

Design resistances of stainless steel blind bolts

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EXECUTIVE SUMMARY

This report describes the testing of stainless steel blind bolts and the analysis of the test results to derive the design resistances for use with BS 5950 and BS EN 1993-1-1.

In 2009, SCI derived the design resistances for carbon steel blind bolts, based on tests.¹

The only change from the previous study was the bolt material. Therefore, testing was undertaken to confirm anticipated behaviour and performance.

An analysis of the test results was undertaken using the methodology in BS EN 1990 to develop design resistances. In general, the calculation of the design resistances follow the established rules in BS 5950 and in BS EN 1993-1-1, using modified cross sectional areas where appropriate.

The previous study of carbon steel bolts established rules to calculate bearing resistance in the connected plate. Limited testing to investigate bearing performance with stainless steel bolts was undertaken, as no significant change in behaviour was anticipated.

The design resistances in tension and shear (which may be compared directly with the design loads) are presented below. A suggested presentation of the data for structural designers is provided in APPENDIX A.

Stainless steel blind bolt – design to BS 5950

Diameter	Tension Capacity P_t (kN)	Shear capacity over thread $P_{s,thread}$ (kN)	Shear capacity over slot $P_{s,slot}$ (kN)	Bearing capacity in 10 mm plate P_{bs} (kN)	
				S275	S355
M8	7.7	10.3	6.5	20.7	24.8
M10	14.3	16.2	11.1	27.6	33.0
M12	20.8	23.6	15.4	32.2	38.5
M16	43.5	44.0	30.1	46.0	55.0

Stainless steel blind bolt – design to BS EN 1993

Diameter	Tension Resistance $F_{t,Rd}$ (kN)	Shear resistance over thread $P_{v,Rd,thread}$ (kN)	Shear resistance over slot $F_{v,Rd,slot}$ (kN)	Bearing resistance in 10 mm plate P_{bs} (kN)	
				S275	S355
M8	7.7	12.3	7.8	65.6	75.2
M10	14.3	19.5	13.3	82.0	94.0
M12	20.8	28.3	18.5	98.4	112.8
M16	43.5	52.8	36.1	131.2	150.4

It is recommended that for bearing, and for combined shear and tension, the rules for ordinary bolts as given in the design Standards may be adopted, respecting the reduced resistances given above.

In connections to thin material, such as the walls of hollow sections, the bending resistance or the deformation of the plate is likely to govern the resistance of the connection. The resistances presented in this report are for the bolt alone.

This report has been prepared by Mr David Brown of the SCI.

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2 INTRODUCTION

The Blind Bolt Company supply blind bolts in both carbon steel and stainless steel. Design resistances for carbon steel bolts were determined by testing and analysis by the SCI in 2009.¹

The Blind Bolt Company engaged SCI to complete a similar exercise for stainless steel bolts. In developing the test program, it was recognised that apart from the influence of the basic bolt material, similar performance was anticipated. A test programme was therefore developed to confirm anticipated behaviour with sufficient data to establish design resistances following the procedures in BS EN 1990.²

2.1 Blind Bolts

A stainless steel blind bolt is illustrated in Figure 2.1. 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 2.1 Stainless steel blind bolt

Stainless steel toggle bolts are supplied in property class 70 material to BS EN ISO 3506³. The minimum ultimate tensile strength is 700 N/mm².

Stainless steel toggle bolts are available in the following diameters:

M8, M10, M12 and M16.

2.2 Bolt dimensions

Table 2.1 gives the area of material at the slot, A_{slot} , and the area of material where the pin is located, A_{pin} .

Table 2.1 Bolt dimensions

Bolt	Nominal diameter, d (mm)	Slot width, c (mm)	Pin diameter, p (mm)	A_{slot} (mm ²)	A_{pin} (mm ²)
M8	8	3.5	1.6	23.2	16.1
M10	10	4	1.6	39.6	30.1
M12	12	5	1.6	54.9	43.7
M16	16	6	1.6	107.4	91.4

The areas in Table 2.1 have been calculated using the following expression:

$$A_{\text{pin}} = \frac{\pi d^2}{4} - \left(\frac{cd \cos \theta}{2} + \frac{d^2 \theta}{2} \right) - \left(\frac{pd \cos \phi}{2} + \frac{d^2 \phi}{2} - pc \right)$$

$$\sin \theta = \frac{c}{d}; \sin \phi = \frac{p}{d}$$

A_{slot} uses the same expression, but with $p = 0$.

3 TEST PROGRAMME

The physical testing was carried out by Intertek NDT of Derby.

All testing was completed in a test machine capable of working either in compression or testing.

3.1 Tension tests

Tension tests were completed in the apparatus shown in Figure 3.1. The test is effectively two U-shaped fabrications, with the bolt to be tested connecting the two parts. The arrangement is tested in compression, which produces tension in the bolt.

