Design resistance of TW Bolts

Report to:	Henry Venables Products Ltd
Document:	RT 1846
Version:	01
Date:	August 2020

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Version	Date	Purpose	Author	Reviewer	Approved
01	08/20	Issue to Henry Venables	DGB		

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EXECUTIVE SUMMARY

TW Bolts, designed as blind fixings for relatively thin wall applications, manufactured by Henry Venables Products Ltd have been tested in shear and tension to determine design resistances for use with BS 5950 or BS EN 1993.

Design resistances in shear are presented below. The resistance values may be compared directly with the ultimate loads applied to the fixing.

Material	TW bolt size	BS 5950 resistance (kN)	BS EN 1993 resistance (kN)
Carbon steel	TW5	13.2	15.9
	TW6	19.5	23.4
	TW8	34.5	41.4
Stainless steel	TW5	11.6	14.0
	TW6	17.3	20.8
	TW8	30.4	36.4

Design resistances in tension are presented below. The resistance values may be compared directly with the ultimate loads applied to the fixing.

Material	TW bolt size	BS 5950 resistance (kN)	BS EN 1993 resistance (kN)
Carbon steel	TW5	4.8	4.8
	TW6	14.1	10.1
	TW8	25.6	18.4
Stainless steel	TW5	7.0	5.0
	TW6	9.8	7.1
	TW8	17.9	12.9

The bearing resistance may be calculated in accordance with the design standard, based on the external diameter of the collar, as given in Table 1.1.

Fixings subject to combined shear and tension should be verified in accordance with the design standard, using the design resistances presented above.

If tension is applied to a fixing in a relatively thin wall application, the deformation of the connected material should be considered at serviceability (working loads) and at the ultimate limit state, as deformation is likely to be the limiting feature of the connection.

Contents

1 TW BOLTS

TW ("thin wall") bolts as supplied by Henry Venables Products Ltd are designed – as the name suggests – to connect relatively thin steel plies together, with access from one side only.

TW bolts consist of a countersunk set screw, located within a machined collar with a low-profile head, and a threaded barrel partly cut with segments. As the set screw is rotated, the segments of the barrel engage with the collar and splay as the set screw is tightened further. As the assembly is tightened, the splayed segments of the barrel bear on the inside face of the connected plies.

TW bolts are shown in Figure 1.1.

Figure 1.1 TW Bolt

1.1 Material

TW Bolts are available in carbon steel or stainless steel.

Carbon steel fixing comprise a property class 10.9 countersunk set screw, with collars and barrels machined from carbon steel with a minimum tensile strength of 690 N/mm^2.

Stainless Steel fixing comprise an A4 property class 70 countersunk set screw, with collars and barrels machined from stainless steel with a minimum tensile strength of 700 N/mm^2.

1.2 Bolt sizes

TW bolts are defined by the diameter of the countersunk set screw. M5, M6 and M8 bolts are available (July 2020). Currently, two lengths of bolt are available, with a maximum clamp length of either 10 mm or 16 mm. Table 1.1 presents the salient dimensions of each bolt.

Table 1.1 TW bolt and hole diameters

TW product Code	Set screw diameter (mm)	Collar outside diameter (mm)	Collar inside diameter (mm)	Hole diameter (mm)
TW5	5	7.8	5.1	8
TW6	6	9.5	6.1	10
TW8	8	12.6	8.2	13

1.3 Physical testing

testing was undertaken by Intertek NDT (Materials Testing) of Derby, who are an ISO/IEC 17025 UKAS accredited metallurgical test laboratory.

1.4 Test programme

Tests were conducted to determine:

- The shear resistance of the TW Bolt, in both carbon and stainless steel.
- The tensile resistance of the TW bolt, in both carbon and stainless steel.

Additional tests were undertaken to investigate:

- The bearing resistance in thin plates (1.5, 2 and 4 mm)
- The potential to pull through thin plates (1.5, 2 and 4 mm)

1.4.1 Shear tests

The aim of the shear tests was to determine the resistance of the TW bolt. The shear test arrangement followed the guidance in section 3.2.1.2 of ECCS publication *The testing of connections with mechanical fasteners in steel sheeting and sections*[1].

