A_s = 43.7 mm^2 for an M12 Blindbolt.

Therefore:

$P_t = 0.7 \times 700 \times 43.7 \times 10^{-3} = 21.4$ kN

3.2.3 Resistance calculations in accordance with BS EN 1993-1-8

The design tension resistance should not more than that calculated in accordance with Table 3.4, where:

$F_{t,Rd} = \frac{0.9 f_{ub} A_s}{\gamma_{M2}}$, where f_{ub} = 700 N/mm^2 for property class 70 bolts and γ_{M2} = 1.25

From Table 1.3, A_s is the tensile area, = 43.7 mm^2 for an M12 Blindbolt.

Therefore:

$$F_{t,Rd} = \frac{0.9 \times 700 \times 43.7}{1.25} \times 10^{-3} = 22.0 \text{ kN}$$

In this example, the resistance is set by the tested resistance calculated in accordance with BS 5950, and by that calculated in accordance with BS EN 1990 for Eurocode design. The final design resistances are:

BS 5950: 21.4 kN

BS EN 1993-1-8: 22.0 kN

3.2.4 Stainless steel bolt tension resistance summary

Table 3.5 presents the design tension resistances for stainless steel blind bolts following the process shown in the preceding sections. Calculations for each bolt diameter are presented in Appendix D.

Table 3.10 Stainless steel Blindbolt tensile resistance

Bolt Diameter	Tensile resistance (kN)	
	BS 5950	BS EN 1993-1-8
M8	5.3	5.3
M10	12.7	12.7
M12	21.4	22.0
M16	42.8	42.9

4 Bearing resistance

No specific bearing tests were undertaken in 2020, as successive tests since 2009 have shown that the rules proposed in RT 1303 are satisfactory. The tests undertaken in 2020 have been used to verify the original recommendations. An example calculation to BS 5950 is presented in section 4.1, and to BS EN 1993-1-8 presented in section 4.2.

4.1 Bearing resistance to BS 5950

The expression for bearing capacity in BS 5950 was prepared to limit deformation at working load (SLS) to approximately 1.5 mm.

RT 1303 proposed that the BS 5950 expression in clause 6.3.3.3 could be adopted for a Blindbolt, using an effective diameter equal to the nominal diameter, less the width of the slot.

One of the M16 shear tests has been used to examine the appropriateness of the proposal in RT 1303.

The M16 bolts were tested in an 8 mm thick plate, grade S355. The slot in an M16 is given in Table 1.3 as 6 mm.

The effective diameter is therefore 16 – 6 = 10 mm.

According to Table 32 of BS 5950, the bearing strength of the connected part is 550 N/mm^2 for grade S355 material.

Thus, according to clause 6.3.3.3, the bearing capacity P_{bs} is given by:

$P_{bs} = 1.0 \times 10 \times 8 \times 550 \times 10^{-3} = 44$ kN

This is approximately equivalent to a working load of $^{44}/_{1.5}$ = 29 kN

Figure 4.1 shows the load-deformation plot for a typical M16 shear test, with a horizontal line at 29 kN. The deformation from an initial application of load is approximately 1.5 mm.

For design according to BS 5950, the bearing resistance may therefore be calculated based on an effective diameter of nominal diameter less the slot width.

