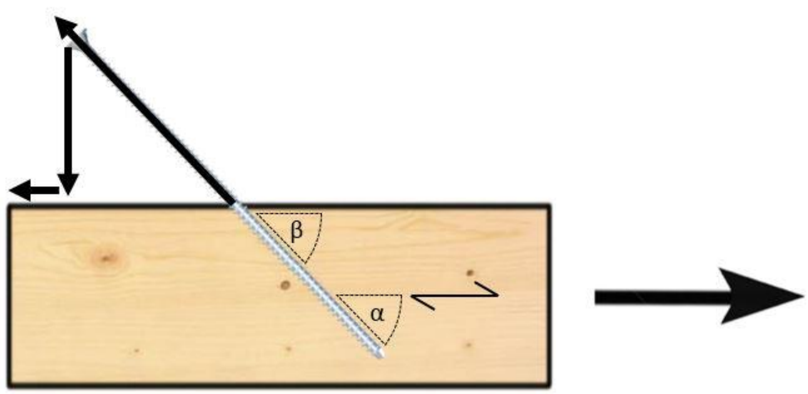
Q: In the simplified truss model, where does the normal force come from? Clamping? And why is it pointing downward. The figure the speaker shows does not show equilibrium with the direction of forces.

This is a good question, because timber engineers are normally trained not to assume friction in the shear plane for conservatism. When Johansen was testing connections with bolts and smooth dowels in the 1940s, there was a very significant effect from friction when bolts were used, which was a function of the degree of pre-tensioning (clamping) in the bolt. However, the conservative approach has been to ignore the effect of friction to account for possible swelling/settling action of the wood over the service life of structures.

For fully threaded inclined screws, there is a clamping force for steel to wood connections, but for wood to wood connections, we assume no clamping force because the threads engage both members. Rather, the friction is assumed to come from loading the joint: when the joint is loaded, a normal force is activated as a result of eccentricity in the connection, as minor deformations allow the joint to be compressed.

The derivation of the normal force is based on the equilibrium of forces at the shear plane for an undeformed fastener, so we treat steel to wood and wood to wood connections the same as far as friction is concerned (see image below). See also the Basic Theory of Inclined Screws webinar (2/4) for information about friction when using symmetrical screw crosses.



Q: How did you determine the factors of safety?

(USA) Reference withdrawal design values and allowable tensile strength are based on specifications outlined in AC233.

In the webinar, when determining the factor of safety for the connections, we are taking the peak tested resistance and dividing it by the adjusted short-term design resistance (with C_D = 1.6), since the test values come from short-term loading. If we would reference normal duration loading design values (with $C_D = 1.0$) the factor of safety would be even greater.

Q: Is the extended Johansen theory available calibrated to North American design standards or is it only applicable for the use with EC5?

We are not aware of any North American confirmation testing using the the Extended Johansen Theory with North American design parameters. The Extended Johansen Theory has been assessed using European design parameters since 2001 ("*Screws with continuous threads in timber connections,"* by Blass & Bejtka*),* but some of these parameters between older and newer studies have changed over time, so this all needs to be kept in mind when comparing one study to the next.

Before simply swapping out European parameters for North American ones, we think there needs to be an examination to see how they compare to one another, such as how they were all derived. After that, North American design values obtained using the Extended Johansen Theory should be compared to test data. This, of course, is just basic diligence. It is worth repeating that European design values/parameters should never be used in North American design, since the codes are calibrated differently.

The results of some ongoing research regarding the Extended Johansen Theory to date can be found in:

> Zhao, R., Joyce, T. & Chui, Y.H. (2018). *Reliability analysis of load-carrying capacity for connections consisting of inclined self-tapping screws.* 2018 World Conference on Timber Engineering.

Q: Ductile connections are very important for seismic connections. Screw tensile failure isn't ductile. How ductile are the withdrawal limit states?

We take "ductility" to mean *the ability to resist load without significant reduction in capacity over large deformations.* Screws loaded axially have high strength and stiffness, but limited ductility. This goes for both withdrawal failure and tensile failure for direct axial loading, since once the withdrawal or tensile capacity of the screws is exceeded, the load carrying capacity drops off significantly.

For inclined screws, if the screw fails in withdrawal, meaning the screw is still intact, there will be some bending of the screw through inclined dowel action which contributes to limited load carrying capacity beyond the point of peak resistance. For inclined screws that fail in tension, there is no residual capacity beyond peak resistance, since the screws are no longer intact. This means that observations regarding ductility and energy dissipation for inclined screws that fail in withdrawal should not be assumed to apply to longer screws under a similar arrangement where tensile failure controls. A good overview of screw-in angles and seismic design (including hybrid inclined + shear screw connections to boost ductility) can be found in the following paper:

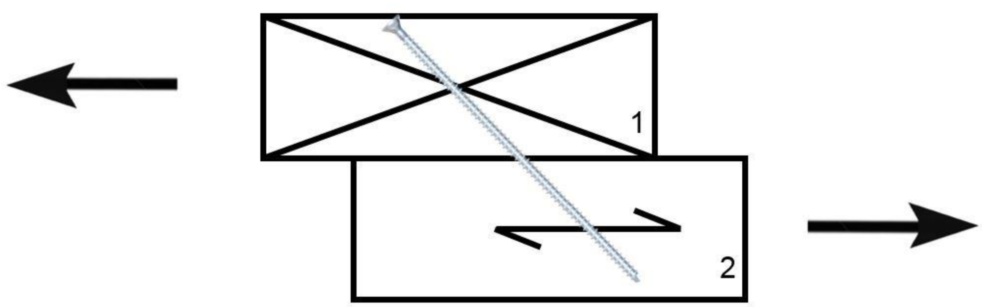
> Hossain, A., Popovski, M. & Tannert, T. (2016). *Cyclic performance of shear connections with self-tapping screws for cross-laminated timber.* 16th World Conference on Earthquake, paper N◦ 2913.

