Design Equation for Withdrawal Resistance of Threaded Fasteners in the Canadian Timber Design Code

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1. INTRODUCTION

1.1 MOTIVATION

The Canadian standard for engineering design in wood CSA O86-09 provides two different design equations for withdrawal resistance of threaded fasteners:

- Wood-Screws: $P_{rw} = \phi\, Y_w\, L_{pt}\, n_F$ where $Y_w = 68\, d_F^{0.82}\, G_0^{1.77}\, (K_T\, K_{SF})$
- Lag-Screws: $P_{rw} = \phi\, Y_w\, L_t\, n_F\, J_E$ where $Y_w = y_w\, (K_D\, K_T\, K_{SF})$

Table 10.6.5.1
Basic withdrawal resistance for lag screws, y_w, N/mm

Species group	Shank diameter, in 1/4	5/16	3/8	7/16	1/2	5/8	3/4	7/8	1
Douglas Fir-Larch	74	97	120	140	170	200	240	280	310
Hem-Fir	37	55	70	86	100	130	150	180	200
Spruce-Pine-Fir	31	42	61	75	91	120	140	170	190
Northern Species	27	42	58	70	84	110	130	150	180

These equations are different from those in the American "National Design Specification for Wood Construction" (NDS) and from other overseas codes. Moreover, there is no guidance for the calculation of withdrawal resistance for self-drilling screws in the Canadian standard.

1.2 OBJECTIVE

The goal of this project was to verify the existing withdrawal resistance models and to offer a design equation for all threaded fasteners used with Canadian engineered wood products.

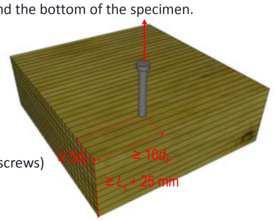
2. BACKGROUND

The NDS design values for withdrawal of wood screws originate from the research of Fairchild (1926). Over 10,000 wood screws were tested in seven wood species. In 1960, Johnson (1960) reported the impact of lead holes, test speed and size of wood screws on withdrawal resistance of various western wood species. Later, Wilkinson & Laatsch (1970) reported a better performance of tapping screws compared to common wood screws.

The NDS design equation for lag screws originates from the work of Newlin and Gahagan (1938) who tested 233 fasteners of different diameters in five wood species to evaluate the impact of lead hole and fastener diameter, and penetration length on withdrawal resistance. In the 1980s, the CSA O86 technical committee adopted a modified version of the NDS design model for the withdrawal resistance of lag screws and presented it in a form of a table of values for visually graded lumber. McLain (1997) proposed new equations based on nonlinear regression analysis for wood screws and lag screws. In 2009, the McLain's equation for wood screws was adopted in CSA O86-09. More recently, Gehloff (2011), Abukari *et al.* (2012), and Baek *et al.* (2012) conducted independent investigations on the withdrawal resistance of self-drilling screws.

3. METHODOLOGY

- Test Standard: EN 1382 (1999)
- Test Conditions: 65% ± 5% HR and 20˚C ± 3°C
- Fastener Insertion: Perpendicular to plane face
- Fastener Withdrawal: Perpendicular to plane face
- Fastener Penetration: Threaded part only. Cushion of 25.4 mm between the end of the fastener and the bottom of the specimen.
- Edge Distance: 10 d_F
- Edge Distance: 5 d_F
- Lead Hole: $0.7d_F$
- Repetitions per series: n = 10
- Total number of tests: 360 (lag screws)
  120 (self-drilling screws)



4. MATERIALS

4.1 FASTENERS

- LAG SCREWS

Fastener diameter (mm/in.)	Length / threaded length (mm)	Lead hole diameter (mm)	Penetration Sawn timber (mm)	Penetration Glulam (mm)
6.35	55/35	4.39	32	32
1/4	125/90		82	51
7.94	75/55	5.56	51	51
5/16	155/105		100	62
9.53	100/55	6.75	55	55
3/8	205/135		131	79
12.7	130/75	9.13	70	70
1/2	255/175		170	133
15.9	155/110	11.9	100	100
5/8	305/165		155	155
19.1	155/110	14.3	102	102
3/4	305/155		146	146