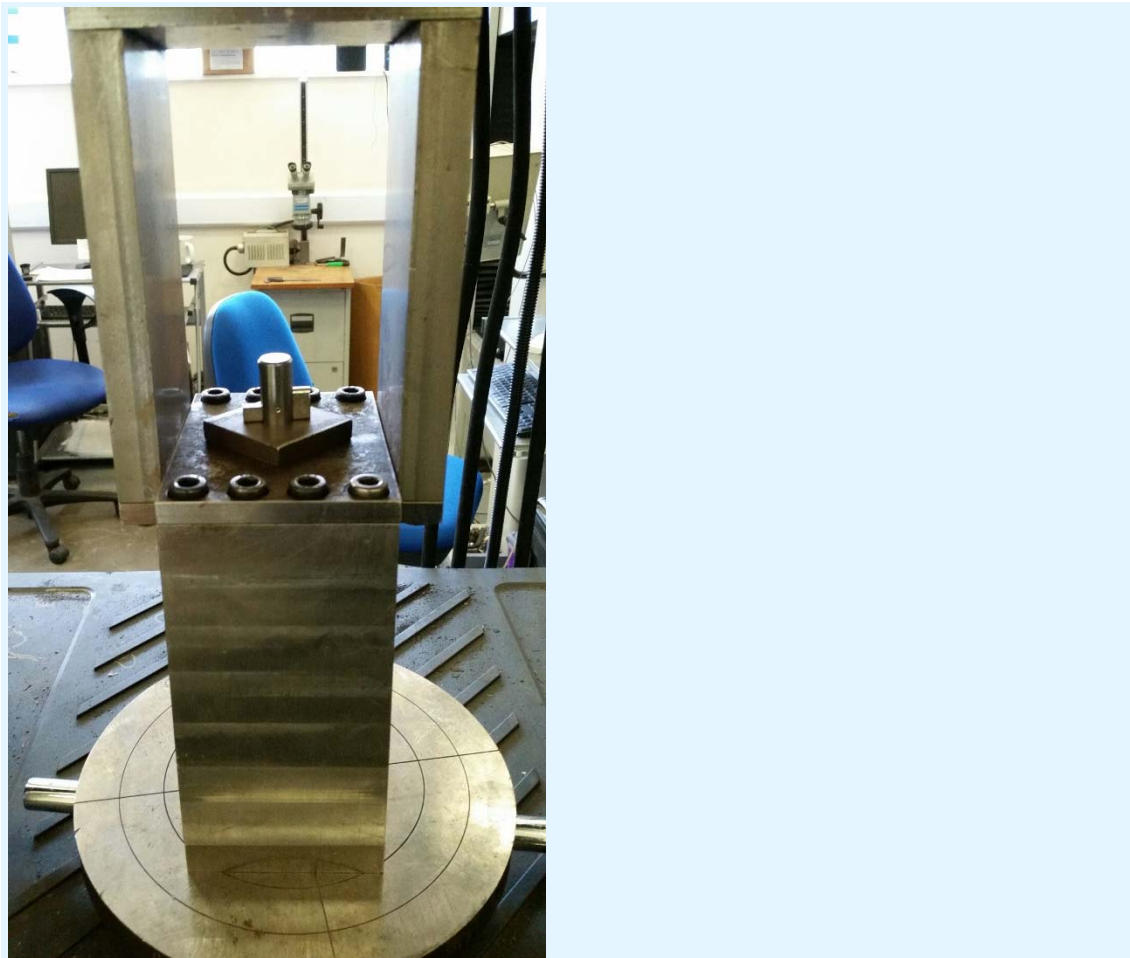


Figure 3.1 Test arrangement – tension tests

A bolt after fracture is shown in Figure 3.2. The fracture is located at the smallest cross section, where the pivot pin is located.



Figure 3.2 Completed tension test

M10 and M16 bolts were tested in tension. Five tests were completed for each diameter.

3.2 Shear tests

The test arrangement for bolt shear is shown in Figure 3.3. The plates are of high strength material, and sized to ensure that the shear plane is located within the slotted length of the bolt. In Figure 3.3, a specially prepared bolt has been used with a slot, but no toggle.

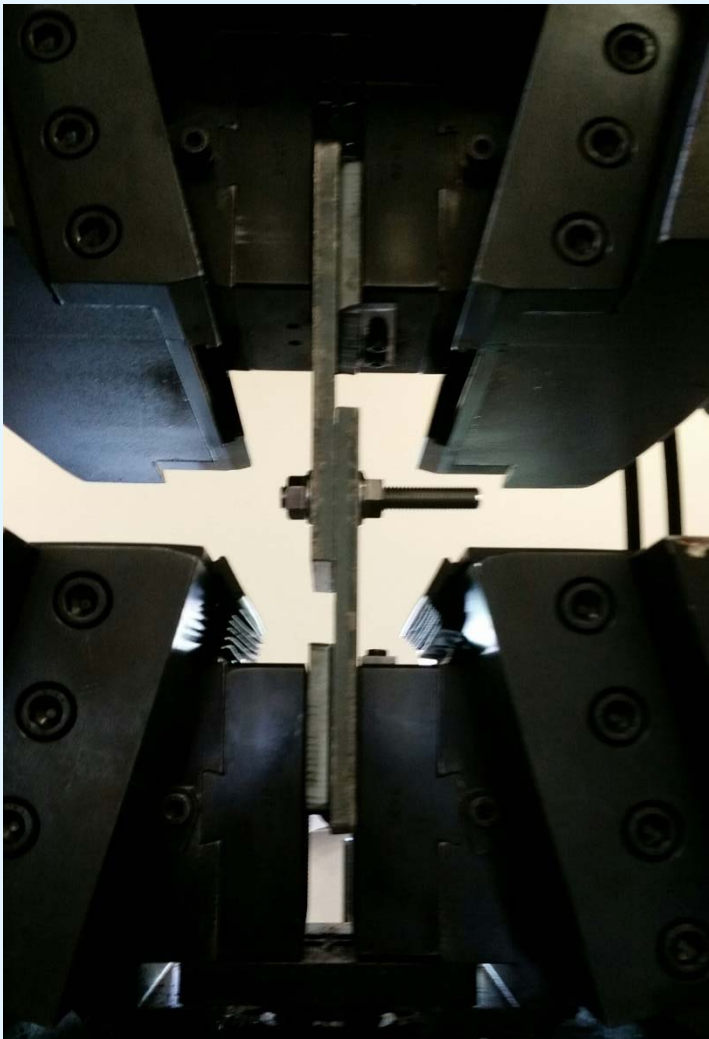


Figure 3.3 Shear tests

M10 and M16 bolts were tested in shear. Five tests were completed for each diameter.

3.3 Bearing tests

The test arrangement for bearing resistance is shown in Figure 3.4. The two external plates are relatively thick, and of high strength steel to minimise any deformation. The central plate of interest is located within the slotted length of the bolt.



Figure 3.4 Bearing tests

The previous tests on carbon steel blind bolts had shown that the bearing resistance exceeded that calculated in accordance with design Standards BS 5950 and BS EN 1993-1-1. The design resistance was therefore conservatively based on the calculated value in accordance with the design Standards. Because no change in performance was anticipated (as the bolt geometry is identical), only limited bearing tests were completed.

Four tests were undertaken with M12 bolts in 5 mm thick S275 material.

Two tests were undertaken with M12 bolts in 10 mm thick S355 material.

3.4 Plate and bolt material tests

Coupon tests were completed to determine the strength of the steel plates used in the bearing tests and the strength of the stainless steel bolts.

Nine tests were completed on the stainless steel bolts.

Three tests were completed on the 5 mm S275 plate and three tests on the 10 mm S355 plate.

4 TEST RESULTS

4.1 Tension tests

The load displacement plots for the M10 and M16 stainless steel blind bolts are shown in Figure 4.1 and Figure 4.2 respectively.

