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Design Resistance of Molabolt Peg Anchors

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

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

For information on courses, telephone direct: +44 (0) 1344 636500 or Email: education@steel-sci.com

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EXECUTIVE SUMMARY

A programme of physical testing has been completed to determine the design resistances of Molabolt peg anchors manufactured from carbon steel and manufactured from stainless steel.

The design resistances have been calculated following the guidance in BS EN 1990[1], Annex D.

In shear, SCI recommend that the design resistances be taken as those for ordinary bolts (Class 8.8 in carbon steel and A2-700 in stainless steel).

In tension, the following design resistances may be taken, which may be compared directly with the ultimate loads on the fixings.

Carbon Steel

Bolt	Design resistance (kN)
M24	110.2
M20	73.8
M16	37.9
M12	46.8
M10	24.4
M8	7.3

Stainless Steel

Bolt	Design resistance (kN)
M12	30.9
M10	19.5
M8	10.3

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

In connections made to thin plate, such as a web or hollow section wall, although the tension resistance of the fixing itself is reduced, the bending resistance or deformation of the plate is likely to govern the resistance of the connection. The resistances given in this report are based on a plate thickness at least 0.5*d* (*d* is the bolt diameter) in S275 plate.

Contents

1 INTRODUCTION

Advance Bolting Solutions wish to present reliable design resistances for Molabolts, for design in accordance with BS 5950 and the Eurocodes. A series of physical tests have been completed and the design resistances determined by SCI, following the procedures in BS EN 1990[1].

1.1 Molabolt peg anchors

A peg anchor is illustrated in Figure 1.1. Peg anchors are generally used as 'blind' fixings to hollow sections, or similar situations, where access is only possible to one end of the fixing.

The product consists of a threaded shank with a central longitudinal channel. A central peg is inserted in this channel, which forces quadrants cut at the end of the anchor to splay out. A nut can then be tightened and the connection completed.

Figure 1.1 Molabolt peg anchor

The Molabolt is available in the following diameters:

In carbon steel: M8, M10, M12, M16, M20, M22 and M24

In stainless steel: M8, M10 and M12.

The bolt material is Class 8.8 and the central pin Class 10.9. In stainless steel, A2-700 is used.

1.2 Design data to be determined

The design resistances to be determined were:

- Shear resistance
- Tension resistance
- Bearing resistance
- Combined shear and tension resistance

1.3 Development of test programme

The SCI proposed that the shear and tension resistances be determined from physical test. Although the shear plane passes through two separate components, of different grades, it was not anticipated that the shear resistance would be any less than for ordinary bolts.

In tension, the performance of a Molabolt was anticipated to differ from an ordinary bolt. More deformation was expected as the splayed end of the shank engages with the supporting plate and deforms under load. Deformation of the edge of the hole was also anticipated. Before testing, it was unclear if the splayed end of the Molabolt would perform as well as an ordinary bolt.

Intuitively, it was concluded that the thickness and grade of the supporting plate would have an impact on the resistance in tension. If the plate was very thin, it was assumed that the plate would deform before the fitting reached its full resistance. In reality, if the supporting plate was thin (as is typical for a connection to a hollow section) the resistance of the plate itself in bending would limit the resistance of the connection. Connections to hollow sections or other thin plates are limited either by deformation or by the resistance of the plate itself (typically determined by considering some form of yield line pattern). Nevertheless, it was felt prudent to undertake limited investigations of the effect of thin plate.

Bearing resistance was not considered in the tests, although general observations can be made from the shear test results. No tests were considered necessary since there was no expectation that the performance of the fixing would differ in any significant way from that of an ordinary bolt. The outside diameter is identical, and the circular central pin fills the void in the shank.

Combined shear and tension tests were not undertaken, as once the shear and tension tests had been used to establish resistances, it was considered that the interaction formulae in the design Standards would remain appropriate.

The test programme was arranged to cover large, intermediate and small diameter fixings, anticipating that design resistances could be interpolated for the remaining diameters.

Five samples were tested in each of the shear and tension tests. This population reflects the impact of Tables D1 and D2 of BS EN 1990, which effectively define the number of standard deviations below the mean which should be taken when determining design values. Although increasing the number of samples would have reduced the reduction from the mean, the beneficial effect becomes less significant

1.3.1 Modification of the test programme

As the testing proceeded, it became clear that in tension, there was a clear difference in behaviour between the larger bolts (which failed by fracture) and smaller diameters, which failed by a pull-through mode. This difference in behaviour implied that results could not be interpolated, and so additional tests were carried out, so that each bolt diameter was tested.

2 TEST PROGRAMME

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

All testing was completed in a test machine which could work in both tension and compression.

Tension tests were undertaken in a test rig shown in Figure 2.1. The test arrangement is effectively two U-shaped fabrications, with the test bolt connecting the two parts. The test machine acts in compression, which results in tension in the bolt.

Figure 2.1 Tension test arrangement

On the underside of the connection, sacrificial plates are used, drilled to the appropriate diameter for the bolt being tested. The test arrangement can therefore be used repeatedly.

Figure 2.2 shows a completed tension test. The splayed ands of the Molabolt have been drawn into the sacrificial plate. The M20 bolt failed by fracture, as can be seen in the figure.

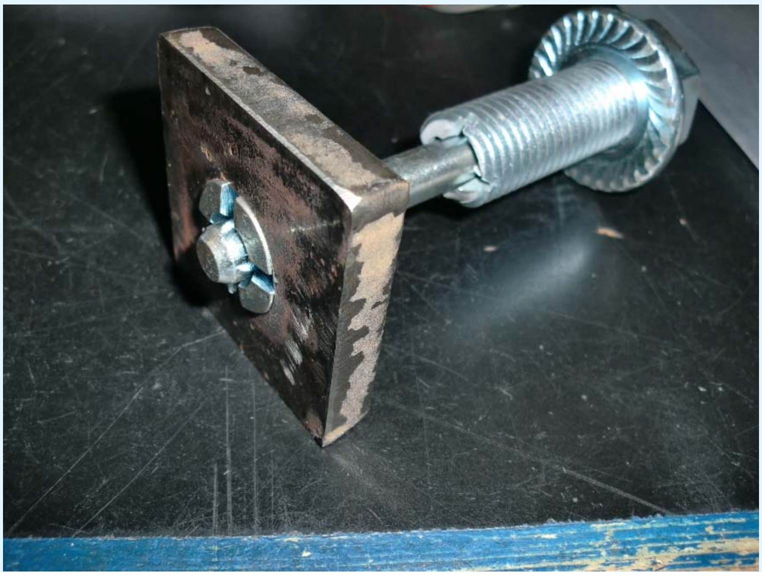

Figure 2.2 Completed tension test; fracture

Figure 2.3 shows the results of testing a smaller diameter assembly. In this case the bolt has not fractured but substantial deformation has allowed the splayed end to be pulled through the hole.

