Clarity brought to blind bolt resistances

By Andy Smith, Steel Construction Institute

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Blind bolts

Blind bolts have been developed to enable easy connections to be made when access to one side of the connection is restricted, such as in a hollow section. A weighted toggle sits within the shaft of the bolt when it is inserted into the hole and will drop across the hole from the inside when the bolt is rotated through 90°. The bolts are manufactured in grade 10.9 material (yield strength of 900N/mm², ultimate tensile strength of 1,000N/mm²) and are available in sizes from M8 to M24.

Due to the unique cross section of the product, and the possible failure mechanisms relating to the toggle, the design rules according to BS 5950-1 or BS EN 1993-1-8 cannot be used without modification. Acting for the manufacturer, SCI commissioned a series of tests on the bolts and developed product specific design rules using an analysis in accordance with BS EN 1990.

Testing programme

Tests were undertaken to establish the tensile resistance, shear resistance and bearing resistance of the bolts, as well as the combined tension and shear behaviour. In common with usual practice, the tensile resistance was determined by applying a compressive force to an assembly consisting of two 'U' shaped blocks bolted together across their tips. Tests were undertaken on three different bolt sizes – M10, M20 and M24.

Shear tests were undertaken across the slotted region of the bolt for the three different bolt sizes to establish the relationship between the shear area and the resistance. The shear resistance of the threaded region is well established, but tests across this plane were carried out for the M10 size to verify the established design rules for use with blind bolts.

The performance of the bolts in combined bending and shear was established by applying a tensile force to a rig that allows the bolt to be angled. M10 and M20 bolts were tested at angles of 30°, 45° and 60°.

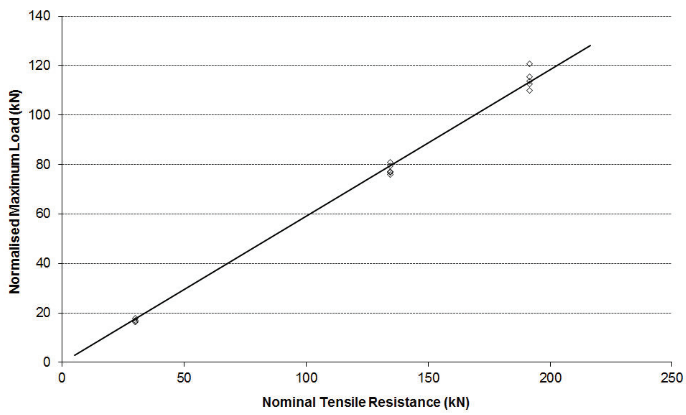
Bearing tests were performed with plate thicknesses of 6mm, 10mm and 15mm, and steel grades of S285 and S355. The majority of these tests failed due to shear of the bolt, but a sufficient number failed through bearing to develop design rules for the bolts.

In addition to the tests on the bolts themselves, coupon tests were performed to establish the strength of the bolt material. Cylindrical samples were cut from the bolts and subjected to a tensile test to establish the yield and ultimate tensile strengths.

Establishing design rules from test data

The test data was used to calibrate the design rules in BS 5950-1 and BS EN 1993-1-8 to be specific to the product. For the tensile resistance, the test results were first normalised to the nominal yield strength using the observed yield strength. These resistances were then compared to the nominal tensile strength calculated using the equation from Eurocode 3 with the minimum cross sectional area (which is the area in the slotted region where the pin is located). This comparison is shown below:

Comparison between nominal and observed tensile resistance



The graph shows consistency between the three different bolt sizes, but a gradient of less than 1.0 for the line of best fit that passes through the origin. For each of the 14 successful tests, a correction factor was calculated as the ratio of the normalised maximum load to the nominal resistance and then these were used to establish a characteristic correction factor using the statistical methods in BS EN 1990, Annex D. This resulted in the following equation for the tensile resistance of blind bolts:

$$F_{t,Rd} = \frac{F_{t,Rk}}{\gamma_{M2}} = \frac{0.537 f_{u,nom} A_t}{\gamma_{M2}}$$

Where $f_{u,nom}$ is the nominal ultimate tensile strength of the bolt material (1,000N/mm^2 in this case), A_t is the tensile area of the bolt and γ_{M2} is the partial factor, defined as 1.25 in the UK National Annex. This is the same equation as found in BS EN 1993-1-8 for the tensile resistance of a bolt, but with a k_2 factor of 0.537, rather than the 0.9 or 0.63 for standard bolts or countersunk bolts respectively. The mean test result, the characteristic tensile resistance (which is a 95% confidence limit) and the design tensile resistance are shown in the following table for the three bolt sizes tested.