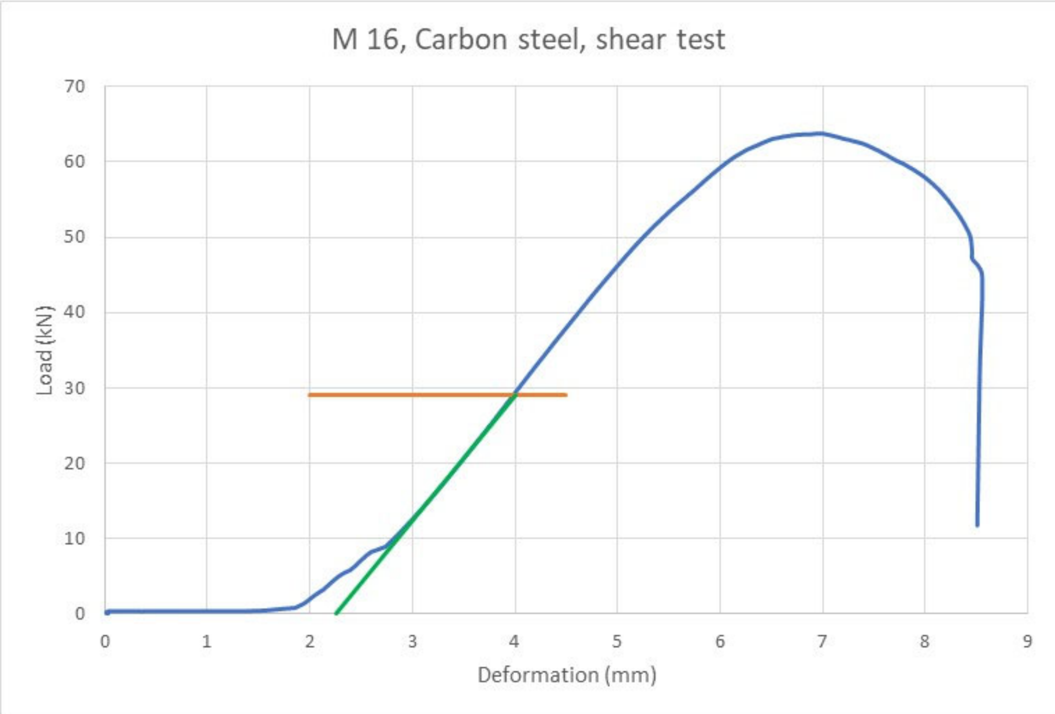

Figure 4.1 Typical carbon steel tension test (M16, test 2) with bearing capacity

4.2 Bearing resistance to BS EN 1993-1-8

In contrast to BS 5950, BS EN 1993-1-8 places no limit on deformation and bearing resistances are much higher.

RT 1303 proposed that for design to BS EN 1993-1-8, bearing resistance be calculated in the normal way, using the nominal bolt diameter.

According to Table 3.4, for bolts not influenced by edge, end, pitch or gauge dimensions, the design bearing resistance is given by:

$$F_{\mathrm{b,Rd}} = \frac{2.5\times1.0\times470\times16\times8}{1.25\times10^{3}} = 120 \text{ kN}$$

Based on the measured plate properties, the tested resistance would be expected to be:

$$F_{\mathrm{b,Rd}} = \frac{2.5\times1.0\times550\times16\times8}{10^{3}} = 176 \text{ kN}$$

As can be seen, this is greatly in excess of the shear resistance of the bolt (approximately 65 kN in Figure 4.1). The bearing resistance for calculations according to BS EN 1993-1-8 should be calculated using the normal rules and the nominal diameter of the bolt.

5 Combined shear and tension

Bolts subjected to combined shear and tension were tested in 2009, in the apparatus shown in Figure 5.1.

