Report

Derivation of Canadian Design Properties for TrussLok®, TrussLok-Z® and LedgerLok® Screws

Submitted to:

Mr. Steven Street
VP – Sales and Marketing
Cullen Building Products Inc.
170 Savannah Oaks Drive
Brantford
ONTARIO N3V 1E7
Tel: (519) 751-2258
Fax : (519) 751-2329
E-mail: S.Street@cullen-bp.com

Submitted by:

Wood Science and Technology Centre
University of New Brunswick
1350 Regent Street
Fredericton. N.B.   E3C 2G6 CANADA
Tel: 506-453-4507; Fax: 506-453-3574
Email: woodsci@unb.ca

Prepared by:

Y. H. Chui, Ph.D, P.Eng
Director

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Introduction

Cullen Building Products (CBP) Inc. is a manufacturer of mechanical connectors and is interested in supplying to its customers proprietary screws manufactured by OMG, Inc., Agawam, MA, USA. CBP is specifically interested in three series of screws marketed under the trade names of TrussLok®, TrussLok-Z® and LedgerLok®. These fasteners are manufactured from heat-treated steel with a relatively short thread length. A prime application considered by CBP is as fasteners for multi-ply built-up wooden beams. For these fasteners to be used in such an application, there is a need to develop engineering design specifications. To that end, a number of test programs have been commissioned by OMG, Inc. and conducted by Wood Science Laboratory, University of Montana. The purpose of this report is to derive engineering design specifications using data generated from these test programs, in accordance with procedures used for deriving similar design specifications in CSA O86-01 (CSA 2005).

Description of Fasteners

Table 1 provides physical specifications for TrussLok®, TrussLok-Z® and LedgerLok® screws.

Table 1 – Physical dimensions of TrussLok®, TrussLok-Z® and LedgerLok® screws.

Property		**TrussLok®**	**TrussLok-Z®**	**LedgerLok®**
Head Style		9.5mm Hex Drive	9.5mm Hex Drive	7.8mm Hex Drive
Lengths		86mm, 127mm, 171mm	73mm, 114mm, 152mm	66mm, 87mm, 92mm, 102mm, 135mm
Diameter	Shank	5.8mm	5.8mm	5.8mm
	Outer thread	7.2mm	7.7mm	7.7mm
	Inner thread	5.5mm	5.1mm	5.1mm
Thread length		38mm	32mm	50mm
No. of threads per 25mm		9	7.3	7.3

Derivation of Engineering Design Specifications

The major engineering design specifications required for the intended application of multi-ply built-up beams are withdrawal and lateral resistances. The derivation of design specifications is described below.

Withdrawal Resistance

The withdrawal resistance of wood screws is dependent upon the diameter of the screw, the specific gravity of wood member and thread length in point side member. Comprehensive test programs conducted to determine withdrawal resistance of TrussLok-Z® and LedgerLok® screws are described in two reports prepared by the University of Montana Wood Science Laboratory (UMWSL 2006a) and (UMWSL 2004a) respectively. The tests were performed according to ASTM D1761 (ASTM 2000). For TrussLok-Z® screw, the following species were tested: western white pine (specific gravity, G = 0.35 – 0.41), lodgepole pine (G = 0.37 – 0.44), western hemlock (G = 0.45 – 0.49), Douglas fir (G = 0.48 – 0.56), and Southern yellow pine (G = 0.47 – 0.58). For LedgerLok® screws, the following species were tested: lodgepole pine (G = 0.41 – 0.45), western redcedar (G = 0.3 – 0.35), western hemlock (G = 0.45 – 0.49), Douglas fir (G = 0.48 – 0.55), and ash (G > 0.58).

Based on the test programs, a number of empirical models depicting the relationship between withdrawal strength and specific gravity of wood were obtained. In general, there were small differences in the degree of goodness of fit of these models to the test data. The following models are selected for predicting dry withdrawal strength (WS) from G.

For TrussLok-Z®,
$WS = 2942G^{1.518}$ lbs per inch thread length in point side member [1]

For LedgerLok®,
$WS = 3912G - 599$ lbs per inch thread length in point side member [2]

The models in Equations [1] and [2] can be compared with those proposed by McLain (1997), which form the basis of the US National Design Specifications (NDS) for wood screws and lag screws. McLain's models are presented below as Equations [3] and [4] respectively.