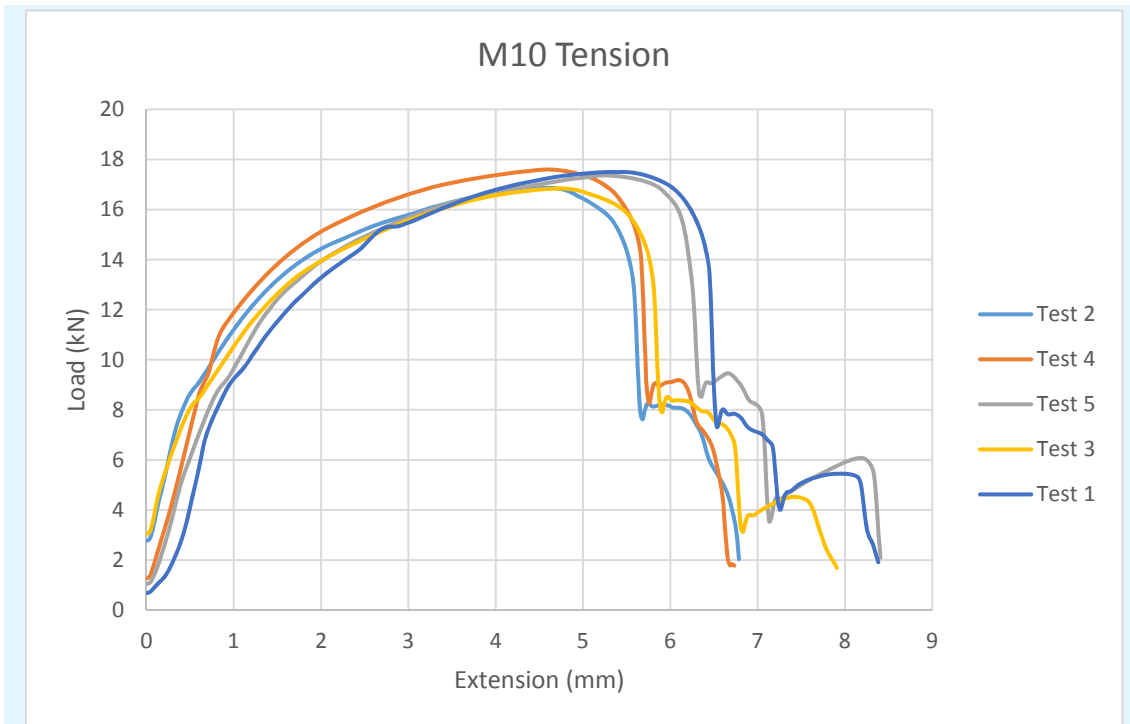


Figure 4.1 M10 tension tests

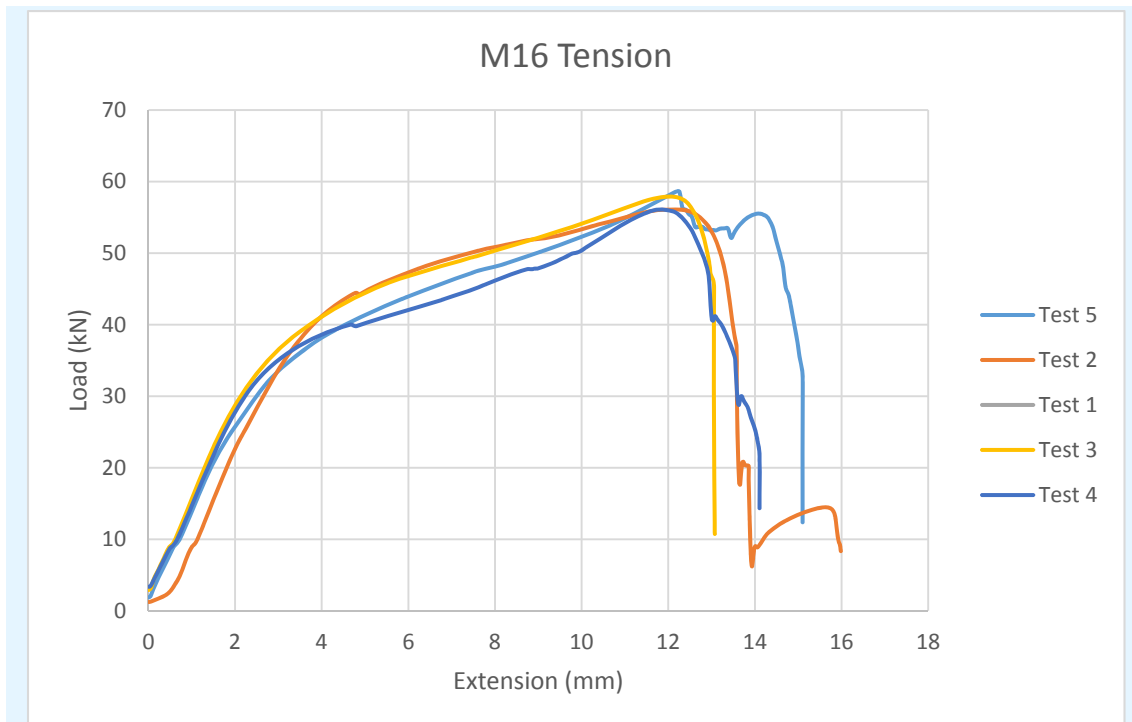


Figure 4.2 M16 tension tests

The ultimate resistances are reported in Table 4.1.

Table 4.1 Tension resistance

Bolt	Test number	Failure load (kN)
M10	1	17.5
	2	16.87
	3	16.84
	4	17.60
	5	17.36
M16	1	58.67
	2	56.09
	3	57.90
	4	56.09
	5	59.81

4.2 Shear tests

The load displacement plots for the M10 and M16 stainless steel blind bolts are shown in Figure 4.3 and Figure 4.4 respectively.