Figure 2.3 Complete tension test; pull-through

Shear tests were conducted with simple lapped plates, using the test machine in tension.

Samples were taken from the bolt material and pin material, supplied by Advanced Bolting Solutions as representative of the material used in all bolts. These were tested in tension in accordance with BS EN ISO 6892-1 to determine the material properties. 24 samples were tested in total.

Test results were provided by Intertek NDT both in report form and as CSV files. These CSV files were used to present the figures in Appendix A.

3 TEST RESULTS

Test results are summarised in this section. The results have a unique test identification number, which may be used to cross reference these summary results to the detailed load-extension figures presented in Appendix A.

3.1 Tension tests – carbon steel

Table 3.1 Carbon steel – tension tests, M8

Bolt	Test ID	Resistance (kN)
M8	54	13.36
	55	19.00
	56	20.14
	57	15.91
	58	14.39

Table 3.2 Carbon steel – tension tests, M10

Bolt	Test ID	Resistance (kN)
M10	59	27.18
	60	26.38
	61	26.31
	62	28.35
	63	26.90

Table 3.3 Carbon steel – tension tests, M12

Bolt	Test ID	Resistance (kN)
M12	6	51.88
	7	51.55
	8	54.65
	9	53.01
	10	50.08

Table 3.4 Carbon steel – tension tests, M16

Bolt	Test ID	Resistance (kN)
M16	64	44.91
	65	52.21
	66	49.58
	67	56.04
	68	50.70

Table 3.5 Carbon steel – tension tests, M20

Bolt	Test ID	Resistance (kN)
M20	1	120.34
	2	111.51
	3	122.15
	4	123.97
	5	118.43

3.2 Tension tests – stainless steel

Table 3.6 Stainless steel – tension tests, M8

Bolt	Test ID	Resistance (kN)
M8	16	11.07
	17	11.14
	18	11.73
	19	11.39
	20	11.84

Table 3.7 Stainless steel – tension tests, M12

Bolt	Test ID	Resistance (kN)
M12	21	33.41
	22	33.52
	23	32.38
	24	32.15
	25	32.71

3.3 Pull-out tests

Table 3.8 Pull-out tests

Bolt	Test ID	Plate Thickness (mm)	Resistance (kN)
M12	26	6	53.07
M12	27	6	50.71
M20	28	6	101.36
M20	29	6	98.00
M12	52	10	54.17
M12	53	10	49.28
M20	50	10	116.53
M20	52	10	125.37

3.4 Shear tests – carbon steel

Table 3.9 Carbon steel – shear tests, M8

Bolt	Test ID	Resistance (kN)
M8	35	26.12
	36	22.38
	37	26.69
	38	22.29
	39	26.72

Table 3.10 Carbon steel – shear tests, M12

Bolt	Test ID	Resistance (kN)
M12	30	52.24
	31	53.46
	32	52.97
	33	54.03
	34	51.55

Table 3.11 Carbon steel – shear tests, M20

Bolt	Test ID	Resistance (kN)
M20	11	146.61
	12	153.31
	13	148.99
	14	153.32
	15	153.42

3.5 Shear tests – stainless steel

Table 3.12 Carbon steel – shear tests, M8

Bolt	Test ID	Resistance (kN)
M8	40	21.99
	41	19.36
	42	20.61
	43	18.78
	44	21.09

Table 3.13 Carbon steel – shear tests, M12

Bolt	Test ID	Resistance (kN)
M12	45	42.17
	46	41.58
	47	41.42
	48	40.05
	49	40.06

3.6 Material properties

Material for bolts and pins was tested to determine the material strengths. Ultimate strengths are shown in Table 3.14.

Table 3.14 Material strengths

Sample	Ultimate strength (N/mm^2)	Average strength (N/mm^2)
Bolt	955	
	959	Average carbon steel
	965	959.7
Bolt	874	Average all bolts
	885	892.7
	865	
Bolt	849	
	836	
	846	
Pin	1428	
	1413	
	1554	
Pin	2088	
	2104	
	2121	
Pin	901	
	877	
	897	
Pin	1353	
	1354	
	1334	
Pin	1007	
	1008	
	1010	

Molabolts are manufactured from Class 8.8 bolts and Class 10.9 pins for the carbon steel assemblies and A2-700 stainless steel.

Subsequent to the testing, it was difficult to determine with confidence which bolt samples were from carbon steel and which from stainless. It would appear from test results in Table 3.14 that one set of results were from carbon steel (showing the higher strengths) and two from stainless steel. In determining the design resistance of the carbon steel assemblies, an average of the three higher strengths (assumed to be the carbon steel) was taken, which is conservative when calculating the resistance.

4 DETERMINATION OF DESIGN RESISTANCES

The procedure for determining resistances follows the guidance in Annex D of BS EN 1990.

Because prior knowledge exists of the performance of these assemblies (including earlier tests), the values of k_n and $k_{d,n}$ from Tables D1 and D2 of Annex D have been based on "V_x known".

When the behaviour under test is similar across bolt diameters, the value of n (the number of numerical test results) has been taken as that of the group, following the principle expressed in BS EN 1993-1-3[2] Clause A.6.3.2.

4.1 Resistances in tension

Because two different forms of failure were observed during the test programme, a slightly different approach was followed in each case, as described in the following sections.

4.1.1 Bolts failing in fracture

The M20 bolts failed in fracture. All the bolts failed in this manner, which was sudden. The sudden failure can be seen in Figure A.5.

The fracture occurred at the cross section where the bolt shank is cut to produce the splayed end. As these cuts extend into the threaded portion of the shank, the fracture occurred at this minimum cross section.

For this type of failure, a simple mechanical model may be determined (see section 4.1.2) and the calculated resistances based on Table D1 of BS EN 1990. The measured resistances are firstly normalised with a correction factor based on the measured material properties. The mean and standard deviation for the five samples are determined and the characteristic resistance determined from:

Characteristic resistance = mean resistance – k_n × standard deviation
(taken from Table C3 of BS EN 1990 for a normal distribution)

In this case, as a mechanical design model is possible, k_n = 1.8, from Table D1.

The average bolt material strength, as measured, is given in Table 3.14 as 959.7 N/mm^2.

The nominal strength of Class 8.8 material, f_{ub} = 800 N/mm^2, as given in Table 3.1 of BS EN 1993-1-8[3]. The correction factor is therefore $800/959.7 = 0.834$.

The calculation of the characteristic resistance is shown in Table 4.1.