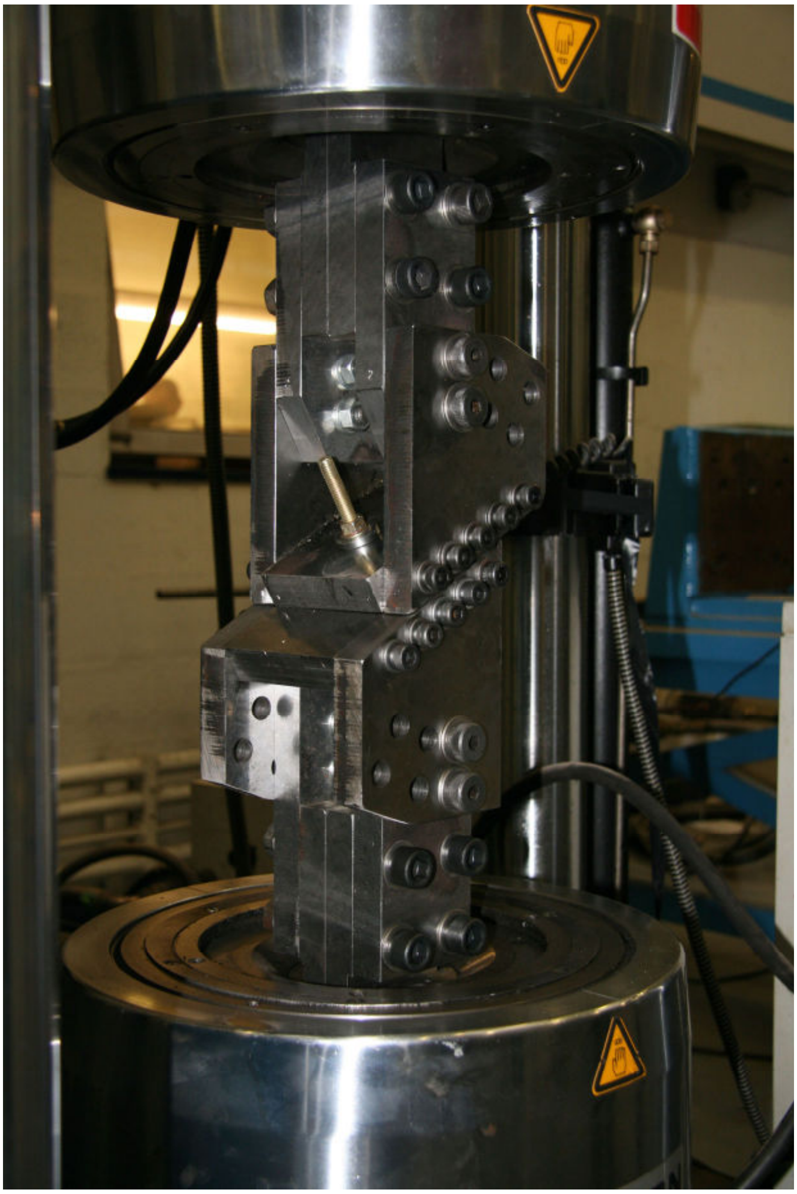

Figure 5.1 Test equipment for bolts subject to combined shear and tension

As the 2020 tests show no significant change in behaviour from the 2009 results, no change is proposed to the use of the rules presented in the design standards. In design to both BS 5950 and BS EN 1993-1-8 the shear capacity ('resistance') and the tension capacity ('resistance') used in the interaction expressions should be the values presented in this report for Blindbolts with a slot.

6 REFERENCES

1 BS EN 1990:2002 + A1:2005 incorporating corrigendum December 2008
Eurocode – Basis of structural design
BSI, 2009

2 BS 5950-1:2002 incorporating corrigendum No. 1 and Amendment No.1
Structural use of steelwork in building – Part 1: Code of practice for design – Rolled and welded sections
BSI, 2007 (Withdrawn)

3 BS EN 1993-1-8:2005 incorporating corrigenda Dec 2005, Sep 2006, July 2009 and Aug 2010
Eurocode3: Design of steel structures – Part 1-8: Design of joints
BSI, 2010

4 BS EN 1993-1-4:2006 + A1:2015
Eurocode 3 – Design of steel structures – Part 1-4: General rules – Supplementary rules for stainless steels
BSI, 2015

Appendix A Test data and resistance calculations – carbon steel shear resistances

M8 carbon steel

material strength	(N/mm^2)
	1155
	1149
	1165
Average	1156

measured diameters (mm)	
8.01	7.93
7.90	7.89
7.92	7.98
7.92	7.91
7.92	7.92
7.92	7.94
Average	7.93

Adjustment factor, α_v 0.872

Shear area 19.7 mm^2

Test number	test shear resistance (kN)	normalised shear resistance (kN)
1	11.32	9.88
2	12.16	10.61
3	11.45	9.99
4	11.99	10.46
	Mean	10.23
	Standard deviation	0.36
	Coefficient of variation	3.5%
	$k_{d,n}$	3.13

BS 5950 resistance
7.9 kN

EN 1993-1-8 resistance
9.5 kN

ULS Design resistance 9.1 kN

BS 5950	**7.9 kN**
EN 1993-1-8	**9.1 kN**

M10 carbon steel

material strength	(N/mm^2)	measured diameters (mm)	
	997	9.88	9.81
	1009	9.81	9.87
	1038	9.82	9.87
Average	1015	9.85	9.83
		9.83	9.81
		9.87	9.87
		Average	9.84