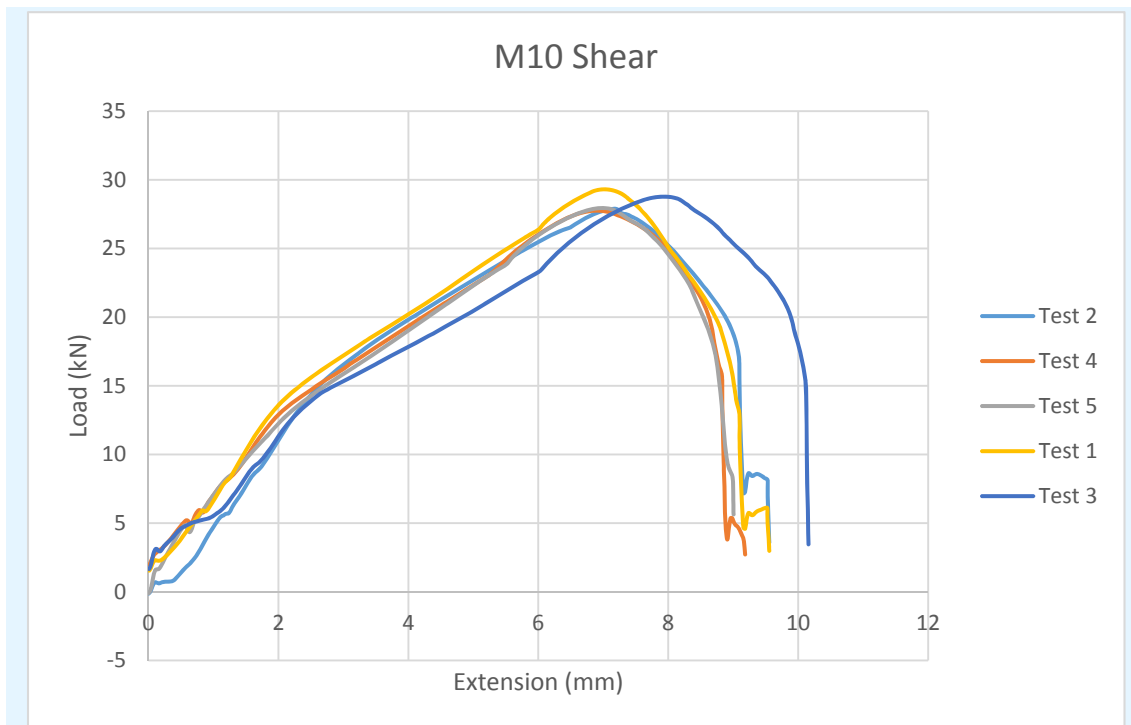


Figure 4.3 M10 shear tests

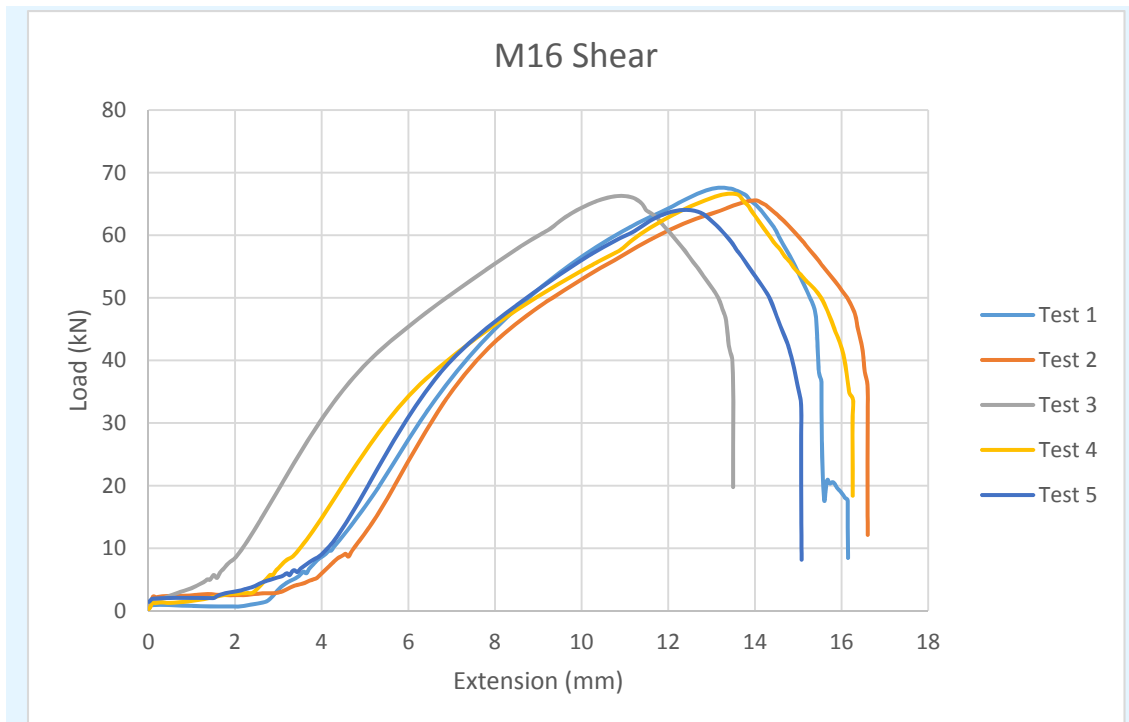


Figure 4.4 M16 shear tests

The ultimate resistances are reported in Table 4.2.

Table 4.2 Shear resistance

Bolt	Test number	Failure load (kN)
M10	1	29.31
	2	27.89
	3	28.77
	4	27.77
	5	27.96
M16	1	67.60
	2	65.56
	3	66.29
	4	66.54
	5	64.05

4.3 Bearing tests

The load displacement plots for the M12 stainless steel blind bolts in 5 mm S275 and 10 mm S355 material are shown in Figure 4.5 and Figure 4.6 respectively