Table 4.1 Characteristic resistance of M20 in tension

Test ID	Measured Resistance (kN)	Average measured resistance (kN)	Normalised Resistance (kN)	Average normalised Resistance (kN)	Standard Deviation (kN)	Characteristic Resistance (kN)
1	120.34		100.31			
2	111.51		92.95			
3	122.15	119.28	101.82	99.43	4.01	92.22
4	123.97		103.34			
5	118.43		98.72			

Adopting the recommended value of $\gamma_{M2} = 1.25$ from the UK National Annex to BS EN 1993-1-8, the design tension resistance is given by:

Design resistance, $F_{t,Rd} = \frac{92.22}{1.25} = 73.8\,\text{kN}$

4.1.2 Predicted ultimate resistance

The tensile area of a M20 bolt is 245 mm^2.

In an M20, Molabolt, the central void is 10 mm diameter, thus reducing the cross-section by $\frac{\pi 10^2}{4} = 78.5$ mm^2.

The four cut slots are each 1.9 mm wide. The remaining annulus of material is 3.83 mm thick, based on the equivalent radius of the tensile area.

The slots further reduce the cross-section by 29.1 mm^2.

Thus the remaining cross-section = 245 – 78.5 – 29.1 = 137.4 mm^2.

The calculated ultimate resistance, based on nominal material strength is therefore:

137.4 × 800× 10^{-3} = 109.9 kN

4.1.3 Calculated resistance

The correction between 109.9 kN (Section 4.1.2) and the characteristic resistance determined by test of 92.22 kN (Table 4.1) is $92.22/109.9 = 0.84$.

Thus the expression for the design resistance is:

$$F_{t,Rd} = \frac{F_{t,Rk}}{\gamma_{M2}} = \frac{0.84\, f_{ub}\, A_t}{\gamma_{M2}}$$

where:

f_{ub} is the nominal ultimate strength of the bolt

A_t is the (reduced) cross-sectional area

γ_{M2} = 1.25, as given by the UK National Annex to BS EN 1993-1-8

Note that this expression should only be applied to M20 bolts and larger, where the four cuts are run into the threaded shank, producing a fracture by failure of the cross-section.

For a M24 bolt, the tensile area is 353 mm^2.

In an M24, Molabolt, the central void is 12.1 mm diameter, thus reducing the cross-section by $\frac{\pi 12.1^2}{4} = 115$ mm^2.

The four cut slots are each 1.9 mm wide. The remaining annulus of material is 4.55 mm thick, based on the equivalent radius of the tensile area.

The slots further reduce the cross-section by 34.6 mm^2.

Thus the remaining cross-section = 355 – 115 – 34.6 = 205.4 mm^2.

The design shear resistance for a M24 Molabolt is therefore:

$$F_{t,Rd} = \frac{F_{t,Rk}}{\gamma_{M2}} = \frac{0.84 \times 800 \times 205}{1.25} \times 10^{-3} = 110.2 \text{ kN}$$

4.1.4 Bolts failing by pull-through – carbon steel

M16 bolts and smaller diameters fail by pull through rather than fracture of the bolt assembly. This behaviour can be seen in the load-extension plots for M8, M10, M12 and M16 bolts seen in Figure A.1 to Figure A.4.

There is no mechanical design model for a pull through failure, as this is complex behaviour. Therefore the design values of resistance have been calculated directly from the test results, using Table D2 of BS EN 1990.

The design values of resistance have been calculated as follows:

Design value of resistance = mean resistance – $k_{d,n}$ × standard deviation
(taken from Table C3 of BS EN 1990 for a normal distribution)

From Table D2, $k_{d,n}$ has been taken as 3.16, for a family of 20 tests and "V_x known"

Design resistances are calculated in the following tables.

Table 4.2 Design value of resistance of M8 in tension

Test ID	Measured Resistance (kN)	Average Resistance (kN)	Standard Deviation (kN)	Design Value of Resistance (kN)
54	13.36			
55	19.00			
56	20.14	16.56	2.92	7.3
57	15.91			
58	14.39			

It should be noted that considerable scatter is observed in the test results for M8 bolts. The coefficient of variation (standard deviation/mean) = 17.6%, compared to 8% for M16 bolts and generally less than 4% for other bolt diameters.

Table 4.3 Design value of resistance of M10 in tension

Test ID	Measured Resistance (kN)	Average Resistance (kN)	Standard Deviation (kN)	Design Value of Resistance (kN)
59	27.18			
60	26.38			
61	26.31	27.02	0.83	24.4
62	28.35			
63	26.90			

Table 4.4 Design value of resistance of M12 in tension

Test ID	Measured Resistance (kN)	Average Resistance (kN)	Standard Deviation (kN)	Design Value of Resistance (kN)
6	51.88			
7	51.55			
8	54.65	52.23	1.71	46.8
9	53.01			
10	50.08			

Table 4.5 Design value of resistance of M16 in tension

Test ID	Measured Resistance (kN)	Average Resistance (kN)	Standard Deviation (kN)	Design Value of Resistance (kN)
64	44.91			
65	52.21			
66	49.58	50.69	4.05	37.9
67	56.04			
68	50.70			

4.1.5 Observations on test results

Two observations may be made on the test results of carbon steel fixings in tension.

Firstly, as noted above, the M8 bolts have a large coefficient of variation (17.6%). This variability can be seen in Figure A.1, but is not seen in other bolt diameters. It is not clear why this is, so additional investigation may be helpful. The initial stiffness (the slope of the curve) appears generally similar, but the ultimate loads are variable.

Secondly, the M16 results are disappointing, such that the design resistance in tension is less than that for a M12 bolt. The coefficient of variation is relatively high (8%) and the mean resistance is less than the mean resistance of an M12. Figure A.4 shows a consistent form of performance under load. The reduced resistance may indicate some change in the geometrical machining of the bolt, but from the fabrication details, no significant differences in the proportions of the M12 and M16 fixings can be observed. The cuts in the M16 bolt include part of the threaded length, whereas those in the M12 do not. The proportion of void to solid material is very similar in each fixing, so the reason for the disparity in results cannot immediately be explained.

4.1.6 Bolts failing by pull-through – stainless steel

The design values of resistance for the stainless steel bolts are shown in the following tables.

