SCREW WITHDRAWAL RESISTANCE IN NEAR-EDGE APPLICATIONS

MyTiCon Timber Connectors
www.myticon.com | 1.866.899.4090 | info@myticon.com

ABSTRACT

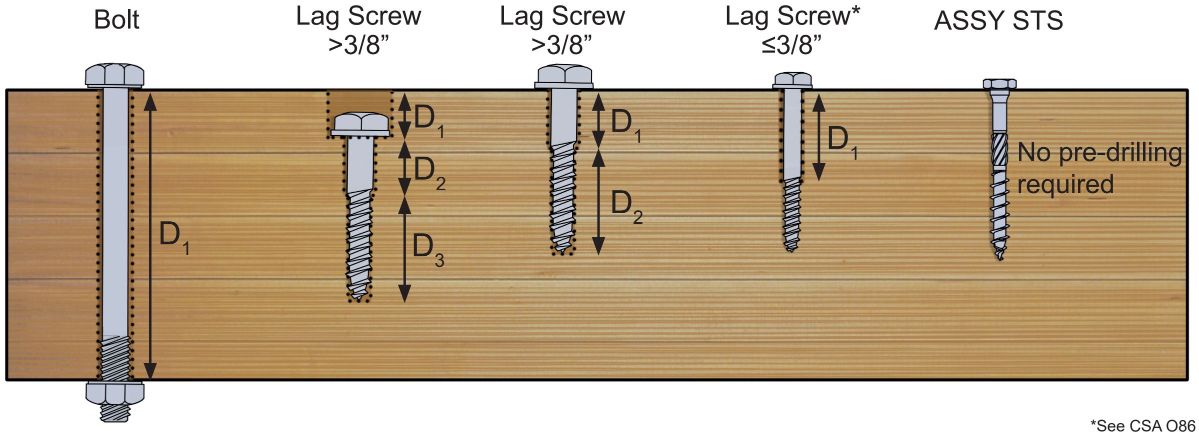
Practical application of long self-tapping screws (STS) in near-edge applications sometimes requires pre-drilling a pilot hole. It is commonly assumed that pre-drilling of a pilot hole with a diameter equal to the minor fastener diameter has no impact on withdrawal resistance. Designers have also assumed that, due to the lack of prescriptive code guidelines, pre-drilling guidelines established for lag screws can be applied to STS and smaller end and edge distances can therefore be used. The question of whether or not this pre-drilling impacts the fastener withdrawal resistances in near-edge applications is addressed in this newsletter.

Common Assumptions, Specifications, and Code Guidelines

The current version of the NDS and CSA O86 does not directly address the design of STS. Designers must therefore rely on the few leading ICC and CCMC approved guidelines. It is observed that designers sometimes use NDS and CSA O86 lag screw design provisions and directly apply the guidance to STS design while not being aware of potential fundamental differences. Lag screws, for instance, need to be installed into pre-drilled holes, while STS are designed to be installed without pre-drilled holes. Lag screws in pre-drilled holes can also be installed with significantly reduced end and edge distances when compared to STS requirements listed in ICC and CCMC reports.

Guidance provided by foreign design standards such as Eurocode 5 or technical reports such as the European Technical Assessment (ETA)—which are based on difficult-to-convert characteristic properties of wood—must be properly considered before being applied to North American timber. This applies, for example, to North American D-Fir, Black Spruce, Southern Yellow Pine, Cedar species, and a variety of engineered wood products such as PSL—but especially for timber of higher density that is more sensitive to splitting, such as D-fir.

The 2014 version of the CSA 086 specifies that no lead holes are required for the threaded portion of lag screws 3/8" diameter and smaller when primarily loaded in withdrawal. Any corresponding changes to the geometry requirements are not outlined, but instead left to the designer. The CSA O86 commentary provides justification on these changes based on STS research—possibly neglecting the influence of unique STS features such as tip shape, outside thread to minor diameter ratio, thread diameter to shank diameter ratio, shank cutters, and the possibility of various installation tools such as impact drills or wrenches.