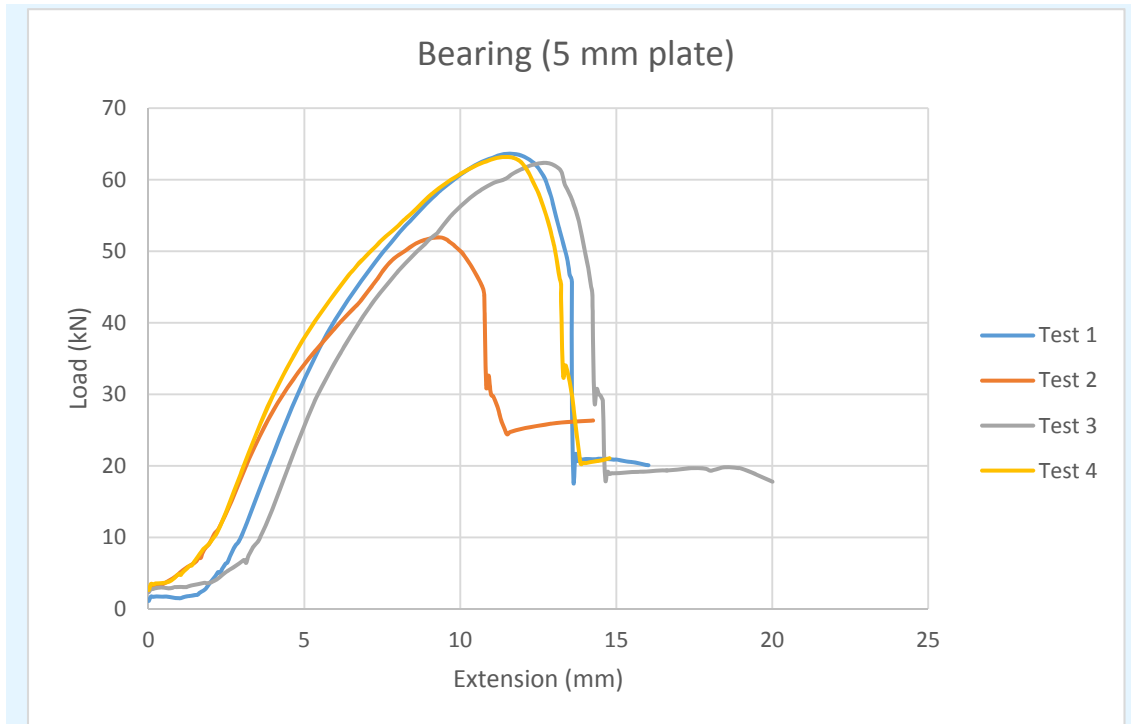


Figure 4.5 M12 in 5 mm S275

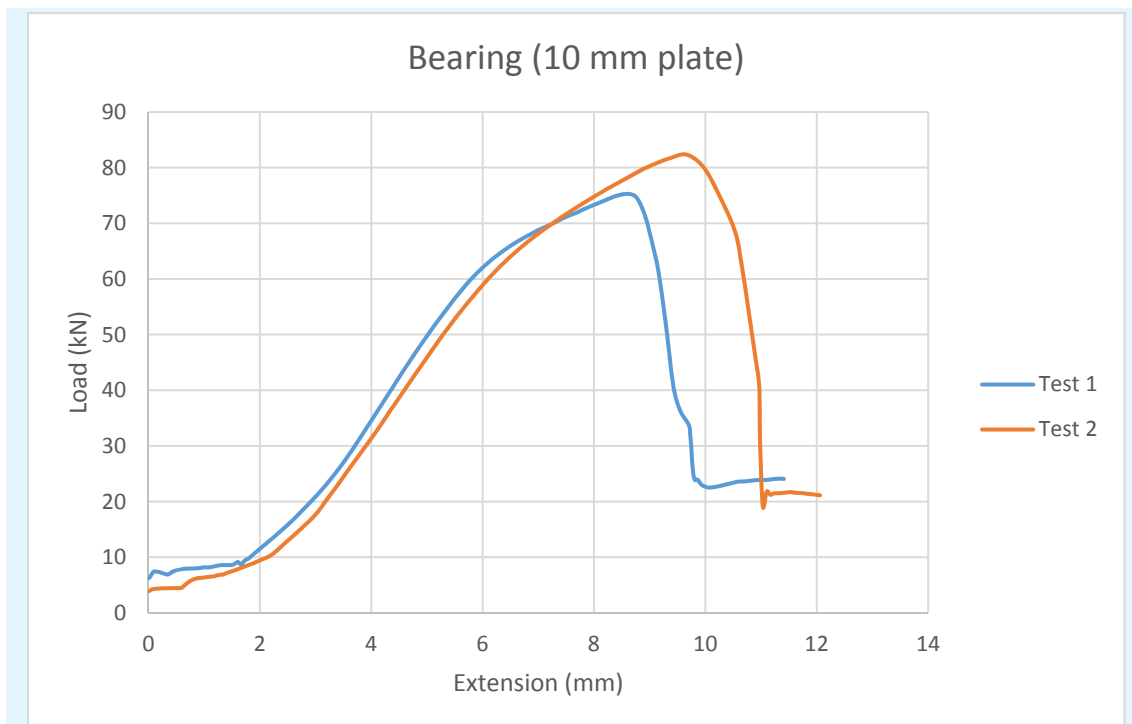


Figure 4.6 M12 in 10 mm S355

4.4 Plate material tests

The results of the coupon tests on the 5 mm and 10 mm plate used in the bearing tests are reported in Table 4.3.

Table 4.3 Plate material tests

Material	Test	Ultimate strength (N/mm ²)
5 mm S275	1	485
	2	485
	3	488
10 mm S355	1	572
	2	572
	3	575

4.5 Bolt material tests

The results of the tests on the stainless steel bolts are reported in Table 4.4.

Table 4.4 Bolt material tests

Bolt	Test	Ultimate strength (N/mm²)
M10	1	797
M12	1	801
	2	759
	3	847
M16	1	744
	2	797
	3	766

5 BOLT RESISTANCE ACCORDING TO DESIGN STANDARDS

The following sections summarise the resistance expressions in BS 5950 and in BS EN 1993-1-8. BS EN 1993-1-4⁴ provides supplementary rules for stainless steel, including specific rules for the bearing resistance and the shear resistance of stainless steel bolts.

5.1 Tension resistance

5.1.1 BS 5950

The tension resistance of bolts is given by:

$$P_t = p_t A_t$$

where:

- P_t is the tension capacity.
- A_t is the tensile stress area of the bolt.
- p_t is the tension strength of the bolt, = $0.7 U_b$.
- U_b is the specified minimum tensile strength of the bolt (700 N/mm² for class 70 stainless steel).

5.1.2 BS EN 1993-1-8

The tension resistance of bolts is given by:

$$F_{t,Rd} = \frac{k_2 f_{ub} A_s}{\gamma_{M2}}$$

where:

- $F_{t,Rd}$ is the tension resistance.
- k_2 = 0.9 for non-countersunk bolts.
- A_s is the tensile stress area of the bolt.
- f_{ub} is the ultimate strength of the bolt (700 N/mm² for class 70 stainless steel).
- γ_{M2} = 1.25, from the UK National Annex to BS EN 1993-1-8.

There is no modification in BS EN 1993-1-4 for the tension resistance of a stainless steel bolt.

5.2 Shear resistance

5.2.1 BS 5950

The shear resistance of bolts is given by:

$$P_s = \rho_{sb} A_s$$

where:

- P_s is the shear resistance.
- A_s is the shear area of the bolt.
- ρ_{sb} is the shear strength of the bolt = $0.4 U_b$.
($0.4 \times 700 = 280 \text{ N/mm}^2$ for class 70 stainless steel).

5.2.2 BS EN 1993-1-4

The shear resistance of bolts is given by:

$$F_v = \frac{\alpha_v f_{ub} A}{\gamma_{M2}}$$

where:

- F_v is the shear resistance.
- $\alpha_v = 0.6$ if the shear plane is in the threaded portion of the bolt.
- A is the shear area of the bolt.
- f_{ub} is the ultimate strength of the bolt (700 N/mm^2 for class 70 stainless steel).
- $\gamma_{M2} = 1.25$, from the UK National Annex to BS EN 1993-1-8.

It should be noted that clause 6.2(3) of BS EN 1993-1-4 states that $\alpha_v = 0.5$ if the shear plane passes through the threaded portion of the bolt. This error is due to be corrected.

5.3 Bearing resistance

5.3.1 BS 5950

The bearing resistance is taken as the minimum of the bearing resistance of the plate, or the bolt.

The bearing resistance of the plate is given by:

$$P_{bs} = k_{bs} d t_p \rho_{bs} \text{ but } \leq 0.5 k_{bs} e t_p \rho_{bs}$$

where:

- P_{bs} is the bearing resistance.
- $k_{bs} = 1.0$ for standard clearance holes.

- p_{bs} is the bearing strength of the material, taken as 460 N/mm² for S275 and 550 N/mm² for S255.
- e is the end distance.
- d is the nominal diameter of the bolt.
- t is the thickness of the connected part.

Note that the BS 5950 resistance is based on limiting the deformation to 1.5 mm at working load.

5.3.2 BS EN 1993-1-8

The bearing resistance is given by:

$$F_{b,Rd} = \frac{k_1 \alpha_b f_u d t}{\gamma_{M2}}$$

where:

- $F_{b,Rd}$ is the bearing resistance.
- k_1 and α_b depend on the geometry of the bolt group, including spacing, edge and end distances.
- f_u is the ultimate strength of the plate material.
- d is the nominal bolt diameter.
- t is the thickness of the plate.
- $\gamma_{M2} = 1.25$, from the UK National Annex to BS EN 1993-1-8.

It should be noted that the modification to the bearing resistance given in clause 6.2(1) of BS EN 1993-1-4 only affects the calculated resistance if the plate material is stainless steel.

If the plate were stainless steel, the ultimate strength of the plate is replaced in the above expression with $f_{u,red}$, where:

$$f_{u,red} = 0.5f_y + 0.6f_u$$

- f_y is the yield strength of the plate.
- f_u is the ultimate strength of the plate.

Note that BS EN 1993-1-8 has no restriction on deformation, so the calculated resistances will be significantly larger than those calculated in accordance with BS 5950.

6 DERIVATION OF DESIGN VALUES

The resistances derived in this section ignore any limitations of the connected parts. For example, the bending or deformation of a hollow section wall will generally be critical, not the tension resistance of the bolt as derived in this section.

Designers will need to complete an individual assessment of the other components in the joint.

The shear resistance of stainless steel bolts is given in BS EN 1993-1-4⁴.

6.1 Tension resistance

The measured bolt resistances have been normalised to the nominal ultimate strength of the bolt. From Table 4.4, the average ultimate strength of the bolt material has been calculated as 787 N/mm².

Following the methodology of BS EN 1990, Annex D, the design resistance has been calculated directly using section D7.3 and Table D2. For this calculation, $k_{d,n}$ has been taken as 3.37, for a group of five tests. The calculation is presented in Table 6.1. The coefficient of variation (CoV) is an indicator of the consistency of the test results – low values indicate consistent results.

