THE EFFECT OF THREAD GEOMETRY ON SCREW WITHDRAWAL STRENGTH

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ABSTRACT

Ultimate withdrawal values for a steel 16mm diameter screw type fixing into dry end grain radiata pine, ranging between 50 and 60 kNs were achieved for the embedment depth of 150mm. The thread profiles used have the thread pitch, thread projection and root depth as variables.
No significant difference in withdrawal capacity was found for the five new thread profiles. All the new thread profiles were however 25% stronger the original 1996 profile.
Due to the inconclusive nature of the results it has not been able to develop relationships between thread profile, timber properties and withdrawal.

INTRODUCTION

The aim of this study was to extend the earlier work into the structural end-grain screw for heavy timber construction. The original screw showed distinct advantage over an equivalent coach screw and it was the authors opinion this benefit could be further improved by varying the thread profile. Five different screw threads were developed to look at a range of thread profiles in end grain withdrawal.

SCREW THREAD DESIGN

In this study we concentrated on three thread profile variables namely, thread pitch (p), thread projection (d) and thread root depth (r) as Figure 1.

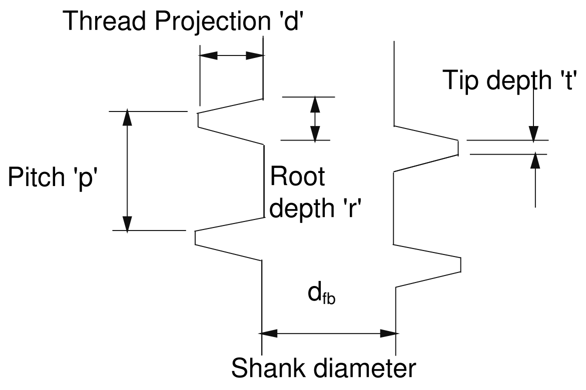

Figure 1: Thread Profile Notation.

Using expression [1] for the design of the thread section as derived by (Gaunt 1996) and expression [2] for the design of the ultimate withdrawal strength of a screw as derived by (Gaunt 1996). A series of different screw threads were developed.

$$\frac{f_y}{f_c} = 3\left(\frac{d}{r}\right)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots[1]$$

where f_y = allowable bending stress on the thread

and f_c = the wood crushing stress parallel to grain

Ultimate withdrawal strength $F = Afs = \left(\left(\left(\pi\left(d_{fb} + 2d\right)p\right) - (lt)\right)D/p\right) \times f_s \quad \ldots\ldots\ldots[2]$

where fs = the allowable wood shear stress

and l = *the length of thread per revolution* $= \left(\left(\pi\left(d_{fb} + 2d\right)\right)^2 + p^2\right)^{0.5}$

and D = the overall thread embedment

The intention was to try to establish a relationship between the thread pitch (p), thread projection (d) and thread root depth (r). To do this all the screws had the same embedment depth of 150mm, an allowable steel bending stress was 275 MPa and a wood crushing stress set at 22 MPa this gives a (d/r) ratio of 2.05.

Therefore by looking at the effect of each variable the following thread profiles were adopted:

- Screw 1 used (d) = 3mm as the original 1996 but with a greater thread pitch.
- Screw 2 used (d) = 6mm with a large (relative to the thread projection) thread pitch.
- Screw 3 used (d) = 9mm with a large (relative to the thread projection) thread pitch.
- Screw 4 used (p) = 12mm as the original screw but greater thread projection.
- Screw 2 used (p) = 12mm & (d) = 3mm as the original screw but with the reduced root depth.

The actual thread profiles adopted for this study are shown in table 1 with figure 2 showing the visual comparison. The thread ratio (d/r) of 2.05 was adopted for this study however this varied (see Figure 2) due to machining difficulties. Screw A in Table 1 is the original 1996 screw.