For wood screws (d=5.8mm),
$WS = 2692\ d^{0.82}\ G^{1.77} = 2692G^{1.77}$ lbs per inch thread length in point side member [3]

For lag screws (d=5.8mm),
$WS = 2743\ d^{0.61}\ G^{1.35} = 2743G^{1.35}$ lbs per inch thread length in point side member [4]

For TrussLok® screws, only limited withdrawal resistance tests with one species (Douglas fir) and one specific gravity value (0.5) were tested (UMWSL 2006c). Equations [1] to [4] and the TrussLok test data are compared in Figure 1. It is apparent that despite the fact that LedgerLok® and TrussLok-Z® have identical thread per inch measure, LedgerLok® withdrawal strength per thread length is substantially higher than TrussLok-Z®. The TrussLok-Z® curve is slightly below the lag screw curve. The limited TrussLok® data shows evidence that the withdrawal strength of this fastener is lower than the other two OMG fasteners and generic lag screw, but above the generic wood screw strength. In view of these results and the information based on McLain's work, it is proposed that Equation [3] (i.e. wood screw equation) be used as a basis for deriving withdrawal strength design capacity for both TrussLok® and TrussLok-Z® and for LedgerLok® Equation [4] (lag screw) shall be used.

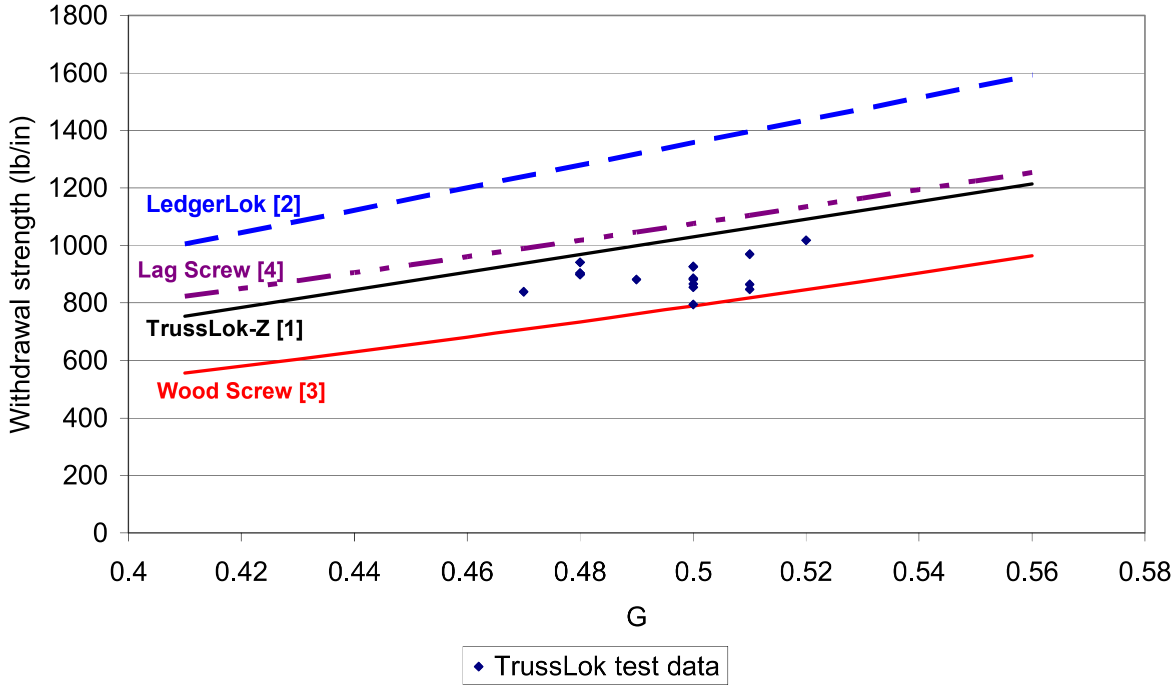

Figure 1 - Comparison of withdrawal strength models and data.

These models will form the basis to calculate the basic withdrawal resistance per penetration length (y_w) in CSA O86-01 (CSA 2005). To convert the above models to calculate y_w, the following modifications are applied.

