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Strength and Ductility of Single Point, Self-Drilling Fasteners in Bending and Shear

Research Report No R872

By

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July 2006

ISSN 1833-2781



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Abstract:

The report describes tests on connections featuring self-drilling screws and gaps between the connected parts. Gaps typically occur when using inserts of a smaller dimension than the overlapping section, e.g. a tube. In such connections, the screws are subjected to the combined actions of shear and bending.

Tests were conducted on single and multiple screw connections loaded in shear. The gap was systematically increased from zero (pure shear) to about 1.3 times the screw diameter. Further gap-tests were conducted where the screw was inserted non-perpendicular to the section and where the screw was over-torqued until the head was removed. These situations occur frequently in practice, particularly when access restrictions prevent perpendicular screw insertion or impede the control of the torque. Based on the tests, design equations are proposed for screw connections with gaps. A reliability analysis is included deriving an appropriate capacity factor for screw connections with gaps.

Keywords:

Self-drillings screws, tubular sections, gap joints, cold-formed structures, tests, design, reliability analysis

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School of Civil Engineering, Research Report R872 Strength and Ductility of Single Point, Self-Drilling Fasteners in Bending and Shear

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Published by:
School of Civil Engineering
The University of Sydney
Sydney, NSW, 2006
AUSTRALIA

July 2006

<http://www.civil.usyd.edu.au>

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1 Introduction

Current rules for screws in shear in the Australian Standard for Cold-formed Steel Structures (AS/NZS4600, 2005) assume the plies are in direct contact so that the screws are subjected to shear with minimal bending effects. However, in certain cases, a gap is required between the plies for constructability, particularly when connections are assembled in the field. For instance, OneSteel has developed systems such as the DuraGal Flooring System, the DuraGal Mezzanine Flooring System and the DuraGal Portal Frame Shed, which use self-drilling screws to connect hollow section members, as exemplified in Figure 1. Inserting an inner tube in an outer tube, and fastening the two together with self-drilling (Tek) screws achieve the connections of these systems, relying on small gaps between the tubes to ease the assembly process. In these systems, the screws are subjected to a combination of shear and bending and the shear capacity may be less than the pure shear capacity. The capacity of the screws may also be affected by other factors prevalent in field assembly such as over-torquing and inserting the screw at a skewed angle.

This report addresses issues relevant to self-drilling screws, where construction tolerances (the varying gap between connected parts), over-torquing, inserting at an angle and impact effects may decrease the capacity from the value determined assuming the Tek self-drilling screw is in static pure shear. Tests are undertaken to determine the detrimental effect of these factors on the shear capacity of ITW-Buildex series 500 12-24x32mm and 14-20x22mm Tek screws. The results are presented as additions to the current design rules in Clause 5.4.2 of AS/NZS4600 (2005) for screwed connections in shear.

2 Test setup

2.1. *Single screws in shear and combined shear and bending*

The tests on single 14-20x22mm and series 500 12-24x32mm screws were performed in a 100kN capacity tension/compression testing machine. The bases supplied by OneSteel were bolted to a base plate in the rig as shown in Figure 2. The plate specimen was clamped in place with packing plates between the base and the plate to create the prescribed gap between the connected walls. Analysis of the product literature has identified that gaps of up to 7mm may occur between the connected walls in the post base connections due to tolerances of the bases and RHS posts. A single self-drilling screw was then drilled through both plate specimen and the base, using a power drill with set torque, as shown in Figure 3. The packing was then removed, and in its place packing strips (of the same thickness as the original packing plates) were inserted along the edges of the plate, as shown in Figure 4. This provided restraint to the edges of the plate such as would exist if the plate was part of an RHS post. The grips were then attached to the plate (Figure 5), and the test was run by applying a constant stroke rate in tension until the screw failed (Figure 6).

For the 14-20x22mm screw tests, the plate specimens were 2mm thick plates cold-cut from the RHS posts supplied by OneSteel. For the series 500 screw tests, the plate specimens were cold-cut mild steel plates of 6mm and 8mm thickness.

2.2. *Single screws in shear and combined shear and bending – Over-torqued*

The tests on single over-torqued screws were prepared by torqueing the screw until the head was removed, as shown in Figure 7. The series 500 screws were drilled through 6mm thick plates, and the screw heads sheared off when over-torqued. This could not be achieved with the 14-20x22mm screws, as they were drilled through plates of 2mm thickness only, and over-torqueing caused the screw to unthread the thickness of the material and the screw spun in the hole. The connections were then tested as described in Section 2.1.

2.3. *Single screws in shear and combined shear and bending - Angled*

The tests on single angled screws, where the screws were not perpendicular to the members, were prepared by scribing on the base a line at an angle of 20° from perpendicular, and approximately drilling the screw in along this line (Figure 8). The connections were then tested as described in Section 2.1. Angled tests were performed for both the series 500 and 14-20x22mm Tek screws.

2.4. *Cantilever tests - Post and base connection tests*

The tests on 14-20x22mm screw groups were performed on the post and base connections, in the laboratory. A 2m section of RHS provided by OneSteel was first screw connected with two screws in opposing faces to a base using a power drill with set torque. When the first screw was drilled in, the self-drilling action was such that no gap existed between the connected walls. The second screw was then inserted, and a gap existed between the connected walls due to the tolerances of the RHS and base. This tolerance was measured accurately previous to insertion of the screws. The base was then fixed to the strong floor of the laboratory, ensuring that the screw with the gap was on the side of the RHS that was to be in tension. A hand-held pressure pack was placed at a height of 1.5m from the base, and a stiff column was used to provide the reaction force, as shown in Figure 9. A ring gauge was placed in-line with the pressure pack to measure the applied force (Figure 9). The test was performed by applying pressure by hand pumping the pressure-pack, with one technician reading the load on the ring gauge and the other measuring the displacement with a tape (Figure 10). The test was continued until the screw connection failed, and the failure load and displacement were recorded. The connections failed by failure of the self-drilling screw on the side of the RHS in tension, which featured a gap.