*See CSA O86 Cl. 12.6.2.1

Figure 1. Comparison of pre-drilling requirements for various timber fasteners.

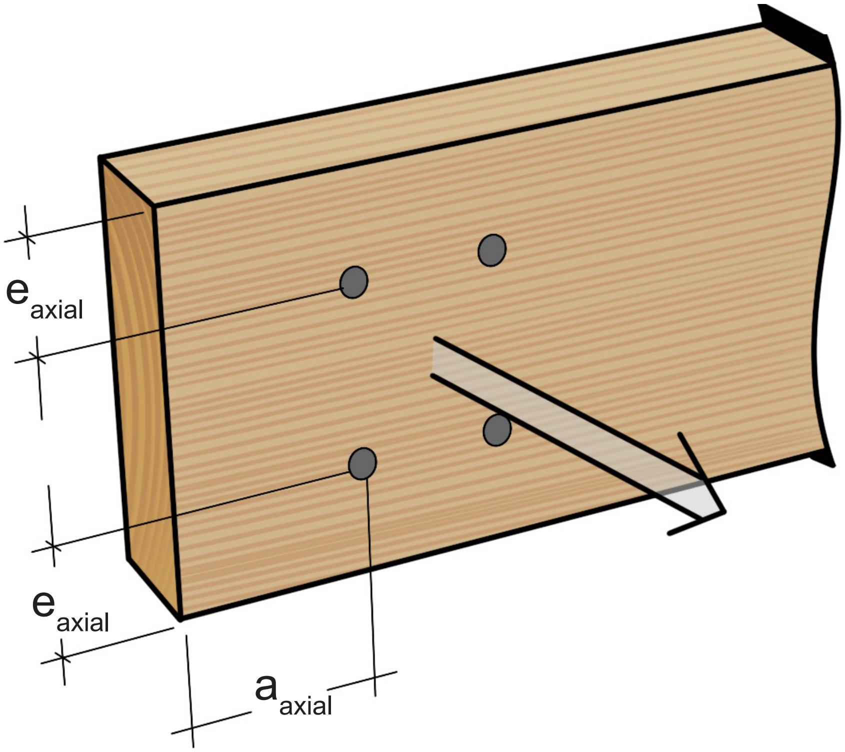
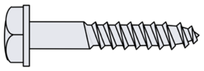


Figure 2. Typical geometry when loaded in withdrawal.

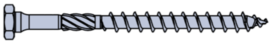
Table 1. Geometry Requirements for Common Lag Screws



Standard	Edge distance e_{axial}	End distance a_{axial}
USA values (NDS)	1.5D	4D
Canadian values (CSA)	1.5D	max(4D,50mm)

Note:
Axial loading only, for G ≤ 0.42.

Table 2. Geometry Requirements for ASSY Self-Tapping Screws



Standard	Screw type	Non-pre-drilled		Pre-drilled*	
		Edge distance e_{axial}	End distance a_{axial}	Edge distance e_{axial}	End distance a_{axial}
USA values (ICC)	Fully threaded	3D	5D	3D	4D
	Partially threaded	5D	10D		
Canadian values (CCMC)	Fully threaded	3D	5D	3D	max(4D,50mm)
	Partially threaded	5D	10D		

Note:
Axial loading only, for G ≤ 0.42.
* Values proposed by MyTicon Timber Connectors

TESTING CAMPAIGN

The testing efforts were targeted to adress:

1. The effect of pre-drilling on the withdrawal performance of ASSY STS
2. The effect of pre-drilling on edge and end distance requirements
3. The effect of near-edge installation on withdrawal resistance

Test Set-Up

Withdrawal testing on 5” wide D-Fir specimen utilizing 5/16” and 3/8” STS was performed. The fasteners were placed into the specimen following the end and edge distances as outlined in Figure 3. Fasteners were installed into pre-drilled holes where the hole was pre-drilled to the full installation depth of 8D and 16D (including the tip), where “D” indicates the fasteners outside thread diameter. Pre-drilled holes for 5/16” and 3/8” STS were made using a 3/16” and 1/4” drill bit respectively. All testing with 8D penetration was performed using partially threaded (PT) STS in accordance with ICC ESR 3179 while 16D penetration test were performed using fully threaded (FT) STS in accordance with ICC ESR 3178 (see Figure 4). PT screws are equipped with a counter thread tip engineered for quick “bite” and reduced splitting forces during installation, while FT STS are equipped with a “drill tip” which promotes further reduction in splitting forces, allowing for smaller end and edge distance requirements when compared to PT STS.