Design value of resistance = mean resistance – $k_{d,n}$ × standard deviation
(taken from Table C3 of BS EN 1990 for a normal distribution)

From Table D2, $k_{d,n}$ has been taken as 3.16, for a family of 10 tests and “V_x known”

Table 4.6 Design value of resistance of M8 in tension (stainless)

Test ID	Measured Resistance (kN)	Average Resistance (kN)	Standard Deviation (kN)	Design Value of Resistance (kN)
16	11.07			
17	11.14			
18	11.73	11.43	0.34	10.3
19	11.39			
20	11.84			

Table 4.7 Design value of resistance of M12 in tension (stainless)

Test ID	Measured Resistance (kN)	Average Resistance (kN)	Standard Deviation (kN)	Design Value of Resistance (kN)
21	33.41			
22	33.52			
23	32.38	32.83	0.61	30.9
24	32.15			
25	32.71			

4.2 Pull-through in thin material

As noted in Section 1.3, limited tests were undertaken to investigate the effect of thin plate on the resistance of the assembly. In general, it would be anticipated that the strength or deformation of the thin plate (a web, or the face of a hollow section) would be the limiting feature, rather than the resistance of the fixing. As there is such a range of possible connection configurations, the assessment of the strength and deformation of the plate must be completed by the connection designer.

M12 bolts were tested in 6 mm and 10 mm plate (two tests in each thickness).

M20 bolts were tested in 6 mm and 10 mm plate (two tests in each thickness).

In both cases the plate was nominally S275 material.

4.2.1 M12 bolts

The load-deformation results for the M12 bolts is shown in Figure A.8.

There is no significant difference between the results in 6 mm and 10 mm plate. The average resistance from the four pull-through tests is 51.8 kN. The average used in the tests to determine the design resistance, as given in Table 4.4, is 52.2 kN. It seems therefore reasonable to assume that if the plate is thicker than 0.5*d* (*d* being the bolt diameter), in S275 steel or stronger, no reduction in resistance need be made.

4.2.2 M20 bolts

The load-deformation results for the M20 bolts are shown in Figure A.9.

For these larger diameter bolts, it is clear that the plate thickness has a significant impact.

In 10 mm plate, the average resistance is 121 kN. This compares to the average tested resistance in Table 4.1 of 119.3 kN. As can be seen from Figure A.9, the bolts failed in a brittle manner, so it is entirely understandable that the resistance is almost identical.

In 6 mm plate the behaviour is quite different. In this case, there is no brittle failure of the bolt, but rather a pull through the plate. In this configuration, the plate is thin enough to allow deformation to occur. The average resistance is reduced by approximately 20%.

Although no firm conclusions can be reached, a tentative observation may be made that to achieve the resistances of the fixings determined by this research, the plate should be at least 0.5*d* and at least grade S275. In most situations, the design resistance would be limited by the strength or deformation of the plate, not the fixing.

4.3 Resistances in shear

The shear plane passes through a Class 8.8 annulus and a Class 10.9 pin. As there are no simple design models to determine the resistance of such a hybrid connection, the design value of resistance has been determined using Table D2 of BS EN 1990.

The design values of resistance have been calculated as follows:

Design value of resistance = mean resistance – $k_{d,n}$ × standard deviation

For the carbon steel tests, $k_{d,n}$ has been calculated by interpolation as 3.20 from Table D2, for a family of 15 tests and "V_x known"

For the stainless steel tests, $k_{d,n}$ has been taken as 3.23 from Table D2, for a family of 10 tests and "V_x known"

The design values of resistance are shown in the following tables.

Table 4.8 Design value of resistance of M8 in shear (carbon steel)

Test ID	Measured Resistance (kN)	Average Resistance (kN)	Standard Deviation (kN)	Design Value of Resistance (kN)
35	26.12			
36	22.38			
37	26.69	24.84	2.3	17.5
38	22.29			
39	26.72			

Table 4.9 Design value of resistance of M12 in shear (carbon steel)

Test ID	Measured Resistance (kN)	Average Resistance (kN)	Standard Deviation (kN)	Design Value of Resistance (kN)
30	52.24			
31	53.46			
32	52.97	52.85	0.98	49.7
33	54.03			
34	51.55			

Table 4.10 Design value of resistance of M20 in shear (carbon steel)

Test ID	Measured Resistance (kN)	Average Resistance (kN)	Standard Deviation (kN)	Design Value of Resistance (kN)
11	146.61			
12	153.31			
13	148.99	151.13	3.15	141.0
14	153.32			
15	153.42			

Table 4.11 Design value of resistance of M8 in shear (stainless steel)

Test ID	Measured Resistance (kN)	Average Resistance (kN)	Standard Deviation (kN)	Design Value of Resistance (kN)
40	21.99			
41	19.36			
42	20.61	20.37	1.30	16.2
43	18.78			
44	21.09			

Table 4.12 Design value of resistance of M12 in shear (stainless steel)

Test ID	Measured Resistance (kN)	Average Resistance (kN)	Standard Deviation (kN)	Design Value of Resistance (kN)
45	42.17			
46	41.58			
47	41.42	41.18	0.83	38.5
48	40.05			
49	40.66			

4.4 Recommended design values in shear

4.4.1 Carbon steel

In carbon steel, the calculated design resistances exceed the resistances for an ordinary bolt, as shown in Table 4.13.

Table 4.13 Comparison of ordinary bolt and Molabolt resistances in shear

Bolt Diameter	Ordinary Bolt Resistance (kN)	Molabolt Resistance (kN)	Potential enhancement
M8	14.1	17.5	24%
M12	32.3	49.7	54%
M20	94	141	50%

In making the comparison in Table 4.13, the 0.85 factor specified in BS EN 1993-1-8 Clause 3.6.1(5) has not been applied to the calculated resistance of the 'ordinary' M8 and M12 bolts in Table 4.13, because Molabolts are not used in clearance holes.

SCI recommends that despite the possible enhancement, the shear resistances for Molabolts are taken as the resistance of the equivalent ordinary bolt.

4.4.2 Stainless steel

In stainless steel, the calculated design resistances exceed the resistances for a stainless steel bolt grade A2-700, as shown in Table 4.14.

Table 4.14 Comparison of ordinary bolt and Molabolt resistances in shear

Bolt Diameter	Bolt Resistance in A2-700 (kN)	Molabolt Resistance (kN)	Potential enhancement
M8	12.3	16.2	32%
M12	28.3	38.5	36%

In making the comparison in Table 4.14, in, the 0.85 factor specified in BS EN 1993-1-8 Clause 3.6.1(5) has not been applied to the calculated resistance of the M8 and M12 bolts in A2-700, because Molabolts are not used in clearance holes.

SCI recommends that despite the possible enhancement, the shear resistances for Molabolts are taken as the resistance of the equivalent bolt based on A2-700 grade steel.

4.5 Bearing resistance

In bearing, the peg anchors present an identical contact surface to that of ordinary bolts. There is no reason to propose alternative rules than those for ordinary Class 8.8 bolts, as given in the design Standards.

In BS 5950[4], the bearing capacity is given in clauses 6.3.3.2 and 6.3.3.3.

In BS EN 1993-1-1[3], the bearing resistance is given in Table 3.4.

4.6 Combined tension and shear

SCI recommend that the rules given in the design Standards for combined tension and shear be observed, with the proviso that the design resistances in tension are those determined in this report.