2.5. *Stub tests*

To ensure that the condition of the 14-20x22mm Tek screw inserted in a single plate is congruent with a Tek screw inserted in an RHS post, a number of stub tests were performed. The stub tests used a 100mm section of the RHS post, with a single Tek screw in one face. The grips of the testing machine were then attached to the face with the screw and the test was performed, as shown in Figure 11.

3 Test specimens

The bases provided by OneSteel consisted of two 30mm sections of equal leg 75mm angles with wall thickness 4mm, welded to an 8mm thick base plate, as shown in Figure 12. The RHS provided was 90x90x2mm RHS G450. The plates used in the single 14-20x22mm screw tests were cold-cut from the RHS sections. The plates used in the series 500 tests were cold-cut from mild-steel plate nominally 6mm and 8mm thick. Approximately half of the 14-

20x22mm self-drilling screws were provided by ITW-Buildex, and the remaining were provided by Ajax, and are of nominal diameter 6.3mm. The series 500 12-24x32mm screws were provided by ITW-Buildex, and are of nominal diameter 5.5mm. The nominal dimensions of the screws are shown in Figure 13. The screws conform to the Australian Standard AS3566 - Class 3 (AS3566 1988). The nominal shear strengths of the 14-20x22mm and series 500 12-24x32mm screws are 10.9kN and 8.8kN respectively, as obtained from the product literature from Buildex (determined from testing).

4 Test procedure and instrumentation

4.1. *Single screw tests (Normal, over-torqued and angled) – Static tests*

A series of tests was performed on single screws as “static” tests. The stroke rate for the static tests was 0.01mm/sec, and a typical test ran for 10min. The readings from the load cell and the displacement of the cross-head were recorded at intervals of 1sec.

4.2. *Cantilever tests (Post and base connection tests)*

The tests on screw groups were performed relatively slowly, with a typical test taking approximately 5min. The applied load and displacement (at 1.5m height from the base) were recorded at failure only. From the applied load at 1.5m height, the applied moment at the base is calculated (applied load \times 1.5m). The shear force at each screw is then calculated by dividing the applied moment by the distance ($d=B-2t-g/2\cong 83\text{mm}$) between the screw in pure shear and the point of contra-flexure of the screw in combined bending and shear, as shown in Figure 1b. An example calculation is shown in Section 6. The gap magnitude (g) in these tests was obtained by accurately measuring the outer dimension of the base and the inner dimension of the RHS post used in each test.

4.3. *Stub tests*

The stub tests were performed on single screws as “static” tests, with a stroke rate of 0.01mm/sec. The readings from the load cell and the displacement of the cross-head were recorded at intervals of 1sec.

4.4. *Single screw tests – Dynamic tests*

A series of tests was performed on single 14-20x22mm screws as “dynamic” tests, on screws that were normally torqued and inserted perpendicular to the member. The stroke rate for the dynamic tests was up to 200mm/sec, at which speed a test would run for approximately 0.025sec. The tests were performed in order to investigate if impact effects could affect the shear strength of the self-drilling screws. The readings from the load cell and the displacement of the cross-head were recorded at intervals of 0.001sec.

5 Test results

5.1. *General*

The test results are summarised in Figures 14 and 15 for 14-20x22mm screws and series 500 screws respectively. The figures plot the failure loads for all specimens, against the

prescribed “gap” (construction tolerance). The failure loads are tabulated in Tables 1 to 6. In these figures and tables the width of the gap is the measured width. An example curve of load against cross-head position is shown in Figure 16.

5.2. *Single screw test results*

The single screw test results for 14-20x22mm screws inserted perpendicular to the member are tabulated in Table 1 and plotted in Figure 14. The single screw test results for series 500 screws inserted perpendicular to the member, through 6mm plate, are tabulated in Table 2 and plotted in Figure 15. The figures show that as the magnitude of the gap is increased the failure load of the screws decreases, as increasingly large bending stresses are induced in the screws. It can be seen that an approximately linear relationship exists between the failure load and the magnitude of the gap. The tests with zero gap give the pure shear capacity of the screws.

Single screw test results for series 500 screws inserted perpendicular to the member, through 8mm plate, are tabulated in Table 3 and plotted in Figure 15. It was determined from these results that the failure loads were not significantly different from those using 6mm plates.

5.3. *Single screw test results – Over-torqued*

The single screw test results for series 500 screws inserted perpendicular to the member and over-torqued, through 6mm plate, are tabulated in Table 2 and plotted in Figure 15. In Figure 15 it can be seen that while the screws have had their heads removed, there is sufficient threaded screw remaining in the material that the failure loads are in general only marginally lower than those for normally torqued screws.

Single screw test results for series 500 screws inserted perpendicular to the member and over-torqued, through 8mm plate, are tabulated in Table 3 and plotted in Figure 15. It was noticed from these tests that over-torqued screws through 8mm plates have slightly higher failure loads than those through 6mm plates, due to the larger material thickness.

5.4. *Single screw test results – Angled*

The single screw test results for 14-20x22mm screws inserted at an angle are tabulated in Table 1 and plotted in Figure 14. The single screw test results for series 500 screws inserted at an angle are tabulated in Table 2 and plotted in Figure 15. It can be seen from the figures that, in general, when the screw is inserted at up to 20° from perpendicular, the scatter of the results is greater than for perpendicular screws, however the mean is approximately the same. Indeed, the failure load may be greater than that for perpendicular screws as in some cases the angled screw becomes jammed, and begins to resist load in tension also.

5.5. *Cantilever test results*

The cantilever test results for 14-20x22mm screws are tabulated in Table 4 and plotted in Figure 14. It can be seen in Figure 14 that the cantilever test results lie slightly below the single screw tests, suggesting that the method of calculating the shear force from the applied moment is not exact (an example of this calculation is shown in Section 6).

5.6. *Stub test results*

The stub test results for 14-20x22mm screws are tabulated in Table 5 and plotted in Figure 14. It can be seen from these results that the single screw tests are sufficiently close to the stub tests that we may assume the single screw tests accurately model screws inserted in RHS members.

