WHITE PAPER

MTC SOLUTIONS

SCREW BUCKLING VALUES FOR COMPRESSION PERPENDICULAR TO GRAIN REINFORCEMENT

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BACKGROUND & PURPOSE

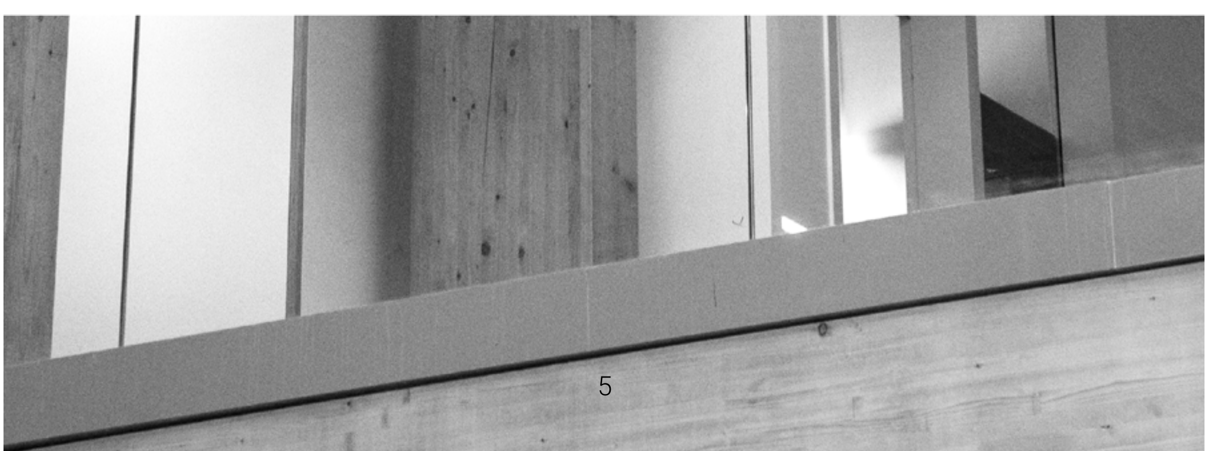
In North American mass timber design, engineers and designers may find that the tools made available to them from design standards make it challenging to truly achieve efficiency in their member selection. Many clauses within these design standards in both the US and Canada are in the long process of being updated to include methodologies for handling topics such as the inclusion of self tapping screws, notch effects, and reinforcements. In the meantime, designers must adapt current methodologies from accepted European design codes which include some of these topics in addition to devising new methodologies for applications that are specific to the state of mass timber construction in North America. Self tapping screws have undoubtedly paved the way for modern mass timber construction, due in part by the extensive research on them over the past two decades: tension, shear, and withdrawal applications of these screws in wood are well documented and understood. However, the behaviour of screws loaded in compression in wood does not have the same amount of literature or standardization dedicated to them when compared to the other screw loading applications.

Common applications for screws in compression are, but not limited to, compression reinforcement perpendicular to grain as a method to increase the resistance of the bearing area of solid timber and softwood glulam (European Technical Approval [ETA], 2018), screwed connections with tension and compression couples, or screw crosses. The design methodology of the latter applications remains outside the scope of this white paper.

Annex 3 of ETA 11/0190 for ASSY self tapping screws (ETA, 2018) presents a full set of equations and cases for both mid-span bearing and beam-end bearing scenarios based on theory for the use of self tapping

screws used as compression reinforcement in wood. These equations in Section A.2.3.4 of the ETA primarily relate to the slenderness and elastic properties of the screw. The equations include a calculation method for the elastic foundation, which aims to provide an estimate of the elastic behaviour of the screw in a specific density of wood. While these equations are not explicitly provided in Eurocode 5 (EC5), the ETA can be referenced as the equations originate from the German National Annex (NA) to EC5. Product approvals such as ETA's that include design equations for topics like bearing reinforcement are the natural last step before standardization, on the basis that these design equations are derived from accepted results of research and are validated through practical experience (Dietsch, 2016).