In accordance with Figure 3.2 of the ECCS publication, two bolts were tested in lapped plates, as shown in Figure 1.2.

Figure 1.2 Test arrangement - shear

The width and length of the steel plates, and the spacing of the fixings followed the recommendations given by ECCS, as shown in Table 1.2.

Table 1.2 Shear test arrangements

TW product Code	Plate width (mm)	End distance (mm)	Fixing pitch (mm)
TW5	80	40	80
TW6	100	50	100
TW8	130	65	310

The shear tests used two 8 mm, S355 plates.

In each case, the shear test was repeated four times.

1.4.2 Tensile tests

Tensile tests were undertaken with a test arrangement following the guidance given in Figure 3.12 of the ECCS publication[1]. This indicates a cruciform arrangement of plates with a single, central fixing. The plates are pulled apart to introduce tension in the fixing.

A testing rig was developed to facilitate this arrangement, as shown in Figure 1.3.

Figure 1.3 Tension test arrangement

A partly dissembled test is shown in Figure 1.4

Figure 1.4 Dissembled test rig (pull-through test)

The cruciform plates were all 50 mm wide. The ‘span’ between clamping plates was 70 mm, as shown in Figure 1.5.

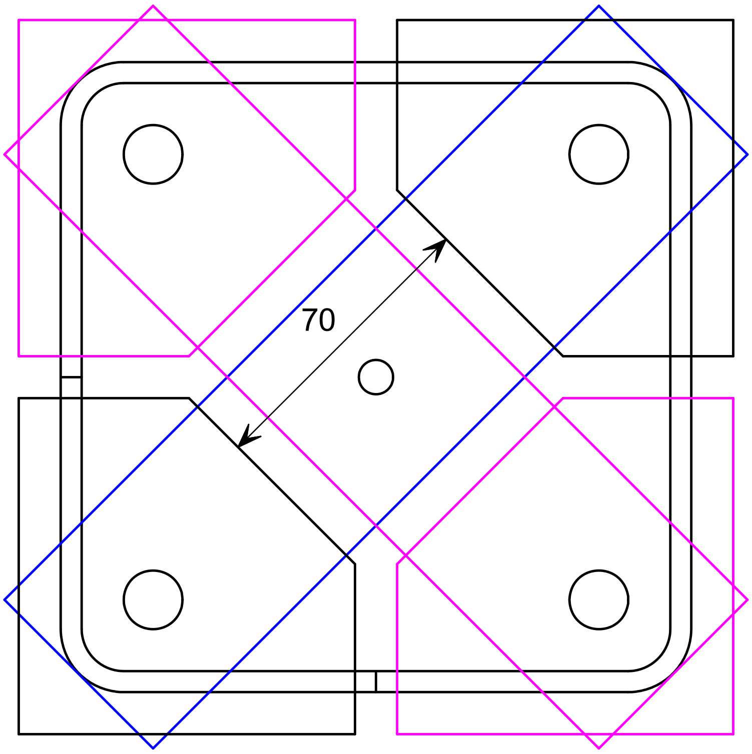

Figure 1.5 Cruciform plates in test rig

To test the tension resistance, both plates were 8 mm, S355.

Six tests of each bolt diameter, in each material, were completed.

1.4.3 Bearing tests

The same arrangement shown in Figure 1.2 was used to investigate bearing performance. In the bearing tests, one plate was 10 mm S355 steel. Three different plate thicknesses were used for the second “sacrificial” plate; 1.5, 2 and 4 mm in S275 steel.

As the TW bolts present a standard circular profile to the plate, it was anticipated that the performance would be identical to that of an orthodox bolt. Three tests in each material thickness were planned.

1.4.4 Pull-through tests

Figure 1.4 shows a disassembled pull-through test arrangement, which utilised the rig shown in Figure 1.3. One plate was 10 mm, S355, tested in combination with the second “sacrificial” plate of 1.5, 2 and 4 mm.