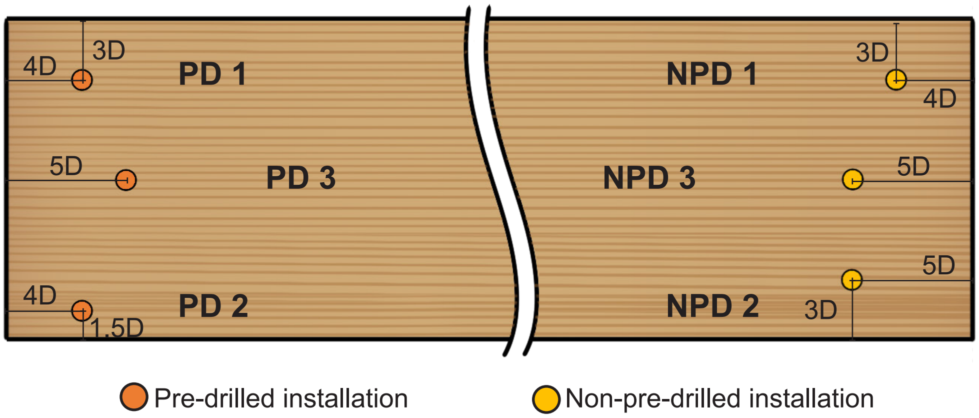


Figure 3. **Installation configuration.**

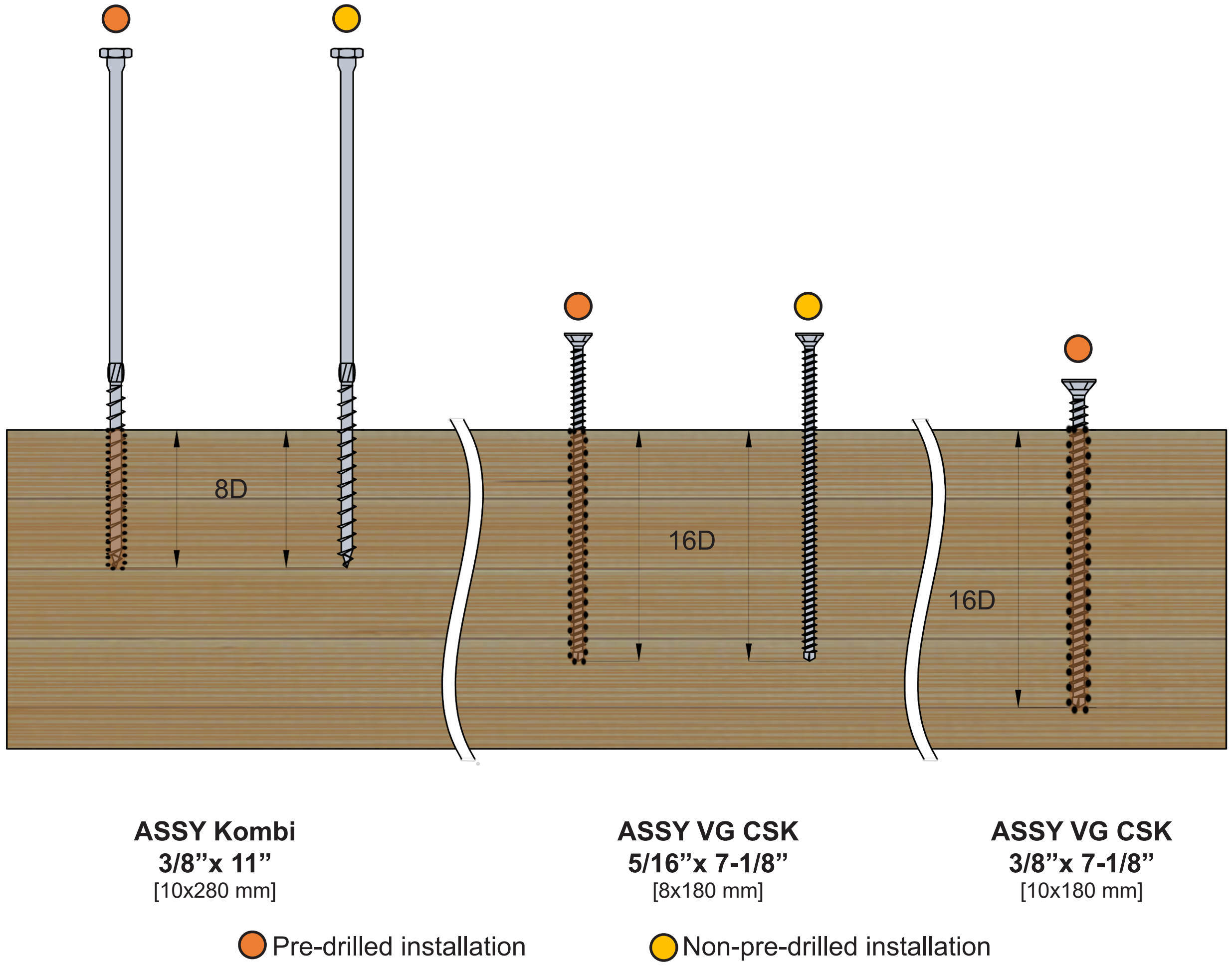


Figure 4. **Screw type used for testing.**

FINDINGS

Observations made during testing and data evaluation indicate that failure can be categorized into three controlling modes.

Block tear-out/splitting:
This failure mode was observed to involve block tear-out/splitting, and crack propagation to the end of the timber, resulting in a higher variability in the data.

Withdrawal failure:
This failure mode was observed to involve shear failure in the wood fiber surrounding the threads with minor splitting on the timber surface.

Tension failure:
This failure mode was observed to involve a net tension failure of the screw, resulting in a small variability in the data.

Figure 5.
Block tear-out /splitting failure [Top]; Withdrawal failure [Middle]; Tension failure [Bottom].

ANALYSIS