Bolt size	$F_{t,Rm}$ (kN)	$F_{t,Rk}$ (kN)	$F_{t,Rd}$ (kN)
M10	16.87	16.16	12.93
M20	78.03	72.28	57.82
M24	114.43	102.89	82.31

An equivalent equation was developed for design to BS 5950-1, where a tensile strength of P_t = 430N/mm^2 is used in place of the value given.

A similar analysis was conducted for the shear resistance of the bolts, and this found that the characteristic correction factor on the Eurocode equation was greater than 1.0. Rather than giving an improvement over the standard defined values, the rules from BS EN 1993-1-8 were adopted without modification, so the resulting design equation is:

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

Where α_v is taken as 0.5 when the shear plane passes through the threaded region and 0.6 when the shear plan passes through the unthreaded region, and A is taken as the shear area of the shear plane in question. The mean, characteristic and design resistances for the slotted region of the bolts for the three sizes are as follows:

Bolt size	$F_{v,Rm}$ (kN)	$F_{v,Rk}$ (kN)	$F_{v,Rd}$ (kN)
M10	32.05	23.78	19.02
M20	148.04	95.13	76.10
M24	257.20	131.71	105.37

The test results also showed an enhancement over the resistances to BS 5950-1, so the rules defined in that standard were adopted unaltered.

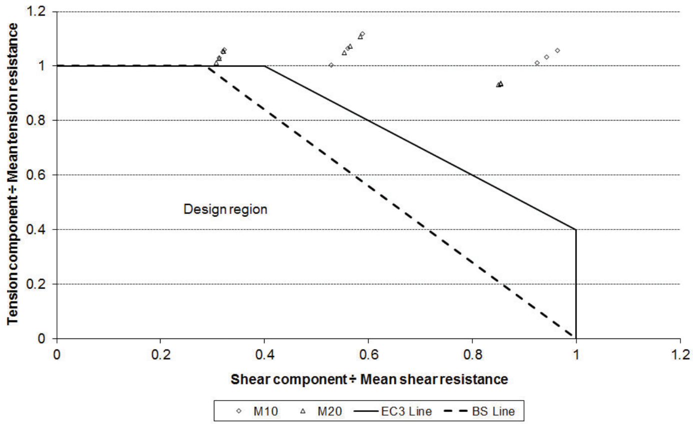
For the combined tension and shear tests, the intention was simply to validate the current design rules:

To EC3: $$\frac{F_{v,Ed}}{F_{v,Rd}} + \frac{F_{t,Ed}}{1.4F_{t,Rd}} \leq 1.0$$

To BS 5950: $$\frac{F_s}{P_s} + \frac{F_t}{P_t} \leq 1.4$$

The test results were split into their tension and shear components and compared to the mean tension and shear resistances from the pure tension and shear tests. These results were then plotted to enable comparison with the rules from the standards. This comparison is shown in the graph below:

Combined tension and shear test results



This plot shows that all of the test results fell outside of the design envelopes for both the Eurocode and British Standard, so the current rules can be adopted for the blind bolts. Making the comparison using the mean test results incorporates a suitable factor of safety as the design resistances will be used in the equations in practice.