For TrussLok® and TrussLok-Z®,
$y_w = C_{Metric} \times C_{DoL} \times C_{5\%} \times 2692G^{1.77} = 290G^{1.77}$ N/mm [5]

For LedgerLok®,
$y_w = C_{Metric} \times C_{DoL} \times C_{5\%} \times 2743G^{1.35} = 295G^{1.35}$ N/mm [6]

where,
C_{Metric} = factor to convert to Metric units = 0.175
C_{DoL} = Duration of load factor = 0.92
$C_{5\%}$ = factor to convert from mean specific gravity to lower 5th percentile value = 0.67 (assuming a normal distribution and a coefficient of variation of 20%)

Using Equations [5] and [6], the basic withdrawal resistance values for the four major Canadian lumber species groups are given in Table 2.

Table 2 – Basic withdrawal resistance (N/mm) of lumber species groups.

Fastener	**Douglas fir (G=0.49)**	**Hem fir (G=0.46)**	**Spruce-pine-fir (G=0.42)**	**Northern species (G=0.35)**
TrussLok® and TrussLok-Z®	82	73	62	45
LedgerLok®	113	103	91	72

Equations [5] and [6] are to be used in conjunction with Clause 10.6.5 of CSA O86-01 to calculate the factored withdrawal resistance of these fasteners.

Lateral Resistance

The lateral resistance of a screw joint is dependent upon the diameter and yield strength of the screw, side member and main member thicknesses, and the embedment strengths of the side and main members. CSA O86-01 provides a series of equations to calculate the lateral resistance of a lag screw or bolt joint. These equations calculate the failure loads for all possible failure modes and the lowest value of these governs the design lateral resistance of the joint.

Apart from the physical dimensions of the joint components, the key material properties required for the calculation of lateral resistance are the yield strength of the fastener and the embedment property of the wood which, similar to withdrawal strength, is related to the specific gravity of wood and diameter of the fastener.

The yield strengths of TrussLok®, TrussLok-Z® and LedgerLok® screws have been tested in three separate test programs (UMWSL 2007, UMWSL 2004b, UMWSL 2006b) by the Wood Science Laboratory, University of Montana according to ASTM F1575 (ASTM 1995). The yield strengths measured over different zones as illustrated in Figure 2 are summarized in Table 3.

In view of the relatively short thread length, except for short LedgerLok® and TrussLok-Z® screws, the yield location likely occurs in the shank. Therefore it is recommended that the shank yield strength be used for design. The 5^{th} percentile yield strength for the worst group shown in Table 3 for each fastener is calculated below.

For TrussLok-Z®,
f_y = 166,825 x (1 – 1.645 x 0.05) = 153,103 psi = 1,055 MPa

For TrussLok®,
f_y = 160,539 x (1 – 1.645 x 0.06) = 144,693 psi = 997 MPa

For LedgerLok®,
f_y = 187,730 x (1 – 1.645 x 0.09) = 159,936 psi = 1,103 MPa

The proposed yield strength is rounded to 1,050 MPa for TrussLok-Z®, 1,000 MPa for TrussLok® and 1,100 MPa for LedgerLok®.

Table 3 – Measured yield strengths (F_{yb}) of TrussLok®, TrussLok-Z® and LedgerLok® screws.

Fastener	Shank F_{yb} (psi)	Transition zone F_{yb} (psi)	Thread zone F_{yb} (psi)
2-7/8” TrussLok-Z®	N/A	231,455 (0.03)	N/A
4-1/2” TrussLok-Z®	166,825 (0.05)	237,676 (0.04)	N/A
6” TrussLok-Z®	170,631 (0.03)	245,676 (0.06)	N/A
3-3/8” TrussLok®	N/A	200,604 (0.03)	N/A
5” TrussLok®	164,078 (0.05)	204,442 (0.03)	N/A
6-3/4” TrussLok®	160,539 (0.06)	204,745 (0.04)	N/A
3-5/8” LedgerLok®	187,730 (0.09)	157,297 (0.06)	208,897 (0.04)
5” LedgerLok®	185,851 (0.04)	143,339 (0.05)	192,600 (0.04)

Note : Values in parentheses are coefficient of variation.