Classification into three apparent failure modes and their respective variability is shown in Figure 6. Observing the respective coefficient of variation measured from the recorded ultimate resistance associated to the failure mode provides insight into the predictability of the failure. Failures associated to properties of the wood such as splitting and cracking typically show larger variation, while failure modes associated to steel failure show lower variation.

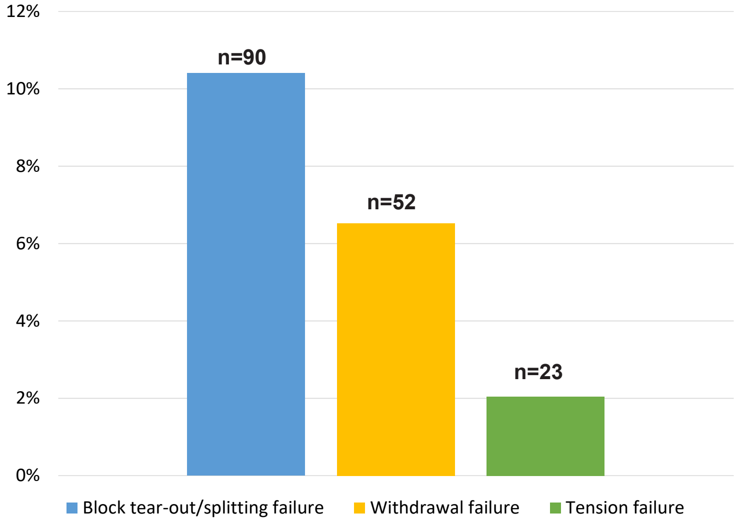


Figure 6. **Average (COV) of the three failure modes.**

Load-displacement relationship recordings provide insight into the performance of STS in withdrawal. Regardless of failure mode, it becomes apparent that all withdrawal failures seen in the testing campaign are typically associated with small deformations. Figure 7 illustrates this finding by showing typical load-displacement behavior for three different failure modes.