Three tests per bolt diameter, in each plate thickness, were planned. After witnessing several tests, it was decided that only two tests in each material thickness were necessary, as the plate simply underwent gross deformation with no evidence of any pull-through.

2 SHEAR TESTS

A TW bolt after testing is shown in Figure 2.1. The shear plane passes through both the bolt and the collar. Further tested samples are shown in Appendix C.

Figure 2.1 Shear test M6, stainless steel

A typical plot of load-deformation is shown in Figure 2.2. It should be noted that the load represents the resistance of two TW fixings.

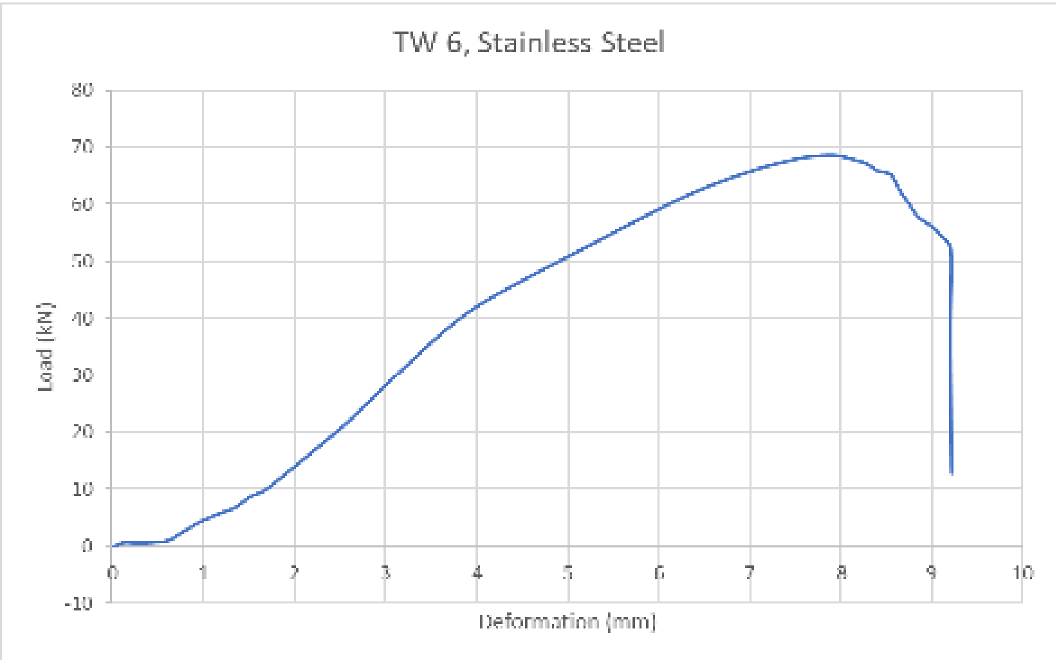

Figure 2.2 Load-deformation, Shear test M6, Stainless steel

2.1 Design shear resistance

Design shear resistances based on test have been determined in accordance with BS EN 1990, Annex D[2].

The calculated resistance in accordance with both BS EN 1993-1-8[3] and BS 5950[4] has been determined.

The design shear resistances are taken as the minimum of that demonstrated by test and the calculated value.

An example calculation, for M6, stainless steel, is shown in section 2.1.1. The detailed calculations for each diameter, in each material, are presented in Appendix A; the results are summarised in section 2.1.4.

2.1.1 Example shear resistance calculation

The following example demonstrates the assessment of the design resistance of a M6 stainless steel TW bolt.

Maximum test loads (for two bolts) are shown in Table 2.1. Test 2 corresponds to Figure 2.2.

Table 2.1 Shear test results, M8, Stainless Steel

Test number	Test resistance (kN)
1	70.08
2	66.66
3	69.45
4	69.32

From material test results supplied by Henry Venables Products Ltd, the measured bolt strength was taken as 759 N/mm^2. The normalised resistances, accounting for the measured material strength are shown in Table 2.2, with the mean value and standard deviation.