Table 1: Screw Profiles

Screw	Pitch 'p' (mm)	Projection 'd'(mm)	Root depth 'r'(mm)	(d/r) ratio
Screw A	12	3	3.00	1.00
1	14.0	3	1.46	2.05
2	22.5	6	2.60	2.30
3	31.0	9	2.90	3.10
4	12.0	6	3.55	1.69
5	12.0	3	1.64	1.83

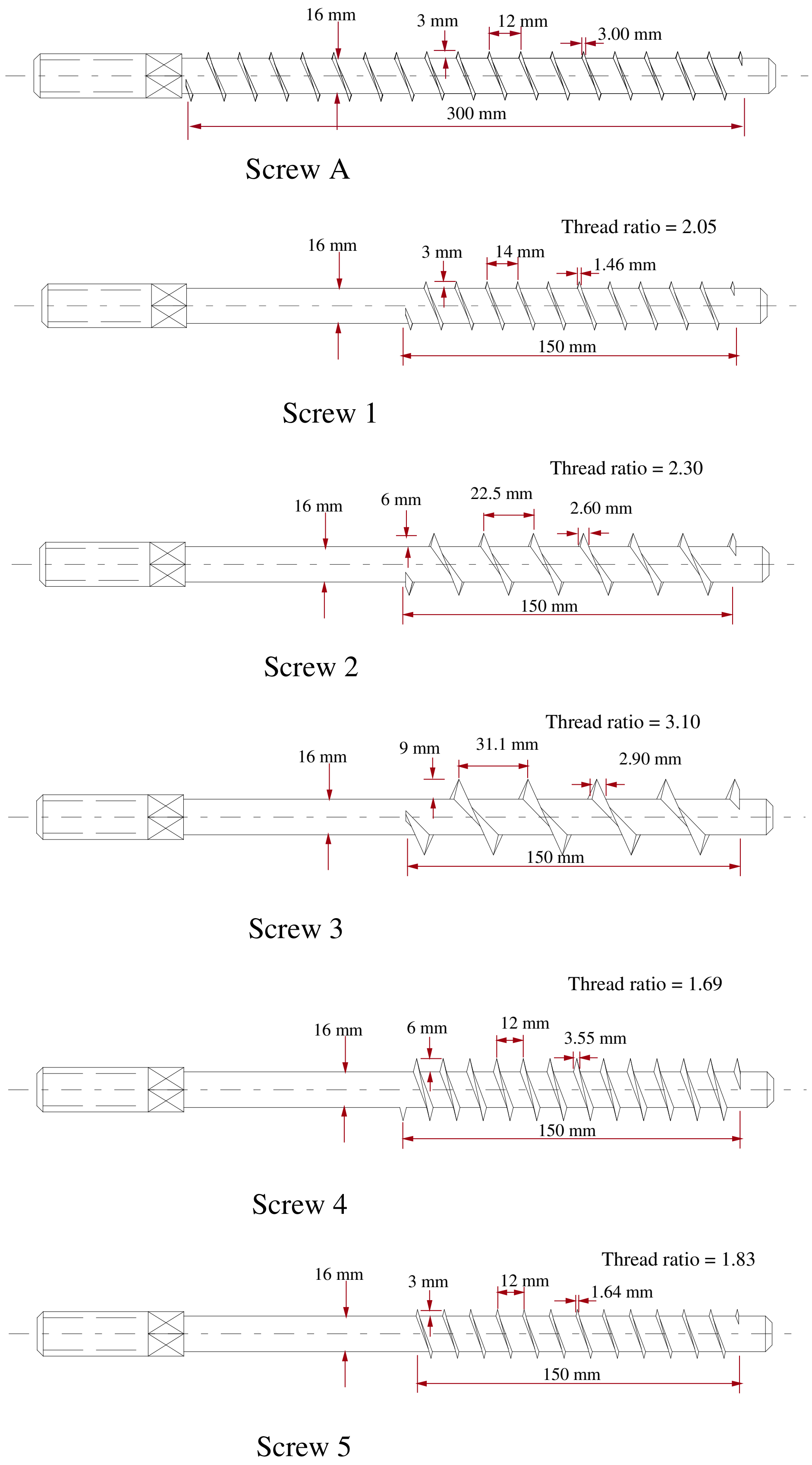

Figure 2: Test Screws.

