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SCI
Steel Knowledge

REPORT TO THE BLIND BOLT COMPANY

DESIGN RESISTANCES OF BLIND BOLTS

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VERSION 01

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EXECUTIVE SUMMARY

In order to verify the load carrying capabilities of blind bolts, a series of tests have been performed at the University of Manchester on M10, M20 and M24 bolts. This report details the testing and analysis of these bolts for design to both the British Standards and the Eurocodes.

A total of 77 tests were performed: 9 coupon tests to determine the material strength; 14 pure tension tests to determine the tensile resistance of the bolts; 15 pure shear tests to determine the shear resistance of the bolts; 18 combined tension and shear tests to validate the design equations in BS 5950-1 and BS EN 1993-1-8; and 21 bearing tests to establish the performance of the bolts in bearing.

An analysis of each type of test was performed using the methodology in BS EN 1990, and a series of design rules, based on current practice for standard bolts, has been proposed. In general, these follow the current rules using modified areas as appropriate, except for the tensile resistance of blind bolts where a reduced strength, determined from the tests, is used. The test results also showed that the combined tension and shear equations in both BS 5950-1 and BS EN 1993-1-8 can be adopted for blind bolts.

The design capacities in tension and shear of blind bolts to BS 5950-1 are presented in the following table. Values for the bolt types that were not tested have been calculated using the equations developed from the tests.

Bolt type	Tension capacity (kN)	Shear capacity of slotted region (kN)
M8*	6.91	9.27
M10	12.94	15.85
M12*	18.81	21.95
M16*	40.16	42.94
M20	57.88	63.41
M24	82.38	87.81

* Tests were not performed on these bolt types

A suggested presentation of the technical information for direct use by structural designers has been proposed in Appendix A.

This report has been prepared by Mr Andy Smith and reviewed by Mr David Brown, both of the SCI.

CONTENTS

1 INTRODUCTION

In order to verify the load carrying capabilities of blind bolts, a series of tests have been performed at the University of Manchester on M10, M20 and M24 bolts. This report details the testing and analysis of these bolts for design to both the British Standards and the Eurocodes.

Figure 1.1 *Blind bolts*

Section 2 summarises the test procedures that were used at the University of Manchester and the results are presented in Section 3. Section 4 details the current design rules to both the British Standards and the Eurocodes. The analysis of the test results is presented in Section 5, and the resulting design equations are summarised in Section 6.

2 TEST PROCEDURES

2.1 Introduction

Four types of test were performed on the blind bolts, as follows:

- Shear
- Tension
- Combined Tension and Shear
- Bearing

The testing procedure for each test is described in the following Sections.

Although the aim of the current proposal is to determine resistances to BS 5950-1[1], the testing regime and procedures have followed that prescribed in the Eurocodes, so that, if CE Marking is progressed at some future date, the test results may be used. In particular, the Eurocodes demand a formal statistical analysis to determine characteristic resistances and design resistances.

Requirements for testing are given in BS 4190[2], which in turn demands that mechanical testing is undertaken in accordance with ISO 898-1[3].

2.2 Shear resistance

Testing the shear resistance of a bolted assembly is straightforward. The tests involve placing sample bolts in appropriate material, such that the shear plane is in the required location. Applied load and deformation are measured.

Plates are made strong and substantial, to minimise the deformation due to bearing in the plates.

Shear at 90° to the slot has not been tested at this time, as the failure mechanism is likely to be complex, involving Vierendeel bending within the shank of the bolt. In any event, the resistance according to BS 5950-1 is likely to be limited by the deformation of the assembly, which is notionally set at 1.5 mm at serviceability loads.

2.3 Tension Resistance

Testing the tensile resistance of a bolted assembly is straightforward. It is relatively common to test bolts in tension by applying a compressive force to an assembly consisting of two "U" shaped blocks, bolted together across their tips. A photo of the test arrangement is shown in Figure 2.1.

Figure 2.1 *Test arrangement for tensile tests*

2.4 Tension and Shear

Rather than calculating a resistance, the testing has been performed simply to demonstrate the appropriateness of the interaction equation in BS 5950-1 and BS EN 1993-1-8[4]. To demonstrate this, tests have been performed with a tension force at angles of 30°, 45° and 60° to the pure tension direction. A photo of the test arrangement is shown in Figure 2.2

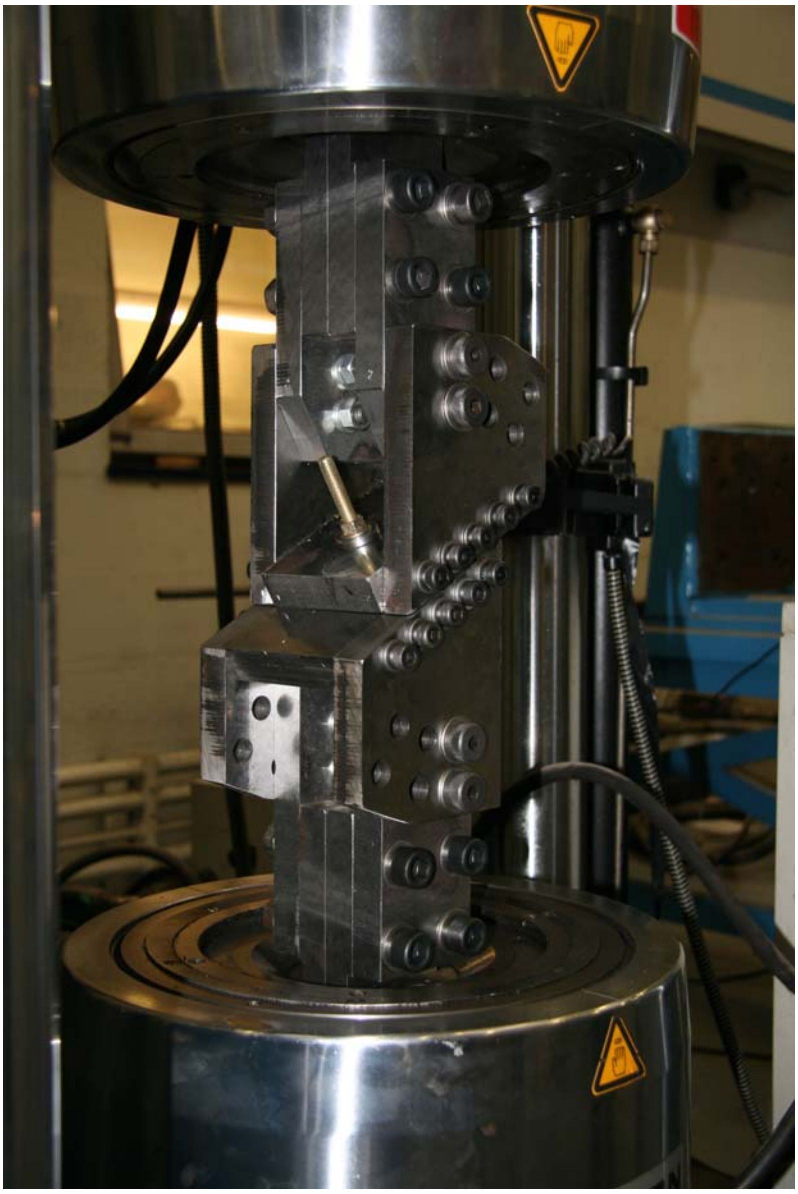

Figure 2.2 *Test arrangement for combined shear and tension*

2.5 Bearing resistance

Bearing resistance is complicated by the variables involved, which include plate thickness and steel grade.

The test arrangement consists of two plates with a third between, as shown in Figure 2.3. The plate of interest is the central, single plate.

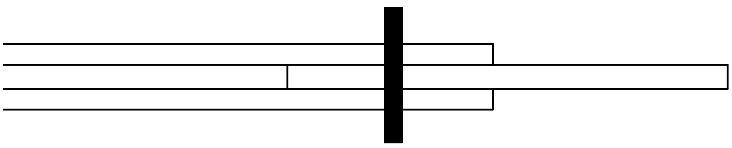

Figure 2.3 *Test arrangement to determine bearing resistance*

Bolts were specially manufactured with a longer slot to enable sheet thicknesses of up to 15 mm to be used in the test. The failure modes for M10 and M20 bolts are shown in Figure 2.4 and Figure 2.5 respectively.

Figure 2.4 *Failure of M10 bolts in bearing*

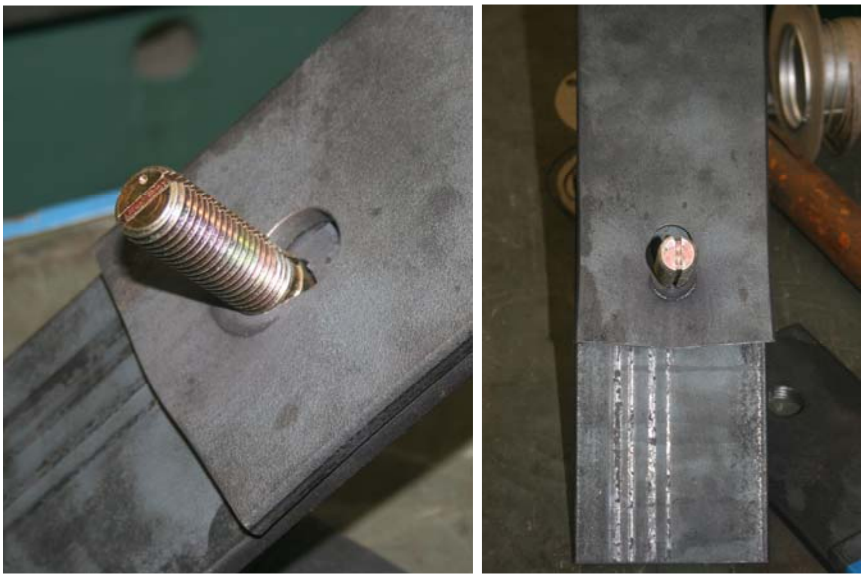

Figure 2.5 *Failure of M20 bolts in bearing*

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3 TEST RESULTS

Testing on the blind bolts was undertaken by the University of Manchester in February 2009. The results are summarised in the following sections, and plots of every test are presented in Appendix B.

3.1 Coupon tests

Samples were taken from each size of bolt to establish the yield strength and ultimate tensile strength of the material. A typical plot of stress against strain is presented in Figure 3.1, and the results are summarised in Table 3.1. The remaining plots are shown in Appendix B.1.

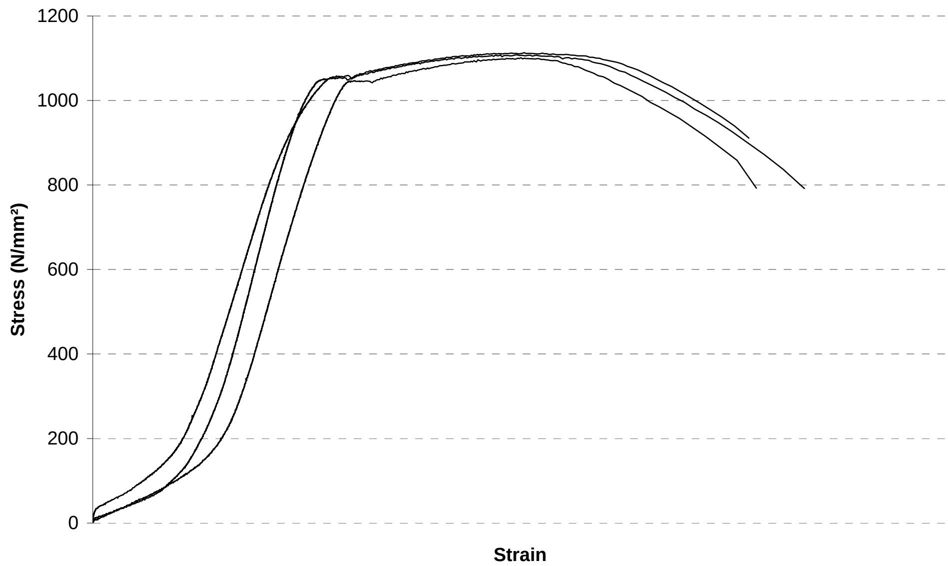

Figure 3.1 *Stress-strain relationship for M10 material*

Table 3.1 *Yield stress, f_{yb}, and ultimate stress, f_{ub}, from coupon tests*

Bolt type	Test number	f_{yb} (N/mm²)	f_{ub} (N/mm²)
M10	1	1059.3	1113.1
	2	1053.9	1107.9
	3	1047.2	1101.4
	Mean	**1053.5**	**1107.5**
M20	1	976.9	1039.9
	2	960.6	1056.1
	3	1013.0	1075.9
	Mean	**983.5**	**1057.3**
M24	1	906.2	1002.5
	2	927.5	1026.0
	3	924.0	1013.8
	Mean	**919.2**	**1014.1**

3.2 Tension tests

Five tensile tests were performed on each of the three bolt sizes. A typical plot of load-deformation is shown in Figure 3.2, and the results of each test are presented in Table 3.2. The remaining plots are shown in Appendix B.2.

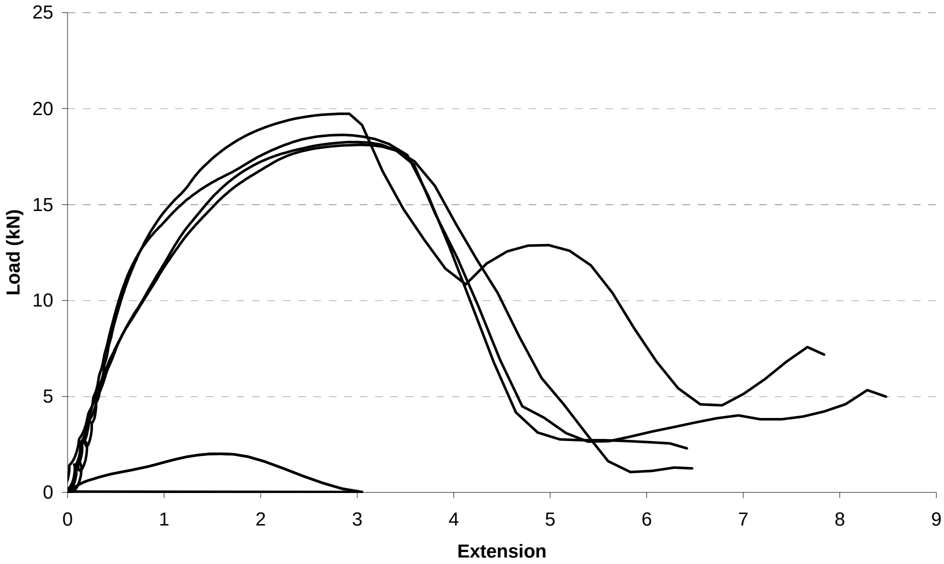

Figure 3.2 *Load-deformation plot for M10 tension tests*

Table 3.2 *Tension test results*

Bolt type	Test number	Maximum tensile force (kN)
M10	1	18.63
	2	19.73
	3	-*
	4	18.26
	5	18.11
M20	1	80.41
	2	81.19
	3	84.00
	4	81.38
	5	85.53
M24	1	115.20
	2	114.09
	3	117.11
	4	111.53
	5	122.29

* Test failed

3.3 Shear tests

Shear tests were performed on each of the three bolt sizes, with the shear plane generally through the slotted region. However, additional tests were also performed on the M10 bolts with the shear plane through the threaded region. A typical plot of load-deformation is shown in Figure 3.3, and the results are summarised in Table 3.3. The remaining plots are shown in Appendix B.3.

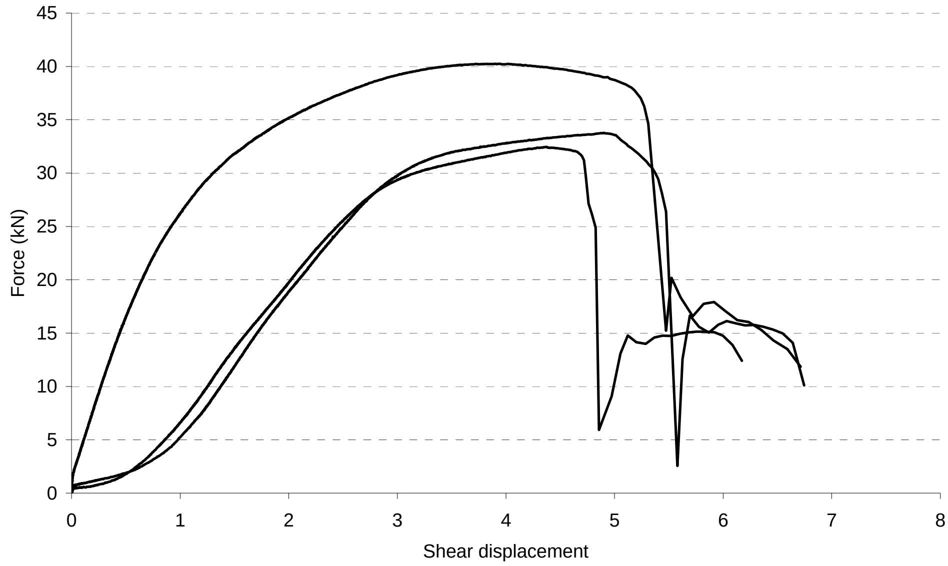

Figure 3.3 *Load-deformation plot for M10 shear tests (shear plane through slotted region)*

Table 3.3 *Shear test results*

Bolt type	Shear plane	Test number	Maximum shear force (kN)
M10	Slotted region	1	40.25
		2	33.77
		3	32.45
	Threaded region	1	58.90
		2	58.35
		3	58.16
M20	Slotted region	1	157.49
		2	150.91
		3	161.16
M24	Slotted region	1	259.98
		2	251.80
		3	261.07
		4	251.57
		5	273.38
		6	267.13

3.4 Combined tension and shear tests

Tests for combined tension and shear were only performed for the M10 and M20 bolts. In each case three tests were performed at each of three angles, 30°, 45° and 60°. A typical load-deformation plot is given in Figure 3.4, and the results are summarised in Table 3.4. The remaining plots are shown in Appendix B.4.