North American standards rely heavily on empirical test results for their acceptance criteria, and thus the European equations used for the screw buckling design value may not be accepted or approved by an authority having jurisdiction (AHJ) or permitting officer. One of the four criteria established in the NDS 2018 Clause 1.1.1.5 specifically allows the use of a material or design where it is demonstrated by analysis based on recognized theory, even when outside the scope or criteria of the NDS. Despite this, AHJ's may still require tested values for designs to be approved. The ICC-ESR Acceptance Criteria 233 (AC233) does not cover buckling or compressive capacities of self tapping screws, which leads to the argument that an analogue methodology must be followed in the interim to provide results from testing which ultimately lead to design values. AC233 is followed regardless, as buckling in this case can be represented as a system between the self tapping screw (slender dowel type fastener) and the embedding wood which provides buckling restraint.



TEST METHODOLOGY & RATIONALE

A series of tests were commissioned by MTC Solutions in order to determine the buckling capacity of fully threaded ASSY screws in glulam specimens. ASSY VG CYL 5/16" & 3/8" [8mm & 10mm] diameter fully threaded screws were selected for testing as they are the most common sizes used in reinforcing applications. ASSY VG CYL are fully threaded screws with cylinder heads which are easy to completely embed into timber members for a flush finish at the surface. The head of the ASSY VG CYL screw is smaller in diameter compared to a countersunk screw and thus should provide conservative results when compared to other fully threaded screw models when examining buckling resistance. For both diameters, 7-1/8" & 8-5/8" [180mm & 220mm] lengths were tested, with the latter chosen to produce the desired buckling failure mode. Screw length is in fact not a variable in the calculation of buckling strength; the design value taken for a screw loaded in compression is the minimum of the length-dependent axial withdrawal (or pushing-in) strength and the buckling resistance. A second shorter screw (180mm) was selected for testing to observe the behaviour of a push-in resistance governed fastener in compression. The test method only examined screws installed at 90 degrees to the direction of the grain in each wood sample. Glulam types tested were: Black Spruce, Douglas-Fir (D.Fir), and Southern Yellow Pine (SYP). These species were chosen on the basis that they accounted for some of the most common structural wood densities. The average tested in-situ specific gravity for all three species samples were reported to be in the range of 0.49-0.50.

The load was concentrated on the head of the fastener (as seen in Figure 1) rather than spread across a steel plate, which may have engaged some strength contribution from the glulam's compression perpendicular to grain resistance under the area of the steel plate. It is assumed that the behaviour of the screw is better isolated using the direct loading application, which also yielded pure buckling failures in each sample tested.

Figure 1. Tapered Punch Direct-Load Application to the Head of the Screw in Glulam

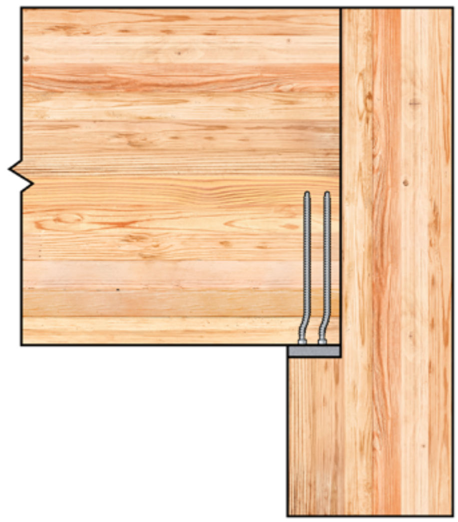
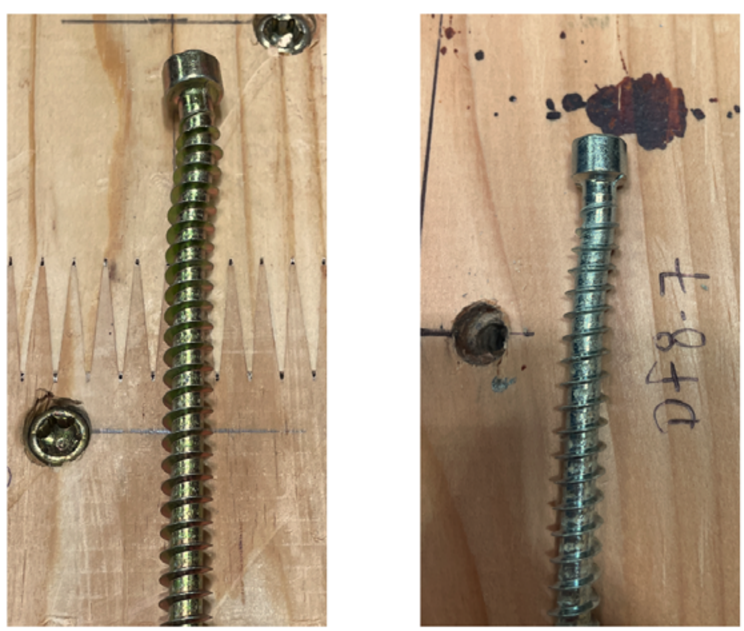