In BS 5950[4], the rule is given in clause 6.3.4.4.

In BS EN 1993-1-8[3], the rule is given in Table 3.4

5 RECOMMENDATIONS

5.1 Design resistances in tension

Design resistances in tension, to be compared against the ultimate loads on the fixing are as follows:

Table 5.1 Carbon steel design resistance in tension

Bolt	Design resistance in tension (kN)
M24	110.2
M20	73.8
M16	37.9
M12	46.8
M10	24.4
M8	7.3

Table 5.2 Stainless steel design resistance in tension

Bolt	Design resistance in tension (kN)
M12	30.9
M10	19.5*
M8	10.3

* The value for M10 bolts has been determined by interpolation, based on bolt area[2].

The resistances quoted above are valid for plate thicknesses of at least 0.5*d* (*d* is the bolt diameter), in S275 steel or stronger.

Designers should be reminded that the strength and deformation of the support must be checked as this is likely to be critical in thin plate.

5.2 Design resistance in shear

In shear, design resistances determined by test show some enhancement compared to the shear resistance of ordinary bolts. It is recommended that the shear resistance of Molabolts is taken to be that of the equivalent diameter ordinary bolt (Class 8.8 for carbon steel bolts and A2-700 for stainless steel bolts). For completeness, these resistances are given below:

Table 5.3 Carbon steel design resistance in single shear

Bolt	Design resistance in shear (kN)
M24	136
M20	94.1
M16	60.3
M12	32.3
M10	22.3
M8	14.1

Table 5.4 Stainless steel design resistance in single shear

Bolt	Design resistance in shear (kN)
M12	28.3
M10	19.5
M8	12.3

Although the resistances in Table 5.3 and Table 5.4 have been determined in accordance with BS EN 1993-1-8, they are equally appropriate for designs to BS 5950.

To determine the bearing resistance, Molabolts should be treated the same as ordinary bolts.

In combined shear and tension, Molabolts should be treated in the same way as ordinary bolts, but with the reduced tension resistances given in Table 5.1 and Table 5.2.

REFERENCES

1 BS EN 1990:2002 + A1:2005 Eurocode – Basis of structural design

2 BS EN 1993-1-3:2006 Eurocode 3- Design of steel structures – Part 1-3: General rules – Supplementary rules for cold-formed members and sheeting

3 BS EN 1993-1-8:2005 Eurocode 3: Design of steel structures – Part 1-8: Design of joints

4 BS 5950-1:2000 Structural use of steelwork in building – Part 1: Code of practice for design – Rolled and welded sections

APPENDIX A TEST RESULTS

A.1 Tension tests

The following figures show load-extension results for each test. The unique test ID is given in each figure and can be related to the summary results in Section 3.