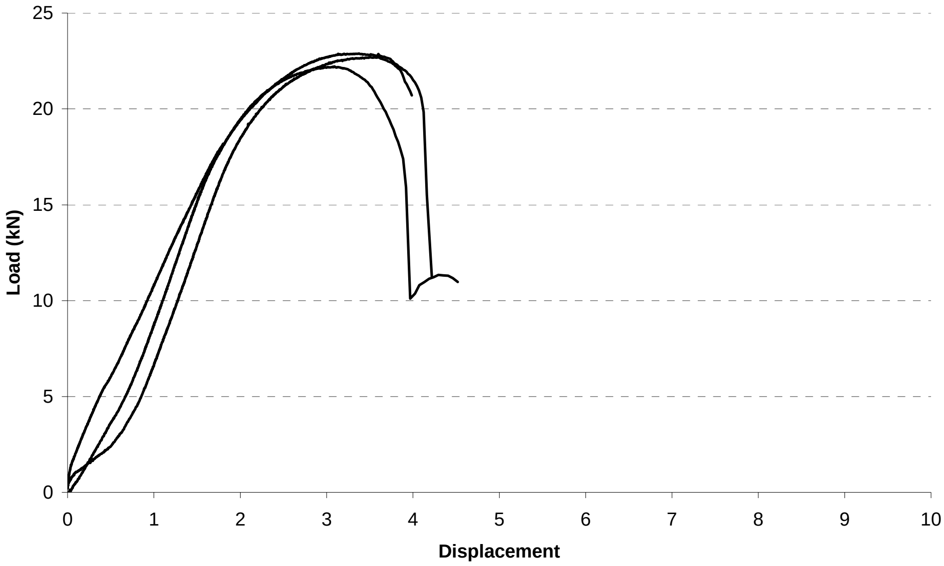

Figure 3.4 *Load-deformation plot for M10 bolts at 30°*

Table 3.4 *Combined tension and shear test results*

Bolt type	Angle	Test number	Maximum force (kN)	Tension component (kN)	Shear component (kN)
M10	30°	1	22.88	19.82	11.44
		2	22.70	19.66	11.35
		3	22.22	19.24	11.11
	45°	1	26.53	18.76	18.76
		2	29.57	20.91	20.91
		3	28.12	19.88	19.88
	60°	1	38.66	19.33	33.48
		2	39.48	19.74	34.19
		3	37.86	18.93	32.78
M20	30°	1	100.53	87.06	50.27
		2	97.88	84.77	48.94
		3	96.32	83.42	48.16
	45°	1	125.11	88.46	88.46
		2	122.53	86.64	86.64
		3	129.31	91.44	91.44
	60°	1	154.42	77.21	133.73
		2	154.53	77.27	133.83
		3	153.68	76.84	133.09

The tension component is calculated as $F\cos\theta$, and the shear component as $F\sin\theta$.

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3.5 Bearing tests

Tests to determine the bearing resistance were performed on each of the three bolt sizes with three thicknesses of plate, each at two different steel grades. A plot of the results from the M10 tests with a 6 mm, S275 plate is shown in Figure 3.5, and the results are summarised in Table 3.5, Table 3.6 and Table 3.7 for the M10, M20 and M24 tests respectively. Plots of all the tests are presented in Appendix B.5.

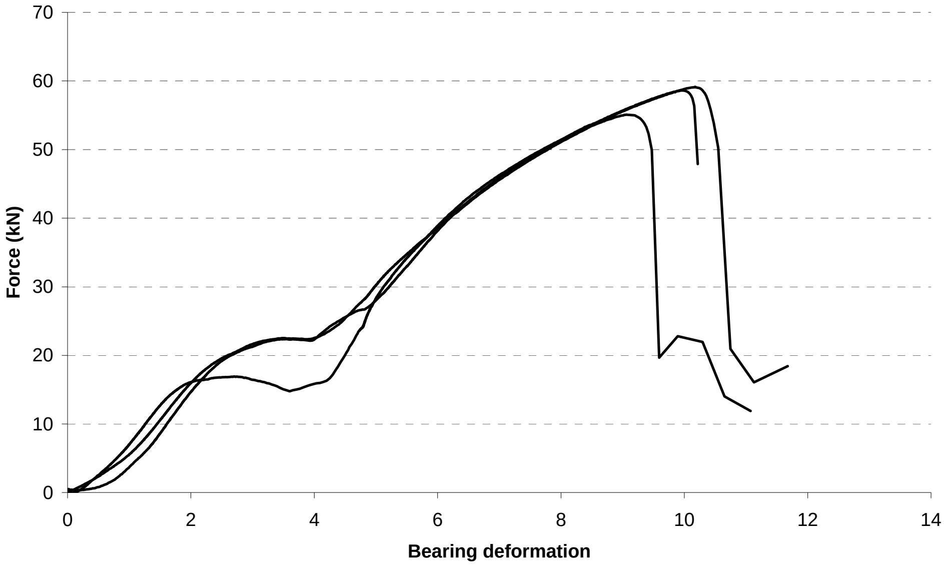

Figure 3.5 *Load-deformation plot for bearing test on M10 bolts in 6 mm, S275 plate*

Table 3.5 *Bearing test results for M10 bolts*

Plate thickness (mm)	Steel grade	Test number	Failure mode	Maximum force (kN)
6	S275	1	Bolt shear	58.60
		2	Bolt shear	55.08
		3	Bolt shear	59.14
	S355	1	Bolt shear	56.10
		2	Bolt shear	55.44
		3	Bolt shear	54.76
10	S275	1	Bolt shear	53.75
		2	Bolt shear	59.67
		3	Bolt shear	56.07
	S355	1	Bolt shear	56.16
		2	Bolt shear	57.26
		3	Bolt shear	53.65
15	S275	1	Bolt shear	51.53
		2	Bolt shear	53.72
		3	Bolt shear	52.57
	S355	1	Bolt shear	54.22
		2	Bolt shear	50.20
		3	Bolt shear	51.30

Table 3.6 *Bearing test results for M20 bolts*

Plate thickness (mm)	Steel grade	Test number	Failure mode	Maximum force (kN)
6	S275	1	Plate bearing	148.41
		2	Plate bearing	146.72
		3	Plate bearing	140.21
	S355	1	Plate bearing	166.49
		2	Plate bearing	172.29
		3	Plate bearing	165.28
10	S275	1	Bolt shear	151.91
		2	Bolt shear	180.08
		3	Bolt shear	155.17
	S355	1	Bolt shear	172.09
		2	Bolt shear	183.98
		3	Bolt shear	151.91
15	S275	1	Bolt shear	135.18
		2	Bolt shear	139.75
		3	Bolt shear	138.04
	S355	1	Bolt shear	133.03
		2	Bolt shear	142.70
		3	Bolt shear	133.82

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Table 3.7 *Bearing test results for M24 bolts*

Plate thickness (mm)	Steel grade	Test number	Failure mode	Maximum force (kN)
6	S275	1	Plate bearing	176.61
		2	Plate bearing	176.68
		3	Plate bearing	179.73
	S355	1	Plate bearing	200.39
		2	Plate bearing	203.64
		3	Plate bearing	212.41
10	S275	1	Plate bearing	267.18
		2	Plate bearing	273.30
		3	Plate bearing	261.97
	S355	1	Plate bearing	282.57
		2	Plate bearing	296.69
		3	Plate bearing	287.46
15	S275	1	Bolt shear	280.84
		2	Bolt shear	244.83
		3	Bolt shear	245.37
	S355	1	Bolt shear	278.98
		2	Bolt shear	288.38
		3	Bolt shear	272.49

4 CURRENT PRACTICE

Currently bolt design is carried out to either BS 5950-1, Section 6 or BS EN 1993-1-8, Table 3.4. The rules in each Standard for the four design cases are summarised in the following Sections. Note that the design values quoted are for standard bolts, rather than for blind bolts.

4.1 Design of bolts in tension

4.1.1 BS 5950-1

The tension resistance of bolts to BS 5950-1 is calculated from:

$$P_t = p_t A_t \tag{1}$$

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, calculated from

$$p_t = 0.7 U_b \leq Y_b \tag{2}$$

where:

U_b is the specified minimum tensile strength of the bolt (1000 N/mm² for grade 10.9)

Y_b is the specified minimum yield strength of the bolt (900 N/mm² for grade 10.9)

4.1.2 BS EN 1993-1-8

The tension resistance of bolts to BS EN 1993-1-8 is calculated from:

$$F_{t,Rd} = \frac{k_2 f_{ub} A_s}{\gamma_{M2}} \tag{3}$$

where:

$F_{t,Rd}$ is the tension resistance

k_2 = 0.9 for non-countersunk bolts

f_{ub} is the ultimate tensile strength of the bolt (1000 N/mm² for grade 10.9)

A_s is the tensile stress area of the bolt

γ_{M2} = 1.25, from the UK National Annex

4.1.3 Design values for grade 10.9 bolts

The design tension resistance of size M10, M20 and M24 bolts in grade 10.9 are given in Table 4.1.

Table 4.1 *Design tension resistance of grade 10.9 bolts*

Size	Tensile stress area (mm²)	P_t (kN)	$F_{t,Rd}$ (kN)
M10	58.0	40.6	41.8
M20	245	171.5	176.4
M24	353	247.1	254.2

4.2 Design of bolts in shear

4.2.1 BS 5950-1

The shear resistance of bolts to BS 5950-1 is calculated from:

$$P_s = p_s A_s \tag{4}$$

where:

P_s is the shear capacity

A_s is the shear area, taken as A_t when the shear plane passes through the threaded region and A when the shear plane does not pass through the threaded region

A is the shank area

p_s is the shear strength, calculated from:

$$p_s = 0.4 U_b \tag{5}$$

4.2.2 BS EN 1993-1-8

The shear resistance of bolts to BS EN 1993-1-8 is calculated from:

$$F_{v,Rd} = \frac{\alpha_v f_{ub} A}{\gamma_{M2}} \tag{6}$$

where:

$F_{v,Rd}$ is the shear resistance

α_v = 0.5 for grade 10.9 when the shear plane passes through the threaded region

α_v = 0.6 when the shear plane passes through the unthreaded region

A is the shear area, taken as A_s when the shear plane passes through the threaded region and A when the shear plane passes through the unthreaded region

4.2.3 Design values for grade 10.9 bolts

The design shear resistance of size M10, M20 and M24 bolts in grade 10.9 are given in Table 4.2.

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Table 4.2 *Design shear resistance of grade 10.9 bolts*

Size	Shear plane	Shear area (mm²)	P_s (kN)	$F_{v,Rd}$ (kN)
M10	Threaded region	58.0	23.2	23.2
	Unthreaded region	78.5	31.4	37.7
M20	Threaded region	245	98.0	98.0
	Unthreaded region	314	125.6	150.7
M24	Threaded region	353	141.2	141.2
	Unthreaded region	452	180.8	217.0

4.3 Design of bolts in combined tension and shear

4.3.1 BS 5950-1

When bolts are subject to combined tension and shear, the following equation from BS 5950-1 should be satisfied in addition to the separate equations for tension and shear:

$$\frac{F_s}{P_s} + \frac{F_t}{P_t} \leq 1.4 \tag{7}$$

4.3.2 BS EN 1993-1-8

When bolts are subject to combined tension and shear, the following equation from BS EN 1993-1-8 should be satisfied in addition to the separate equation for tension:

$$\frac{F_{v,Ed}}{F_{v,Rd}} + \frac{F_{t,Ed}}{1.4 F_{t,Rd}} \leq 1.0 \tag{8}$$

4.3.3 Design envelopes for grade 10.9 bolts

The envelopes shown in Figure 4.1 have been generated from the above equations and the values given in Table 4.1 and Table 4.2.

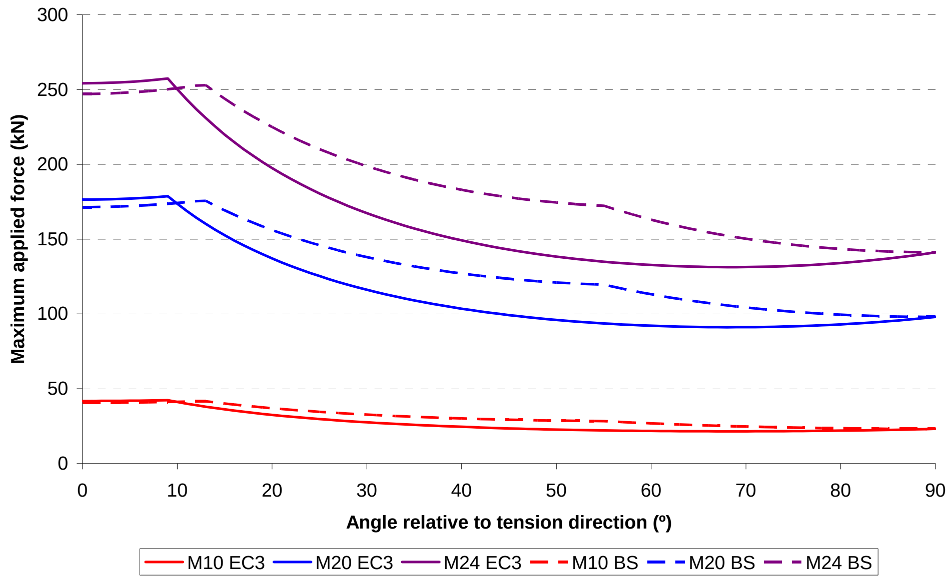

Figure 4.1 *Design envelopes for combined bending and shear*

4.4 Design of bolts in bearing

4.4.1 BS 5950-1

The bearing resistance of bolts to BS 5950-1 is taken as the minimum of P_{bb}, the bearing resistance of the bolt, and P_{bs}, the bearing resistance of the plate. These are calculated from the following equations:

$$P_{bb} = dt_p p_{bb} \tag{9}$$

where:

d is the nominal diameter of the bolt

t_p is the thickness of the connected part

p_{bb} is the bearing strength of the bolt, calculated from:

$$p_{bb} = 0.7\left(U_b + Y_b\right) \tag{10}$$

$$P_{bs} = k_{bs} dt_p p_{bs} \leq 0.5 k_{bs} et_p p_{bs} \tag{11}$$

where:

k_{bs} = 1.0 for standard clearance holes

e is the end distance, measured from the edge of the sheet to the centre-line of the hole

p_{bs} is the bearing strength of the connected part, taken as 460 N/mm² for S275 steel and 550 N/mm² for S355 steel

Note that these expressions are based on limiting the deformation at working load to 1.5 mm, rather than the stress-carrying capability of the bolt

4.4.2 BS EN 1993-1-8

The bearing resistance of bolts to BS EN 1993-1-8 is calculated from:

$$F_{\mathrm{b,Rd}} = \frac{k_1 \alpha_{\mathrm{b}} f_{\mathrm{u}} dt}{\gamma_{\mathrm{M2}}} \tag{12}$$

where:

$F_{\mathrm{b,Rd}}$ is the bearing resistance

f_{u} is the ultimate tensile strength of the plate material, taken as 430 N/mm² for S275 steel and 510 N/mm² for S355 steel

d is the nominal diameter of the bolt

t is the thickness of the plate

α_{b} and k_1 are coefficients calculated from the following equations:

$$\alpha_{\mathrm{b}} = \min\left\{\alpha_{\mathrm{d}}; \frac{f_{\mathrm{ub}}}{f_{\mathrm{u}}}; 1.0\right\} \tag{13}$$

$$\alpha_{\mathrm{d}} = \frac{e_1}{3d_0} \tag{14}$$

$$k_1 = 2.8\frac{e_2}{d_0} - 1.7 \le 2.5 \tag{15}$$

where:

e_1 is the edge distance in the direction of the applied load, measured from the edge of the sheet to the centre-line of the hole

e_2 is the edge distance perpendicular to the direction of the applied load, measured from the edge of the sheet to the centre-line of the hole

d_0 is the diameter of the hole (taken as 11 mm for M10 bolts, 22 mm for M20 bolts and 26 mm for M24 bolts)

4.4.3 Design values for grade 10.9 bolts

The design bearing resistance of size M10, M20 and M24 bolts in grade 10.9 are given in Table 4.3 for plate thicknesses of 6 mm, 10 mm and 15 mm, and steel grades of S275 and S355. The edge distances, e_1 and e_2, are taken as 25 mm for M10 bolts, 50 mm for M20 bolts and 60 mm for M24 bolts (the same dimensions that were used in the tests).

Table 4.3 *Design bearing resistance of grade 10.9 bolts*

Size	Plate thickness (mm)	P_{bs} (kN)		$F_{v,Rd}$ (kN)	
		S275	**S355**	**S275**	**S355**
M10	6	27.6	33.0	39.1	43.4
	10	46.0	55.0	65.2	77.3
	15	69.0	82.5	97.7	115.9
M20	6	55.2	66.0	78.2	92.7
	10	92.0	110.0	130.3	154.6
	15	138.0	165.0	195.5	231.8
M24	6	66.2	79.2	95.3	113.0
	10	110.4	132.0	158.8	188.3
	15	165.6	264.0	238.2	282.5

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5 DERIVATION OF CHARACTERISTIC AND DESIGN VALUES

The resistances that are derived in this section ignore any effect from the connected parts – i.e. the tension resistance in the wall of a hollow section will almost certainly be limited by the deformation of the hollow section wall, not the resistance of the bolt itself. It is recommended that the presentation of the bolt resistances should be accompanied by a warning that designers will have to address any possible effects of the supporting material themselves.