METHOD

The six screws in figure 2 were produced at the New Zealand Forest Research Institute.

Each screw was used for twenty end-grain withdrawal tests with a 150mm embedment. The timber used was dry radiata glue laminated material comprising. The screws were located clear of any finger joints, knots and areas of sloping grain.

The screws were installed into an over length (by at least 25mm), 16mm diameter pilot hole.

TEST RESULTS

The following tables 2 and 3 summarise the test results for the different screws. Screw A is the screw used in the earlier (Gaunt 1996) study.
There are no results for screw 3 as after the first test there was a major thread failure making any further tests impossible. It should be noted the high (d/r) ratio of 3.1, ie.. the thread was to slender.
Withdrawal strength versus nominal density and average shear stress are plotted in figures 3 & 4 with the equations for the regression lines in table 4.

Table 2: Summary of End-grain Test Results.

	Screw Number	**Final Torque** Nm	**Failure Load** kN	**M.C** %	**Nominal Density** kg/m^3	**Radial Shear Stress** MPa	**Tang Shear Stress** MPa	**Average Shear Stress** MPa
Average **CoV %** **5th %ile**	**1**	54.5 23 27.1	61.9 16 48.3	10.3 13 9.1	475 10 412	12.1 12 10.3	11.9 19 8.5	12.0 13 9.8
Average **CoV** **5th %ile**	**2**	71.5 21 53.5	60.2 14 50.9	9.9 10 9.0	432 12 367	10.8 14 9.2	10.6 12 8.9	10.7 11 9.0
Average **Std Deviation** **CoV** **5th %ile**	**3**		Screw thread failed after first test					
Average **CoV** **5th %ile**	**4**		56.4 11 48.1	10.8 12 9.4	424 10 381	10.6 13 8.6	11.0 14 8.9	10.8 12 9.1
Average **CoV** **5th %ile**	**5**	34.7 22 22.7	57.0 16 48.2	10.2 6 9.4	443 10 394	11.3 16 8.5	11.4 16 9.2	11.3 14 9.5
Average **CoV** **5th %ile**	**Original Screw Screw A**	108.0 35 72.6	48.3 13 39.0	12.6 14 10.8	458 8 390	13.4 12 11.3	12.9 14 10.3	13.1 11 11.0

Note: 20 replicates were used for each depth of embedment.

Table 3: Summary of Side-grain Test Results.

	Screw Number mm	Failure Load kN	Maximum Load kN
Average	**1**	57.2	83.0
CoV %		19	
5th %ile		45.3	
Average	**2**	40.5	82.1
CoV		39	
5th %ile		29.1	
Average	**4**	78.4	92.2
CoV		12	
5th %ile		66.5	
Average	**5**	56.7	74.3
CoV		12	
5th %ile		50.3	

The average failure loads in table 3 should be treated with caution, as, apart from screw 4, all the screws suffered extensive damage after the first side grain withdrawal test. Hence the maximum load shown is generally the result of the first test.

The side grain tests results are based on ten replicates

DISCUSSION

From table 2 it is seen that the screws 1,2,4 & 5 all appear to have similar withdrawal strengths and thus making it difficult to distinguish between the effects of the different thread profiles. The wood properties measured for each screw namely average small clear shear stress and nominal density do not vary greatly between the different screws. Hence they can be assumed not to significantly affect the withdrawal loads.

However all of the new screws have a withdrawal strength approximately 25% greater than the original screw (Screw A). The difference cannot be explained by the wood properties and test method as these are similar to the new screws.

The failure mode in 60% of the tests was initially a wood shear failure followed by splitting along the grain. The remainder of the tests failed in shear only. This type failure leads to the screws pulling a cylindrical plug of wood (ie.. by shear parallel to grain action) out of the test piece. This shear cylinder is bounded by the thread tips with a length equal to the 150mm embedment. The shear cylinder is also intersected by the thread tips producing a helical shape on the outside surface. Equation [2] indicates that increasing the surface area of the withdrawn shear cylinder should increase the available shear area thus increasing the withdrawal strength.