Table 2.2 Shear test results, M8, Stainless Steel

Test number	Test resistance (kN)	Normalised resistance (kN)
1	70.08	64.65
2	66.66	63.34
3	69.45	64.07
4	69.32	63.95
	mean	64.01
	standard deviation	0.54
	coefficient of variation	0.8%

The ULS design resistance has been determined directly in accordance with D7.3 of BS EN 1990 Annex D.

From Table D2, $k_{d,n}$ has the value of 3.44 for 4 tests and "V_x known"

Based on tests, the design resistance of two TW bolts is therefore given by:

$F_{Rd(2)}$ = 64.01 – 3.44 × 0.54 = 62.15 kN

and the design resistance of one TW bolt is therefore 31.1 kN

2.1.2 Calculated design resistance – Eurocode

The TW bolt consists of a set screw and concentric collar; both must be sheared, as shown in Figure 2.1.

The tensile area of an M6 screw is 20.1 mm^2

From manufacturing data (see Table 1.1), the collar has an outside diameter of 9.5 mm and an inside diameter of 6.1 mm; the cross-sectional area is therefore 41.7 mm^2.

The shear resistance of a component is given in Table 3.4 of BS EN 1993-1-8 as:

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

From material specifications, the ultimate strength of the screw and collar are taken to be 700 N/mm^2.

The shear resistance of the screw is therefore:

$$F_{v,Rd(screw)} = \frac{0.6 \times 700 \times 20.1}{1.25} \times 10^{-3} = 6.8 \text{ kN}$$

The shear resistance of the collar is therefore:

$$F_{v,Rd(collar)} = \frac{0.6 \times 700 \times 41.7}{1.25} \times 10^{-3} = 14.0 \text{ kN}$$

The total resistance = 6.8 + 14.0 = 20.8 kN (compared to the test resistance of 31.1 kN)

2.1.3 Calculated design resistance – BS 5950

The shear resistance of a component is given in clause 6.3.2.1 as:

$$P_s = p_s A_s$$

where $p_s = 0.4 U_b$

The shear resistance of the screw is therefore:

$P_{s(screw)}$ = 0.4 × 700 × 20.1 × 10^{-3} = 5.6 kN

The shear resistance of the collar is therefore:

$P_{s(collar)}$ = 0.4 × 700 × 41.7 × 10^{-3} = 11.7 kN

The total resistance = 5.6 + 11.7 = 17.3 kN

2.1.4 Design resistances in shear

Following the process demonstrated in section 2.1.1, 2.1.2 and 2.1.3 the values for all bolts are presented in Table 2.3. In every case, the resistance determined from the tests is higher than that calculated in accordance with the design standard; the resistances calculated in accordance with the design standard (shown in bold) should be adopted.

Table 2.3 Design shear resistance

Material	TW bolt size	Resistance from test (kN)	BS 5950 resistance (kN)	BS EN 1993 resistance (kN)
Carbon steel	TW5	23.7	**13.2**	**15.9**
	TW6	31.3	**19.5**	**23.4**
	TW8	54.0	**34.5**	**41.4**
Stainless steel	TW5	20.9	**11.6**	**14.0**
	TW6	31.1	**17.3**	**20.8**
	TW8	41.4	**30.4**	**36.4**

3 TENSION TESTS

In tension, most TW bolts failed by simple fracture of the set screw, as shown in Figure 3.1.

Figure 3.1 Tension test M6, stainless steel

M5 carbon TW fixings exhibited a different failure mechanism, in that the splayed segments of the barrel distorted and eventually fractured. This behaviour is more variable than fracture of the set screw and is manifest in a relatively high coefficient of variation in the test results. A typical M5 carbon steel TW bolt after test is shown in Figure 3.2.

Figure 3.2 Tension test M5, carbon steel

M8 carbon TW fixings exhibited a third from of failure. As the 8 mm plate bent, the contact with the head of the collar was applied as a point load on each edge of the head. This can be seen in Figure 3.3, where the contact with the head of the collar has formed indentations in the 8 mm plate. A typical M8 carbon steel TW bolt after test is shown in Figure 3.4.