5.1 Tension resistance

The failure loads presented in Table 3.2 must first be normalised to the nominal ultimate tensile strength of the material to take account of the variability of the material strength between batches. This is done using the following equation:

$$R_{\text{adj}} = R_{\text{obs}} \frac{f_{\text{u,nom}}}{f_{\text{u,obs}}} \tag{16}$$

where:

R_{adj} is the normalised failure load

R_{obs} is the observed test results

$f_{\text{u,nom}}$ is the nominal ultimate tensile strength of the material

$f_{\text{u,obs}}$ is the observed ultimate tensile strength of the material

The normalised failure loads are presented in Table 5.1.

Table 5.1 *Normalised tension test results*

Bolt type	Test number	R_{obs} (kN)	$f_{\text{u,obs}}$ (N/mm²)	$f_{\text{u,nom}}$ (N/mm²)	R_{adj} (kN)
M10	1	18.63	1107	1000	16.82
	2	19.73	1107	1000	17.81
	4	18.26	1107	1000	16.49
	5	18.11	1107	1000	16.35
M20	1	80.41	1057	1000	76.06
	2	81.19	1057	1000	76.79
	3	84.00	1057	1000	79.44
	4	81.38	1057	1000	76.97
	5	85.53	1057	1000	80.89
M24	1	115.20	1014	1000	113.60
	2	114.09	1014	1000	112.51
	3	117.11	1014	1000	115.48
	4	111.53	1014	1000	109.98
	5	122.29	1014	1000	120.59

In the equations given in Section 4.1, the tensile resistance is related to the tensile area of the bolt. For the blind bolts, the minimum area occurs at the location of the pivot pin, where the cross-section is as shown in Figure 5.1. The relevant dimensions for each size of bolt are given in Table 5.2, together with the calculated cross-sectional area, A_t (calculated from Equation (17)).

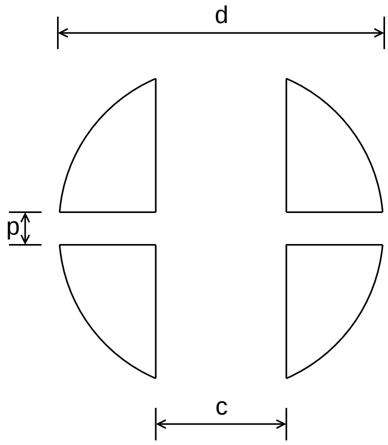

Figure 5.1 *Dimensions of tensile area of blind bolts*

Table 5.2 *Bolt dimensions*

Bolt type	*d* (mm)	*c* (mm)	*p* (mm)	A_t (mm²)
M10	10	4	1.6	30.1
M20	20	8	2.0	134.6
M24	24	10	2.0	191.6

$$A_t = \frac{\pi d^2}{4} - \left(\frac{cd\cos\theta}{2} + \frac{d^2\theta}{2}\right) - \left(\frac{pd\cos\phi}{2} + \frac{d^2\phi}{2} - pr\right) \qquad (17)$$

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

By comparing the normalised test results, R_{adj}, to the predicted resistance, R_{pred} (taken as $A_t f_{u,nom}$), a correction factor, *b*, can be calculated for each test and the mean and standard deviation of the entire set of tests can be determined. These correction factors are presented in Table 5.3.

Table 5.3 *Correction factors for tension test results*

Bolt type	Test number	R_{adj} (kN)	R_{pred} (kN)	*b*
M10	1	16.82	30.10	0.559
	2	17.81	30.10	0.592
	4	16.49	30.10	0.548
	5	16.35	30.10	0.543
M20	1	76.06	134.60	0.565
	2	76.79	134.60	0.571
	3	79.44	134.60	0.590
	4	76.97	134.60	0.572
	5	80.89	134.60	0.601
M24	1	113.60	191.58	0.593
	2	112.51	191.58	0.587
	3	115.48	191.58	0.603
	4	109.98	191.58	0.574
	5	120.59	191.58	0.629
			Mean	**0.580**
			Standard Deviation	**0.0234**

Figure 5.2 shows a comparison of R_{adj} and R_{pred}, and it is clear from this that the data from the three different sizes of bolt can be treated as a single population, as a line through the origin also passes through each set of test data.

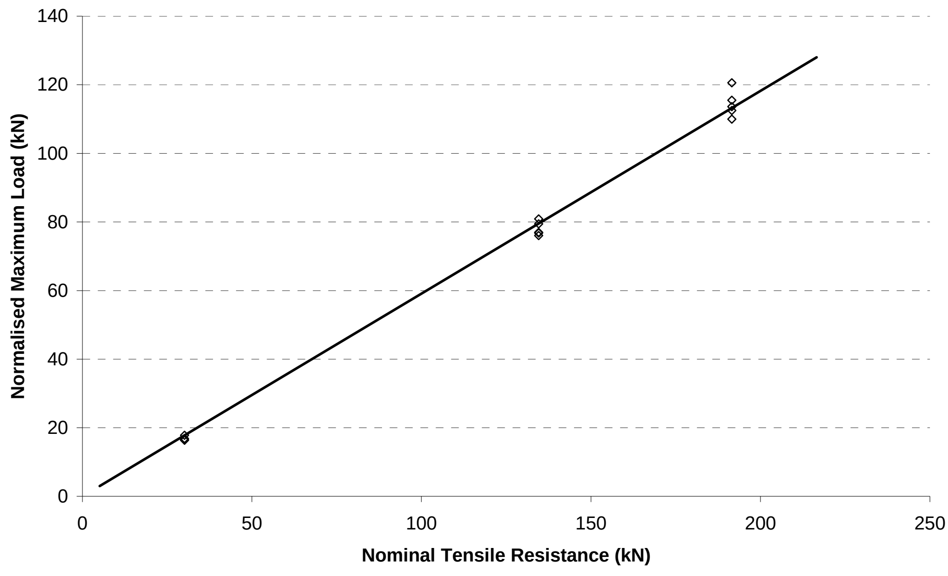

Figure 5.2 *Comparison of the normalised maximum load and the nominal tensile resistance*

The design resistance is calculated using Equation (18), based on BS EN 1990[5], Equation (D.1).

$$X_{\mathrm{d}} = \frac{X_{\mathrm{k}}}{\gamma_{\mathrm{m}}} = \frac{X_{\mathrm{b=1}}\left(m_{\mathrm{b}} - k_{\mathrm{n}} s_{\mathrm{b}}\right)}{\gamma_{\mathrm{m}}} \tag{18}$$

where:

X_d is the design resistance of property X

$X_{k(n)}$ is the characteristic resistance of property X, derived from n tests

γ_m is the relevant partial safety factor, in this case γ_{M2}

$X_{b=1}$ is the resistance of property X corresponding to a correction factor of $b = 1$

m_b is the mean correction factor

k_n is an adjustment coefficient that depends on the number of tests that have been undertaken, taken from BS EN 1990, Table D1

s_b is the standard deviation of the correction factor

For a set of 14 tests, $k_n = 1.856$ from Table D1 of BS EN 1990 (V_x unknown has been used, as there is no prior knowledge of the variation of the tests). Applying this to the values given in Table 5.3 gives the following design equation:

$$F_{\mathrm{t,Rd}} = \frac{F_{\mathrm{t,Rk}}}{\gamma_{\mathrm{M2}}} = \frac{0.537 f_{\mathrm{u,nom}} A_{\mathrm{t}}}{\gamma_{\mathrm{M2}}} \tag{19}$$

Note that this is equivalent to Equation (3) with $k_2 = 0.537$, using the minimum tensile area of the blind bolts.

For design to the British Standards, Equation (1) can be used with $p_t = 430$ N/mm² (calculated from Equation (19) with $\gamma_{M2} = 1.25$).

The design tension resistances for the blind bolts are presented in Table 5.4.

Table 5.4 *Design tension resistances for blind bolts*

Bolt size	Design tension resistance, $P_{t,Rd}$ (kN)
M10	12.93
M20	57.82
M24	82.31

5.2 Shear resistance

The failure loads presented in Table 3.3 are again normalised using Equation (16). These are presented in Table 5.5.

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Table 5.5 *Normalised shear test results*

Bolt type	Shear plane	Test number	R_{obs} (kN)	$f_{u,obs}$ (N/mm²)	$f_{u,nom}$ (N/mm²)	R_{adj} (kN)
M10	Slotted region	1	40.25	1107	1000	36.35
		2	33.77	1107	1000	30.49
		3	32.45	1107	1000	29.30
	Threaded region	1	58.90	1107	1000	53.19
		2	58.35	1107	1000	52.69
		3	58.16	1107	1000	52.51
M20	Slotted region	1	157.49	1057	1000	148.96
		2	150.91	1057	1000	142.73
		3	161.16	1057	1000	152.42
M24	Slotted region	1	259.98	1014	1000	256.37
		2	251.80	1014	1000	248.30
		3	261.07	1014	1000	257.44
		4	251.57	1014	1000	248.07
		5	273.38	1014	1000	269.58
		6	267.13	1014	1000	263.41

For the shear tests, the predicted resistance is calculated using Equation (6), taking α_v as 0.5 for the threaded region and 0.6 for the slotted region, γ_{M2} as 1.0 and A as the shear area of the region in question (so for the slotted region, A is calculated from Equation (17) with p = 0). The predicted resistances and the corresponding correction factors are given in Table 5.6.

Table 5.6 *Normalised shear test results*

Bolt type	Shear plane	Test number	R_{adj} (kN)	A (mm²)	R_{pred} (kN)	b
M10	Slotted region	1	36.35	39.6	23.78	1.69
		2	30.49	39.6	23.78	1.42
		3	29.30	39.6	23.78	1.36
	Threaded region	1	53.19	58.0	29.00	2.03
		2	52.69	58.0	29.00	2.01
		3	52.51	58.0	29.00	2.01
M20	Slotted region	1	148.96	158.5	95.12	1.66
		2	142.73	158.5	95.12	1.59
		3	152.42	158.5	95.12	1.69
M24	Slotted region	1	256.37	219.5	131.72	1.97
		2	248.30	219.5	131.72	1.91
		3	257.44	219.5	131.72	1.98
		4	248.07	219.5	131.72	1.91
		5	269.58	219.5	131.72	2.08
		6	263.41	219.5	131.72	2.03

The correlation between different sets of test results is again compared by plotting R_{adfj} against R_{pred}. This is shown in Figure 5.3.

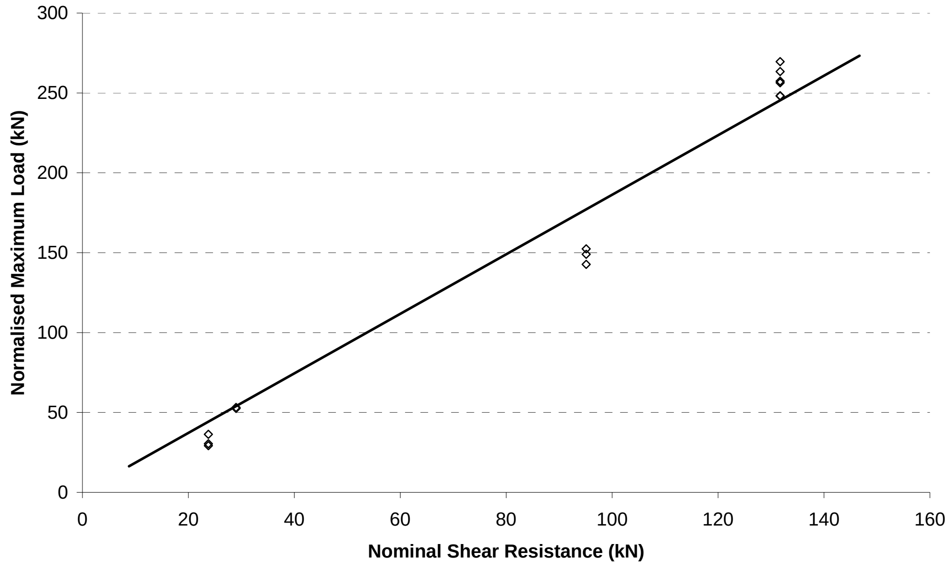

Figure 5.3 *Comparison of the normalised maximum load and the nominal shear resistance*

In the shear case it is clear that the different bolt sizes and shear regions do not belong to the same set of data, as each set is distant from the line. A characteristic shear resistance is calculated for each combination individually, using Equation (18). These are shown in Table 5.7.

Table 5.7 *Normalised shear test results*

Bolt type	Shear plane	Test number	b	$X_{b=1}$	m_b	s_b	k_n	b_k	X_k
M10	Slotted region	1	1.69	23.78	1.49	0.176	3.37	0.90	21.42
		2	1.42						
		3	1.36						
	Threaded region	1	2.03	29.00	2.02	0.013	3.37	1.97	57.17
		2	2.01						
		3	2.01						
M20	Slotted region	1	1.66	95.12	1.65	0.055	3.37	1.46	139.02
		2	1.59						
		3	1.69						
M24	Slotted region	1	1.97	131.72	1.98	0.065	2.18	1.84	242.19
		2	1.91						
		3	1.98						
		4	1.91						
		5	2.08						
		6	2.03						

b_k is the characteristic correction factor

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In general, the characteristic correction factors are all greater than 1.0 and so are showing an enhancement over the values given by the Eurocode equations. The exception is for the M10 bolts in the slotted region, where an exceptionally high variation between the three tests results in a characteristic correction factor of 0.9. Based on the variability of the other tests, it is felt that this variation is extreme, and that further tests would reduce this variability and improve the characteristic correction factor to a value greater than 1.0. It is therefore recommended that the design rules from BS EN 1993-1-8 be adopted for all the bolt sizes, rather than specifying shear resistances based on the test results. The design values in each case are given in Table 5.8.

For design to the British Standards, the test results again show an enhancement over the rules in BS 5950-1, so the rules defined in the Standard should be used with the shear areas taken as shown in Table 5.2. The design capacities are shown in Table 5.8.

Table 5.8 *Design shear resistances for blind bolts*

Bolt size	Shear plane	Design shear resistance, $P_{v,Rd}$, from tests (kN)	Design shear resistance, $P_{v,Rd}$, according to BS EN 1993-1-8 (kN)	Design shear capacity, P_s, according to BS 5950-1 (kN)
M10	Slotted region	17.13	19.02	15.85
	Threaded region	45.74	23.20	23.20
M20	Slotted region	111.21	76.1	63.41
M24	Slotted region	193.75	105.37	87.81

5.3 Combined tension and shear

The equations for combined tension and shear presented in Section 4.3 can be rearranged into the following general form:

$$\frac{F_{t,Ed}}{AF_{t,Rd}} + \frac{F_{v,Ed}}{BF_{v,Rd}} \le 1.0 \qquad (20)$$

where:

$F_{t,Ed}$ is the design tension force on the bolt

$F_{t,Rd}$ is the design tension resistance of the bolt

$F_{v,Ed}$ is the design shear force on the bolt

$F_{E,Rd}$ is the design shear resistance of the bolt

A is a constant, taken as 1.4 in both the British Standard and Eurocode

B is a constant, taken as 1.4 in the British Standard and 1.0 in the Eurocode

Equation (20) can then be rearranged into the following form:

$$\frac{F_{\mathrm{t,Ed}}}{F_{\mathrm{t,Rd}}} \leq A - \frac{A}{B}\frac{F_{\mathrm{v,Ed}}}{F_{\mathrm{v,Rd}}} \qquad (21)$$

By comparing the results of the combined tension and shear tests in Table 3.4 to the mean results from the pure tension and pure shear tests, the validity of the current design rules can be verified (note that the safety factors will be incorporated by using design resistances and forces, so mean values can be used here to assess the design rules). The results are plotted in Figure 5.4.

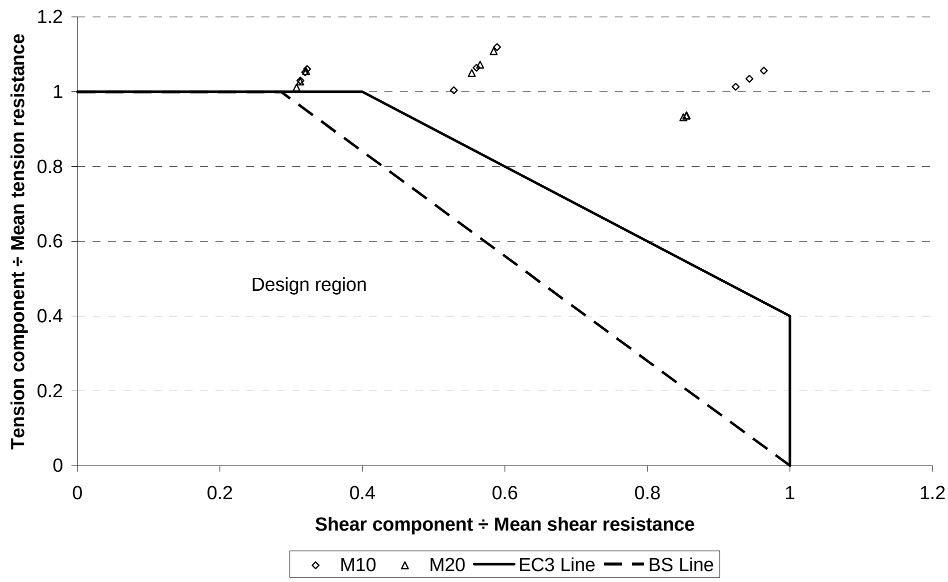

Figure 5.4 *Results of combined tension and shear tests*

As none of the test results fall within the design region, there is no reason to believe that the current design rules do not apply to blind bolts. The test results indicate that more favourable rules might be appropriate, but further testing would be required to establish these rules as most of these tests have failed in tension rather than a combined mechanism. For now it is recommended that the current rules, as shown in Equations (7) and (8), are adopted for blind bolts.