However:

- neither increasing the thread projection thus increasing the overall dimeter of the cylinder
- nor increasing the thread pitch to reduce the loss of area due to the thread tips projecting through the cylinder walls

appears to increase the ultimate withdrawal load. Thus the test results do not line up with the theoretical predictions. One of the conclusion here must be that the expression [2] has not been validated by the test results.

The reasons for the increase in strength of screws 1, 2, 4 & 5 are not immediately obvious, the author still believes that thread ratio d/r has an effect. As all of these screws have slender threads (d/r approx 2.0) whereas Screw A has a stocky thread (d/r = 1.0). The rationale behind this argument is that the slender threads are doing less damage to the timber as they are installed thus the timber shear cylinder is left more intact.

Also these inconclusive results mean it has not been possible to reliably predict the failure loads from the basic wood properties using either the strength formula derived earlier (Gaunt 1996) or by any other means.

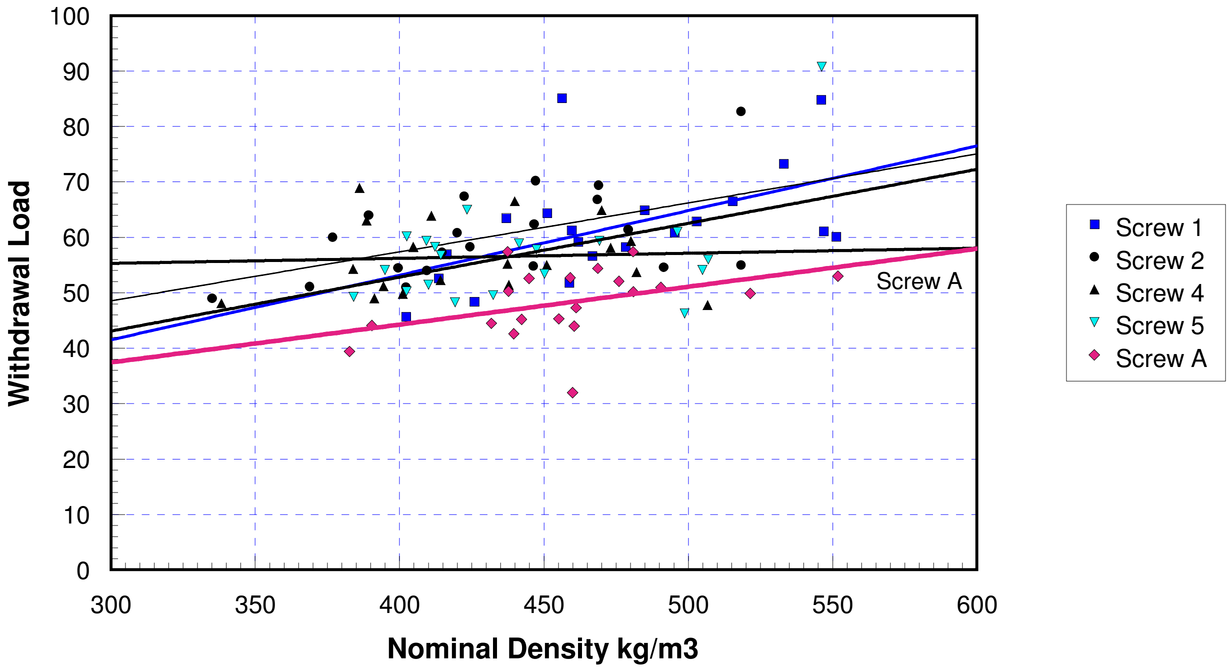

Figure 3: Plot of Withdrawal Strength versus Nominal Density for the 150mm Embedment.