Figure 3.3 Tension test plate, M8, carbon steel

Figure 3.4 Tension test M8, carbon steel

3.1 Design tension resistance

Design tension resistances based on test have been determined in accordance with BS EN 1990, Annex D[2].

The calculated resistance in accordance with both BS EN 1993-1-8[3] and BS 5950[4] has been determined.

The design tension resistances are taken as the minimum of that demonstrated by test and the calculated value.

An example calculation, for M6, carbon steel, is shown in section 3.1.1. The detailed calculations for each diameter, in each material, are presented in Appendix B; the results are summarised in section 3.1.4.

3.1.1 Example tension resistance calculation

The following example demonstrates the assessment of the design resistance of a M6 carbon steel TW bolt.

Maximum test loads are shown in Table 3.1.

Table 3.1 Tension test results, M6, carbon Steel

Test number	Test resistance (kN)
1	20.94
2	21.34
3	31.16
4	22.46
5	22.32
6	21.46

From material test results supplied by Henry Venables Products Ltd, the measured bolt strength was taken as 1095 N/mm^2. The normalised resistances, accounting for the measured material strength are shown in Table 3.2, with the mean value and standard deviation.

Table 3.2 Tension test results, M8, Stainless Steel

Test number	Test resistance (kN)	Normalised resistance (kN)
1	20.94	19.12
2	21.34	19.49
3	31.16	19.32
4	22.46	20.51
5	22.32	20.38
6	21.46	19.6
	mean	19.74
	standard deviation	0.57
	coefficient of variation	2.9%

The ULS design resistance has been determined directly in accordance with D7.3 of BS EN 1990 Annex D.

From Table D2, $k_{\text{d,n}}$ has the value of 3.33 for 6 tests and “V_x known”

Based on tests, the design resistance of a TW bolts is therefore given by:

$F_{\text{Rd(2)}}$ = 19.74 – 3.33 × 0.57 = 17.8 kN

3.1.2 Calculated design resistance – Eurocode

The tensile area of an M6 screw is 20.1 mm^2

The tension resistance of a component is given in Table 3.4 of BS EN 1993-1-8 as:

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

where k_2 = 0.63 for a countersunk bolt.

From material specifications, the ultimate strength of the screw is 1000 N/mm^2.

The tension resistance of the screw is therefore:

$$F_{t,Rd} = \frac{0.63 \times 1000 \times 20.1}{1.25} \times 10^{-3} = 10.1 \text{ kN}$$

3.1.3 Calculated design resistance – BS 5950

The shear resistance of a component is given in clause 6.3.4.3 as:

$$P_t = p_t A_t$$

where p_t = 700 N/mm^2 for property class 10.9 bolts.

The tension resistance of the screw is therefore:

$P_t = 700 \times 20.1 \times 10^{-3} = 14.1$ kN

3.1.4 Design resistances in tension

Following the process demonstrated in sections 3.1.1, 3.1.2 and 3.1.3 2.1.1, the values for all bolts are presented in Table 2.3. The values shown in bold should be adopted, being the minimum of the values determined from test and by calculation in accordance with the design standard.

Table 3.3 Design tension resistance

Material	TW bolt size	Resistance from test (kN)	BS 5950 resistance (kN)	BS EN 1993 resistance (kN)
Carbon steel	TW5	**4.8**	9.9	7.2
	TW6	17.8	**14.1**	**10.1**
	TW8	27.2	**25.6**	**18.4**
Stainless steel	TW5	8.1	**7.0**	**5.0**
	TW6	13.8	**9.8**	**7.1**
	TW8	23.2	**17.9**	**12.9**

4 BEARING RESISTANCE

The test arrangement shown in Figure 1.2 was used to examine bearing behaviour, with a 10 mm S355 plate connected to S275 plates of 1.5, 2 and 4 mm thickness.

As anticipated, the thin plate suffered considerable deformation before the tests were stopped. Figure 4.1 shows a deformed plate after disassembly.