5.4 Bearing resistance

For design to the Eurocodes, the bearing resistance is a function of the ultimate strength of the connection, whereas for British Standard design it is defined by restricting the deformation of the connection to 1.5 mm. The two cases are considered separately.

5.4.1 Bearing resistance to BS EN 1993-1-8

The connection used in the test can either fail through bearing of the plate, bearing of the bolt, or through double shear. Table 5.9 compares the calculated bearing resistances for each test setup with the calculated resistance of the bolt in double shear.

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Table 5.9 *Design bearing resistance of grade 10.9 bolts*

Size	Plate thickness (mm)	$F_{v,Rd}$ (kN)		$2P_{v,Rd}$ (kN)
		S275	S355	
M10	6	39.1	43.4	38.0
	10	65.2	77.3	38.0
	15	97.7	115.9	38.0
M20	6	78.2	92.7	152.2
	10	130.3	154.6	152.2
	15	195.5	231.8	152.2
M24	6	95.3	113.0	210.7
	10	158.8	188.3	210.7
	15	238.2	282.5	210.7

From Table 5.9 it is clear that, based on the dimensions in the test setup, the bearing failure would only be expected to dominate for M20 bolts in 6 mm S275 & S355 plate and in 10 mm S275 plate, and for M24 bolts in 6 mm and 10 mm S275 & S355 plate. Reference to Table 3.5, Table 3.6 and Table 3.7 shows that this is confirmed by the tests, except for the M20 bolts in 10 mm S275 plate, which failed in bolt shear. The tests that failed in bearing are summarised in Table 5.10.

Table 5.10 *Bearing test results for M20 bolts*

Bolt type	Plate thickness (mm)	Steel grade	Test number	Maximum force (kN)
M20	6	S275	1	148.41
			2	146.72
			3	140.21
		S355	1	166.49
			2	172.29
			3	165.28
M24	6	S275	1	176.61
			2	176.68
			3	179.73
		S355	1	200.39
			2	203.64
			3	212.41
M24	10	S275	1	267.18
			2	273.30
			3	261.97
		S355	1	282.57
			2	296.69
			3	287.46

The actual material properties of the plate steel are not known, so the nominal ultimate tensile strength has been assumed and the test results cannot be normalised. A plot of the maximum observed load against the bearing resistance is shown in Figure 5.5, and it is clear a line through the origin does not pass through all of the data, so each set must be treated individually.

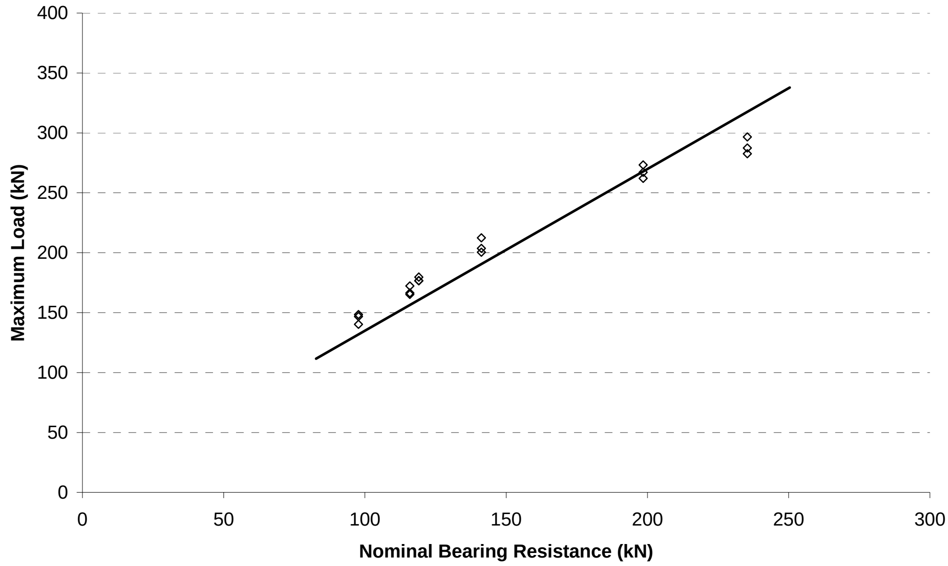

Figure 5.5 *Comparison of the maximum load with the nominal bearing resistance*

The characteristic resistance in each case is calculated in the same way as the shear resistance. This process is shown in Table 5.11.

Table 5.11 *Bearing test results for M20 bolts*

Bolt type	Plate thickness (mm)	Steel grade	Test number	b	$X_{b=1}$	m_b	s_b	k_n	b_k	X_k
M20	6	S275	1	1.52						
			2	1.50	97.73	1.48	0.044	3.37	1.34	130.51
			3	1.43						
		S355	1	1.44						
			2	1.49	115.91	1.45	0.032	3.37	1.34	155.39
			3	1.43						
M24	6	S275	1	1.48						
			2	1.48	119.08	1.49	0.015	3.37	1.44	171.67
			3	1.51						
		S355	1	1.42						
			2	1.44	141.23	1.45	0.044	3.37	1.31	184.53
			3	1.50						
M24	10	S275	1	1.35						
			2	1.38	198.46	1.35	0.029	3.37	1.25	248.37
			3	1.32						
		S355	1	1.20						
			2	1.26	235.38	1.23	0.030	3.37	1.12	264.74
			3	1.22						

As the characteristic correction factors are all greater than 1.0, they are showing an enhancement over the values given by the Eurocode equations. It is therefore recommended that the design rules from BS EN 1993-1-8 be adopted for all bolt sizes, rather than specifying bearing resistances based on the test results. The design values in each case are given in Table 5.12.

Table 5.12 *Design bearing resistance for blind bolts*

Size	Plate thickness (mm)	Design bearing resistance, $F_{b,Rd}$, from tests (kN)		Design bearing resistance, $F_{b,Rd}$, according to BS EN 1993-1-8 (kN)	
		S275	S355	S275	S355
M10	6	-	-	39.1	43.4
	10	-	-	65.2	77.3
	15	-	-	97.7	115.9
M20	6	104.4	124.3	78.2	92.7
	10	-	-	130.3	154.6
	15	-	-	195.5	231.8
M24	6	137.3	147.6	95.3	113.0
	10	198.7	211.8	158.8	188.3
	15	-	-	238.2	282.5

5.4.2 Bearing resistance to BS 5950-1

The bearing capacities in BBS 5950-1 are based on limiting the deformation of the connection at working load to 1.5 mm. In the tests there is a certain amount of the load and deflection that reflects the bedding-in of the connection, rather than actual deformation. To counteract this, the gradient of the load vs. deformation plot has been determined for the section after the bedding-in, as shown in Figure 5.6.

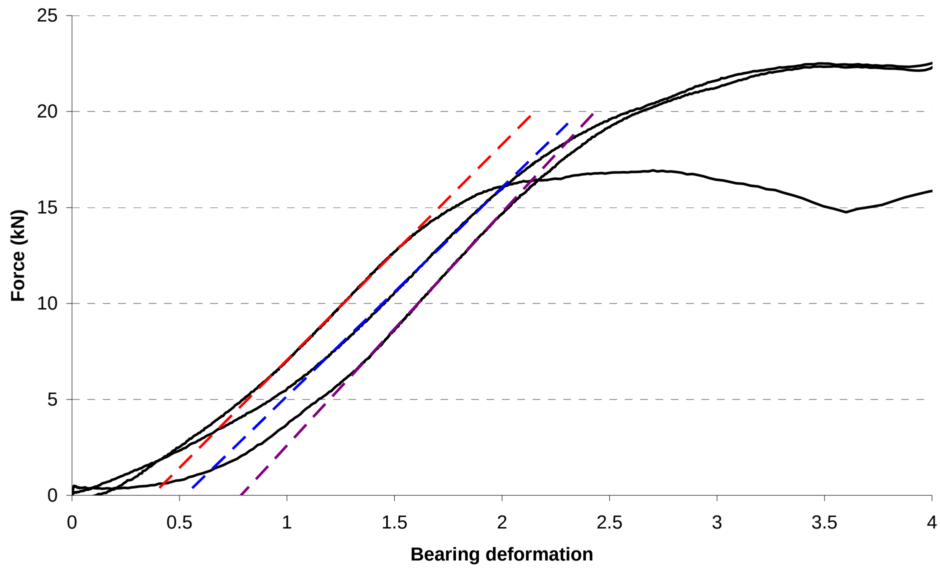

Figure 5.6 *Initial gradients for M10 bolts in 6 mm S275 plate*

The gradients in each case are presented in Table 5.13.

Table 5.13 *Initial gradients from bearing tests*

Bolt type	Plate thickness (mm)	Steel grade	Initial gradient of each test (kN/mm)		
			Test 1	**Test 2**	**Test 3**
M10	6	S275	11.23	10.88	12.14
		S355	9.23	11.48	11.11
	10	S275	21.97	25.53	26.69
		S355	25.41	27.60	17.97
	15	S275	21.16	19.46	27.56
		S355	26.78	23.01	20.75
M20	6	S275	12.18	17.30	19.16
		S355	18.54	21.78	20.89
	10	S275	22.29	23.10	24.40
		S355	21.24	25.97	25.53
	15	S275	29.52	27.23	27.69
		S355	26.73	26.97	26.36
M24	6	S275	21.25	21.90	21.17
		S355	30.99	30.47	31.35
	10	S275	41.50	41.70	40.06
		S355	45.89	34.22	40.19
	15	S275	59.52	50.85	41.81
		S355	48.78	50.93	49.42

The initial gradients can be converted into a bearing capacity by multiplying by the limiting deformation (1.5 mm), and a factor of 1.5 to account for the difference between the design load and the working load (taken as the average of the dead load and live load factors). The resulting bearing capacities in each case are presented in Table 5.14.

Table 5.14 *Initial gradients from bearing tests*

Bolt type	Plate thickness (mm)	Steel grade	Bearing capacity from each test (kN)			P_{bs} (kN)
			Test 1	Test 2	Test 3	
M10	6	S275	25.27	24.48	27.31	16.56
		S355	20.78	25.83	24.99	19.80
	10	S275	49.43	57.44	60.06	27.60
		S355	57.17	62.10	40.44	33.00
	15	S275	47.62	43.79	62.01	41.40
		S355	60.24	51.76	46.68	49.50
M20	6	S275	27.40	38.93	43.11	33.12
		S355	41.71	49.00	47.00	39.60
	10	S275	50.15	51.98	54.89	55.20
		S355	47.78	58.43	57.45	66.00
	15	S275	66.41	61.26	62.29	82.80
		S355	60.14	60.69	59.31	99.00
M24	6	S275	47.82	49.28	47.64	38.64
		S355	69.72	68.55	70.53	46.20
	10	S275	93.37	93.81	90.13	64.40
		S355	103.25	77.00	90.42	77.00
	15	S275	133.93	114.41	94.08	96.60
		S355	109.76	114.59	111.20	115.50

Also shown in Table 5.14 are predicted bearing capacities, P_{bs}, using a modified version of the equation from BS 5950-1:

$$P_{bs} = k_{bs}(d - c)t_p p_{bs} \leq 0.5 k_{bs} e t_p p_{bs} \qquad (22)$$

where:

k_{bs} = 1.0 for standard clearance holes

d is the diameter of the bolt

c is the width of the slot

t_p is the thickness of the plate

e is the end distance, measured from the edge of the sheet to the centre-line of the hole

p_{bs} is the bearing strength of the connected part, taken as 460 N/mm² for S275 steel and 550 N/mm² for S355 steel

The modification has been made to Equation (11) to take account of the reduced area that the bearing force will transfer over. In the majority of cases in Table 5.14, the bearing capacities from the tests are greater than the prediction using Equation (22), as shown in Table 5.7 where the line shows a gradient of 1.0.

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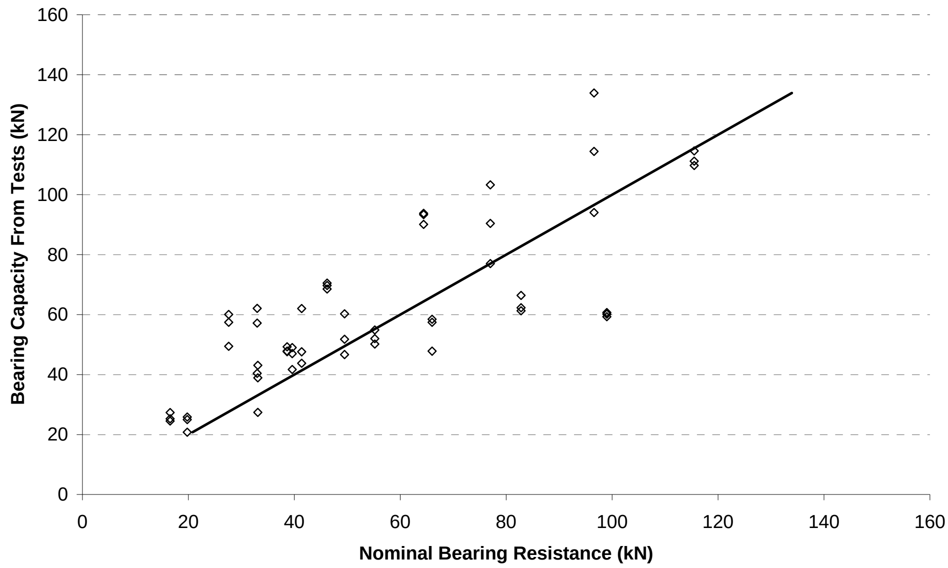

Figure 5.7 *Comparison of the bearing capacities from tests with the nominal bearing resistance*

Although there are a few cases below the equality line in Figure 5.7, it is felt that the rule proposed in Equation (22) should be adopted for the design of the blind bolts. The majority of the test evidence supports the modification to the BS 5950-1 equation, and the ultimate loads that the connections can support is vastly superior to the bearing capacities (the bearing capacities are approximately half of the maximum test loads). The bearing capacities that should be used for design are shown in Table 5.15, together with the bearing capacities calculated from the test results in Section 5.4.1.

Table 5.15 *Design bearing resistance for blind bolts*

Size	Plate thickness (mm)	Design bearing resistance, $F_{b,Rd}$, from tests (kN)		Design bearing capacity, P_b, according to BS 5950-1 (kN)	
		S275	S355	S275	S355
M10	6	-	-	16.56	19.80
	10	-	-	27.60	33.00
	15	-	-	41.40	49.50
M20	6	104.4	124.3	33.12	39.60
	10	-	-	55.20	66.00
	15	-	-	82.80	99.00
M24	6	137.3	147.6	38.64	46.20
	10	198.7	211.8	64.40	77.00
	15	-	-	96.60	115.50

6 SUMMARY OF DESIGN RULES FOR BLIND BOLTS

This section summarises the design equations derived in Section 5, and can be used for blind bolts in the range M8 to M24, using grade 10.9 steel.