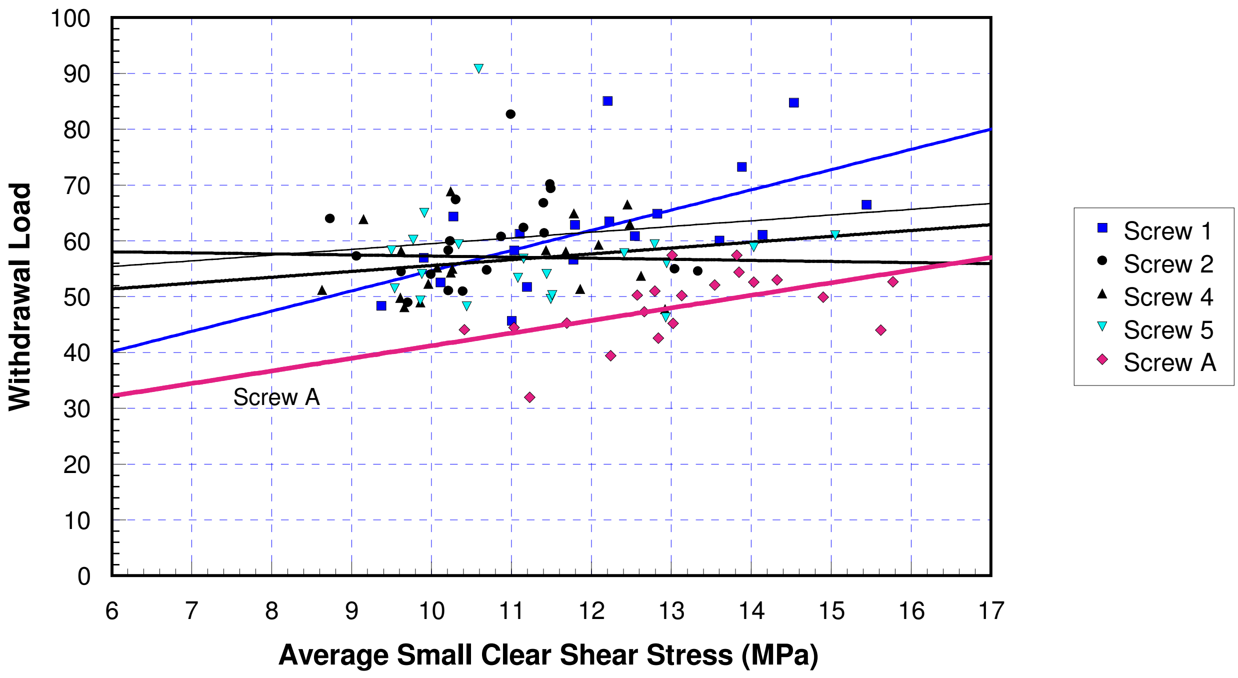

Figure 4: Plot of Withdrawal Strength versus Average Small Clear Shear Stress for the 150 mm Embedment

REGRESSION ANALYSIS

Table 4 shows the regression statistics for the different screws. It should be noted that in general there are no significant regressions (low r^2 values) between maximum load and either nominal density or average small clear shear strength. There is however expected trend for increasing density or shear strength to a corresponding increase in withdrawal resistance.

Table 4: End grain Regression Statistics.

Nominal Density, x (kg/m3) against Maximum Load, y (kN) for a 150 mm embedment						
y = ax + b	**Screw A**	**Screw 1**	**Screw 2**	**Screw 3**	**Screw 4**	**Screw 5**
X variable, a	17.02	6.58	22.06	Screw	52.57	13.91
Intercept, b	0.068	0.117	0.088	thread	0.009	0.097
r^2	0.171	0.281	0.277	failed after	0.004	0.22
Standard Error	5.91	8.80	7.14	first test	6.54	8.45

Average Shear Strength, x (MPa) against Maximum Load, y (kN) for a 150 mm embedment						
y = ax + b	**Screw A**	**Screw 1**	**Screw 2**	**Screw 3**	**Screw 4**	**Screw 5**
X variable, a	17.22	18.44	49.28	Screw	45.13	59.25
Intercept, b	2.37	3.62	1.02	thread	1.04	-0.20
r^2	0.286	0.347	0.020	failed after	0.046	0.001
Standard Error	5.49	8.62	8.32	first test	6.40	9.60