Adjustment factor, α_v 1.000   Shear area 39.6 mm^2

Test number	test shear resistance (kN)	normalised shear resistance (kN)
1	26.07	26.07
2	25.25	25.25
3	25.02	25.02
4	23.48	23.48
	Mean	24.96
	Standard deviation	1.08
	Coefficient of variation	4.3%
	$k_{d,n}$	3.13

BS 5950 resistance
15.8 kN

EN 1993-1-8 resistance
19.0 kN

ULS Design resistance 21.6 kN

	BS 5950	**15.8**	**kN**
0.9	**EN 1993-1-8**	**19.0**	**kN**

M12 carbon steel

material strength	(N/mm^2)
	1084
	1114
	1095
Average	1098

measured diameters (mm)	
11.91	11.82
11.96	11.97
11.94	12.03
11.93	11.89
11.96	11.90
11.90	11.91
Average	11.93

Adjustment factor, α_v 0.917

Shear area 54.9 mm^2

Test number	test shear resistance (kN)	normalised shear resistance (kN)
1	34.77	31.87
2	33.65	30.84
3	33.18	30.41
4	33.87	31.05
	Mean	31.04
	Standard deviation	0.61
	Coefficient of variation	2.0%
	$k_{d,n}$	3.13

BS 5950 resistance
22.0 kN

EN 1993-1-8 resistance
26.4 kN

ULS Design resistance 29.1 kN

BS 5950	**22.0 kN**
EN 1993-1-8	**26.4 kN**

M14 carbon steel

material strength	(N/mm^2)
	1065
	1069
	1082
Average	1072

measured diameters (mm)	
13.96	13.92
13.98	13.98
13.96	14.00
13.98	13.95
14.00	14.01
13.98	13.98
Average	13.98

Adjustment factor, α_v 0.935

Shear area 72.6 mm^2

Test number	test shear resistance (kN)	normalised shear resistance (kN)
1	44.98	42.03
2	51.06	47.72
3	48.59	45.41
4	44.76	41.83
	Mean	44.25
	Standard deviation	2.84
	Coefficient of variation	6.4%
	$k_{d,n}$	3.13

BS 5950 resistance

29.0 kN

EN 1993-1-8 resistance

34.8 kN

ULS Design resistance 35.4 kN

BS 5950	**29.0**	**kN**
EN 1993-1-8	**34.8**	**kN**

M16 carbon steel

material strength	(N/mm²)		measured diameters (mm)	
	1174		15.63	15.98
	1197		15.97	15.97
	1186		15.98	15.99
Average	1186		15.97	15.96
			15.92	15.99
			15.94	15.98
			Average	15.94

Adjustment factor, α_v 0.847

Shear area 107.4 mm^2

Test number	test shear resistance (kN)	normalised shear resistance (kN)
1	62.00	52.49
2	63.84	54.05
3	66.36	56.18
4	66.40	56.21
	Mean	54.73
	Standard deviation	1.81
	Coefficient of variation	3.3%
	$k_{d,n}$	3.13

BS 5950 resistance

43.0 kN

EN 1993-1-8 resistance

51.6 kN

ULS Design resistance 49.1 kN

BS 5950	**43.0**	**kN**
EN 1993-1-8	**49.1**	**kN**

M20 carbon steel

material strength	(N/mm^2)
	1125
	1072
	1077
Average	1091

measured diameters (mm)	
19.92	19.98
19.97	19.99
20.02	20.02
19.98	19.99
19.97	20.03
20.00	20.01
Average	19.99

Adjustment factor, α_v 0.917

Shear area 158.5 mm^2

Test number	test shear resistance (kN)	normalised shear resistance (kN)
1	107.73	98.76
2	102.32	93.80
3	103.21	94.62
4	100.55	92.18
	Mean	94.84
	Standard deviation	2.80
	Coefficient of variation	3.0%
	$k_{d,n}$	3.13