6.1 Design of bolts in tension

6.1.1 BS 5950-1

The tension resistance of bolts to BS 5950-1 is calculated from:

$$P_{\mathrm{t}} = p_{\mathrm{t}} A_{\mathrm{pin}} \tag{23}$$

where:

P_{t} is the tension capacity

p_{t} is the tension strength of the bolt, taken as 430 N/mm²

A_{pin} is the tensile stress area of the bolt, calculated from:

$$A_{\mathrm{pin}} = \frac{\pi d^2}{4} - \left(\frac{cd\cos\theta}{2} + \frac{d^2\theta}{2}\right) - \left(\frac{pd\cos\phi}{2} + \frac{d^2\phi}{2} - pr\right)$$
$$\sin\theta = \frac{c}{d};\ \sin\phi = \frac{p}{d} \tag{24}$$

where:

d is the diameter of the bolt

c is the width of the slot

p is the diameter of the pin

6.1.2 BS EN 1993-1-8

The tension resistance of bolts to BS EN 1993-1-8 is calculated from:

$$F_{\mathrm{t,Rd}} = \frac{k_2 f_{\mathrm{ub}} A_{\mathrm{pin}}}{\gamma_{\mathrm{M2}}} \tag{25}$$

where:

$F_{\mathrm{t,Rd}}$ is the tension resistance

k_2 = 0.537 for blind bolts

f_{ub} is the ultimate tensile strength of the bolt (1000 N/mm² for grade 10.9)

A_{pin} is the tensile stress area of the bolt, calculated using Equation (24)

γ_{M2} = 1.25, from the UK National Annex

6.2 Design of bolts in shear

6.2.1 BS 5950-1

The shear resistance of bolts to BS 5950-1 is calculated from:

$$P_{s} = p_{s} A_{s} \tag{26}$$

where:

P_s is the shear capacity

A_s is the shear area, taken as A_t when the shear plane passes through the threaded region and A_{slot} when the shear plane does not pass through the threaded region

p_s is the shear strength, taken as 400 N/mm²

A_t is the tensile area of the threaded region

A_{slot} is the area of the slotted region, calculated from:

$$A_{slot} = \frac{\pi d^2}{4} - \left(\frac{cd \cos\theta}{2} + \frac{d^2 \theta}{2} \right); \quad \sin\theta = \frac{c}{d} \tag{27}$$

6.2.2 BS EN 1993-1-8

The shear resistance of bolts to BS EN 1993-1-8 is calculated from:

$$F_{v,Rd} = \frac{\alpha_v f_{ub} A}{\gamma_{M2}} \tag{28}$$

where:

$F_{v,Rd}$ is the shear resistance

α_v = 0.5 for grade 10.9 when the shear plane passes through the threaded region

α_v = 0.6 when the shear plane passes through the slotted region

A is the shear area, taken as A_s when the shear plane passes through the threaded region and A_{slot} when the shear plane passes through the unthreaded region

A_s is the tensile area of the threaded region

6.3 Design of bolts in combined tension and shear

6.3.1 BS 5950-1

When bolts are subject to combined tension and shear, the following equation from BS 5950-1 should be satisfied in addition to the separate equations for tension and shear:

$$\frac{F_s}{P_s} + \frac{F_t}{P_t} \le 1.4 \tag{29}$$

6.3.2 BS EN 1993-1-8

When bolts are subject to combined tension and shear, the following equation from BS EN 1993-1-8 should be satisfied in addition to the separate equation for tension:

$$\frac{F_{\mathrm{v,Ed}}}{F_{\mathrm{v,Rd}}} + \frac{F_{\mathrm{t,Ed}}}{1.4F_{\mathrm{t,Rd}}} \leq 1.0 \tag{30}$$

6.4 Design of bolts in bearing

6.4.1 BS 5950-1

The bearing resistance of bolts to BS 5950-1 is taken as the minimum of P_{bb}, the bearing resistance of the bolt, and P_{bs}, the bearing resistance of the plate. These are calculated from the following equations:

$$P_{\mathrm{bb}} = (d - c)t_{\mathrm{p}}\,p_{\mathrm{bb}} \tag{31}$$

where:

d is the nominal diameter of the bolt

t_{p} is the thickness of the connected part

p_{bb} is the bearing strength of the bolt, taken as 1300 N/mm²

$$P_{\mathrm{bs}} = k_{\mathrm{bs}}(d - c)t_{\mathrm{p}}\,p_{\mathrm{bs}} \leq 0.5k_{\mathrm{bs}}et_{\mathrm{p}}\,p_{\mathrm{bs}} \tag{32}$$

where:

k_{bs} = 1.0 for standard clearance holes

e is the end distance, measured from the edge of the sheet to the centre-line of the hole

p_{bs} is the bearing strength of the connected part, taken as 460 N/mm² for S275 steel and 550 N/mm² for S355 steel

Note that these expressions are based on limiting the deformation at working load to 1.5 mm, rather than the stress-carrying capability of the bolt

6.4.2 BS EN 1993-1-8

The bearing resistance of bolts to BS EN 1993-1-8 is calculated from:

$$F_{\mathrm{b,Rd}} = \frac{k_1\alpha_{\mathrm{b}}f_{\mathrm{u}}dt}{\gamma_{\mathrm{M2}}} \tag{33}$$

where:

$F_{\mathrm{b,Rd}}$ is the bearing resistance

f_{u} is the ultimate tensile strength of the plate material, taken as 430 N/mm² for S275 steel and 510 N/mm² for S355 steel

d is the nominal diameter of the bolt

t is the thickness of the plate

α_{b} and k_1 are coefficients calculated from the following equations:

$$\alpha_{\mathrm{b}} = \min\left\{\alpha_{\mathrm{d}};\frac{f_{\mathrm{ub}}}{f_{\mathrm{u}}};1.0\right\} \tag{34}$$

$$\alpha_{\mathrm{d}} = \frac{e_1}{3d_0} \tag{35}$$

$$k_1 = 2.8\frac{e_2}{d_0} - 1.7 \leq 2.5 \tag{36}$$

where:

e_1 is the edge distance in the direction of the applied load, measured from the edge of the sheet to the centre-line of the hole

e_2 is the edge distance perpendicular to the direction of the applied load, measured from the edge of the sheet to the centre-line of the hole

d_0 is the diameter of the hole (taken as 11 mm for M10 bolts, 22 mm for M20 bolts and 26 mm for M24 bolts)

6.5 Bolt dimensions

There are currently 5 sizes of blind bolts, and the relevant dimensions of each bolt are presented in Table 6.1 for use with the above formulae.

Table 6.1 *Blind bolt dimensions and areas*

Bolt type	d (mm)	c (mm)	p (mm)	d_0 (mm)	A_{pin} (mm²)	A_{slot} (mm²)	A_s (mm²)
M8	8.0	3.5	1.6	9.0	16.1	23.2	36.6
M10	10.0	4.0	1.6	11.0	30.1	39.6	58.0
M12	12.0	5.0	1.6	13.0	43.7	54.9	84.3
M16	16.0	6.0	1.4	18.0	93.4	107.4	156.7
M20	20.0	8.0	2.0	22.0	134.6	158.5	244.8
M24	24.0	10.0	2.0	26.0	191.6	219.5	352.5

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7 CONCLUSIONS

A series of tests were undertaken on M10, M20 and M24 blind bolts in grade 10.9 material to establish the tension, shear and bearing capabilities of the materials. Through a statistical analysis of the test results and a comparison with the current codes of practice, a series of design rules have been established, which are presented in Section 6. The design values for tension and shear for design to BS 5950-1 are summarised in Table 7.1. The bearing resistances are not quoted as they depend on the dimensions of the supporting material, but design equations are presented in Section 6.4.

Table 7.1 *Summary of design tension and shear capacities to BS 5950-1*

Bolt type	Tension capacity (kN)	Shear capacity of slotted region (kN)
M8*	6.91	9.27
M10	12.94	15.85
M12*	18.81	21.95
M16*	40.16	42.94
M20	57.88	63.41
M24	82.38	87.81

* Tests were not performed on these bolt types

The characteristic values for tension and shear for design to BS EN 1993-1-8 are summarised in Table 7.2. These should be converted to design values by using the partial safety factor γ_{M2}, which is defined as 1.25 in the UK National Annex.

Table 7.2 *Summary of characteristic tension and shear capacities to BS EN 1993-1-8*

Bolt type	$F_{t,Rk}$ (kN)	$F_{v,Rk}$ (kN)
M8*	8.63	13.91
M10	16.17	23.78
M12*	23.49	32.93
M16*	50.16	64.42
M20	72.29	95.12
M24	102.89	131.72

* Tests were not performed on these bolt types

The tests also showed that the current rules for combined tension and shear in both the British Standards and the Eurocodes can be used for the design of blind bolts.

Appendix A presents a suggested layout for the technical data of blind bolts.

8 REFERENCES

1. BS 5950-1: 2000
Structural use of steelwork in building. Code of practice for design – Rolled and welded sections.
British Standards Institution, 2000
2. BS 4160: 2001
ISO metric black hexagon bolts, screws and nuts – specification.
British Standards Institution, 2001
3. BS EN ISO 898-1: 2009
Mechanical properties of fasteners made of carbon steel and alloy steel. Bolts, screws and studs with specified property classes – Coarse thread and fine pitch thread.
British Standards Institution, 2009
4. BS EN 1993-1-8: 2005
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British Standards Institution, 2005
5. BS EN 1990: 2002
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6. SCI & BCSA
Joints in Steel Construction: Simple Connections, P212
The Steel Construction Institute, Ascot 2002

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APPENDIX A TECHNICAL INFORMATION

A.1 Design to BS 5950-1

Diameter	Tension capacity	Shear capacity over thread	Shear capacity over slot	Bearing capacity in 10 mm plate	
				S275	S355
	P_t (kN)	$P_{s,thread}$ (kN)	$P_{s,slot}$ (kN)	P_b (kN)	P_b (kN)
M8	6.9	14.6	9.3	20.7	24.8
M10	12.9	23.2	15.9	27.6	33.0
M12	18.8	33.7	22.0	32.2	38.5
M16	40.2	62.7	42.9	46.0	55.0
M20	57.9	97.9	63.4	55.2	66.0
M24	82.4	141.0	87.8	64.4	77.0

These values are suitable for design to BS 5950-1 and can be used without further reduction for comparison to factored loads. Bearing resistances for different plate thicknesses can be calculated by scaling the values in proportion to the thickness, but should only be used where the distance from the centre line of the hole to the end of the plate is greater than $1.25d$. Combined tension and shear should satisfy the following equation:

$$\frac{F_s}{P_s} + \frac{F_t}{P_t} \le 1.4$$

A.2 Design to BS EN 1993-1-8

Diameter	Tension resistance	Shear resistance over thread	Shear resistance over slot
	$F_{t,Rd}$ (kN)	$F_{v,Rd,thread}$ (kN)	$F_{v,Rd,slot}$ (kN)
M8	6.9	14.6	11.1
M10	12.9	23.2	19.0
M12	18.8	33.7	26.3
M16	40.1	62.7	51.5
M20	57.8	97.9	76.1
M24	82.3	141.0	105.4

These are design values for use with BS EN 1993-1-8, and a partial safety factor of $\gamma_{M2} = 1.25$ has already been applied. Bearing resistances should be calculated from BS EN 1993-1-8, Table 3.4, taking d as the nominal diameter of the bolt. Combined tension and shear should satisfy the following equation:

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

A.3 General note

The above tension resistances make no allowance for the deformation or yield of the connected parts. An appropriate design model for connections in hollow sections can be found in Joints in Steel Construction: Simple Connections[6].