5.7. *Single screw tests – Dynamic tests*

The single screw test results for 14-20x22mm screws inserted perpendicular to the member and tested dynamically are tabulated in Table 6 and plotted in Figure 14. The failure loads are on average 15% higher than the static tests, however in Figure 14 they lie within the general scatter.

6 Design equations

In Figure 14 a mean straight line through all the failure loads for the single 14-20x22mm screws is plotted. The equation of this line is given by eqn. (1). In Figure 15 a mean straight line through all the failure loads for the single series 500 screws is plotted. The equation of this line is given by eqn. (2).

$$V_{bg} = V_b \left(1.14 - 0.548 \frac{g}{d_f} \right) \quad (g \leq 8\text{mm}) \quad (1)$$

$$V_{bg} = V_b \left(0.98 - 0.418 \frac{g}{d_f} \right) \quad (g \leq 8\text{mm}) \quad (2)$$

In equations (1,2), V_{bg} is the shear capacity of a screw connection with a gap, V_b is the pure shear capacity in the absence of a gap, g is the prescribed gap between connected walls, and d_f is the screw diameter.

Since these equations are means of all the single screw failure loads, they account for all the variables investigated, i.e. construction tolerances (gaps), over-torqueing, inserting at an angle and impact effects. A single design equation for the nominal capacity of general screw connections with gaps may be determined by averaging eqns (1) and (2), and is given by eqn. (3).

$$V_{bg} = V_b \left(1 - 0.5 \frac{g}{d_f} \right) \quad (g \leq 8\text{mm}) \quad (3)$$

In a design situation, the nominal (pure) shear capacity (V_b) would be determined from Clause 5.4.2.5 of AS/NZS4600 (2005), which specifies that the shear capacity be determined by testing. An engineer using this Clause would use the nominal shear capacity given by the product literature for the screws being used. In accordance with the nomenclature of AS/NZS4600, we can deduce the design equations 5.4.2.5(1) and 5.4.2.5(2) following, where the term V_{bg} represents the nominal strength of a screw inserted in the field, where construction tolerances (gaps) may occur in combination with over-torqueing, inserting at an angle and impact effects. The following Clause is proposed for screw connections with gaps:

5.4.2.5 Screws in shear with gaps The design shear force (V_{bg}^*) on a screw in a connection with a gap between the connected plies shall satisfy-

$$V_{bg}^* \leq \Phi V_{bg} \quad 5.4.2.5(1)$$

where

Φ = Capacity factor for a screw in shear with gap = 0.5

V_{bg} = Nominal capacity of a screw in shear with gap

$$= V_b \left(1 - 0.5 \frac{g}{d_f}\right) \quad 5.4.2.5(2)$$

V_b = Nominal capacity of a screw in pure shear determined according to Clause 5.4.2.4.

g = Nominal gap between connected walls ≤ 8 mm

d_f = Nominal screw diameter

The value of the capacity factor of 0.5 was determined by a reliability analysis of the single screw test data to the Australian Standard, presented in Appendix A. The design strength (ΦV_{bg}) is plotted in Figures 14 and 15 for 14-20x22mm and series 500 screws respectively for the capacity factors of 0.5 and 0.6 (a reliability analysis to the North American Standard yields a capacity factor of 0.6).

7 Conclusions

Single screw test data has been presented for 14-20x22mm and series 500 12-24x32mm single point, self-drilling fasteners (Tek screws). The failure loads for single screws have been shown to compare well with tests on short RHS posts (stub tests) and long RHS posts (cantilever tests), such that the single screw tests may be considered representative of screw groups. The single screw tests included screws inserted perpendicular to the face of the member into which they are inserted, with gaps representing construction tolerances of up to 8mm, screws inserted at up to 20° from the perpendicular, screws that were over-torqued until the head was removed, and screws tested dynamically to represent impact loading.

A single design equation has been presented which may be used to determine the reduced shear capacity of Tek screws in connections featuring gaps. The reduction in capacity from the nominal (pure) shear capacity due to construction tolerances (gaps) includes the effects of over-torquing, inserting at an angle and impact. The design equation is in a form congruent with the Australian Standard AS/NZS4600 (2005) pertaining to the strength of Tek screws in shear, and is a function of the magnitude of the construction tolerance.

8 Acknowledgements

This work was undertaken as part of a research project (2001-311) within the Cooperative Research Centre for Welded Structures (CRC-WS). The CRC-WS was established and is supported under the Australian Government's Cooperative Research Centres Program. The testing materials were provided by OneSteel Market Mills Pipe & Tube.

9 References

AS3566 (1988). *Screws - Self-drilling - for the Building and Construction Industries*. Sydney, Standards Australia.

AS/NZS4600 (2005). *Cold-formed Steel Structures, AS/NZS 4600*. Sydney, Standards Australia.

AS/NZS4600Supplement1 (1998). *Cold-formed Steel Structures - Commentary to AS/NZS4600:1996*. Sydney, Standards Australia.

Tables

Perpendicular		Angled	
Measured Gap Failure Load		Measured Gap Failure Load	
(mm)	(kN)	(mm)	(kN)
0	13.5	0	16.2
0	13.3	0	12.6
0	13.1	0	15
0	13.3	0	13.1
2.5	11.9	2.5	11.2
2.5	12.9	2.5	10.6
2.5	12.1	2.5	11.2
2.5	8.9	2.5	11
4	8.7	4	9.3
4	8.8	4	11.7
4	10.5	4	7.6
4	11	4	9.6
5	8.3	4	12.9
		4	8.2
		4	10.1
		4	10.4
6.3	7.2	6.3	8.7
6.3	7	6.3	6.7
6.3	7.9	6.3	4.8
6.3	7.7	6.3	6.3
8	3.9	8	3.8
8	5.9	8	7.2
8	7.9	8	3.6