BS 5950 resistance

63.4 kN

EN 1993-1-8 resistance

76.1 kN

ULS Design resistance 86.1 kN

BS 5950	**63.4 kN**
EN 1993-1-8	**76.1 kN**

M24 carbon steel

material strength	(N/mm^2)	measured diameters (mm)	
	1090	23.91	23.92
	1063	23.88	23.98
	1093	23.92	23.93
Average	1082	23.94	23.93
		23.90	23.92
		23.94	23.92
		Average	23.92

Adjustment factor, α_v 0.927

Shear area 219.5 mm^2

Test number	test shear resistance (kN)	normalised shear resistance (kN)
1	152.2	141.11
2	146.8	136.10
3	144.35	133.83
4	139.49	129.33
	Mean	135.09
	Standard deviation	4.90
	Coefficient of variation	3.6%

BS 5950 resistance
87.8 kN

EN 1993-1-8 resistance
105.4 kN

ULS Design resistance 135.1 kN

BS 5950	**87.8**	**kN**
EN 1993-1-8	**105.4**	**kN**

M30 carbon steel

material strength	(N/mm²)
	1060
	1029
	1090
Average	1060

measured diameters (mm)	
29.91	29.99
29.95	29.94
29.93	29.89
29.94	30.00
29.87	30.01
29.97	29.95
Average	29.95

Adjustment factor, α_v 0.945

Shear area 343 mm²

Test number	test shear resistance (kN)	normalised shear resistance (kN)
1	242.20	228.98
2	209.98	198.52
3	212.71	201.10
4	207.51	196.18
	Mean	206.19
	Standard deviation	15.32
	Coefficient of variation	7.4%

BS 5950 resistance

137.2 kN

EN 1993-1-8 resistance

164.6 kN

ULS Design resistance 206.2 kN

BS 5950	**137.2**	**kN**
EN 1993-1-8	**164.6**	**kN**

Appendix B Test data and resistance calculations – stainless steel shear resistances

M8 stainless steel

material strength	(N/mm^2)	measured diameters (mm)	
	748	7.97	7.95
	754	7.94	7.97
	756	7.94	7.95
Average	753	7.96	7.94
		7.96	7.94
		7.96	7.94
		Average	7.95

Adjustment factor, α_v 0.936

Shear area 23.2 mm^2

Test number	test shear resistance (kN)	normalised shear resistance (kN)
1	14.93	13.97
2	14.53	13.60
3	14.29	13.37
4	14.02	13.12
	Mean	13.51
	Standard deviation	0.36
	Coefficient of variation	2.7%
	$k_{d,n}$	3.23

BS 5950 resistance
6.5 kN

EN 1993-1-4 resistance
7.8 kN

ULS Design resistance 12.3 kN

BS 5950	**6.5**	**kN**
EN 1993-1-8	**7.8**	**kN**

M10 stainless steel

material strength	(N/mm²)
	746
	748
	751
Average	748

measured diameters (mm)	
9.96	9.94
9.96	9.96
9.95	9.95
9.97	9.96
9.95	9.95
9.95	9.95
Average	9.95

Adjustment factor, α_v 0.940

Shear area 39.6 mm^2

Test number	test shear resistance (kN)	normalised shear resistance (kN)
1	24.73	23.24
2	24.34	22.87
3	23.74	22.31
4	23.51	22.09
	Mean	22.63
	Standard deviation	0.52
	Coefficient of variation	2.3%
	$k_{d,n}$	3.23

BS 5950 resistance

11.1 kN

EN 1993-1-4 resistance

13.3 kN

ULS Design resistance 20.9 kN

BS 5950	**11.1**	**kN**
EN 1993-1-8	**13.3**	**kN**

M12 stainless steel

material strength	(N/mm^2)
	775
	776
	792
Average	781

measured diameters (mm)	
11.98	11.92
11.96	11.94
11.93	11.94
11.94	11.94
11.95	11.95
11.95	11.95
Average	11.95

Adjustment factor, α_v 0.900

Shear area 54.9 mm^2

Test number	test shear resistance (kN)	normalised shear resistance (kN)
1	34.40	30.97
2	34.22	30.81
3	33.80	30.43
4	33.92	30.54
	Mean	30.69
	Standard deviation	0.25
	Coefficient of variation	0.8%
	$k_{d,n}$	3.23