APPENDIX B TEST RESULTS

B.1 Coupon tests

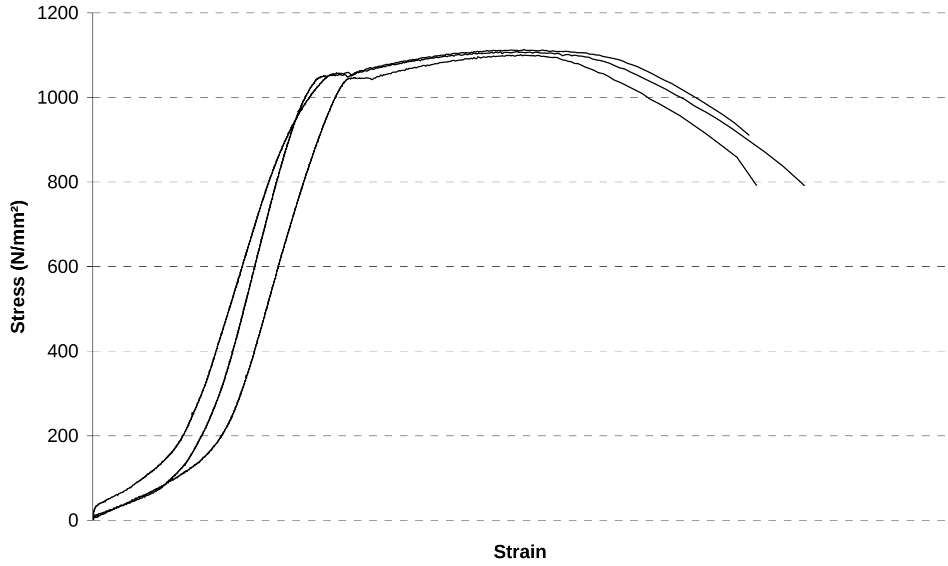

Figure B.1 *Stress-strain relationship for M10 material*

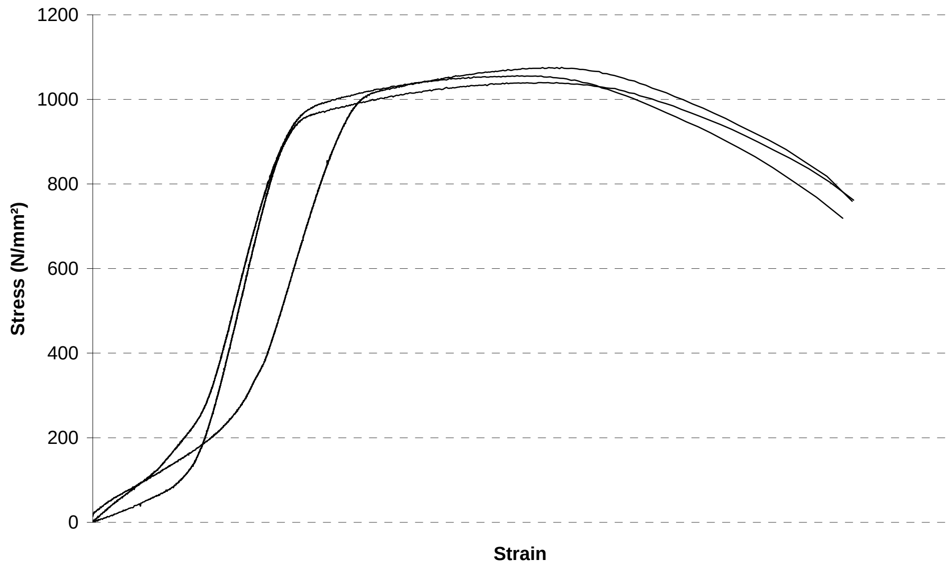

Figure B.2 *Stress-strain relationship for M20 material*

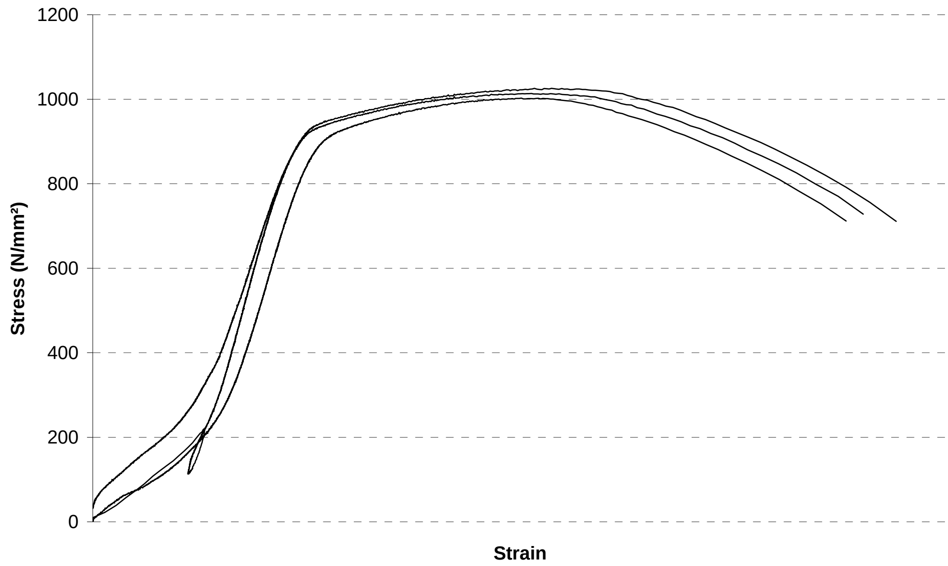

Figure B.3 *Stress-strain relationship for M24 material*

B.2 Tension tests

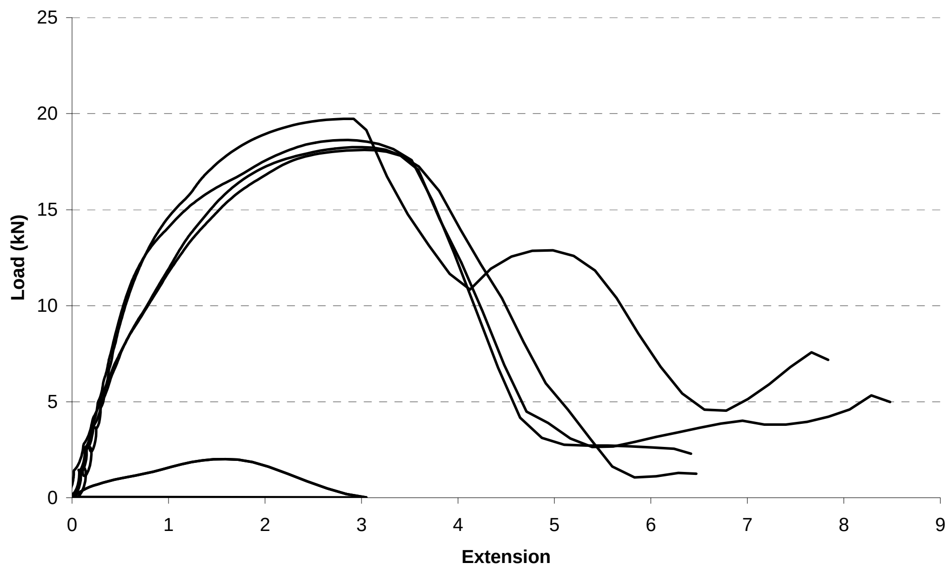

Figure B.4 *Load-deformation plot for M10 tension tests*

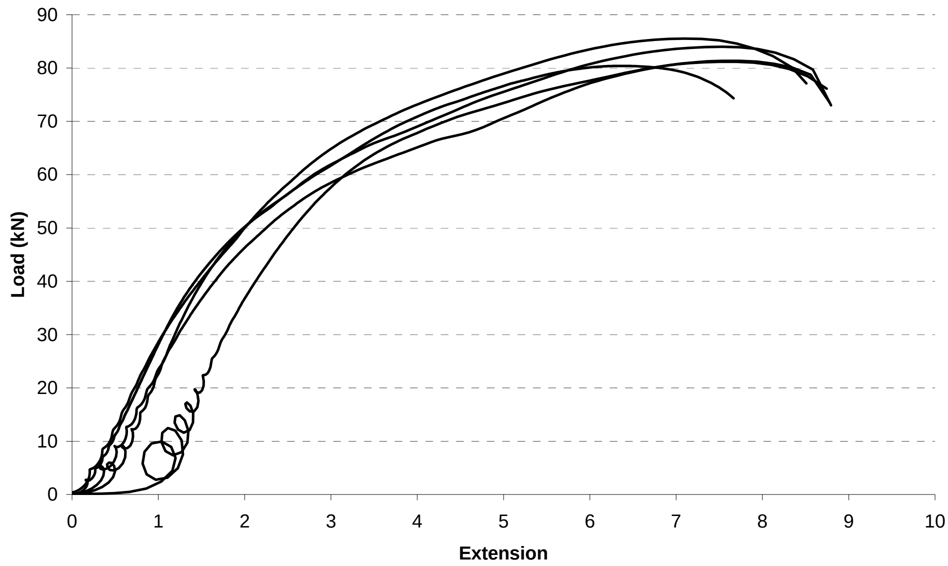

Figure B.5 *Load-deformation plot for M20 tension tests*

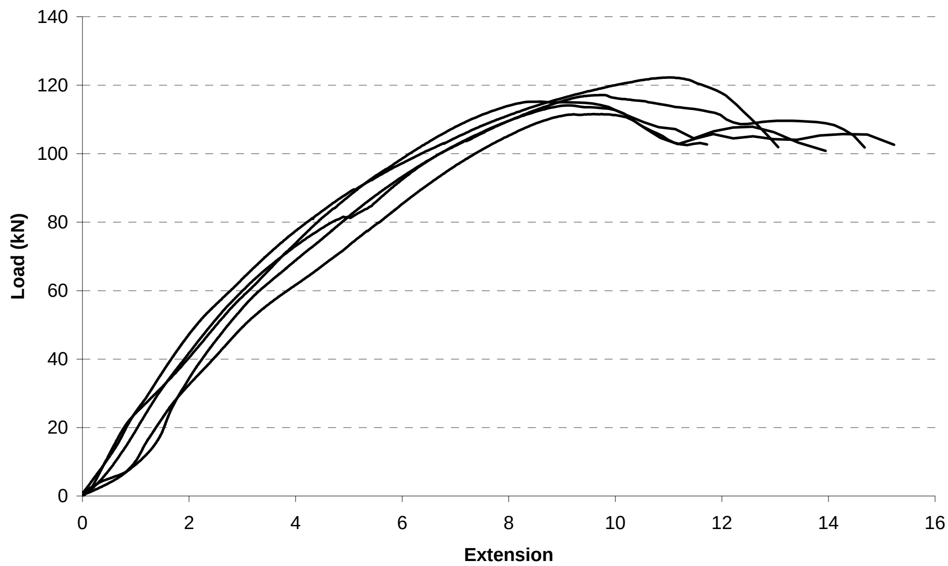

Figure B.6 *Load-deformation plot for M24 tension tests*

B.3 Shear tests

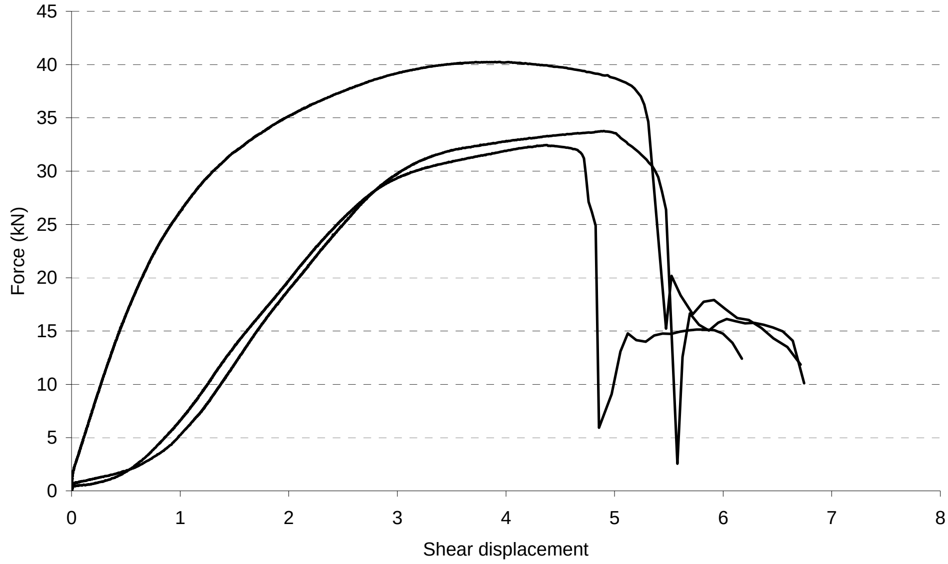

Figure B.7 *Load-deformation plot for M10 shear tests (shear plane through slotted region)*

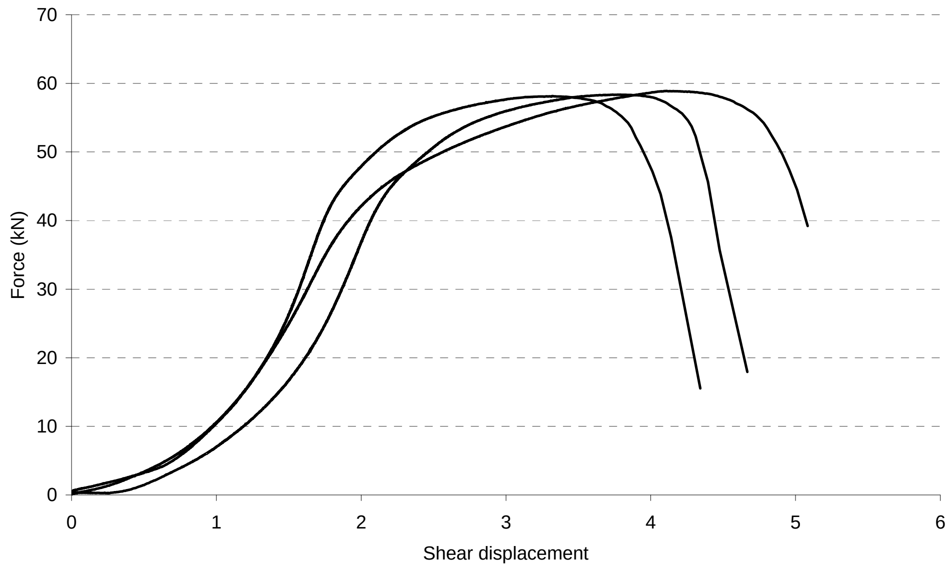

Figure B.8 *Load-deformation plot for M10 shear tests (shear plane through threaded region)*

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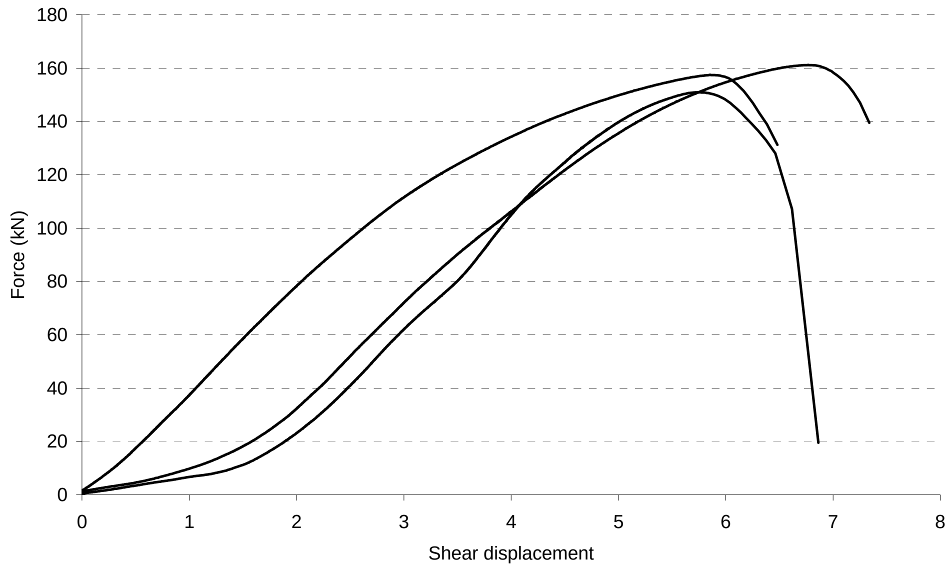

Figure B.9 *Load-deformation plot for M20 shear tests (shear plane through slotted region)*

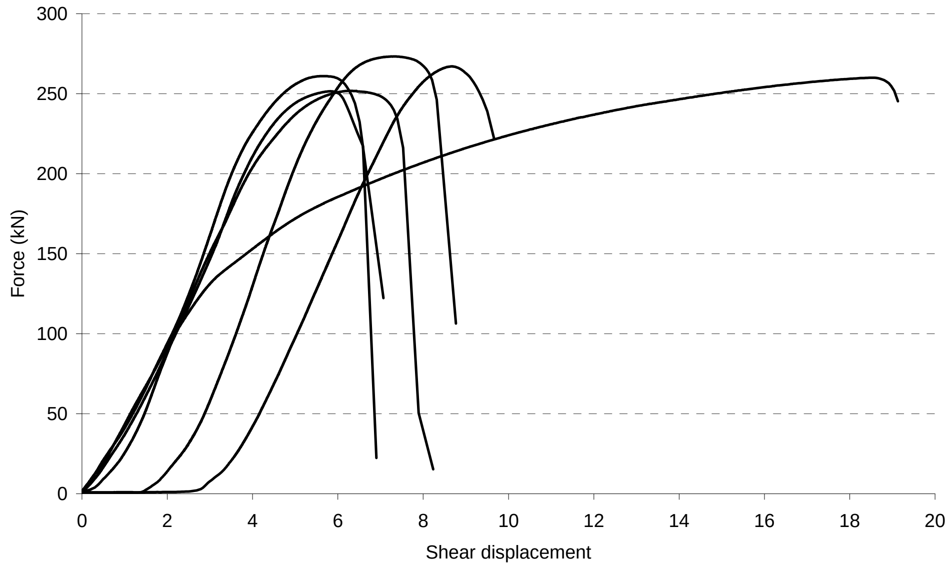

Figure B.10 *Load-deformation plot for M24 shear tests (shear plane through slotted region)*

B.4 Combined tension and shear tests

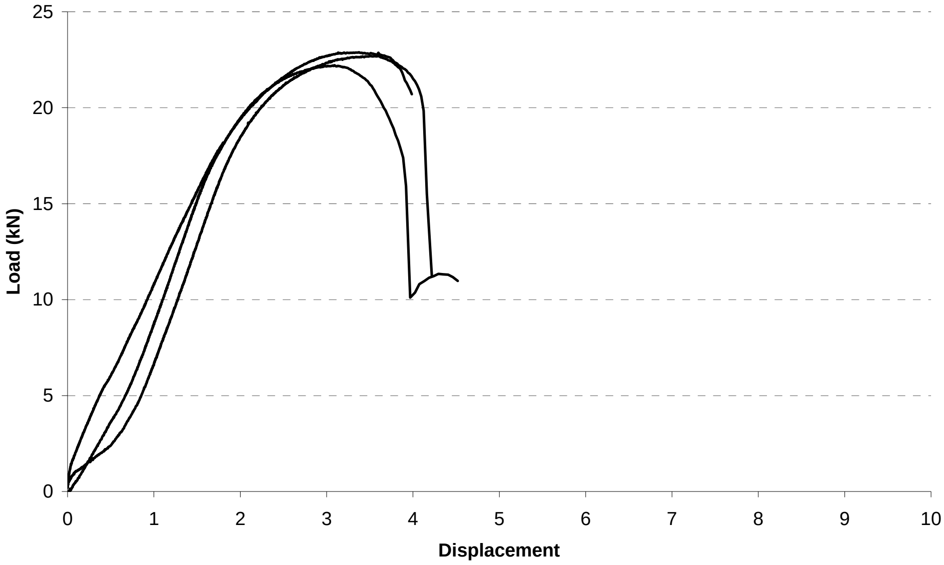

Figure B.11 *Load-deformation plot for M10 bolts at 30º*

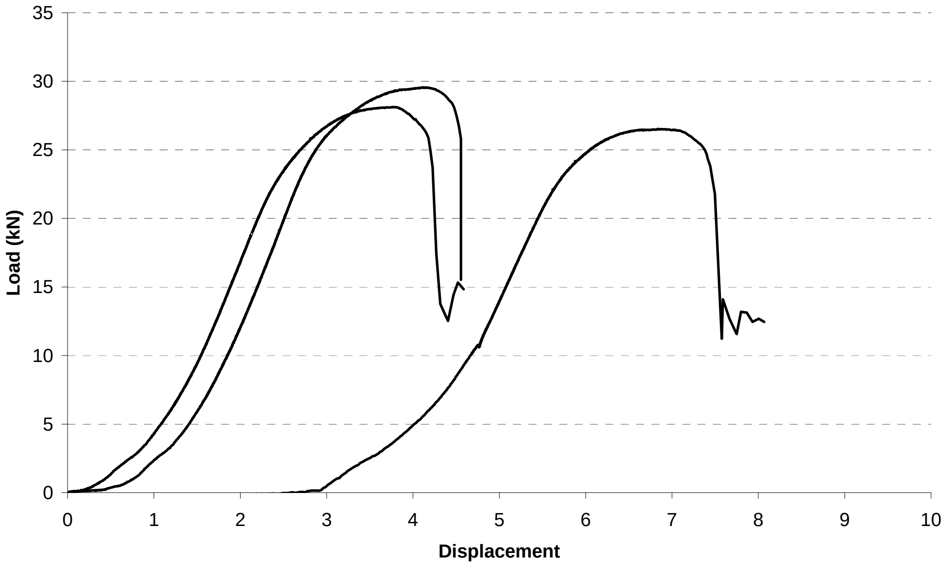

Figure B.12 *Load-deformation plot for M10 bolts at 45º*

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Figure B.13 *Load-deformation plot for M10 bolts at 60º*