Table 1: Test results on single 14-20x22 screws

Perpendicular		Over-Torqued		Angled	
Measured Gap Failure Load		Measured Gap Failure Load		Measured Gap Failure Load	
(mm)	(kN)	(mm)	(kN)	(mm)	(kN)
0	9.8	0	8.4	0	9.3
0	9.9	0	9.4	0	9.9
		0	8.7	0	8.6
				0	9.2
2.5	6.3	2.5	5.7	2.5	6.3
2.5	8.1	2.5	7.1	2.5	8.3
2.5	6.8	2.5	6.9	2.5	7.8
2.5	6.2	2.5	6.7	2.5	7.7
4	5.9	4	5		
4	7.2	4	5.7		
4	6.5	4	3.8		
4	6.5	4	4.9		
6.3	5.4	6.3	4.6	6.3	3.6
6.3	5.2	6.3	4.1	6.3	4.2
6.3	4.6	6.3	3.7	6.3	3.9
6.3	4.6	6.3	3.9	6.3	4.4
8	3.8	8	5	8	3.3
8	3.9	8	3.9	8	2.4
8	4.3	8	2.5	8	4.3
8	4	8	3.4	8	3.6

Table 2: Test results on single series 500 screws through 6mm plate

Measured Gap (mm)	Plate thickness (mm)	Perpendicular	Over-torqued
		Failure Load (kN)	Failure Load (kN)
0	8	9.6	11.8
0	8	9.4	10
0	8	9	10.3
0	8	9.5	
4	8	6.5	
4	8	7.4	
4	8	6.7	

Table 3: Test results on single series 500 screws through 8mm plate

Specimen	Measured		Max. Deflection of RHS (mm)
	Gap (mm)	Failure Load (kN)	
CANT_1	3.4	8.9	40
CANT_2	2.7	8.8	95
CANT_3	2.8	9.4	110

Table 4: Cantilever test results on 14-20x22 screw groups – post and base connections

Specimen	Measured		Failure Load (kN)
	Gap (mm)		
STUB_1	2.5		12.1
STUB_2	2.5		12.6
STUB_3	2.5		11.1
STUB_4	0		12.6
STUB_5	0		13.6

Table 5: Stub test results on single 14-20x22 screws inserted into stubs

Measured Gap (mm)	Test Speed (mm/sec)	Failure Load (kN)
4	10	11.8
4	10	11.2
4	50	11.3
4	200	11.5

Table 6: Test results on single 14-20x22 screws – Dynamic tests

Figures

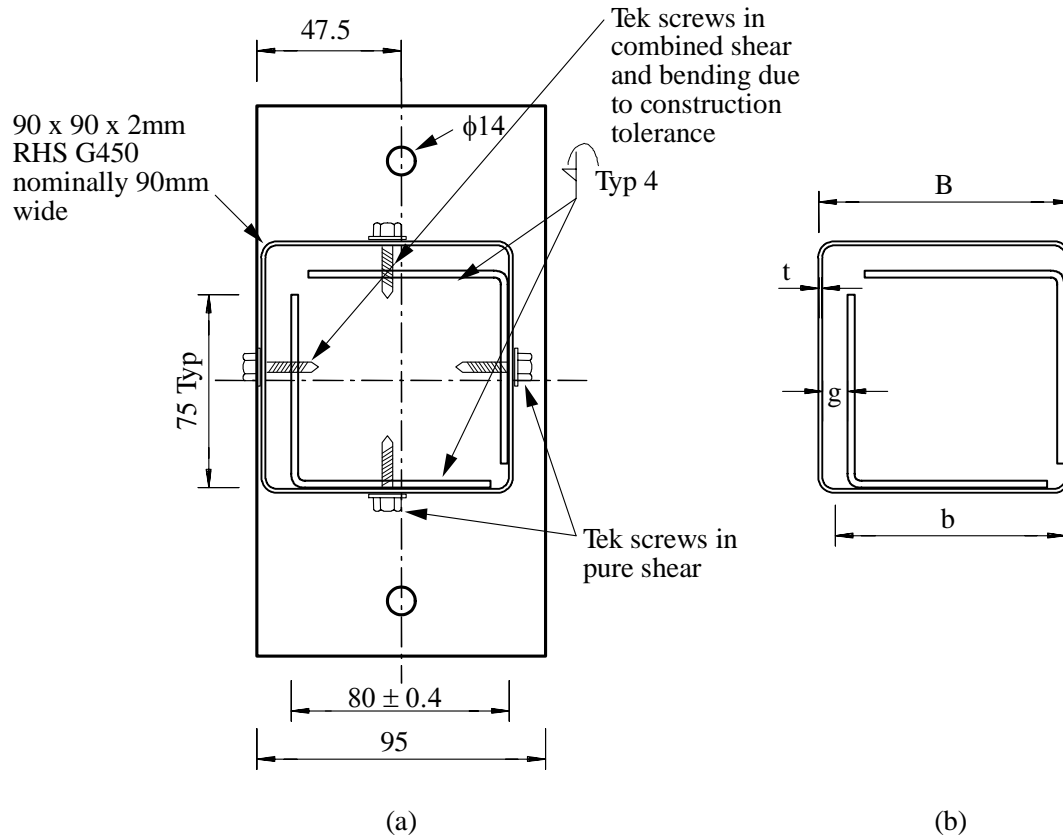


Figure 1: Post to base connection showing where shear and bending in Tek screws occurs