Figure 4.1 Typical bearing test

A typical load-deformation plot for a TW6 bolt in 4 mm material is shown in Figure 4.2

Figure 4.2 Typical load deformation (TW6 in 4 mm plate)

As can be seen from Figure 4.2, the test resistance is approximately 75 kN for two bots, or 35 kN for a single bolt.

From Table 1.1, a TW6 is effectively a 9.5 mm dowel.

According to BS EN 1993-1-8, if edge, end and pitch distances do not reduce the resistance, (which they do not, in the specified test arrangement), the bearing resistance of a single bolt is given in Table 3.4 as:

$$F_{b,Rd} = \frac{2.5 \times 1.0 \times f_u dt}{\gamma_{M2}}$$

The ultimate strength of the 4 mm plate was measured as 411 N/mm^2. Omitting the partial material factor, the resistance may be computed as:

$F_{b,Rd} = 2.5 \times 1.0 \times 411 \times 9.5 \times 4 \times 10^{-3} = 39$ kN

The comparison between 35 kN and 39 kN indicates that as expected, the design rules in the standard may be used to compute the bearing resistance of TW bolts, taking the diameter *d* as the outside diameter of the collar (as listed in Table 1.1).

5 PULL-THROUGH BEHAVIOUR

Two tests were conducted with each bolt diameter, in each material thickness. Although three tests of each combination were planned, the tests simply demonstrated that the thin plate underwent gross deformation. There was no evidence of any pull through. Figure 5.1 shows a typical plate after disassembly.

Figure 5.1 Typical pull-through test

It is clear that in thin plate, the critical design check will always be the allowable deformation of the plate. In common with any other fixing to thin plate, the designer must carefully consider local deformation.

6 REFERENCES

1 The testing of connections with mechanical fasteners in steel sheeting and sections
ECCS, 2009

2 BS EN 1990:2002+A1:2005 Eurocode _ basis of structural design
BSI, 2009

3 BS EN 1993-1-8: 2005 Eurocode 3: Design of steel structures – Part 1-*: Design of joints
BSI, 2010

4 BS 5950-1: 2000 Structural use of steelwork in building – Part 1: Code of practice for design – Rolled and welded sections
BSI, 2007

Appendix A SHEAR RESISTANCE

This appendix records the detailed calculations for the shear resistance of carbon steel and stainless steel TW bolts.

TW5 Carbon

Specified ultimate strength (N/mm^2)	1000	Screw tensile area	14.2	mm^2
Measured ultimate strength (N/mm^2)	1095	collar OD	7.8	mm
collar ultimate strength (N/mm^2)	690	collar ID	5.1	mm
		collar area	27.4	mm^2

Test resistances

Test	Test result (kN)	Normalised result (kN)			
1	54.4	49.7	**BS 5950**		
2	55.9	51.0	Screw	5.7	kN
3	56.8	51.9	Collar	7.6	kN
4	57.2	52.2	Total	13.2	kN
	mean	51.2			
	standard deviation	1.13	**BS EN 1993**		
	coefficient of variation	2.2%	Screw	6.8	kN
			Collar	9.1	kN
	$k_{d,n}$	3.44	Total	15.9	kN

design resistance from test (kN) 47.3 for two bolts

design resistance per bolt (kN) 23.7 for one bolt

TW6 Carbon

Specified ultimate strength (N/mm²)	1000	Screw tensile area	20.1 mm²
Measured ultimate strength (N/mm²)	1095	collar OD	9.5 mm
collar ultimate strength (N/mm²)	690	collar ID	6.1 mm
		collar area	41.7 mm²

Test resistances

Test	Test result (kN)	Normalised result (kN)		
1	73.3	67.0	**BS 5950**	
2	78.5	71.7	Screw	8.0 kN
3	76.1	69.5	Collar	11.5 kN
4	77.8	71.1	Total	19.5 kN
	mean	69.8		
	standard deviation	2.12	**BS EN 1993**	
	coefficient of variation	3.0%	Screw	9.6 kN
			Collar	13.8 kN
	$k_{d,n}$	3.44	Total	23.4 kN

design resistance from test (kN) 62.5 for two bolts

design resistance per bolt (kN) 31.3 for one bolt

TW8 Carbon

Specified ultimate strength (N/mm²)	1000	Screw tensile area	36.6 mm²
Measured ultimate strength (N/mm²)	1095	collar OD	12.6 mm
collar ultimate strength (N/mm²)	690	collar ID	8.2 mm
		collar area	71.9 mm²