Table 6.1 Analysis of tension test results

Bolt	Test	Measured resistance (kN)	Normalised resistance (kN)	Average	Std Deviation	CoV	Design resistance (kN)
M16	1	58.67	52.18	51.33	1.45	2.8%	46.4
	2	56.09	49.89				
	3	57.90	51.50				
	4	56.09	49.89				
	5	59.81	53.20				
M10	1	17.50	15.57	15.33	0.32	2.1%	14.3
	2	16.87	15.01				
	3	16.84	16.84				
	4	17.60	15.65				
	5	17.36	15.44				

A predicted tension resistance has been calculated based on $A_{pin} \times f_{ub}$.

A correction factor can then be determined so that the design resistance can be related to the predicted resistance. This is shown in Table 6.2 for the M16 and M10 bolts.

Table 6.2 Derivation of correction factor from $A_{pin} \times f_{ub}$

Bolt	Resistance from test (Table 6.1) (kN)	A_{pin} (mm ²)	Predicted resistance (kN)	Correction factor
M16	46.4	91.4	64.0	0.73
M10	14.3	30.1	21.1	0.68

The lower value of 0.68 has been adopted to calculate the design resistances of the four bolt diameters available in stainless steel. The use of Table D2 from section D7.3 means that no γ_{M2} factor need be applied to the calculated resistance. The design resistance is therefore given by:

$$F_{t,Rd} = 0.68 f_{ub} A_{pin}$$

The final design values are shown in Table 6.3.

Table 6.3 Tension resistance – design values

Bolt	A_{pin} (mm ²)	Design resistance (kN)
M16	91.4	43.5
M12	43.7	20.8
M10	30.1	14.3
M8	16.1	7.7

6.2 Shear resistance for use with BS EN 1993-1-4

The measured bolt resistances have been normalised to the nominal ultimate strength of the bolt. From Table 4.4, the average ultimate strength of the bolt material has been calculated as 787 N/mm².

Following the methodology of BS EN 1990, Annex D, the design resistance has been calculated directly using section D7.3 and Table D2. For this calculation, $k_{d,n}$ has been taken as 3.37, for a group of five tests. The calculation is presented in Table 6.4. The coefficient of variation (CoV) is an indicator of the consistency of the test results – low values indicate consistent results.

Table 6.4 Analysis of shear test results

Bolt	Test	Measured resistance (kN)	Normalised resistance (kN)	Average	Std Deviation	CoV	Design resistance (kN)
M16	1	67.60	60.13	58.73	1.18	2.0%	54.8
	2	65.56	58.31				
	3	66.29	58.96				
	4	66.64	59.27				
	5	64.05	56.97				
M10	1	29.31	26.07	25.21	0.6	2.4%	23.2
	2	27.89	24.81				
	3	28.77	25.59				
	4	27.77	24.70				
	5	27.96	24.78				

A predicted shear resistance has been calculated based on $0.6 \times f_{ub} \times A_{slot}$ (see section 5.2.2).

A correction factor can then be determined to that the design resistance can be related to the predicted resistance. This is shown in Table 6.5 for the M16 and M10 bolts.

Table 6.5 Derivation of correction factor from $0.6 \times f_{ub} \times A_{slot}$

Bolt	Resistance from test (Table 6.4) (kN)	A_{slot} (mm ²)	Predicted resistance (kN)	Correction factor
M16	54.8	107.4	45.1	1.22
M10	23.2	39.6	16.6	1.40

Table 6.5 shows that the design resistances derived from the tests are larger than the values given by the Eurocode expressions. It is recommended that the Eurocode expressions be used to determine the characteristic and design

resistances. The design resistance is simply the characteristic resistance divided by γ_{M2} (see section 5.2.2). The design resistance is therefore given by:

$$F_v = \frac{0.6f_{ub}A_{slot}}{\gamma_{M2}}$$

The final design values are shown in Table 6.6.

Table 6.6 Shear resistance across slot – characteristic and design values for use with BS EN 1993-1-4

Bolt	A_{slot} (mm ²)	Characteristic resistance (kN)	Design resistance (kN)
M16	107.4	45.1	36.1
M12	54.9	23.1	18.5
M10	39.6	16.6	13.3
M8	23.2	9.7	7.8

6.2.1 Shear resistance over thread

No modification to the expressions given in the design Standard is necessary. The design resistances are given in Table 6.7, based on the expression given in section 5.2.2 with $\alpha_v = 0.6$. Note that this conflicts with the note to clause 6.2(3) of BS EN 1993-1-4, where α_v through the threaded portion of the bolt is to be taken as 0.5. This error is due to be corrected in the revised Eurocode.

Table 6.7 Shear resistance across threads – design values for use with BS EN 1993-1-4

Bolt	A_s (mm ²)	Design resistance (kN)
M16	157	52.8
M12	84.3	28.3
M10	58.0	19.5
M8	36.6	12.3

6.3 Shear resistance for use with BS 5950

A predicted resistance has been calculated, based on $0.4U_b \times A_{slot}$ (see section 5.2.1).

A correction factor can then be determined so that the design resistance can be related to the predicted resistance. This is shown in Table 6.8 for the M16 and M10 bolts.

Table 6.8 Derivation of correction factor from $0.4U_b \times A_{slot}$

Bolt	Resistance from A_{slot} (mm ²) test (Table 6.4) (kN)	Predicted resistance (kN)	Correction factor	
M16	54.8	107.4	30.1	1.82
M10	23.2	39.6	11.1	2.09

Table 6.8 shows that the design resistances developed from tests are greater than the resistances according to the BS 5950 expressions. It is recommended that the BS 5950 expressions be used to determine the design resistances. The design resistances are given by:

$$P_s = p_{sb}A_s$$

where:

$$p_{bs} = 0.4U_b \quad (U_b = 700 \text{ N/mm}^2 \text{ for class 70 stainless steel bolts}).$$

The final design values are shown in Table 6.9.

Table 6.9 Shear resistance across slot – design values for use with BS 5950

Bolt	A_{slot} (mm ²)	Design resistance (kN)
M16	107.4	30.1
M12	54.9	15.4
M10	39.6	11.1
M8	23.2	6.5

6.3.1 Shear resistance over thread

No modification to the expressions given in the design Standard is necessary. The design resistances are given in Table 6.10, based on the expression given in section 5.2.1.

Table 6.10 Shear resistance across threads – design values for use with BS 5950

Bolt	A_s (mm ²)	Design resistance (kN)
M16	157	44.0
M12	84.3	23.6
M10	58.0	16.2
M8	36.6	10.3

6.4 Bearing resistance

For design to BS 5950, the bearing resistance is adjusted to limit deformation at working load to 1.5 mm. There is no such restriction in BS EN 1993-1-8, so the resistance according to the Eurocode will be significantly higher than that according to BS 5950.

6.4.1 Bearing resistance for use with BS 5950

To determine the appropriate bearing resistance, it is assumed that the 1.5 mm limit is under load and that the initial slip present in connections is ignored.