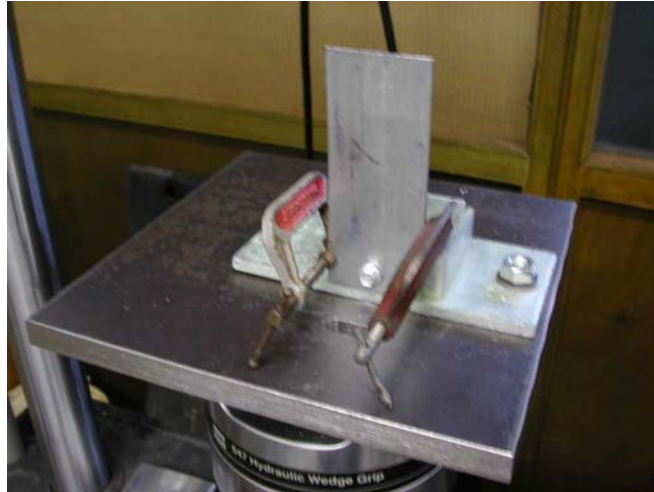


Figure 2: Insertion of screw for single screw test



Figure 3: Single screw inserted with packing



Figure 4: Packing replaced by edge packing

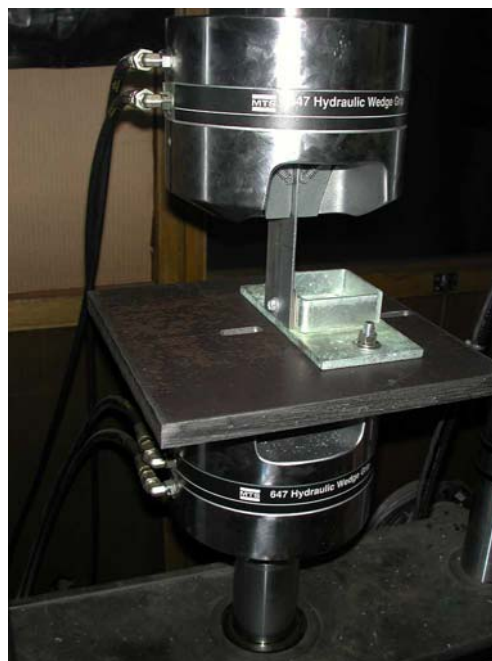


Figure 5: Single screw test



Figure 6: Single screw test after failure

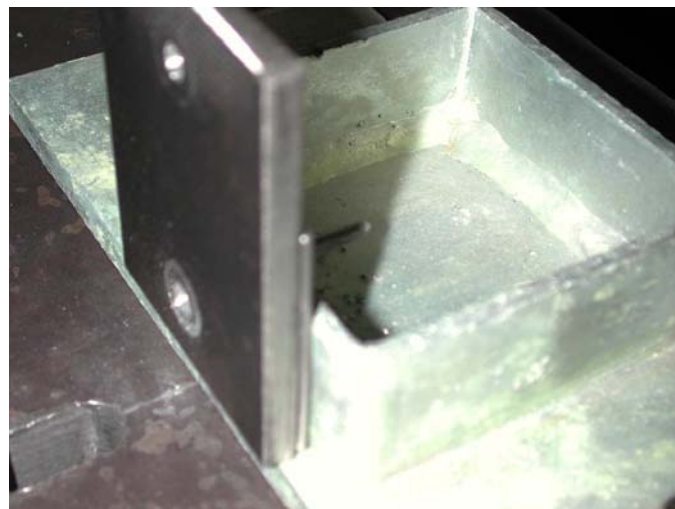


Figure 7: Single screw over-torqued until the head is removed



Figure 8: Single screw inserted at an angle of approximately 20°



Figure 9: Cantilever test setup



Figure 10: Cantilever test near failure

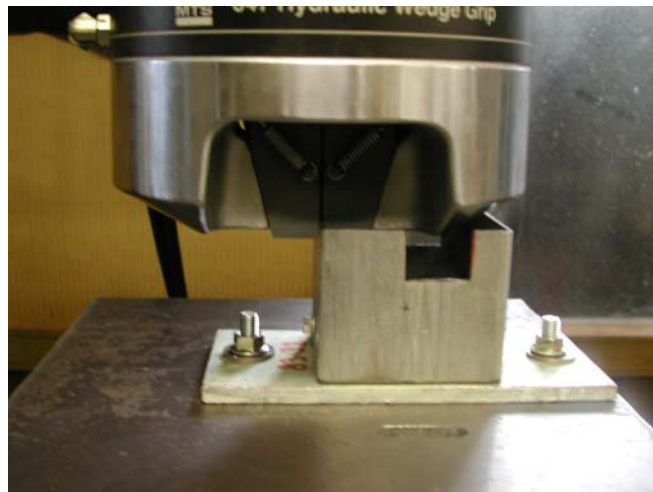
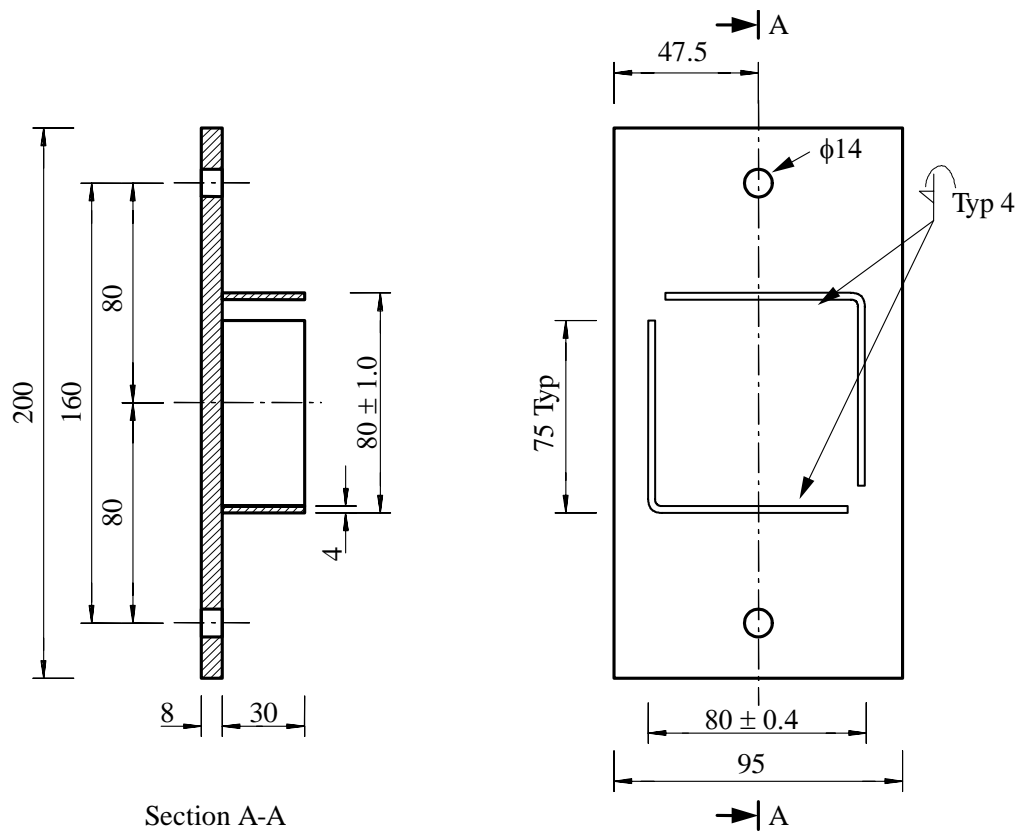


Figure 11: Stub test setup

**Figure 12: Detail of base**

Screw Size Identification

For all screw descriptions in the Buildex range, the first figure indicates the gauge of the screw (g), the second figure indicates the threads per inch (TPI), and the third figure indicates the length of the screw (mm).

eg. 14-10x20mm
= 14 gauge, 10 threads per inch, 20mm in length.