BS 5950 resistance

15.4 kN

EN 1993-1-4 resistance

18.4 kN

ULS Design resistance 29.9 kN

BS 5950	**15.4**	**kN**
EN 1993-1-8	**18.4**	**kN**

M16 stainless steel

material strength	(N/mm^2)	
	751	
	747	
	760	
Average	753	

measured diameters (mm)	
15.95	15.96
15.96	15.96
15.95	15.96
15.94	15.95
15.94	15.95
15.95	15.97
Average	15.95

Adjustment factor, α_v 0.933

Shear area 107.4 mm^2

Test number	test shear resistance (kN)	normalised shear resistance (kN)
1	61.72	57.57
2	61.64	57.49
3	62.44	58.24
4	60.34	56.28
	Mean	57.40
	Standard deviation	0.82
	Coefficient of variation	1.4%
	$k_{d,n}$	3.23

ULS Design resistance 54.8 kN

BS 5950 resistance
30.1 kN

EN 1993-1-4 resistance
36.1 kN

BS 5950	**30.1 kN**
EN 1993-1-8	**36.1 kN**

Appendix C Test data and resistance calculations – carbon steel tensile resistances

M8 carbon steel

material strength	(N/mm²)	measured diameters (mm)	
	1155	8.01	7.93
	1149	7.90	7.89
	1165	7.92	7.98
Average	1156	7.92	7.91
		7.92	7.92
		7.92	7.94
		Average	7.93

Adjustment factor, α_t 0.880

tensile area 15.7 mm²

Test number	test tension resistance (kN)	normalised tension resistance (kN)
1	12.43	10.94
2	12.94	11.39
3	13.06	11.49
4	13.99	12.31
5	14.25	12.54
6	13.11	11.54
	Mean	11.70
	Standard deviation	0.60
	Coefficient of variation	5.2%
	$k_{d,n}$	3.13

BS 5950 resistance
11.0 kN

EN 1993-1-8 resistance
11.3 kN

ULS Design resistance 9.8 kN

BS 5950	**9.8**	**kN**
EN 1993-1-8	**9.8**	**kN**

M10 carbon steel

material strength	(N/mm^2)
	997
	1009
	1038
Average	1015

measured diameters (mm)	
9.88	9.81
9.81	9.87
9.82	9.87
9.85	9.83
9.83	9.81
9.87	9.87
Average	9.84

Adjustment factor, α_t 1.000

tensile area 30.1 mm^2

Test number	test tension resistance (kN)	normalised tension resistance (kN)
1	16.08	16.08
2	15.25	15.25
3	16.12	16.12
4	15.36	15.36
5	16.07	16.07
6	16.94	16.94
	Mean	15.97
	Standard deviation	0.61
	Coefficient of variation	3.8%
	$k_{d,n}$	3.13

ULS Design resistance 14.1 kN

BS 5950 resistance

21.1 kN

EN 1993-1-8 resistance

21.7 kN

BS 5950	**14.1 kN**
EN 1993-1-8	**14.1 kN**

M12 carbon steel

material strength	(N/mm^2)	measured diameters (mm)	
	1084	11.91	11.82
	1114	11.96	11.97
	1095	11.94	12.03
Average	1098	11.93	11.89
		11.96	11.90
		11.90	11.91
		Average	11.93

Adjustment factor, α_t 0.922

tensile area 43.7 mm^2

Test number	test tension resistance (kN)	normalised tension resistance (kN)
1	29.03	26.77
2	27.15	25.04
3	26.93	24.84
4	27.79	25.63
5	26.36	24.31
6	28.86	26.62
	Mean	25.53
	Standard deviation	0.99
	Coefficient of variation	3.9%
	$k_{d,n}$	3.13

ULS Design resistance 22.4 kN

BS 5950 resistance

30.6 kN

EN 1993-1-8 resistance

31.5 kN

BS 5950	**22.4**	**kN**
EN 1993-1-8	**22.4**	**kN**

M14 carbon steel

material strength	(N/mm^2)
	1065
	1069
	1082
Average	1072

measured diameters (mm)	
13.96	13.92
13.98	13.98
13.96	14.00
13.98	13.95
14.00	14.01
13.98	13.98
Average	13.98