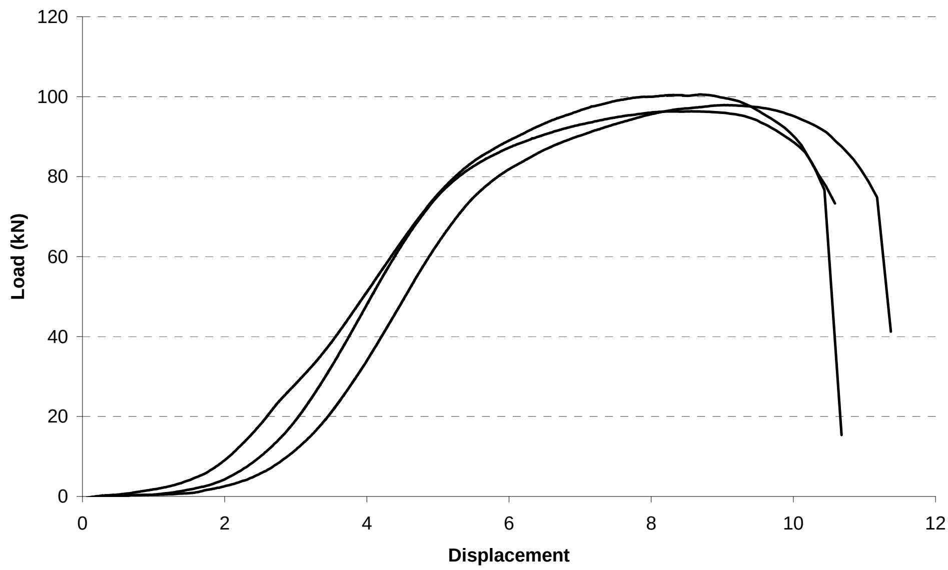

Figure B.14 *Load-deformation plot for M20 bolts at 30º*

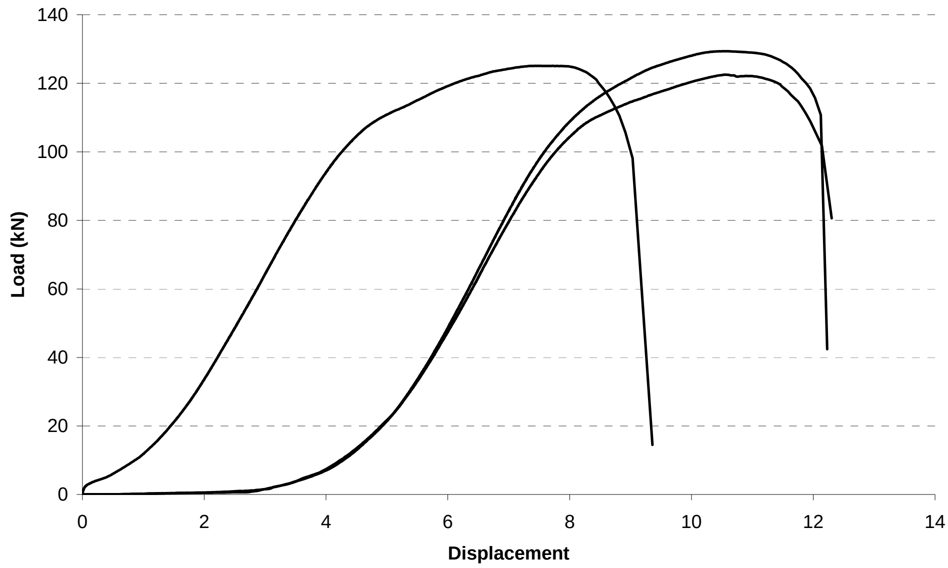

Figure B.15 *Load-deformation plot for M20 bolts at 45º*

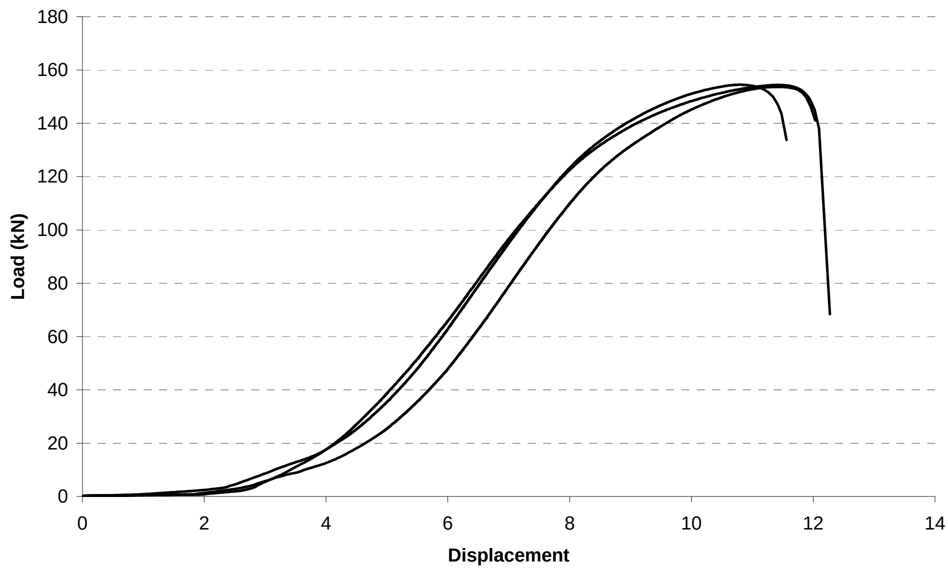

Figure B.16 *Load-deformation plot for M20 bolts at 60º*

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B.5 Bearing tests

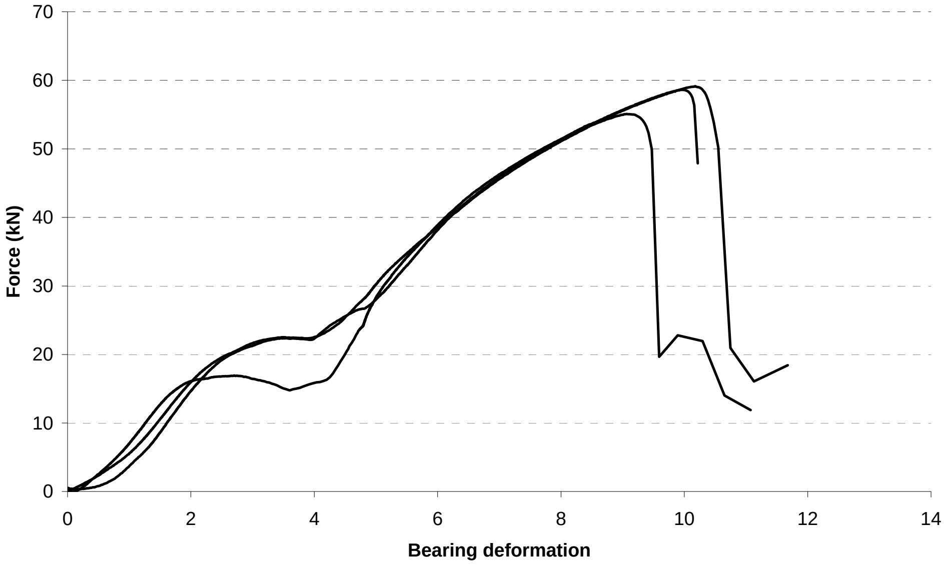

Figure B.17 *Load-deformation plot for bearing test on M10 bolts in 6 mm, S275 plate*

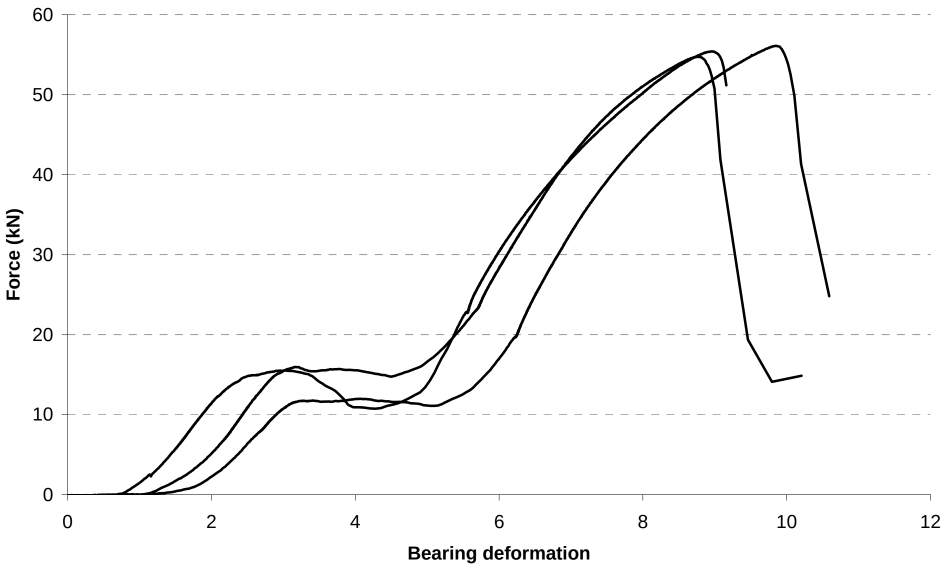

Figure B.18 *Load-deformation plot for bearing test on M10 bolts in 6 mm, S355 plate*

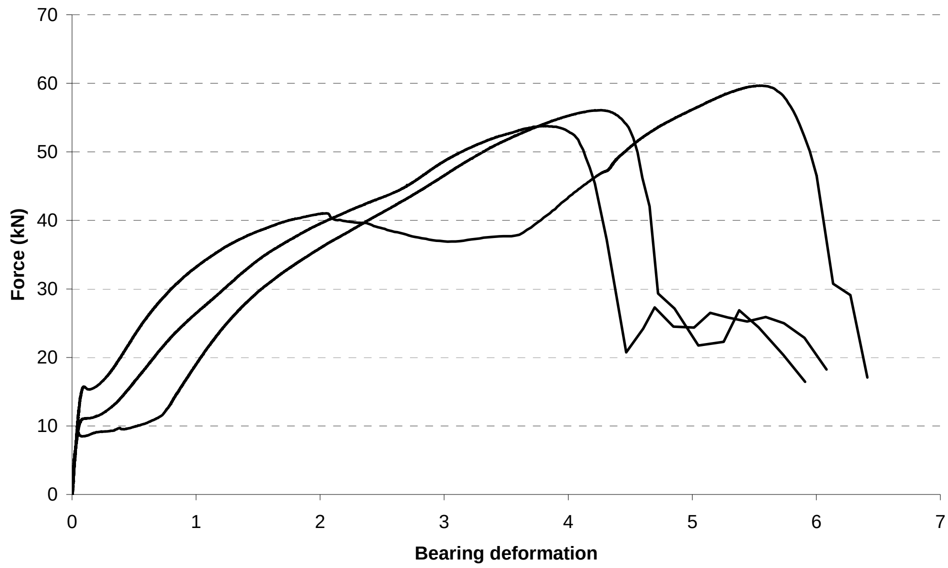

Figure B.19 *Load-deformation plot for bearing test on M10 bolts in 10 mm, S275 plate*

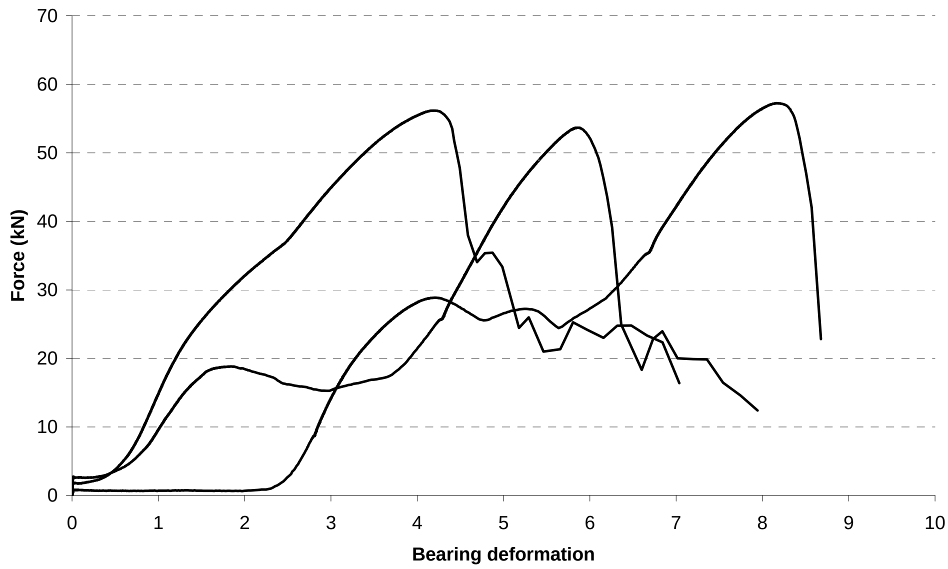

Figure B.20 *Load-deformation plot for bearing test on M10 bolts in 10 mm, S355 plate*

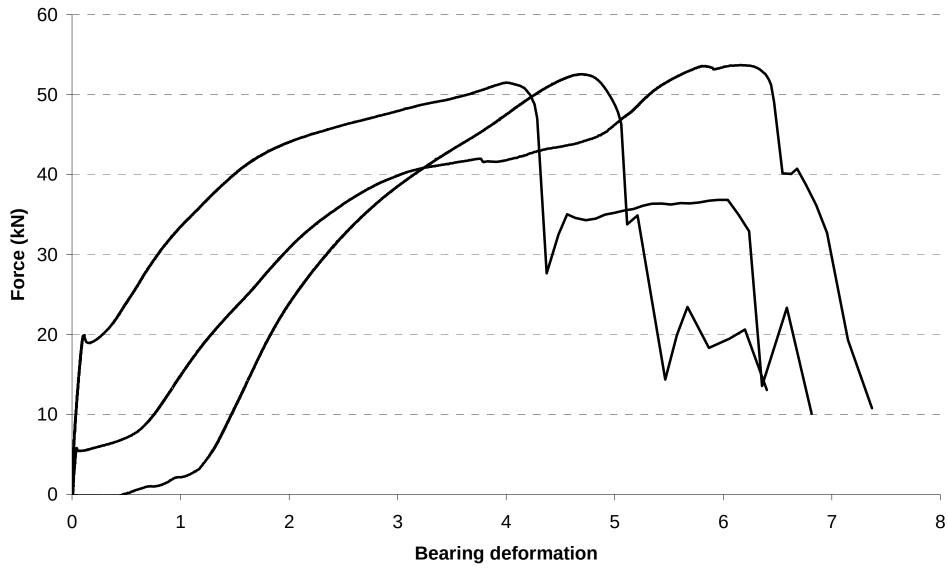

Figure B.21 *Load-deformation plot for bearing test on M10 bolts in 15 mm, S275 plate*

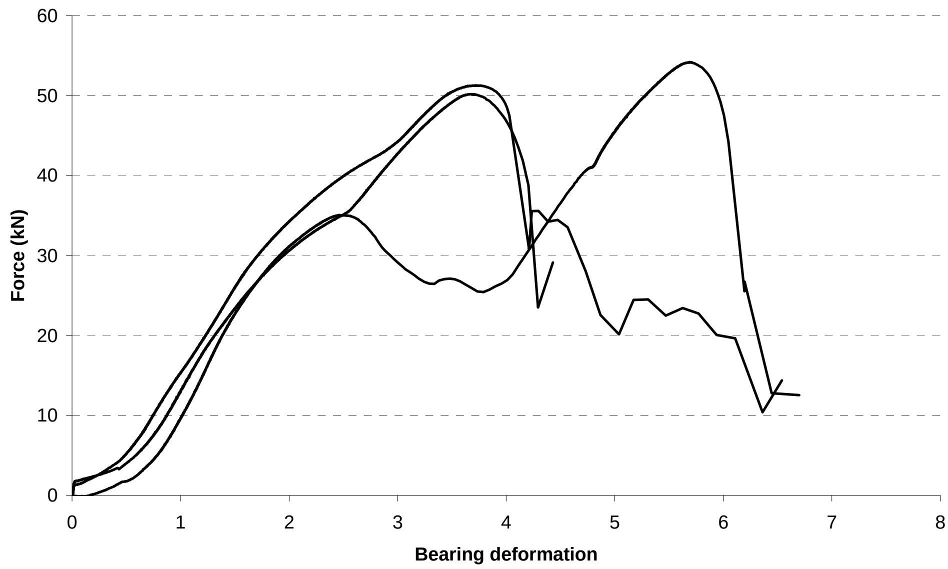

Figure B.22 *Load-deformation plot for bearing test on M10 bolts in 15 mm, S355 plate*

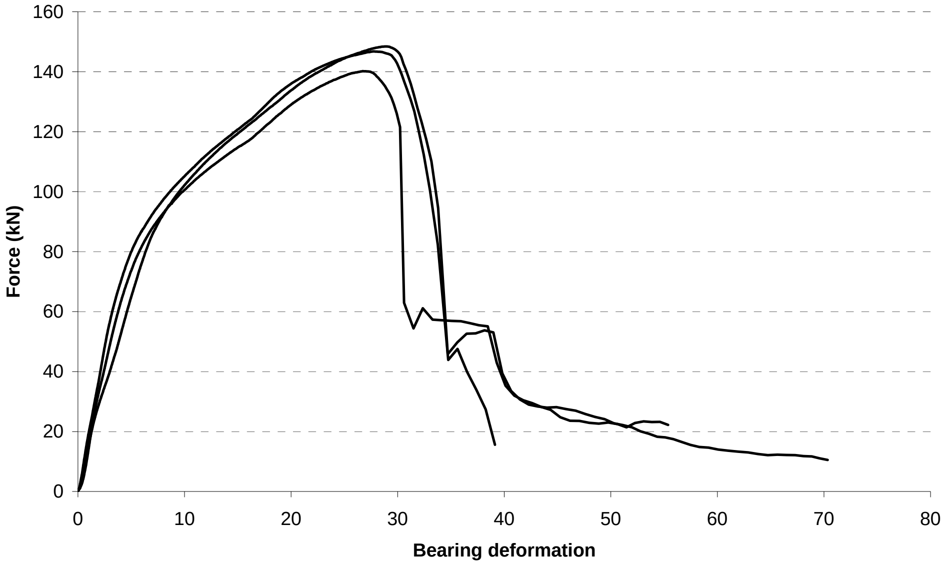

Figure B.23 *Load-deformation plot for bearing test on M20 bolts in 6 mm, S275 plate*

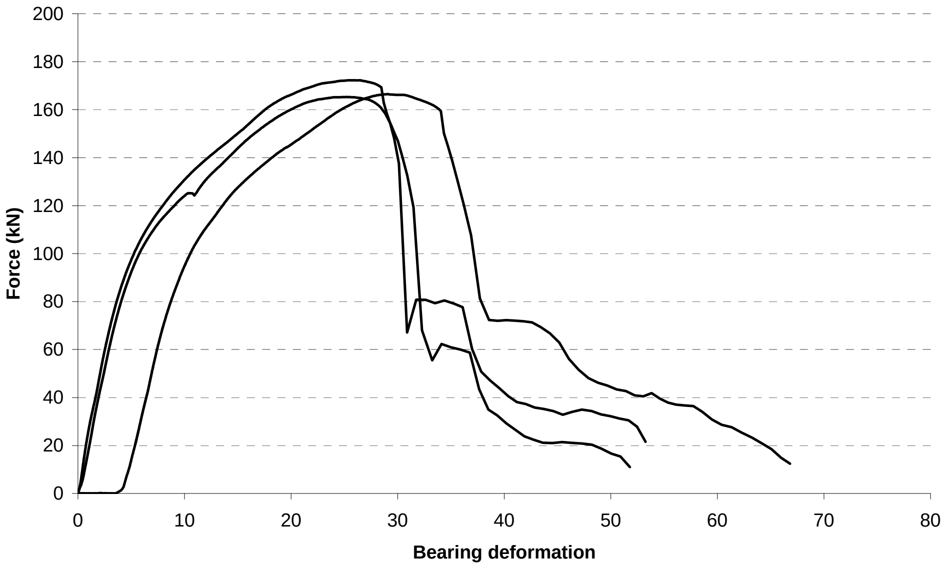

Figure B.24 *Load-deformation plot for bearing test on M20 bolts in 6 mm, S355 plate*

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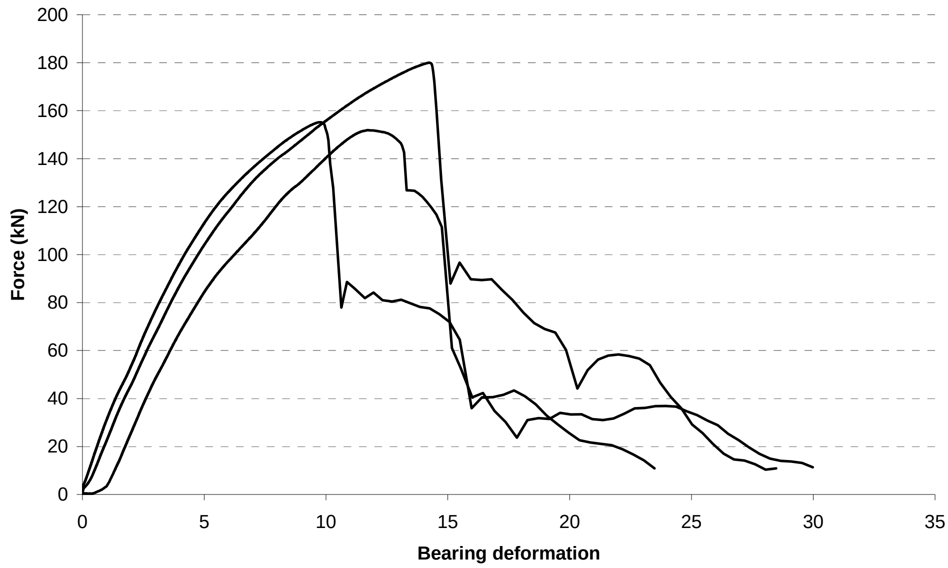