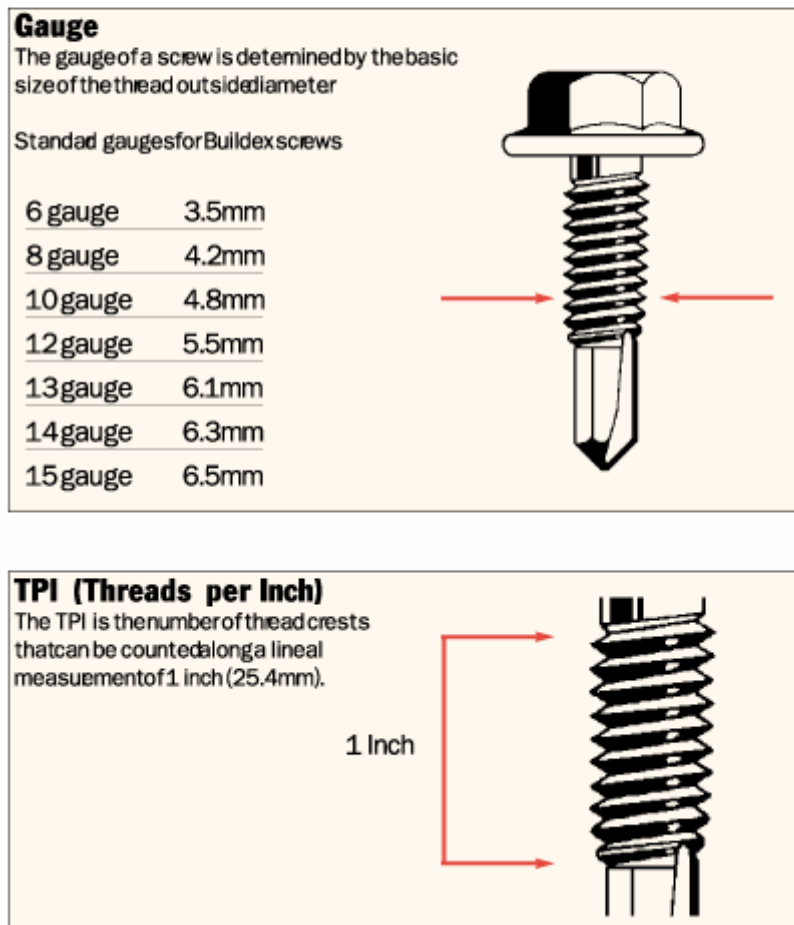


Figure 13: Nominal dimensions of the Tek screws tested (14-20x22mm and 12-24x32mm)
 (obtained from the product literature from Buildex)