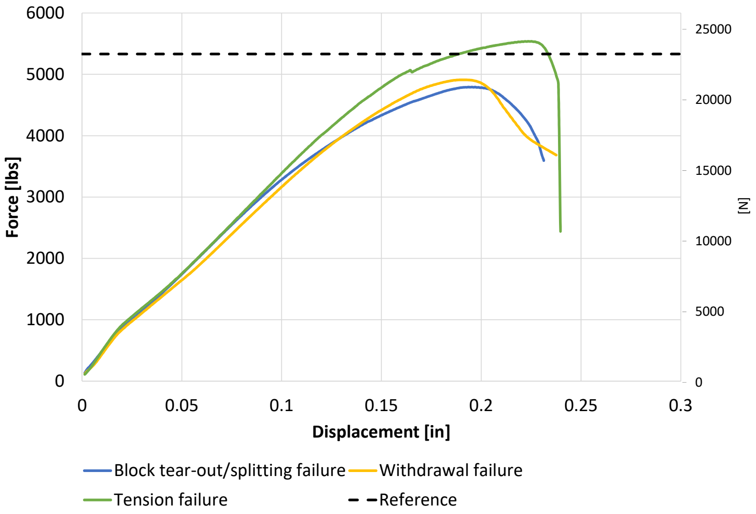


Figure 7. **Typical load-displacement relationship for the three failure modes for 5/16” [8mm] screws at 16D penetration, with average net tension resistance indicated (“Reference”).**

Influence of Pre-Drilling on Withdrawal Capacity

This testing campaign also investigated the influence of pre-drilling on the withdrawal resistance and failure mode of the fasteners. The results showed that pre-drilled screws yielded similar results to non-pre-drilled screws.

Test setup PD1 and NDP1 with 3/8” PT screws at 8D penetration in pre-drilled holes maintained a COV of 7% while boosting the ultimate average withdrawal resistance by 8.2% indicating the effect of the pre-drilled holes can be considered insignificant for near-edge applications.

Test setup PD1 and NDP1 with 5/16” FT screws at 16D penetration in pre-drilled holes maintained a COV of 6.2% while boosting the ultimate average withdrawal resistance by 0.6% indicating the effect of the pre-drilled holes can also be considered insignificant for near-edge applications. Although not illustrated, similar findings were noticed when comparing configuration PD3 to NPD3.