Test resistances

Test	Test result (kN)	Normalised result (kN)		
1	138.1	126.1	**BS 5950**	
2	131.4	120.0	Screw	14.6 kN
3	131.4	120.0	Collar	19.8 kN
4	141.5	129.2	Total	34.5 kN
	mean	123.8		
	standard deviation	4.60	**BS EN 1993**	
	coefficient of variation	3.7%	Screw	17.6 kN
			Collar	23.8 kN
	$k_{d,n}$	3.44	Total	41.4 kN

design resistance from test (kN) 108.0 for two bolts

design resistance per bolt (kN) 54.0 for one bolt

TW5 Stainless

Specified ultimate strength (N/mm^2)	700	Screw tensile area	14.2 mm^2
Measured ultimate strength (N/mm^2)	759	collar OD	7.8 mm
collar ultimate strength (N/mm^2)	700	collar ID	5.1 mm
		collar area	27.4 mm^2

Test resistances

Test	Test result	Normalised result (kN)		
			BS 5950	
1	46.2	42.6		
2	45.9	42.3	Screw	4.0 kN
3	46.5	42.9	Collar	7.7 kN
4	46.0	42.4	Total	11.6 kN
	mean	42.5		
	standard deviation	0.24	**BS EN 1993**	
	coefficient of variation	0.6%	Screw	4.8 kN
			Collar	9.2 kN
	$k_{d,n}$	3.44	Total	14.0 kN

design resistance from test (kN) 41.7 for two bolts

design resistance per bolt (kN) 20.9 for one bolt

TW6 stainless

Specified ultimate strength (N/mm^2)	700	Screw tensile area	20.1 mm^2
Measured ultimate strength (N/mm^2)	759	collar OD	9.5 mm
collar ultimate strength (N/mm^2)	700	collar ID	6.1 mm
		collar area	41.7 mm^2

Test resistances

Test	Test result (kN)	Normalised result (kN)		
			BS 5950	
1	70.1	64.6		
2	68.7	63.3	Screw	5.6 kN
3	69.5	64.1	Collar	11.7 kN
4	69.3	63.9	Total	17.3 kN
	mean	64.0		
	standard deviation	0.54	**BS EN 1993**	
	coefficient of variation	0.8%	Screw	6.8 kN
			Collar	14.0 kN
	$k_{d,n}$	3.44	Total	20.8 kN

design resistance from test (kN) 62.1 for two bolts

design resistance per bolt (kN) 31.1 for one bolt

TW8 Stainless

Specified ultimate strength (N/mm^2)	700	Screw tensile area	36.6 mm^2
Measured ultimate strength (N/mm^2)	759	collar OD	12.6 mm
collar ultimate strength (N/mm^2)	700	collar ID	8.2 mm
		collar area	71.9 mm^2

Test resistances

Test	Test result (kN)	Normalised result (kN)		
			BS 5950	
1	127	117.2	Screw	10.2 kN
2	120	111.1	Collar	20.1 kN
3	108	99.3	Total	30.4 kN
4	116	106.9		
	mean	108.6		
	standard deviation	7.50	**BS EN 1993**	
	coefficient of variation	6.9%	Screw	12.3 kN
			Collar	24.2 kN
	$k_{d,n}$	3.44	Total	36.4 kN

design resistance from test (kN)	82.8	for two bolts
design resistance per bolt (kN)	41.4	for one bolt

Appendix B TENSION RESISTANCE

This appendix records the detailed calculations for the tension resistance of carbon steel and stainless steel TW bolts.