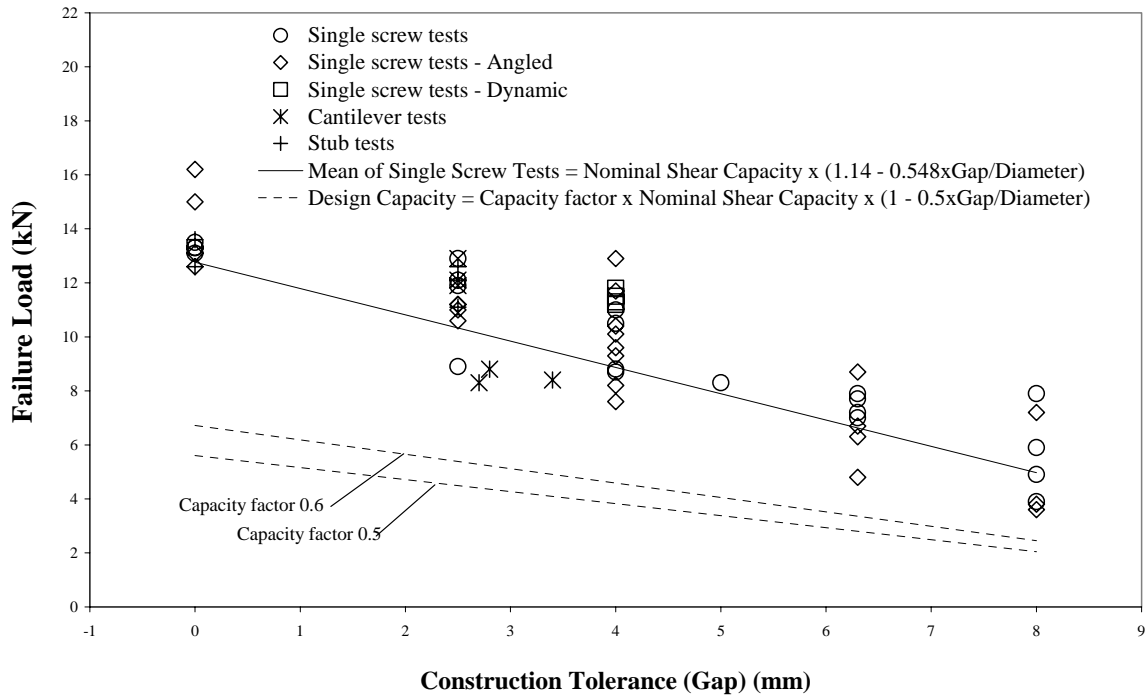


Figure 14: Test results of 14-20x22 Tek screws

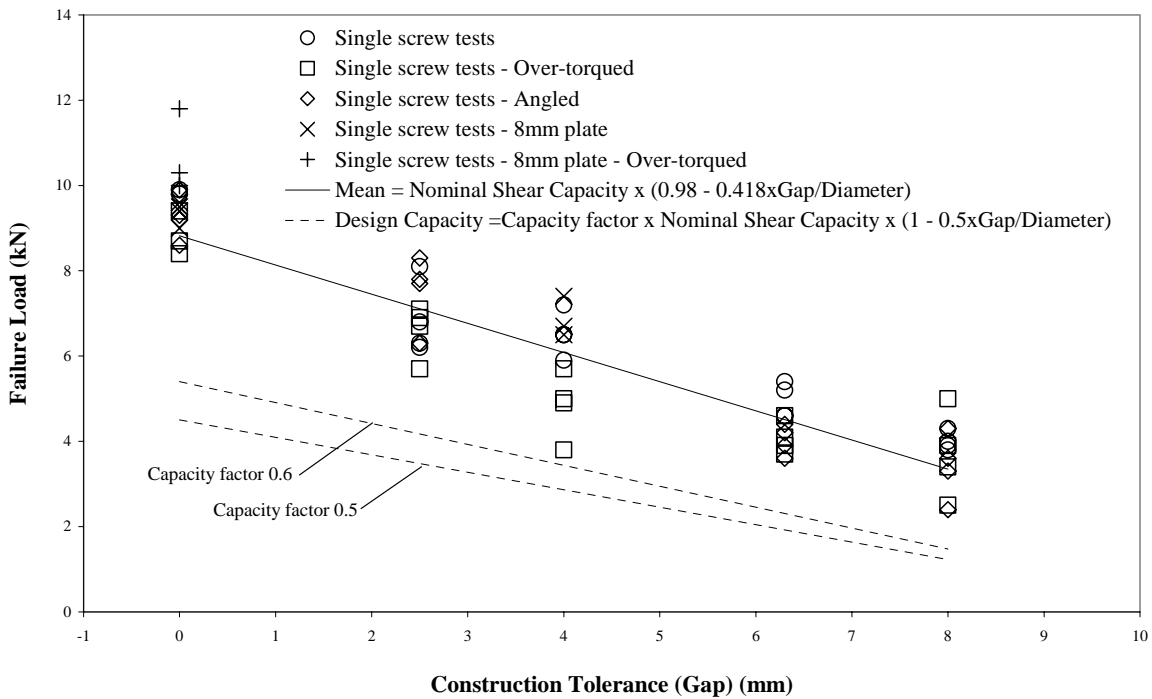


Figure 15: Test results of series 500 (12-24x32mm) Tek screws

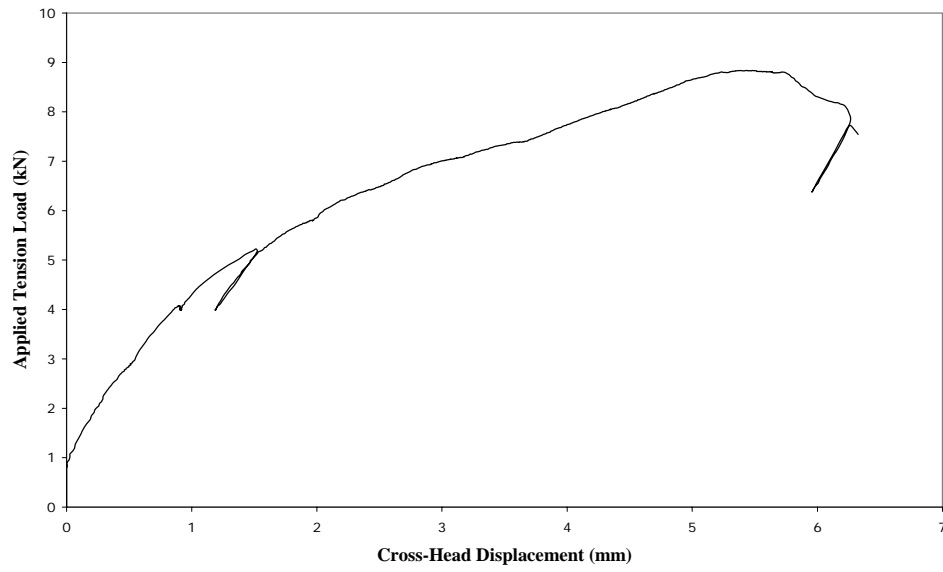


Figure 16: Load against cross-head displacement curve (single screw test, 4mm gap)

Appendix A: Reliability analysis of the single screw test data

The reliability analysis of the single screw test data follows the equations given in AS/NZ 4600 Supplement 1 (1998), Clause 1.6.2.2. The relevant coefficients used in the equations are summarised in Table A1. The equations used in the analysis are the same as those given in the Clause and are not reprinted here, except for the following eqns (A1,A2) which are used in place of Equation C1.6.2.2(4) and C1.6.2.2(6),

$$R_m = R_n (V_m F_m P_m) \quad (A1)$$

$$V_R = (V_V^2 + V_F^2 + V_P^2)^{0.5} \quad (A2)$$

where V_m = mean of (Measured pure shear capacity/Nominal pure shear capacity))
 F_m = mean of (Measured value of gap/Nominal value of gap)
 P_m = mean of (Test strength/Nominal test strength (Equation 3))
 V_V = coefficient of variation of (Measured pure shear capacity/Nominal pure shear capacity)
 V_F = coefficient of variation of (Measured value of gap/Nominal value of gap)
 V_P = coefficient of variation of (Test strength/Nominal test strength (Equation 3))

The capacity factor (Φ) is here determined for the dead and live load combination of 1.25G+1.5Q where the factors 1.25 and 1.5 are the ultimate limit state load factors for dead and live loads respectively. The equation for the reliability index (β) as a function of the dead to live load ratio (G/Q) (Equation C1.6.2.2(2) in Clause 1.6.2.2) is plotted in Figures A1 and A2 for various values of capacity reduction factors (Φ) for 14-20x22 and Series 500 12-24x32mm screws respectively. Using the suggested value given in Clause 1.6.2.2 of a target reliability index of 4.5 for connections and a ratio (G/Q) of 0.2, the appropriate capacity reduction factor for the single screw test results is $\Phi=0.5$ for both types of screws.