Adjustment factor, α_t 0.936

tensile area 58.3 mm^2

Test number	test tension resistance (kN)	normalised tension resistance (kN)
1	39.08	36.59
2	40.46	37.88
3	40.87	38.26
4	41.84	39.17
5	39.56	37.04
6	39.93	37.38
	Mean	37.72
	Standard deviation	0.93
	Coefficient of variation	2.5%
	$k_{d,n}$	3.13

ULS Design resistance 34.8 kN

BS 5950 resistance

40.8 kN

EN 1993-1-8 resistance

42.0 kN

BS 5950	**34.8 kN**
EN 1993-1-8	**34.8 kN**

M16 carbon steel

material strength	(N/mm^2)
	1174
	1197
	1186
Average	1186

measured diameters (mm)	
15.63	15.98
15.97	15.97
15.98	15.99
15.97	15.96
15.92	15.99
15.94	15.98
Average	15.94

Adjustment factor, α_t 0.850

tensile area 87.4 mm^2

Test number	test tension resistance (kN)	normalised tension resistance (kN)
1	56.83	48.29
2	54.15	46.01
3	64	54.39
4	56.15	47.71
5	53.93	45.83
6	58.45	49.67
	Mean	48.65
	Standard deviation	3.16
	Coefficient of variation	6.5%
	$k_{d,n}$	3.13

BS 5950 resistance

61.2 kN

EN 1993-1-8 resistance

62.9 kN

ULS Design resistance 38.8 kN

BS 5950	**38.8**	**kN**
EN 1993-1-8	**38.8**	**kN**

M20 carbon steel

material strength	(N/mm^2)	
	1125	
	1072	
	1077	
Average	1091	

measured diameters (mm)	
19.92	19.98
19.97	19.99
20.02	20.02
19.98	19.99
19.97	20.03
20.00	20.01
Average	19.99

Adjustment factor, α_t 0.917

tensile area 134.6 mm^2

Test number	test tension resistance (kN)	normalised tension resistance (kN)
1	82.22	75.41
2	83.29	76.40
3	79.78	73.18
4	80.78	74.09
5	82.44	75.62
6	82.02	75.23
	Mean	74.99
	Standard deviation	1.16
	Coefficient of variation	1.5%
	$k_{d,n}$	3.13

ULS Design resistance 71.4 kN

BS 5950 resistance

94.2 kN

EN 1993-1-8 resistance

96.9 kN

BS 5950	**71.4**	**kN**
EN 1993-1-8	**71.4**	**kN**

M24 carbon steel

material strength	(N/mm^2)	measured diameters (mm)	
	1090	23.91	23.92
	1063	23.88	23.98
	1093	23.92	23.93
Average	1082	23.94	23.93
		23.90	23.92
		23.94	23.92
		Average	23.92

Adjustment factor, α_t 0.930

tensile area 191.6 mm^2

Test number	test tension resistance (kN)	normalised tension resistance (kN)
1	133.01	123.71
2	129.42	120.37
3	132.43	123.17
4	133.09	123.78
5	129.06	120.04
6	130.25	121.14
	Mean	122.04
	Standard deviation	1.72
	Coefficient of variation	1.4%
	$k_{d,n}$	3.13

BS 5950 resistance

134.1 kN

EN 1993-1-8 resistance

138.0 kN

ULS Design resistance 116.7 kN

BS 5950	**116.7**	**kN**
EN 1993-1-8	**116.7**	**kN**

M30 carbon steel

material strength	(N/mm^2)
	1060
	1029
	1090
Average	1060

measured diameters (mm)	
29.91	29.99
29.95	29.94
29.93	29.89
29.94	30.00
29.87	30.01
29.97	29.95
Average	29.95

Adjustment factor, α_t 0.947

tensile area 287.2 mm^2

Test number	test tension resistance (kN)	normalised tension resistance (kN)
1	187.51	177.59
2	189.49	179.47
3	189.71	179.68
4	190.08	180.03
5	190.34	180.27
6	193.25	183.03
	Mean	180.01
	Standard deviation	1.76
	Coefficient of variation	1.0%
	$k_{d,n}$	3.13