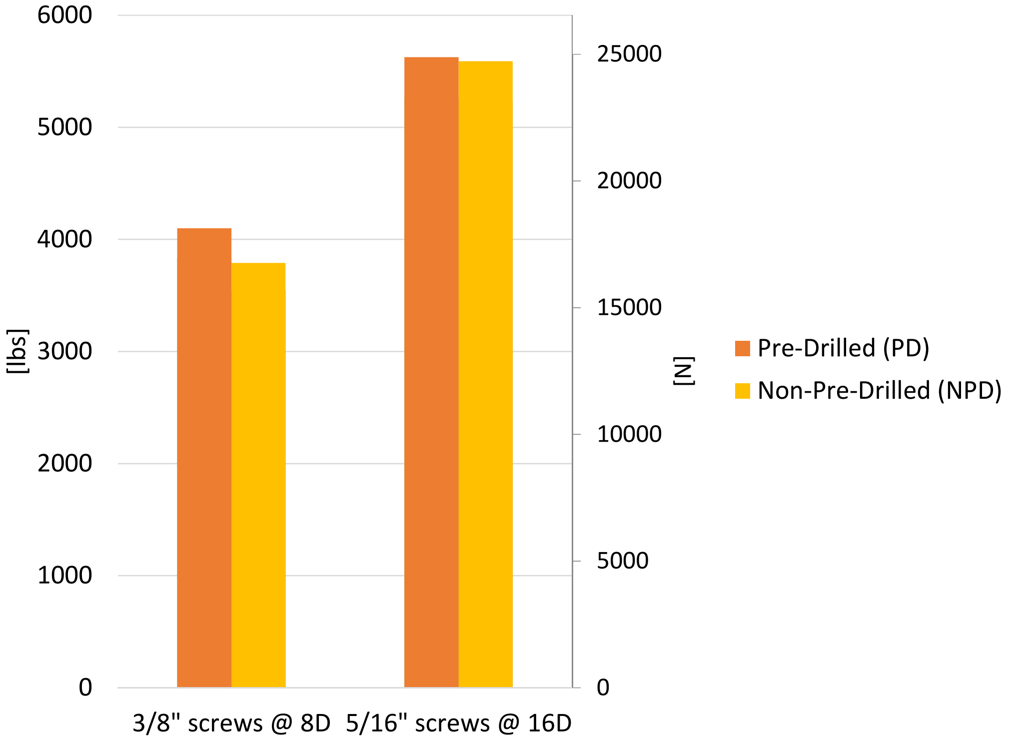


Figure 8. **Average peak load for 3/8” [10mm] partially threaded screws at 8D penetration and 5/16” [8mm] fully threaded screws at 16D penetration, for setup PD1 and NPD1.**

As shown in Figure 9, while fasteners in configuration PD1 were able to achieve a slightly higher peak withdrawal resistance than those in NPD1, the failure modes for fasteners in pre-drilled holes also tended to be characterized by block tear-out/splitting more often than fasteners in non-pre-drilled holes for this configuration.

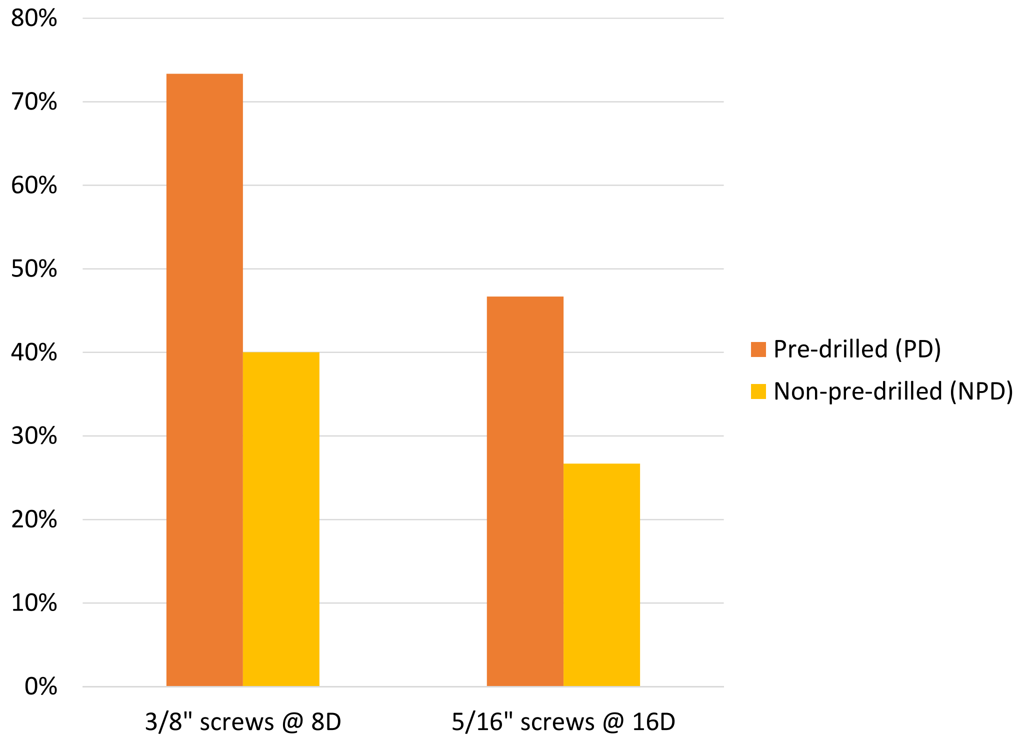


Figure 9. **Proportion of block tear-out/splitting failure for 3/8” [10mm] partially threaded screws at 8D penetration and 5/16” [8mm] fully threaded screws at 16D penetration, for setup PD1 and NPD1.**