Figure B.25 *Load-deformation plot for bearing test on M20 bolts in 10 mm, S275 plate*

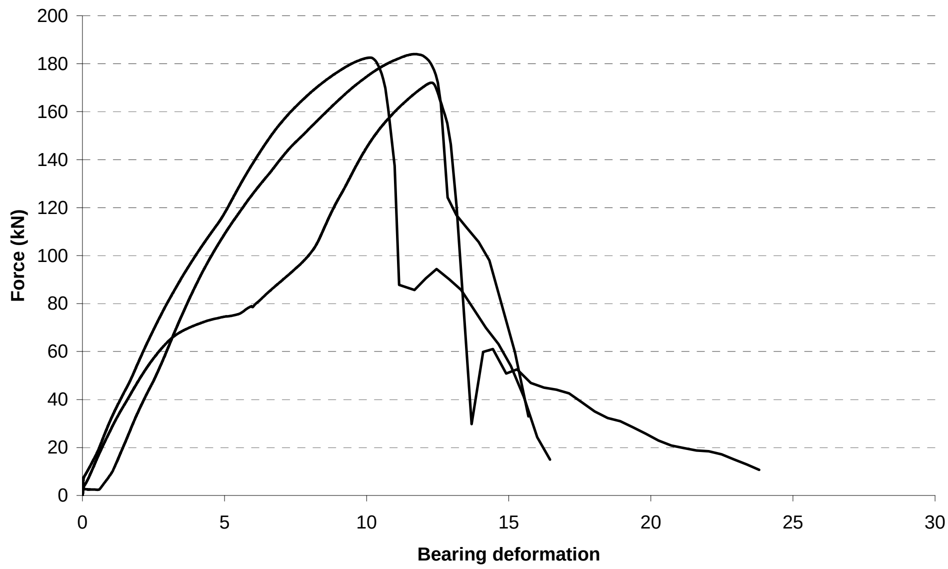

Figure B.26 *Load-deformation plot for bearing test on M20 bolts in 10 mm, S355 plate*

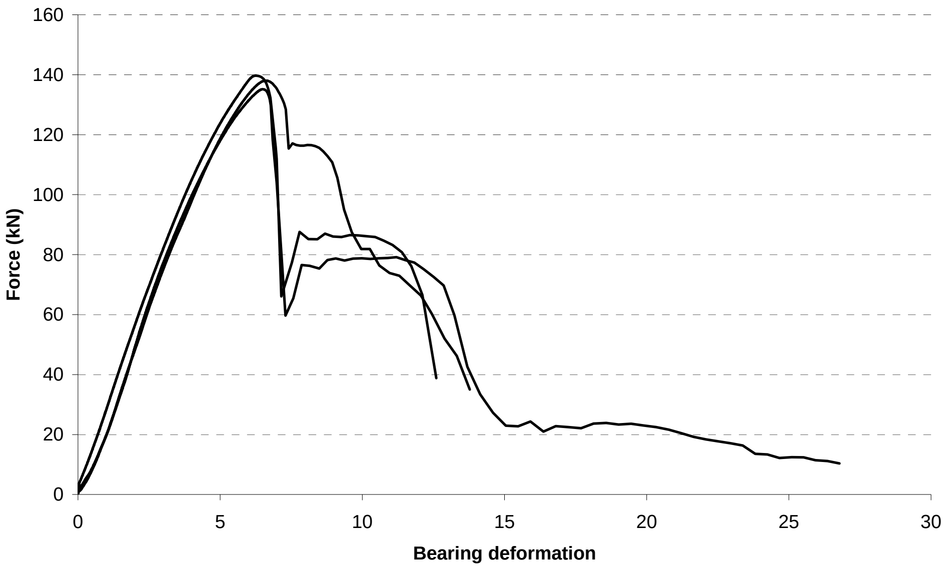

Figure B.27 *Load-deformation plot for bearing test on M20 bolts in 15 mm, S275 plate*

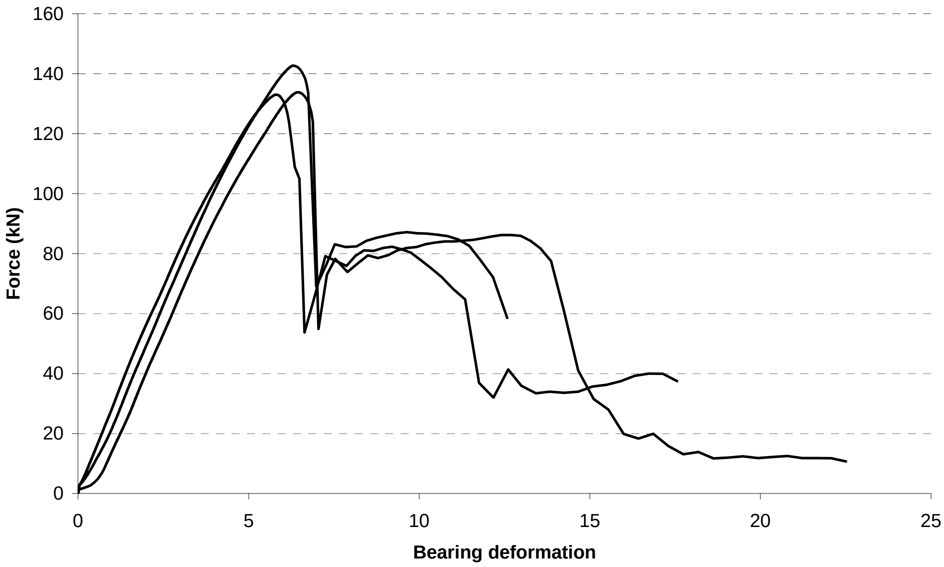

Figure B.28 *Load-deformation plot for bearing test on M20 bolts in 15 mm, S355 plate*

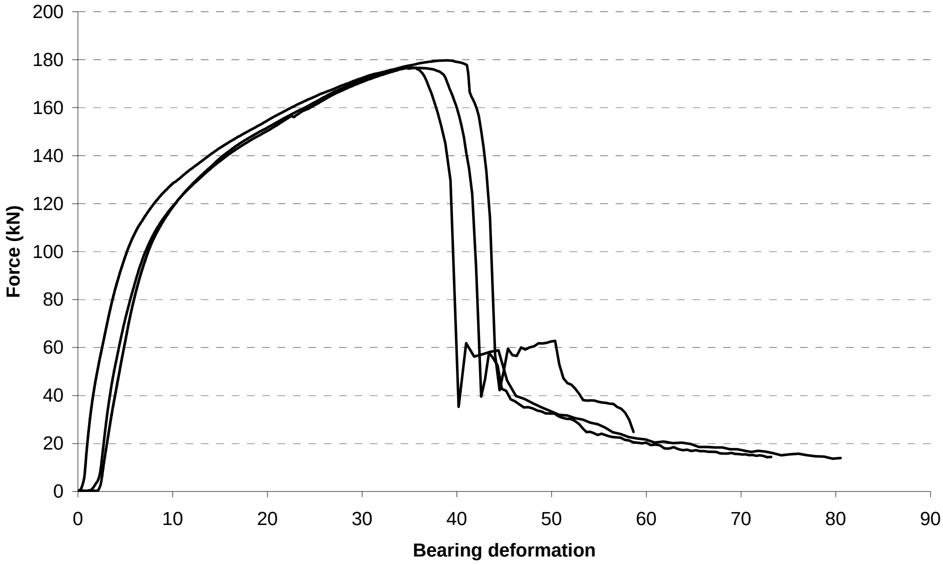

Figure B.29 *Load-deformation plot for bearing test on M24 bolts in 6 mm, S275 plate*

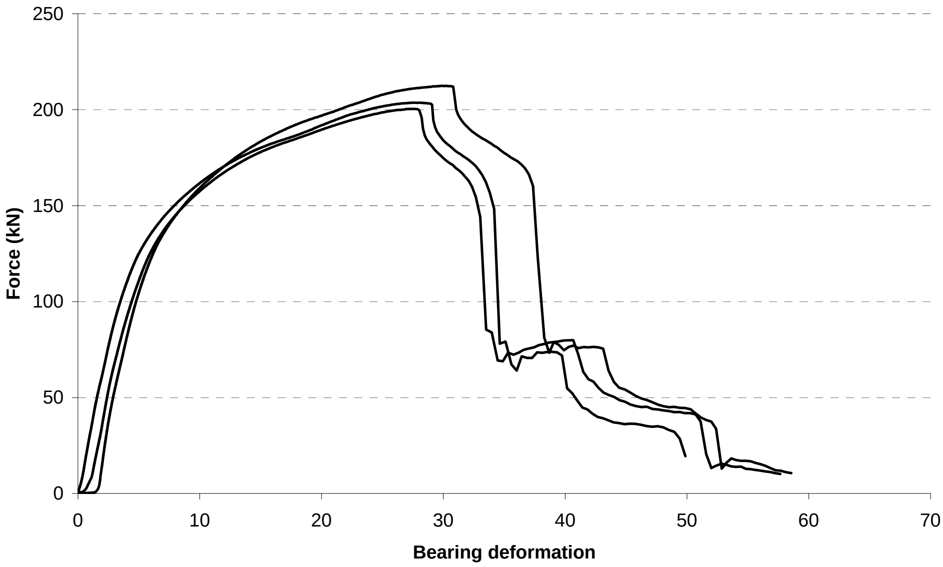

Figure B.30 *Load-deformation plot for bearing test on M24 bolts in 6 mm, S355 plate*

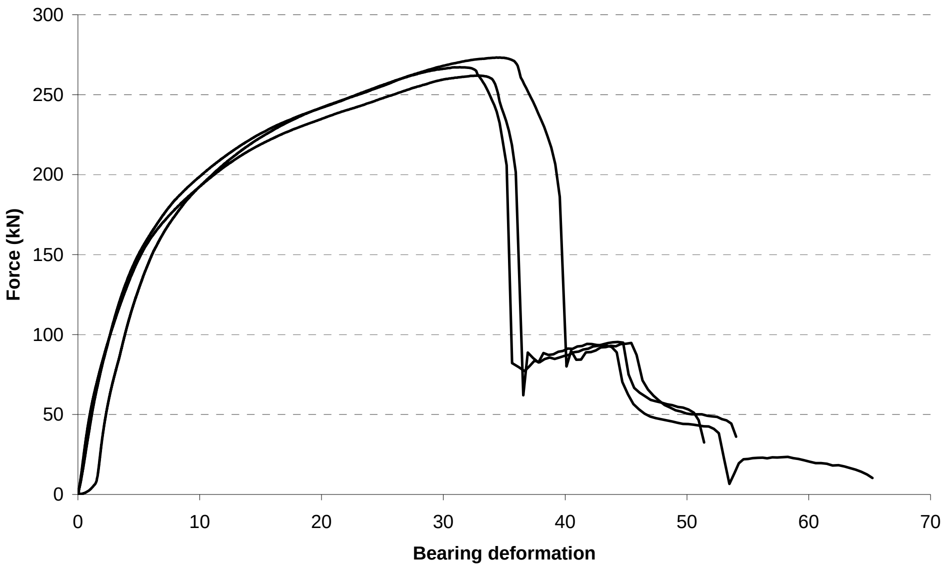

Figure B.31 *Load-deformation plot for bearing test on M24 bolts in 10 mm, S275 plate*

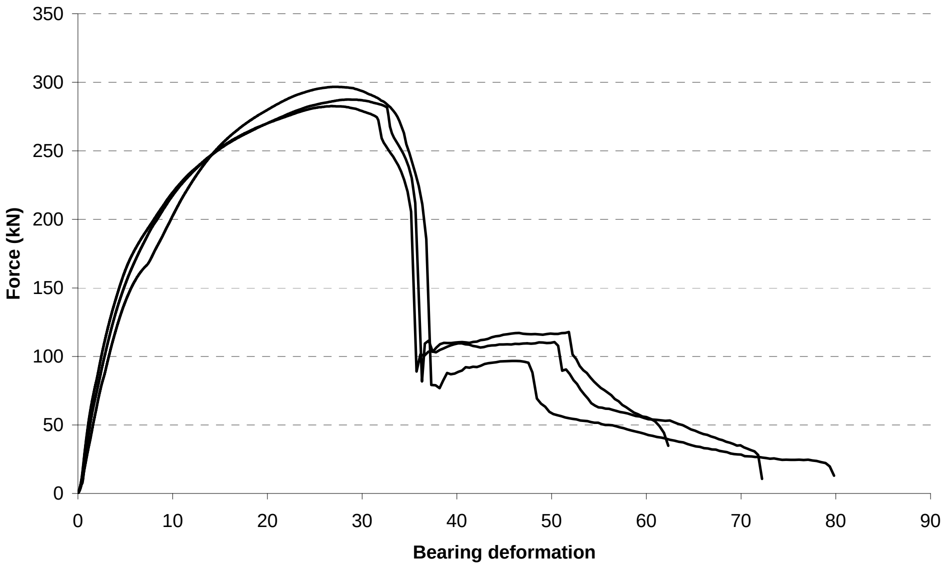

Figure B.32 *Load-deformation plot for bearing test on M24 bolts in 10 mm, S355 plate*

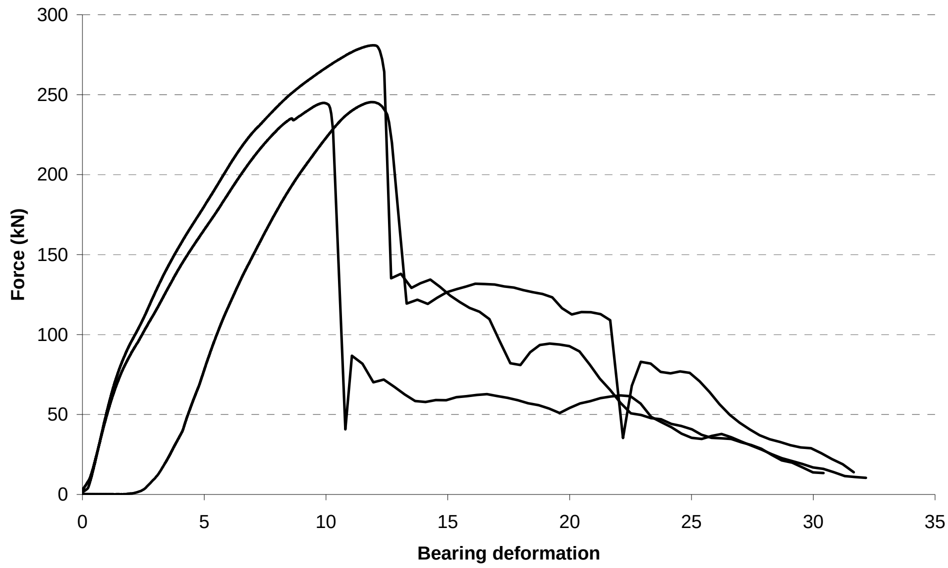

Figure B.33 *Load-deformation plot for bearing test on M24 bolts in 15 mm, S275 plate*

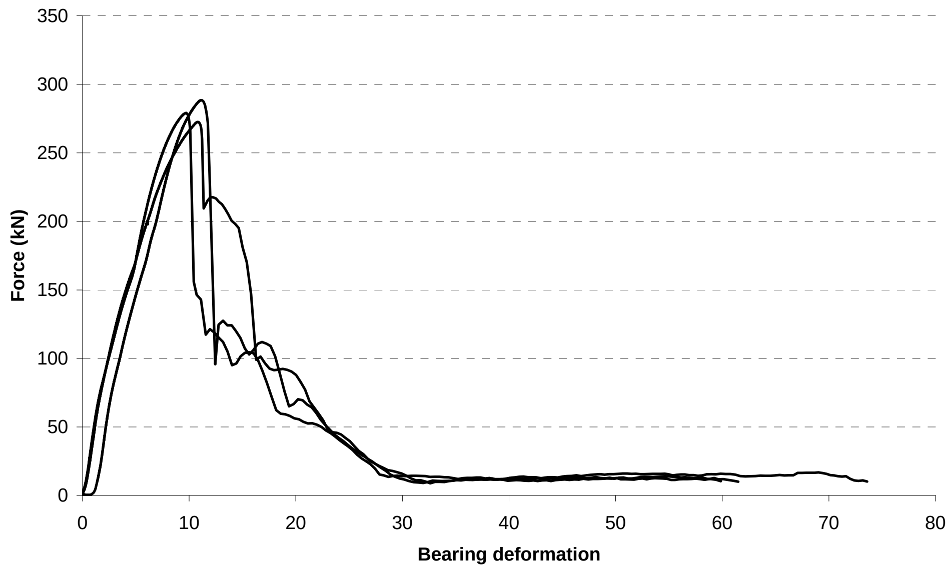

Figure B.34 *Load-deformation plot for bearing test on M24 bolts in 15 mm, S355 plate*