BS 5950 resistance

201.0 kN

EN 1993-1-8 resistance

206.8 kN

ULS Design resistance 174.5 kN

BS 5950	**174.5**	**kN**
EN 1993-1-8	**174.5**	**kN**

Appendix D Test data and resistance calculations – stainless steel tensile resistances

M8 stainless steel

material strength	(N/mm^2)		measured diameters (mm)	
	748		7.97	7.95
	754		7.94	7.97
	756		7.94	7.95
Average	753		7.96	7.94
			7.96	7.94
			7.96	7.94
			Average	7.95

Adjustment factor, α_t 0.941

tensile area 18.7 mm^2

Test number	test tension resistance (kN)	normalised tension resistance (kN)
1	7.42	6.98
2	8.34	7.85
3	7.44	7.00
4	7.07	6.66
5	6.81	6.41
6	8.09	7.62
	Mean	7.09
	Standard deviation	0.55
	Coefficient of variation	7.8%
	$k_{d,n}$	3.16

BS 5950 resistance
9.2 kN

EN 1993-1-4 resistance
9.4 kN

ULS Design resistance 5.3 kN

BS 5950	**5.3 kN**
EN 1993-1-4	**5.3 kN**

M10 stainless steel

material strength	(N/mm^2)	measured diameters (mm)	
	746	9.96	9.94
	748	9.96	9.96
	751	9.95	9.95
Average	748	9.97	9.96
		9.95	9.95
		9.95	9.95
		Average	9.95

Adjustment factor, α_t 0.944

tensile area 30.1 mm^2

Test number	test tension resistance (kN)	normalised tension resistance (kN)
1		
2	16.18	15.27
3	16.93	15.98
4	16.73	15.79
5	17.34	16.37
6	19.33	18.25
	Mean	16.33
	Standard deviation	1.14
	Coefficient of variation	7.0%
	$k_{d,n}$	3.16

BS 5950 resistance

14.7 kN

EN 1993-1-4 resistance

15.2 kN

ULS Design resistance 12.7 kN

BS 5950	**12.7 kN**
EN 1993-1-4	**12.7 kN**

M12 stainless steel

material strength	(N/mm^2)
	775
	776
	792
Average	781

measured diameters (mm)	
11.98	11.92
11.96	11.94
11.93	11.94
11.94	11.94
11.95	11.95
11.95	11.95
Average	11.95

Adjustment factor, α_t 0.904

tensile area 43.7 mm^2

Test number	test tension resistance (kN)	normalised tension resistance (kN)
1	26.61	24.07
2	26.87	24.30
3	25.91	23.43
4	27.36	24.75
5	25.89	23.42
6	25.73	23.27
	Mean	23.87
	Standard deviation	0.59
	Coefficient of variation	2.5%
	$k_{d,n}$	3.16

ULS Design resistance 22.0 kN

BS 5950 resistance
21.4 kN

EN 1993-1-4 resistance
22.0 kN

BS 5950	**21.4**	**kN**
EN 1993-1-4	**22.0**	**kN**

M16 stainless steel

material strength	(N/mm^2)
	751
	747
	760
Average	753

measured diameters (mm)	
15.95	15.96
15.96	15.96
15.95	15.96
15.94	15.95
15.94	15.95
15.95	15.97
Average	15.95

Adjustment factor, α_t 0.935

tensile area 87.4 mm^2

Test number	test tension resistance (kN)	normalised tension resistance (kN)
1	54.10	50.61
2	62.60	58.56
3	56.35	52.71
4	58.51	54.73
5	53.53	50.08
6	61.54	57.57
	Mean	54.04
	Standard deviation	3.54
	Coefficient of variation	6.5%
	$k_{d,n}$	3.16

ULS Design resistance 42.9 kN

BS 5950 resistance

42.8 kN

EN 1993-1-4 resistance

44.0 kN

BS 5950	**42.8**	**kN**
EN 1993-1-4	**42.9**	**kN**