TW5 Carbon

Specified ultimate strength (N/mm^2)	1000	Screw tensile area	14.2	mm^2
Measured ultimate strength (N/mm^2)	1095			

Test resistances

Test	Test result (kN)	Normalised result (kN)			
1	10.0	9.2	**BS 5950**		
2	9.8	9.0	Screw	9.9	kN
3	13.3	12.2			
4	9.8	9.0			
5	10.8	9.8			
6	13.7	12.5			
	mean	10.3			
	standard deviation	1.64	**BS EN 1993**		
	coefficient of variation	16.0%	Screw	7.2	kN
	$k_{d,n}$	3.33			
	design resistance from test (kN)	4.8			

TW6 Carbon

Specified ultimate strength (N/mm^2)	1000	Screw tensile area	20.1 mm^2
Measured ultimate strength (N/mm^2)	1095		

Test resistances

Test	Test result (kN)	Normalised result (kN)		
1	20.94	19.1	**BS 5950**	
2	21.34	19.5	Screw	14.1 kN
3	21.16	19.3		
4	22.46	20.5		
5	22.32	20.4		
6	21.46	19.6		
	mean	19.7		
	standard deviation	0.57	**BS EN 1993**	
	coefficient of variation	2.9%	Screw	10.1 kN
	$k_{d,n}$	3.33		
	design resistance from test (kN)	17.8		

TW8 Carbon

Specified ultimate strength (N/mm^2)	1000	Screw tensile area	36.6 mm^2
Measured ultimate strength (N/mm^2)	1095		
collar ultimate strength (N/mm^2)			

Test resistances

Test	Test result (kN)	Normalised result (kN)		
1	35.1	32.1	**BS 5950**	
2	38.2	34.9	Screw	25.6 kN
3	38.6	35.2		
4	33.5	30.6		
5	36.6	33.5		
6	35.5	32.4		
	mean	33.1		
	standard deviation	1.76	**BS EN 1993**	
	coefficient of variation	5.3%	Screw	18.4 kN
	$k_{d,n}$	3.33		
	design resistance from test (kN)	27.2		

TW5 Stainless

Specified ultimate strength (N/mm²)	700	Screw tensile area	14.2 mm²
Measured ultimate strength (N/mm²)	759		

Test resistances

Test	Test result	Normalised result (kN)		
1	9.06	8.4	**BS 5950**	
2	8.93	8.2	Screw	7.0 kN
3	9.03	8.3		
4	8.96	8.3		
5	8.98	8.3		
6	8.95	8.3		
	mean	8.3		
	standard deviation	0.05	**BS EN 1993**	
	coefficient of variation	0.6%	Screw	5.0 kN
	$k_{d,n}$	3.33		
	design resistance from test (kN)	8.1		

TW6 stainless

Specified ultimate strength (N/mm²)	700	Screw tensile area	20.1 mm²
Measured ultimate strength (N/mm²)	759		

Test resistances

Test	Test result (kN)	Normalised result (kN)		
1	15.3	14.1	**BS 5950**	
2	15.3	14.1	Screw	9.8 kN
3	15.6	14.4		
4	15.4	14.2		
5	15.6	14.4		
6	15.5	14.2		
	mean	14.2		
	standard deviation	0.14	**BS EN 1993**	
	coefficient of variation	1.0%	Screw	7.1 kN
	$k_{d,n}$	3.33		
	design resistance from test (kN)	13.8		

TW8 Stainless

Specified ultimate strength (N/mm^2)	700	Screw tensile area	36.6 mm^2
Measured ultimate strength (N/mm^2)	759		

Test resistances

Test	Test result (kN)	Normalised result (kN)		
1	27.06	25.0	**BS 5950**	
2	28.86	26.6	Screw	17.9 kN
3	27.3	25.2		
4	27.31	25.2		
5	27.13	25.0		
6	27.2	25.1		
	mean	25.3		
	standard deviation	0.63	**BS EN 1993**	
	coefficient of variation	2.5%	Screw	12.9 kN
	$k_{d,n}$	3.33		
	design resistance from test (kN)	23.2		

Appendix C TESTED SAMPLES

Photos of tested TW bolts are shown in this Appendix.