Effect of Near-Edge Installation on Withdrawal Resistance

Design standards such as the NDS and CSA O86 allow near-edge installation of lag screws where the distance to the edge is only 1.5D and the distance to the end is 4D, with and without full length pre-drilled holes (in dependence of the lag screw diameter). Findings presented in this paper indicate that near-edge installation of STS loaded in withdrawal shall not be directly correlated to guidelines of lag screws, as STS loaded in withdrawal in near-edge applications seem to be increasingly prone to splitting failure modes, even with pre-drilled holes. This is especially true for large diameter fasteners with large thread penetration lengths, as seen in Table 3, below. It is important to note the timber used in this testing campaign was limited to D-fir—a wood species known for greater sensitivity to splitting—so it is anticipated that the results provided here represent a worst-case scenario. If it is decided that that the data obtained is not offering clear direction for STS in pre-drilled holes, more research may be required to provide greater insight into geometry requirements for future code revisions (for example, involving other North American timber species). Despite the observed variability in the failure modes and peak withdrawal resistances for the various installation configurations, high factors of safety are still apparent when comparing average ultimate withdrawal resistance to values listed in the ICC and CCMC reports.

Table 3. Average peak load, COV, and proportion of block tear-out failures for the different screw setup.

		3/8” screws at 8D pre-drilled					
		PD 2	PD 1	PD 3	Control	W	P_{rw}
Average peak load	**[lbs]**	**3900**	**3838**	**3974**	**4285**	**977**	**1809**
	[N]	17356	17077	17685	19068	4348	8050
COV	**[%]**	13.2%	5.4%	10.6%	8.9%	-	-
Block tear-out / splitting failure	**[%]**	87%	80%	40%	0%	-	-
		5/16” screws at 16D pre-drilled					
		PD 2	PD 1	PD 3	Control	W	P_{rw}
Average peak load	**[lbs]**	**4924**	**5267**	**4791**	**5331**	**1603**	**2481**
	[N]	21913	23438	21321	23725	7131	11040
COV	**[%]**	8.5%	6.3%	9.1%	2.5%	-	-
Block tear-out / splitting failure	**[%]**	93%	53%	20%	0%	-	-
		3/8” screws at 16D pre-drilled					
		PD 2	PD 1	PD 3	Control	W	P_{rw}
Average peak load	**[lbs]**	**6977**	**7599**	**N/A**	**8607**	**2079**	**3876**
	[N]	31047	33814	N/A	38300	9250	17250
COV	**[%]**	7.1%	7.7%	N/A	2.4%	-	-
Block tear-out / splitting failure	**[%]**	100%	100%	N/A	0%	-	-

Note:

1. Control: Average ultimate peak load from testing in non-pre-drilled holes with geometry in accordance with ICC reports
2. USA: Ajusted withdrawal design value (W) with C_D = 1.6
3. Canada: Factored withdrawal resistance (P_{rw}) with K_D = 1.15

CONCLUSION

Pre-drilling STS ASSY screws with a drill bit diameter of 3/16” and 1/4” for 5/16” and 3/8” diameter screws, respectively, does not seem to greatly influence the withdrawal capacity when compared to STS in non-pre-drilled holes. A greater proportion of block tear-out/splitting failure modes, however, was observed for STS in pre-drilled holes.

For larger diameter screws with long thread penetration lengths, the greatest influence on peak withdrawal values for near-edge applications was observed. Therefore, is it not recommended to use geometry requirements for lag screws loaded in withdrawal for STS in pre-drilled holes. For the time being, peak withdrawal values achieved for the installation configuration PD1 (3D edge distance and 4D end distance) seem sufficiently conservative when compared to the design values listed in Table 3.

References

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Contact Us

info@myticon.com
1.866.899.4090

Technical Support

support@myticon.com
1.866.899.4090

MyTiCon Timber Connectors

3-8287, 124th Street, Surrey, BC, Canada, V3W 9G2
www.myticon.com

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