The results shown in Figure 4.5 and Figure 4.6 have been reviewed and the slope of the load-displacement curve after the initial slip has been estimated. The slopes are shown in Figure 6.1 (5 mm, S275 plate) and Figure 6.2 (10 mm, S355 plate). The line indicating the initial stiffness and a trendline used to establish the gradient for display on the figure are superimposed.

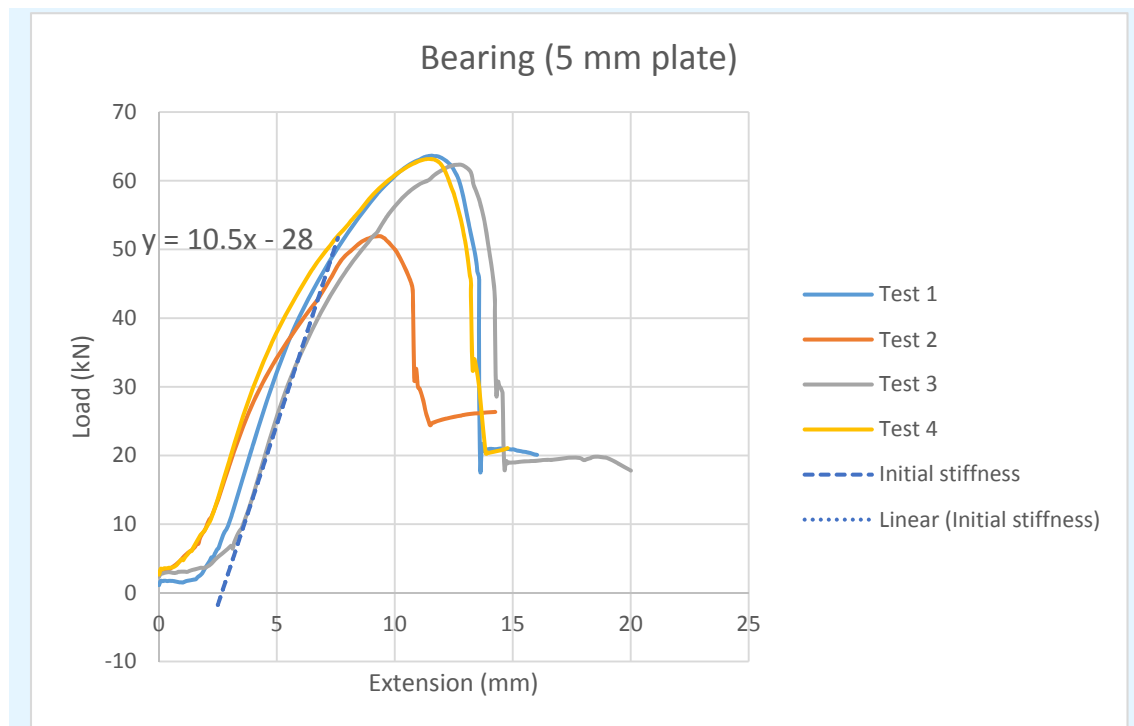


Figure 6.1 M12 in 5 mm S275, with deformation slope assessment

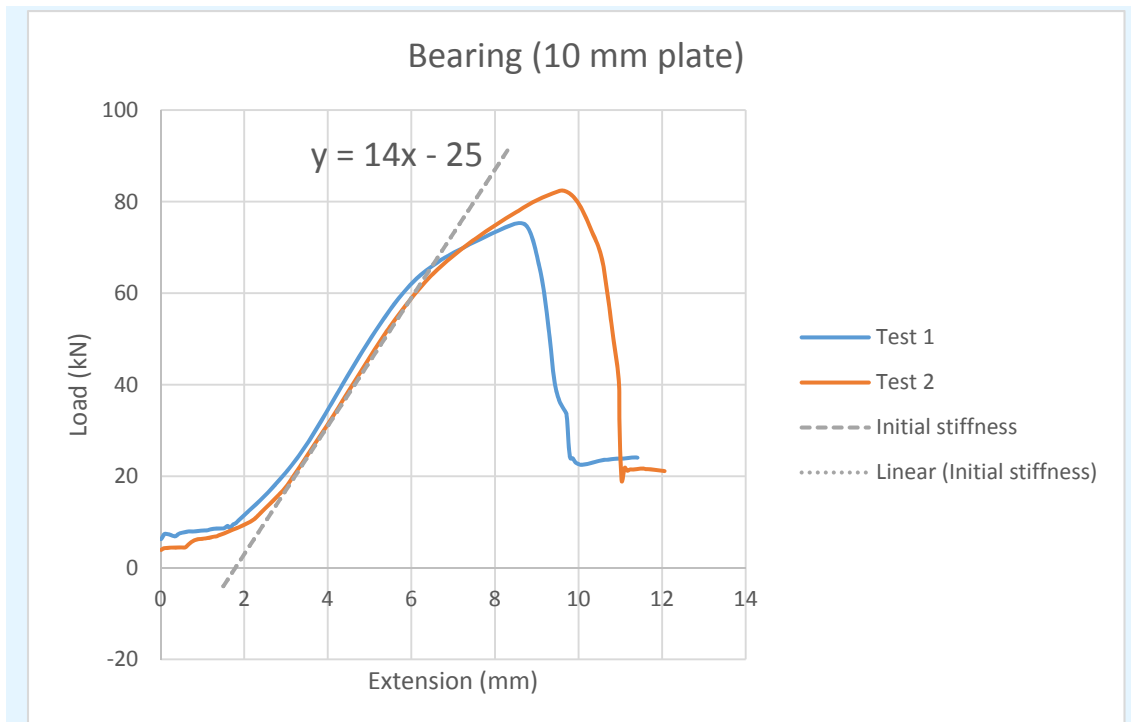


Figure 6.2 M12 in 10 mm S355, with deformation slope assessment

S275 plate

In 5 mm S275 plate, the initial slope has been estimated with a gradient of 10.5 kN/mm (see Figure 6.1). If the deformation is limited to 1.5 mm, and including a factor of 1.5 to allow for the approximate ratio between working and ultimate loads, the bearing resistance of an M12 bolt is given by:

$$P_{bs} = 10.5 \times 1.5 \times 1.5 = 23.6 \text{ kN}$$

If it is assumed that the width of the slot is neglected in calculating the predicted bearing resistance, then the resistance according to BS 5950 (see section 5.3.1) is given by:

$$P_{bs} = 1.0 \times (12 - 5) \times 460 \times 5 \times 10^{-3} = 16.1 \text{ kN}$$

The mean ultimate load in the tests was 60.28 kN (53.62 kN after normalising for the measured plate strength), significantly larger than the resistance derived from either approach.

S355 plate

In 10 mm S355 plate, the initial slope has been estimated with a gradient of 14 kN/mm (see Figure 6.2). If the deformation is limited to 1.5 mm, and including a factor of 1.5 to allow for the approximate ratio between working and ultimate loads, the bearing resistance of an M12 bolt is given by:

$$P_{bs} = 14 \times 1.5 \times 1.5 = 31.5 \text{ kN}$$

If it is assumed that the width of the slot is neglected in calculating the predicted bearing resistance, then the resistance according to BS 5950 (see section 5.3.1) is given by:

$$P_{bs} = 1.0 \times (12 - 5) \times 550 \times 10 \times 10^{-3} = 38.5 \text{ kN}$$

The mean ultimate load in the tests was 78.86 kN (70.14 kN after normalising for the measured plate strength), significantly larger than the resistance derived from either approach.