The bearing resistance is defined in different ways to the Eurocodes and British Standards. In BS EN 1993-1-8, the bearing resistance is the ultimate strength of the connection, and the analysis showed that there is no change to the design rules in the standard as the presence of the slot appears not to have an effect. The design equation is therefore:

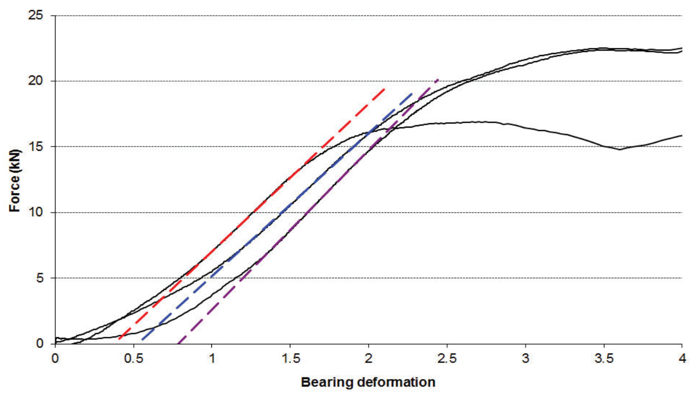
$$F_{b,Rd} = \frac{k_1 \alpha_b f_u d t}{\gamma_{M2}}$$

Where k_1 and α_b are factors that take into account the geometry of the plate and hole, f_u is the ultimate tensile strength of the plate material, d is the diameter of the hole and t is the thickness of the plate. The mean, characteristic and design resistances for the tests that failed in bearing rather than in shear are as follows:

Bolt size	Plate thickness	Steel grade	$F_{b,m}$ (kN)	$F_{b,Rk}$ (kN)	$F_{b,Rd}$ (kN)
M20	6mm	S275	144.6	97.8	78.2
		S355	168.1	115.9	92.7
M24	6mm	S275	177.4	119.1	95.3
		S355	204.8	141.3	113.0
	10mm	S275	267.9	198.5	158.8
		S355	289.5	235.4	188.3

For design to the British Standards, the bearing resistance is a serviceability limit, allowing a maximum deformation under working loads of 1.5mm. For each test, the gradient of the slope after bedding in was determined, as shown in the following graph:

Initial gradients for M10 bolts in 6mm S275 plates

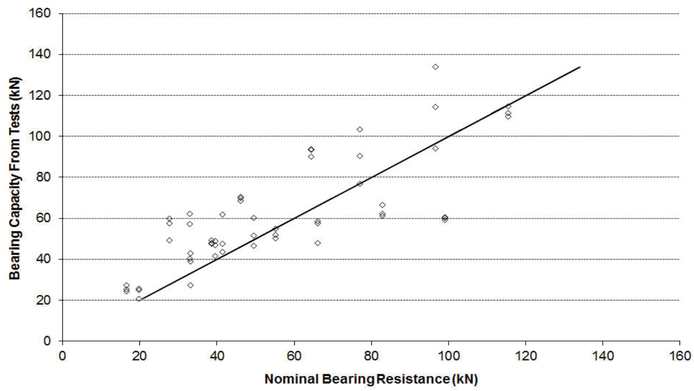


The bearing capacity of each test was calculated by multiplying the gradient by the deformation limit (1.5mm) and a factor of 1.5 that accounts for the difference between design load and working load (taken as the average of the dead load and live load factors). All of these capacities were significantly lower than the bearing resistances to Eurocode 3 shown above. A modified version of the BS 5950-1 equation was used to calibrate the bearing capacity:

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

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, p_{bs} is the bearing strength of the connected part and *e* is the end distance. This equation was used to develop a nominal bearing capacity for each test, and the results were plotted:

Comparison of the bearing capacities from tests with the nominal bearing resistance



As the vast majority of the test results are above or close to the unity line, the bearing capacity is effectively a serviceability limit, and the bearing resistances are significantly lower than the ultimate design bearing resistances given by the Eurocodes, it was decided that the modified equation given previously could be applied for design to the Eurocodes.

The design equations for blind bolts have been developed to be consistent with the current rules in both the Eurocodes and British Standards, and can be applied for other sizes of blind bolts within the range tested as long as the proportions are similar. More information on blind bolts, including all of the design properties, is available from www.blindbolt.co.uk. The test results and design values given above should give confidence in the values that are quoted, and enable the designer to use them without further modification. ■

www.blindbolt.co.uk