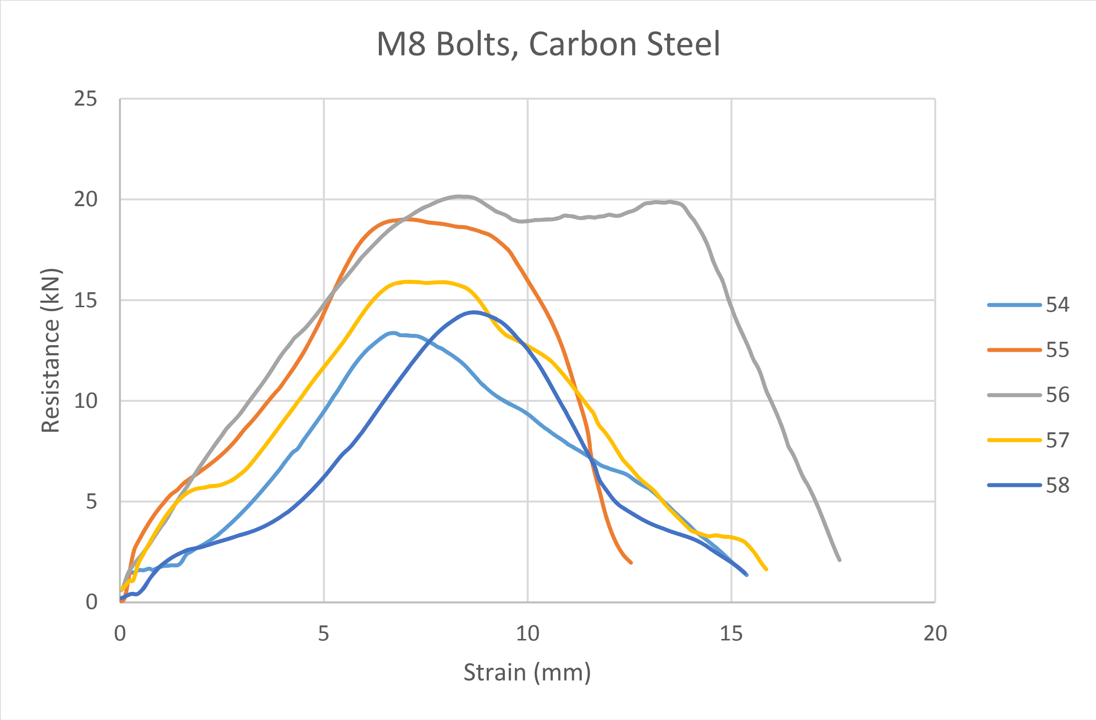

Figure A.1 M8 carbon steel test results

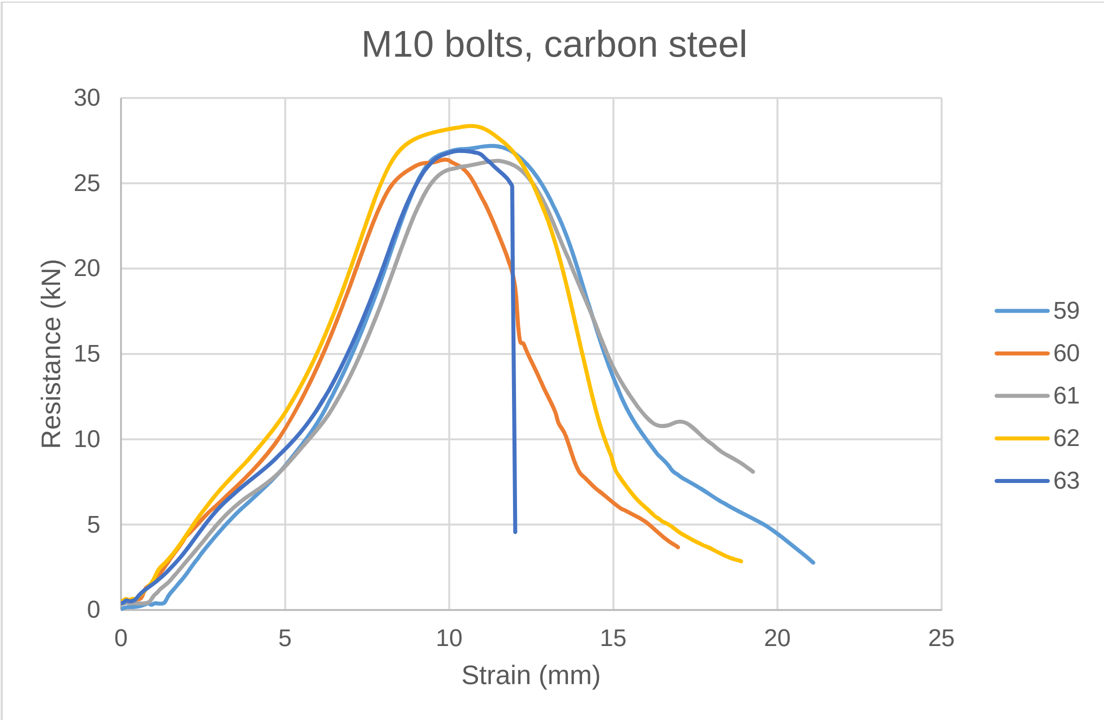

Figure A.2 M10 carbon steel test results

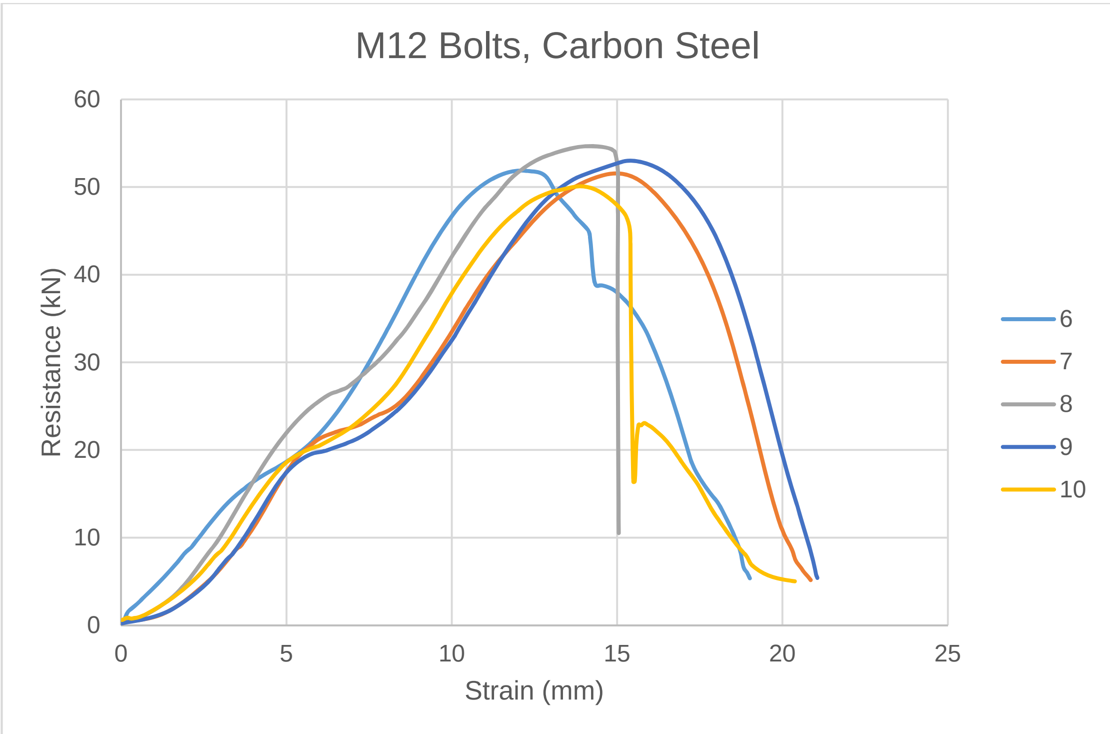

Figure A.3 M12 carbon steel test results