- SELF-DRILLING SCREWS

Fastener diameter (mm)	Length / threaded length (mm)	Lead hole diameter (mm)	Penetration (mm)
6	160/64	N/A	**36**
			64
8	160/100	N/A	**48**
			96
12	**380/145**	**9.13**	**72**
			144

4.2 WOOD PRODUCTS

- SAWN TIMBER

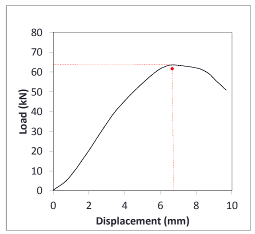
Douglas-Fir

- GLULAM

Douglas-Fir, Spruce-Pine-Fir and Black spruce

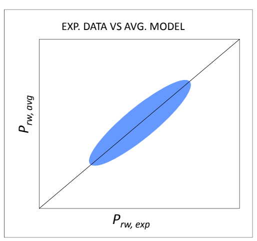
5. ANALYSIS OF RESULTS

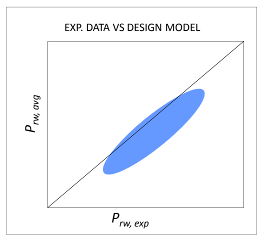
- COLLECTION OF VALUES
  - Peak Load (kN)
  - Peak Load Displacement (mm)



- EVALUATION OF THE DESIGN MODEL

To evaluate a design model, the predicted average values need to be compared to the collected experimental data. A good model will predict average values as close as possible to the experimental data. In other words, the data cloud needs to show a close tendency to the theoretical line (figure on left). Secondly, the characteristic values from the model must not show more than 5% of the data cloud over the theoretical line when compared to the experimental values.





6. EVALUATION OF MODELS

To evaluate and determine a single design equations for withdrawal resistance of all threaded fasteners, five withdrawal resistance models were compared to the collected experimental data:

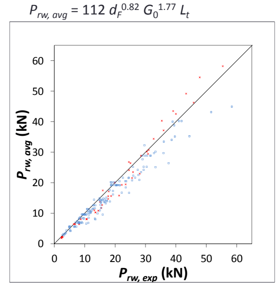
- CSA O86 equation for wood-screws;
- NDS-2012 equation for lag-screws;
- NDS-2012 equation for wood-screws;
- McLain (1997) equation for lag-screws; and
- MHBH (1982) equation for lag screws

The Canadian model for withdrawal of wood screws appeared to be the best from a performance and harmonisation point of view.

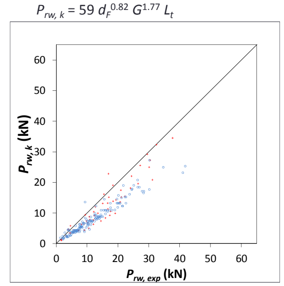
Design Method Equations	Mean Error	RMSE	Abs. % Error	Pseudo R^2
CSA WS	1.57	2.99	14.2%	92.8%
NDS LS	0.58	2.16	9.00%	96.3%
NDS WS	-1.05	5.12	13.4%	79.4%
McLain LS	-1.77	2.83	13.6%	93.7%
Morrisson LG	1.50	2.68	11.4%	94.3%

- CSA O86 equation for wood-screws

$P_{rw,\,avg} = 112\, d_F^{0.82}\, G_0^{1.77}\, L_t$



$P_{rw,\,k} = 59\, d_F^{0.82}\, G^{1.77}\, L_t$



7. CONCLUSIONS

The lack of design equation for withdrawal of lag screws in glulam, discrepancies between design values obtained for lag screws and wood screws of the same diameters as well as lack of information for self-drilling screws in the Canadian standard for engineering design in wood CSA O86 served as motivation for this project. After compiling an experimental database of 2580 tests and analysing five different design models, a single equation was found satisfactory to predict the withdrawal resistance of all threaded type fasteners of large diameters (d_F > 6 mm) in Canadian wood products. Because of its satisfactory performance and for the sake of harmonisation, the model which was proposed and adopted by the standard technical committee CSA O86 is:

- CSA O86 equation for wood-screws

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