	Series 500	
	14-20x22mm	12-24x32mm
V_m	1.26	1.05
F_m	1	1
P_m	0.98	1.02
R_m/R_n	1.24	1.07
V_V	0.086	0.054
V_F	0.05	0.05
V_P	0.120	0.139
V_R	0.195	0.193
G_m/G	1.05	1.05
V_G	0.1	0.1
Q_m/Q	1	1
V_Q	0.25	0.25

Table A1: Coefficients used in reliability analysis (see Clause 1.6.2.2 of AS/NZ4600 Supplement 1 (1998) for the relevant values of means and coefficients of variation)

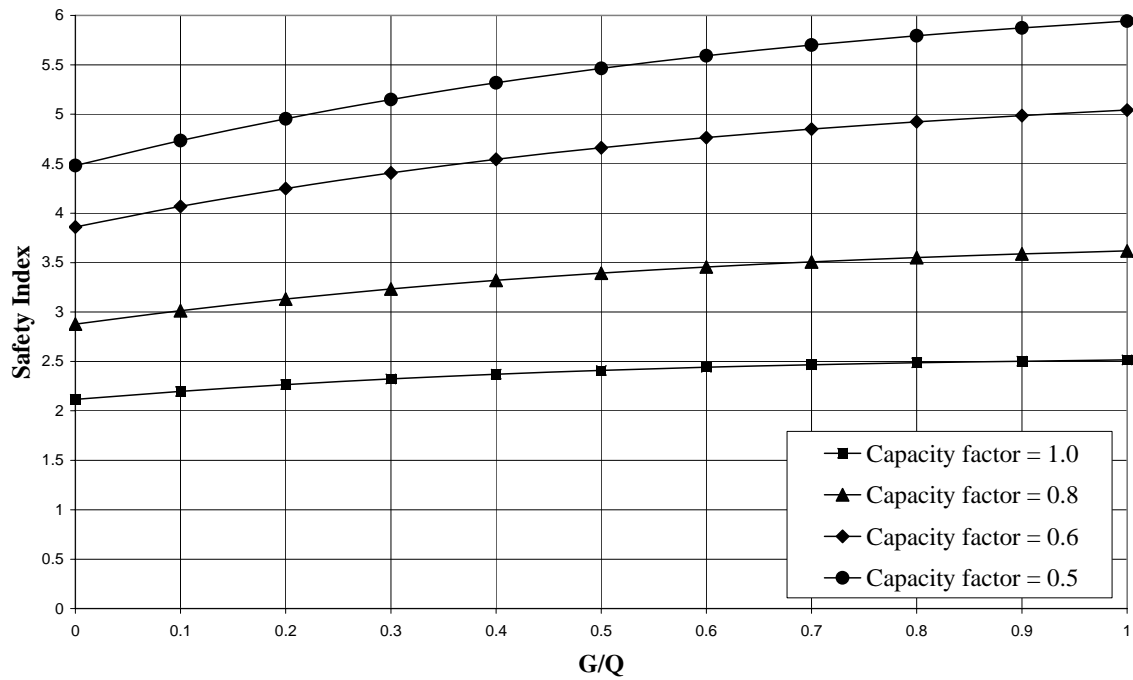


Figure A1: Safety index (β) for single screw test results for 14-20x22 Tek screws

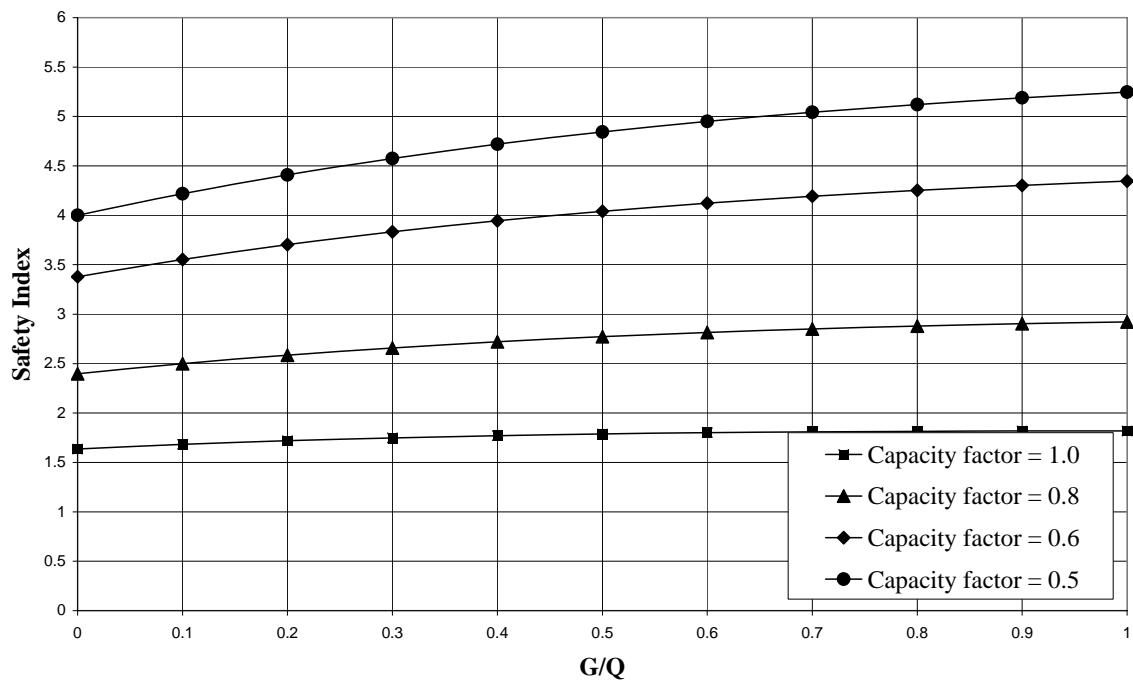


Figure A2: Safety index (β) for single screw test results for Series 500 12-24x32 Tek screws