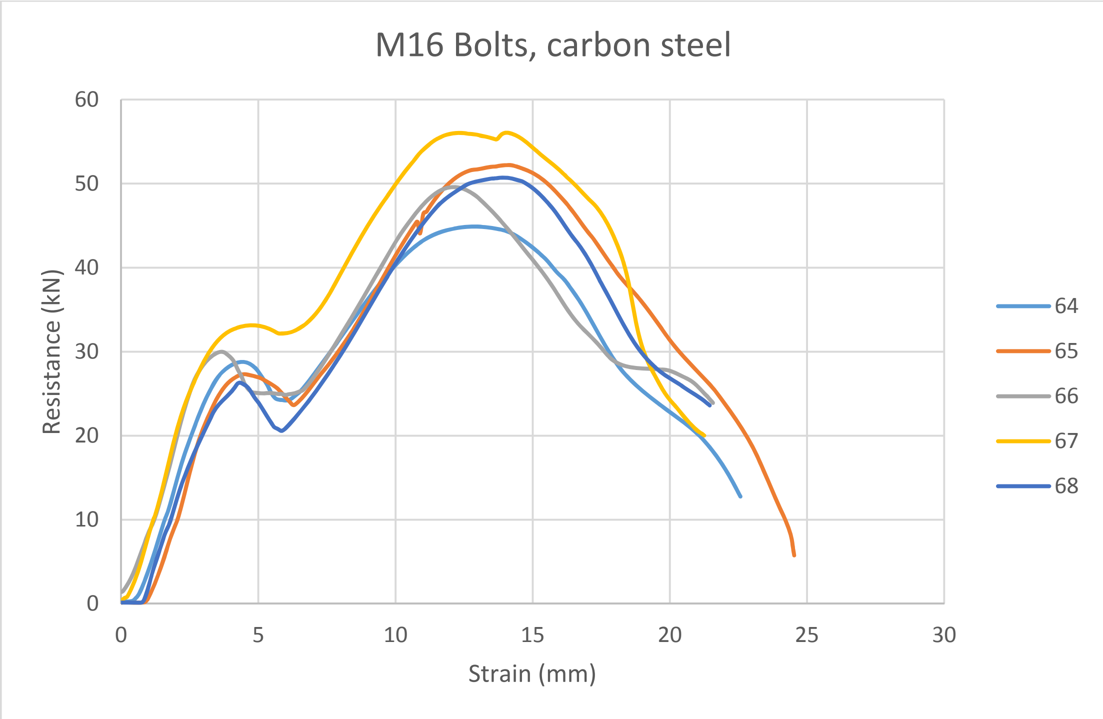

Figure A.4 M16 carbon steel test results

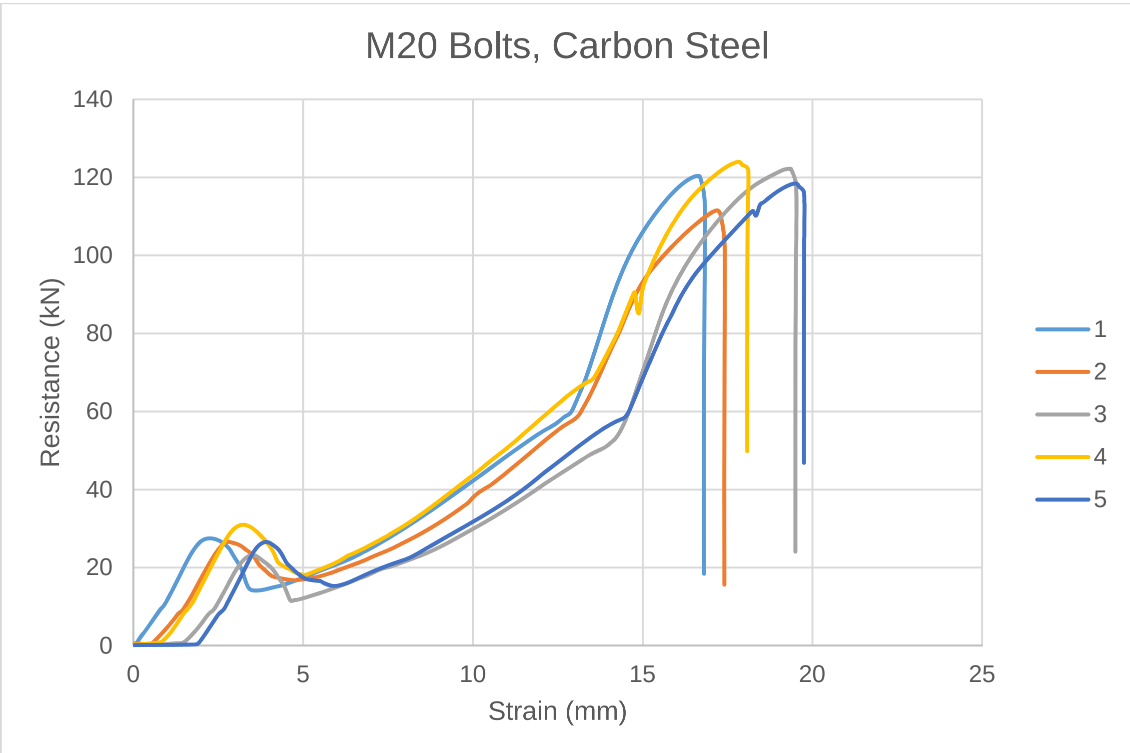

Figure A.5 M20 carbon steel test results

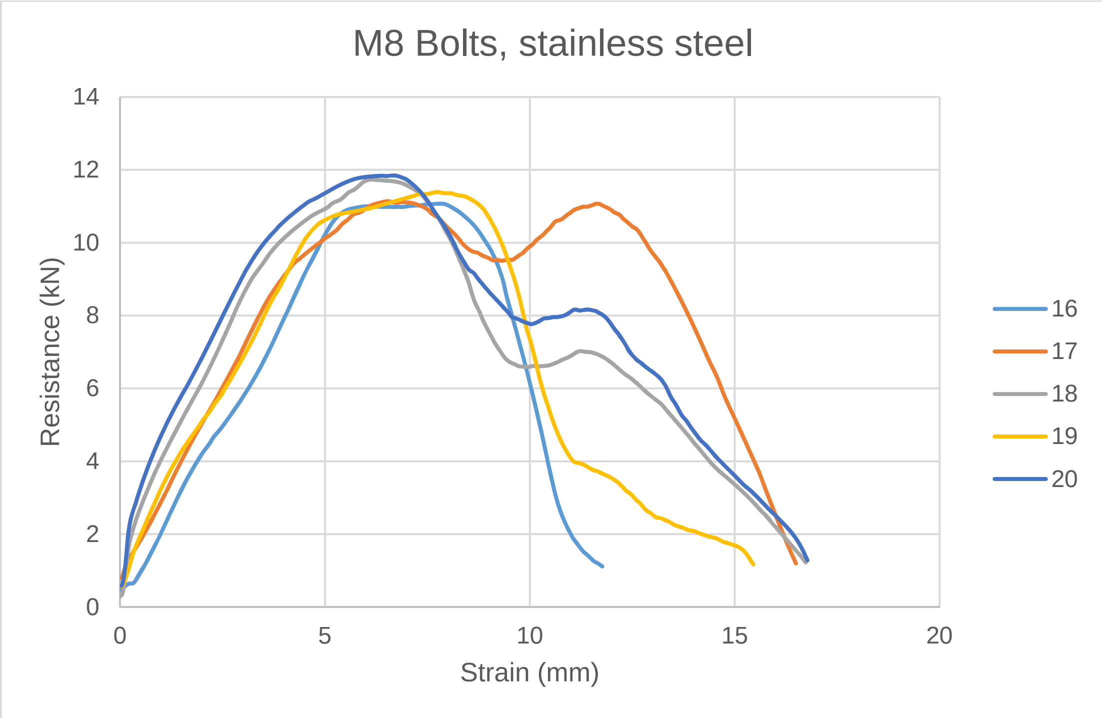

Figure A.6 M8 stainless steel test results