6.4.2 Recommended rule for bearing resistance to BS 5950

It is recommended that the bearing resistance be calculated using the BS 5950 expression, but with the nominal diameter reduced to neglect the slot in the bolt shank. The design expression is therefore:

$$P_{bs} = k_{bs}(d - c) t_p \rho_{bs}$$

where:

c is the width of the slot (see Table 2.1).

The remaining terms are as defined in section 5.3.1.

The resulting resistances, in 10 mm plate, are given in Table 6.11.

Table 6.11 Bearing resistance for use with BS 5950

Bolt	Diameter d (mm)	Slot width c (mm)	Bearing resistance in 10 mm plate, P_{bs} (kN)	
			S275 ($\rho_{bs} = 460 \text{ N/mm}^2$)	S355 ($\rho_{bs} = 550 \text{ N/mm}^2$)
M8	8	3.5	20.7	24.8
M10	10	4	27.6	33.0
M12	12	5	32.2	38.5
M16	16	6	46.0	55.0

6.4.3 Bearing resistance for use with BS EN 1993-1-8

BS EN 1993-1-4 makes no modification to the bearing resistance when the plate material is carbon steel – the modification only affects the resistance when the plate is stainless steel.

BS EN 1993-1-8 has no limit to the deformation. The earlier test program¹ recommended the Eurocode rules be used without modification, with no allowance required for the slot.

Adopting this recommendation gives the design resistances indicated in Table 6.12 for the tested combinations, calculated in accordance with section 5.3.2, assuming $k_1 = 2.5$ and $\alpha_b = 1.0$.

Table 6.12 also indicates the characteristic resistance according to the design Standard (simply design resistance $\times 1.25$), which might be indicative of the approximate resistance expected in the tests. The actual test results (not normalised for the measured plate strength) are also shown in Table 6.12.

Table 6.12 Bearing resistance for the tested combinations of bolts and plate

Bolt	Design resistance (kN)	Characteristic resistance (kN)	Mean measured resistance (kN)
M12 in 5 mm S275	49.2	61.5	60.3
M12 in 10 mm S355	112.8	141.0	78.9

The comparison of calculated characteristic resistance and test result is quite misleading for 10 mm S355 plate. This is because the double shear resistance expected in the test is approximately 90 kN.

This value can be inferred from Table 6.6 and Table 6.5, by taking the characteristic resistance of an M12 bolt (23.1 kN) and increasing this by a correction factor of (say) 2.0, leading to a likely test result of approximately 46 kN.

The double shear resistance would be in the order of 90 kN, which is approximately the resistance found in the tests (79 kN). In this case, therefore, bearing was not critical, so the characteristic resistance of 141 kN is irrelevant.

The same argument can be followed with the 5 mm S275 plate. The resistance determined from the tests is significantly lower (60.3 kN), but this may be because the shear planes are close together. It is assumed that in this case, the resistance is rather less than double shear.

In all the tests, the bolts eventually failed on a single shear plane.

It is recommended that the bearing resistance for use with BS EN 1993-1-8 is calculated using the Eurocode expressions without modification.

The resulting resistances, in 10 mm plate, are given in Table 6.13, assuming $k_1 = 2.5$ and $\alpha_b = 1.0$.

Table 6.13 Bearing resistance for use with BS EN 1993-1-8

Bolt	Diameter <i>d</i> (mm)	Bearing resistance in 10 mm plate, $F_{b,Rd}$ (kN)	
		S275 ($f_u = 410 \text{ N/mm}^2$)	S355 ($f_u = 470 \text{ N/mm}^2$)
M8	8	65.6	75.2
M10	10	82.0	94.0
M12	12	98.4	112.8
M16	16	131.2	150.4

6.5 Design of bolts in combined tension and shear

The testing completed under this programme showed no unexpected behaviour and it is concluded that, as recommended for carbon steel blind bolts¹, the interaction expressions of combined tension and shear be adopted without modification, but recognising the reduced design resistances given in this report.

The interaction expressions are given below.

BS 5950

$$\frac{F_s}{P_s} + \frac{F_T}{P_T} \leq 1.4$$

BS EN 1993-1-8

$$\frac{F_{v,Ed}}{F_{v,Rd}} + \frac{F_{t,Ed}}{1.4F_{t,Rd}} \leq 1.0$$

REFERENCES

- 1 RT 1303 Design Resistances of Blind Bolts
SCI, 2009
- 2 BS EN 1990: 2002+A1:2005
Eurocode – Basis of structural design
BSI 2009
- 3 BS EN ISO 3506:2009
Mechanical properties of corrosion-resistant stainless steel fasteners; Part1: Bolts, screws and studs
BSI, 2009
- 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. TECHNICAL DATA

The resistances calculated in this report are presented below in a format appropriate for technical literature.

Stainless steel blind bolt – design to BS 5950

Diameter	Tension Capacity P_t (kN)	Shear capacity over thread $P_{s,thread}$ (kN)	Shear capacity over slot $P_{s,slot}$ (kN)	Bearing capacity in 10 mm plate P_{bs} (kN)	
				S275	S355
M8	7.7	10.3	6.5	20.7	24.8
M10	14.3	16.2	11.1	27.6	33.0
M12	20.8	23.6	15.4	32.2	38.5
M16	43.5	44.0	30.1	46.0	55.0

These capacities are suitable for design to BS 5950-1 and can be compared directly with factored loads. Bearing resistances for different thicknesses can be calculated by scaling the values given in proportion to the thickness, but should only be used when the end distance is greater than $2d$.

Bolts subject to combined tension and shear should satisfy the following expression:

$$\frac{F_s}{P_s} + \frac{F_T}{P_T} \leq 1.4$$

Note that the above tension capacities make no allowance for the deformation or yield of the supporting parts.

Stainless steel blind bolt – design to BS EN 1993

Diameter	Tension Resistance $F_{t,Rd}$ (kN)	Shear resistance over thread $P_{v,Rd,thread}$ (kN)	Shear resistance over slot $F_{v,Rd,slot}$ (kN)	Bearing resistance in 10 mm plate P_{bs} (kN)	
				S275	S355
M8	7.7	12.3	7.8	65.6	75.2
M10	14.3	19.5	13.3	82.0	94.0
M12	20.8	28.3	18.5	98.4	112.8
M16	43.5	52.8	36.1	131.2	150.4

These design resistances are suitable for design to BS EN 1993 and can be compared directly with design loads. The quoted bearing resistances assume $k_1 = 2.5$ and $\alpha_b = 1.0$. For different arrangements the bearing resistance should

be calculated using the expression in Table 3.4 of BS EN 1993-1-8, with d as the nominal diameter of the blind bolt.

Bolts subject to combined tension and shear should satisfy the following expression:

$$\frac{F_{v,Ed}}{F_{v,Rd}} + \frac{F_{t,Ed}}{1.4F_{t,Rd}} \leq 1.0$$

Note that the above tension capacities make no allowance for the deformation or yield of the supporting parts.