WITHDRAWAL DEPTH

From the earlier study (Gaunt 1996) in which screw A was used over a range of embedment depths (150, 200, 250 and 300 mm). It was noted that the failure loads increased in almost direct proportion to the embedment depth. The ultimate withdrawal values for screw A in dry end grain radiata pine were 48, 66 ,83 & 97 kN's for the embedment depths of 150, 200, 250 & 300 mm respectively or 320 N/mm of embedment. Figure 5 shows the effect on withdrawal strength for the different embedment depths.

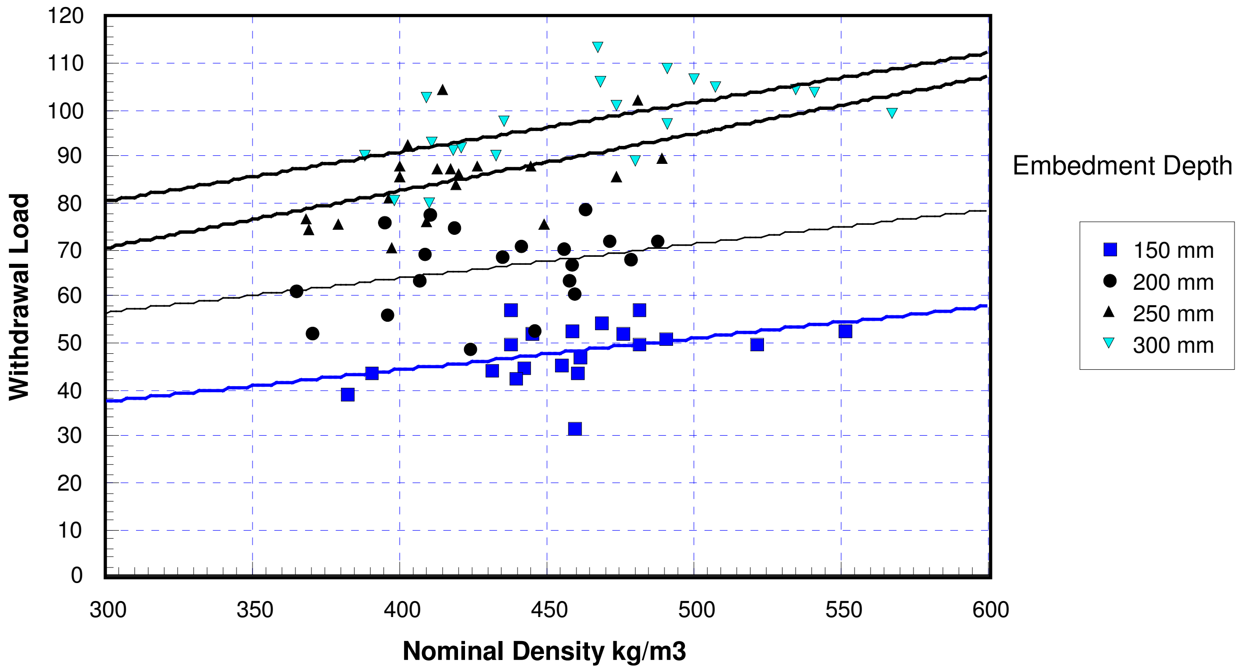

Figure 5: Plot of Withdrawal Strength versus Nominal Density for Screw A for 150, 200, 250, and 300mm Embedments

CONCLUSIONS

- There appears to be no difference in withdrawal strength between screws 1, 2, 4, and 5. However all these screws have a withdrawal resistance 25% higher than screw A.
- There is no significant relationship between withdrawal strength and wood density or wood shear strength.. There is the trend of increasing withdrawal strength with increasing wood density and wood shear strength.
- The prediction formula does not appear to predict the withdrawal strength well.
- All the screws show useable withdrawal resistance.

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