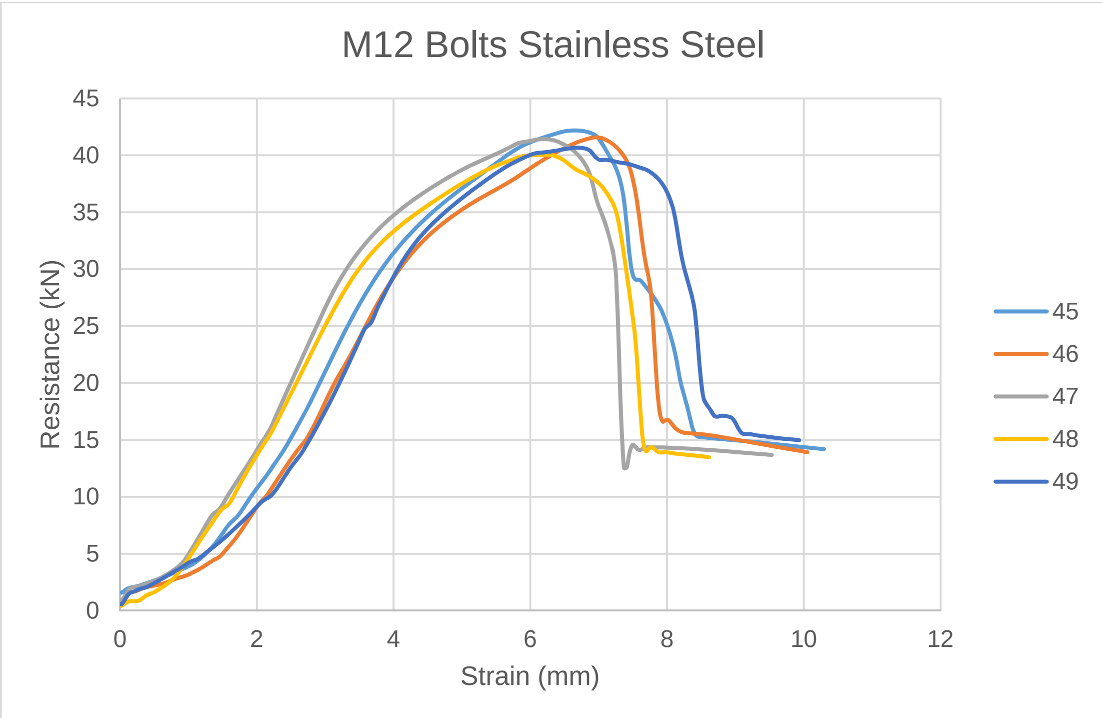

Figure A.7 M12 stainless steel test results

A.2 Pull-through tests in thin material

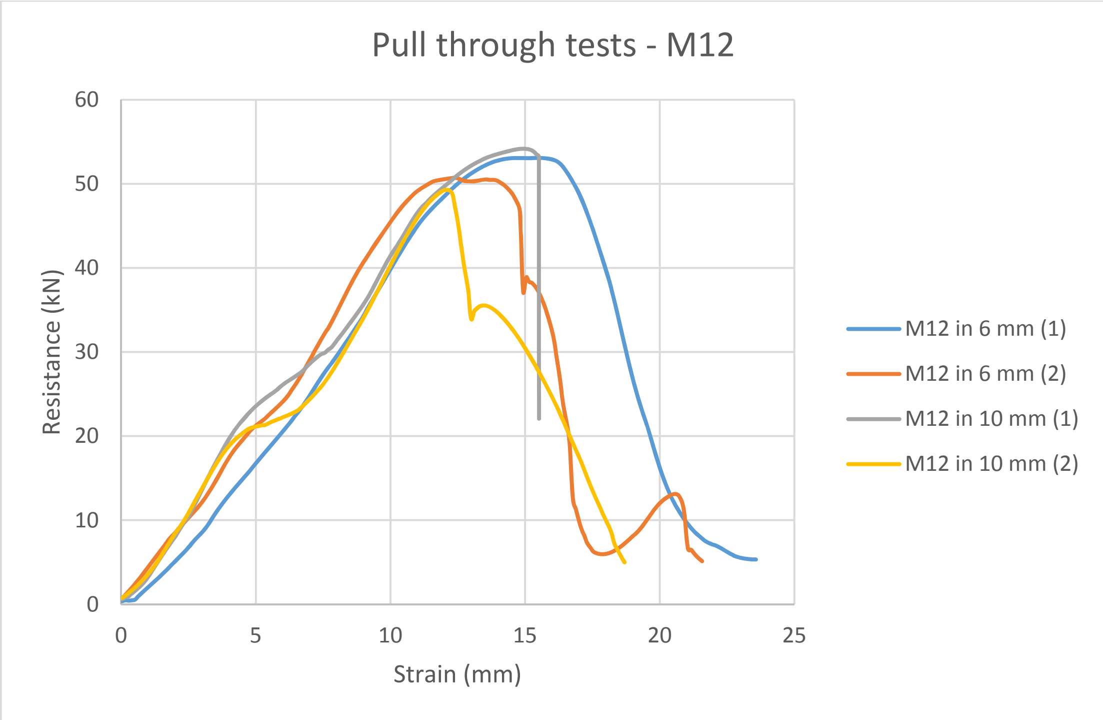

Figure A.8 M12 pull-through tests

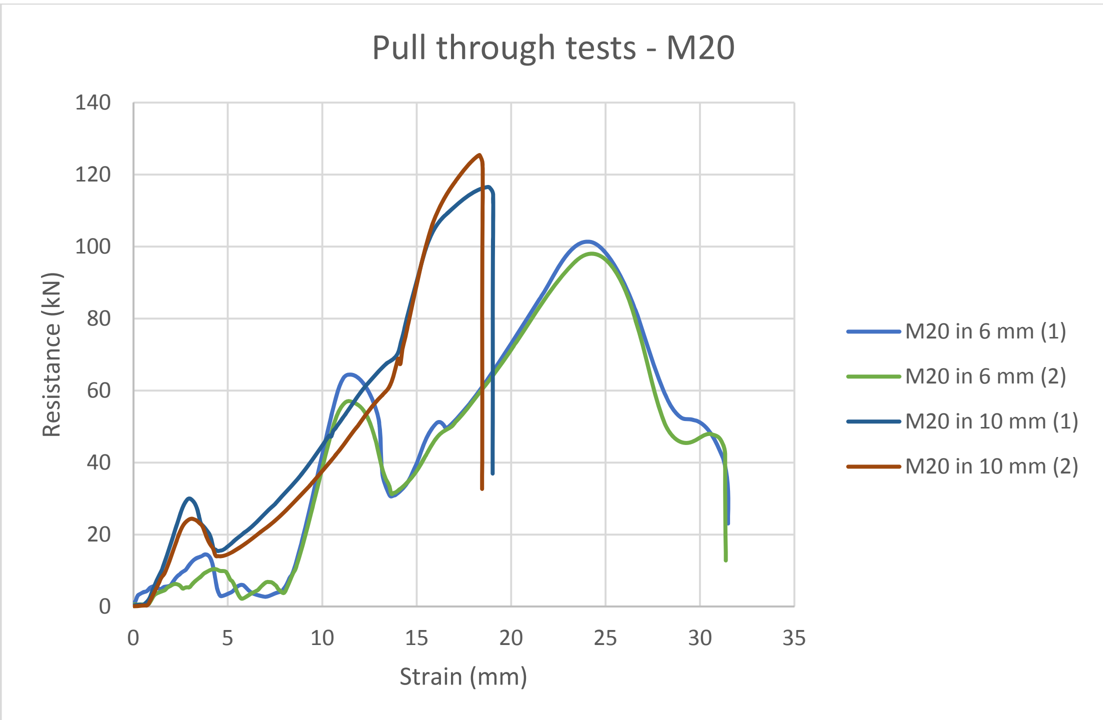

Figure A.9 M20 pull-through tests