Figure 2. Buckled Screws in an Assembly for Bearing Reinforcement

The test series were comprised of 16 screws of both diameters which were tested in each of the 3 species of glulam, for a total 96 screws. The screws exhibited the expected S-shape deformation under compression loading as shown in Figure 3 below. The wood fibre effectively restrained the screw, with less of a pronounced effect towards the screw head. As the screw buckling behaviour and boundary conditions can be seen as a wood-screw system – similar to screw withdrawal – it is conservative to apply the factor of safety of 5 for wood system failures (NDS/ASD). An analysis using ASTM D5457 was performed to obtain the 5th percentile buckling strength values for factored design.



(a) *(b)*

Figure 3. S-Shaped Yielding of Buckled ASSY VG CYL Screws

NDS-ASD VALUES

The ASD design values in Table 1 were derived with a factor of safety of 5 applied to the average ultimate capacity of the screws tested for buckling in each wood species, per NDS and AC233 specifications for wood-screw systems. These values may be referenced in calculating reinforced compression perpendicular to grain capacity; a design example with referenced equations can be found in the Timber Reinforcement Guide. Similar to screw tensile design values, screw buckling design values shall not be increased from short-term loading with C_D.

Table 1. Allowable Screw Buckling Values, W_c

Screw Diameter (mm)	Design Value, W_c (lbs)	Species
8	1420	D.Fir, SYP, Black Spruce
10	2220	D.Fir, SYP, Black Spruce

Notes:

1. The values in the table above are applicable for all lengths of 5/16" [8mm] and 3/8" [10mm] fully threaded ASSY VG screws.

Refer to Structural Screw Catalog

CSA & NDS - LRFD

LRFD Values (NDS)

Notably, the format conversion factor K_F is not required here as the NDS Clause N.3.1 of Annex N (2018) states that these format conversion factors shall not apply when the reference resistances are determined in accordance with ASTM D 5457. The resistance factor (ϕ) is equal to 0.65 and all other adjustment factors apply, with the exception of the load-duration factor, C_D.

LRFD/LSD Values (CSA)

The 5th Percentile Weibull 2-parameter analysis per ASTM D5457 includes the resistance factor (ϕ) of 0.8 in the design values published in Table 3. All standard modification factors apply, but the value shall not be increased for short term loading conditions with K_D.

Table 2. American LRFD 5th percentile Weibull 2-parameter analysis per ASTM D5457

Screw Diameter (mm)	F_{5th} x 0.65 (lbs)	Species
8	4290	D.Fir, SYP, Black Spruce
10	6760	D.Fir, SYP, Black Spruce

Notes:

1. The values in the table above are applicable for all lengths of 5/16" [8mm] and 3/8" [10mm] fully threaded ASSY VG screws.

Table 3. Canadian LRFD/LSD 5th percentile Weibull 2-parameter analysis per ASTM D5457

Screw Diameter (mm)	F_{5th} x 0.8 (lbs)	Species
8	5280	D.Fir, SYP, Black Spruce
10	8320	D.Fir, SYP, Black Spruce

Notes:

1. The values in the table above are applicable for all lengths of 5/16" [8mm] and 3/8" [10mm] fully threaded ASSY VG screws.

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