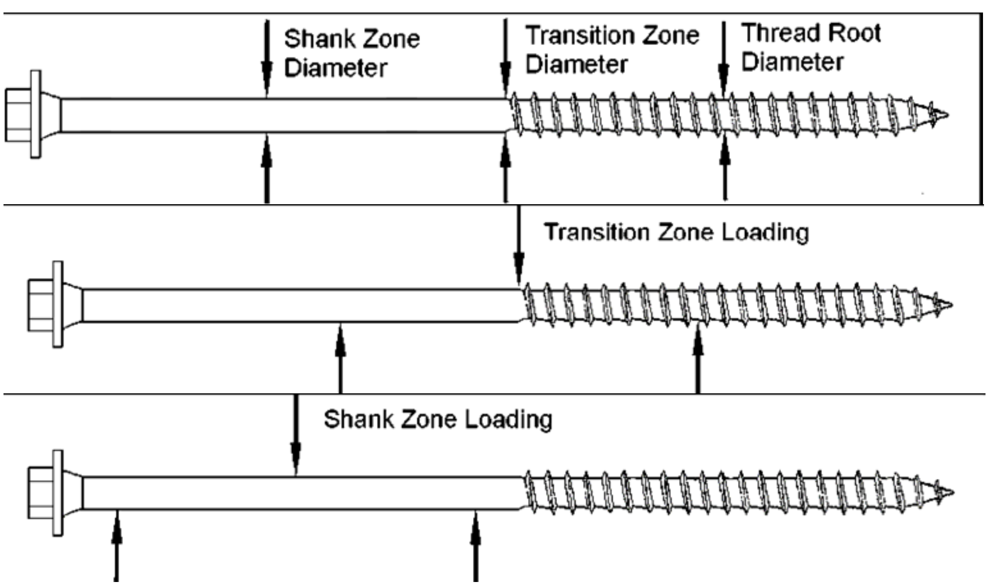

Figure 2 – Screw bending test loading arrangements.

Embedment strength was determined for the following species : western redcedar (G = 0.3 – 0.35), lodgepole pine (G = 0.41 – 0.45), Douglas fir (G = 0.48 – 0.55), western hemlock (G = 0.45 – 0.49), and ash (G > 0.58). The test procedure and results are discussed in a report prepared by Wood Science Laboratory, University of Montana (UMWSL 2004c). Although only LedgerLok® screw was tested, the embedment test results should also be applicable to the other two fasteners since their diameters and yield properties are close.

As in the case of most wood design standards, the dry embedment strength of wood was found to correlate well with specific gravity. The test report by UMWSL presents the following empirical models depicting dry embedment strength (ES) and specific gravity (G) for parallel and perpendicular to grain.

For parallel to grain,
$ES = 12293\ G^{1.077}$ psi $= 84\ G^{1.077}$ MPa [7]

For perpendicular to grain,
$ES = 12128\ G^{1.26}$ psi $= 84\ G^{1.26}$ MPa [8]

Equations [7] and [8] can be converted into corresponding models for calculating embedment strength of wood members similar to those presented in Clause 10.6.6.1.2 of CSA O86. As per O86 procedure adopted for other mechanical fasteners, the conversion is achieved by applying two factors to each of Equations [7] and [8]:
$C_{5\%} = 0.8$ (to convert from mean property to lower 5th percentile property)
$C_{MC} = 0.89$ (to convert from test MC of 12% to the dry service condition of 15% in CSA O86).

Therefore, for parallel-to-grain loading the embedment strength for use with CSA O86 is given in Equation [9],
f_1 (or f_2) $= 0.89 \times 0.8 \times 84\ G^{1.077} = 59.8\ G^{1.07}$ MPa [9]

The corresponding equation for perpendicular-to-grain loading is given in Equation [10].
f_1 (or f_2) $= 0.89 \times 0.8 \times 84\ G^{1.26} = 59.8\ G^{1.26}$ MPa [10]

Summary of Design Specifications

Clause 10.6 in CSA O86-01 (CSA 2005) shall be used to design joints containing TrussLok®, TrussLok-Z® and LedgerLok® screws with details given in Table 1, with the following deviations:

1. Connection geometry requirements, such as spacing, end and edge distances, shall follow Clause 10.9.2 (for nails and spikes) instead of Clause 10.6.2 (for lag screws).

2. The basic withdrawal resistance, y_w, in Clause 10.6.5 shall be calculated using Equation [5] or [6].
3. The yield strength (f_y) in Sentence 10.6.6.1.2 is 1,050 MPa for TrussLok-Z® screws, 1,000 MPa for TrussLok® and 1,100 MPa for LedgerLok® screws.
4. The embedment strength (f_1 and f_2) in Sentence 10.6.6.1.2 is given in Equation [9] for loading parallel to grain and in Equation [10] for loading perpendicular to grain.

In addition, for Structural Composite Lumber (SCL) members, conditions 2 and 4 can be applied, provided test evidence is developed to identify an equivalent specific gravity value for the material.

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