Inclined screws can still be incorporated as a part of seismic design by employing capacity-based design principles. Since inclined screws produce predictable, high strength connections, it is easy to design them with sufficient overstrength to assign ductility and energy dissipation to ductile "fuses" in the structural system. A great example can be found in this Youtube video of a shake table test at UC San Diego in 2017. There are inclined screws from MyTiCon used all throughout the structure for steel plate connections, including the energy dissipating U-brackets, which can be seen here:

https://youtu.be/Y8e-FCGk_AM?t=22s

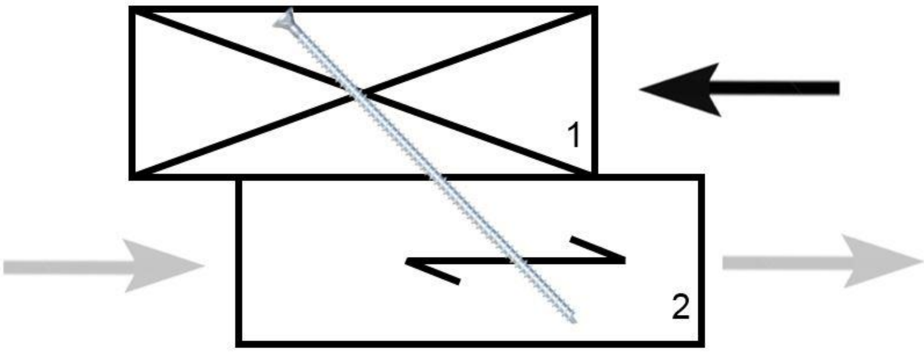
Q: What is the effect of having one member in an inclined screw connection loaded parallel to grain and the other member loaded perpendicular grain?

Let's assume a loading condition like in the picture below:



Looking at the screw capacity alone, the only effect would be that in member 1, the withdrawal capacity would be higher, since the angle to the grain (α) is 90 degrees. For member 2, the angle to the grain (α) would be whatever angle the screw is installed relative to the shear plane.

Most of the testing, however, assumes the timber is loaded parallel to the grain, which is the strongest loading direction for wood in tension and compression. In the picture above, member 1 is being loaded in tension perpendicular to the grain, which is a very low strength loading direction, which could also produce failure modes not accounted for in the design model. Exceptions to the parallel to the grain loading rule include CLT where sufficient anchorage can be achieved in plies where the loading is parallel to the gain, and for some situations where the wood oriented perpendicular to grain (member 1) is loaded in compression (such as ledgers), as illustrated in the photo below:



Q: How do you account the withdrawal strength of inclined screws when you have several self-tapping screws (group effect)?

Before answering the question, it can be mentioned that NDS and CSA O86 do not account for group action effects for axially loaded fasteners. Furthermore, North American group action factors for laterally loaded fasteners are partially based on the cross-sectional area of the connected members, which makes them awkward to apply to mass timber panels.

Surveying the various studies and design standards for inclined screw connections, you will find a variety of proposals to account for group action effects. Some have made use of the factor $n_{ef} = n^{0.9}$ where *n* is the number of screws acting together in a connection. This is an empirical formula for axially loaded fasteners found in EC5. This formula is generally found to be too conservative for large numbers of inclined screws, however, and newer writings tend to favor newer research showing that a reduction factor of 0.9 is sufficient to cover wood to wood and steel to wood inclined screw connections. Therefore, we use **$n_{ef} = \max[n^{0.9}; 0.9 \cdot n]$**, which generally gives us $n_{ef} = 0.9 \cdot n$. This formula is easy to use and does not reference the cross-sectional area of the wood, so it also works well for massive timber panels.

It is also important to specify that power tools with torque-clutches should be used for steel to wood connections, because this will promote even pre-tensioning and therefore even load sharing. Test data from MyTiCon also confirms the suitability of the above stated group action factors.

Q: Just to clarify, CSA 086 does not provide an interaction-style equation for combined lateral and axial loading? Does MyTiCon recommend using the simplified truss model and using the screw's axial capacity only?

CSA O86 does not provide an interaction-style equation for combined loading.

We promote the use of the simplified truss model method using North American design values for the axial capacities, for angles between the screw axis and the line of the force in the range of $30° \leq \beta \leq 45°$.

Keep an eye out on our "Knowledge Base" section of our website for more information on design procedures and equations:

http://www.my-ti-con.com/knowledge-base

Q: What if the screw is penetrated in CLT in parallel to grain direction?

This question can be answered by referring to the earlier question about parallel and perpendicular to grain loading, we can elaborate a bit more on CLT: Tensile loads carried by CLT should be assumed to be carried by plies with the grain oriented parallel to the tensile force. Cross-wise layers can transfer tensile forces to parallel-oriented layers, but tensile forces cannot be transferred between adjacent plies in the cross-wise layers because, even without gaps, the edges are unglued.

Many studies have verified the high performance of inclined screws in CLT (many of these can be found in the final "Resources/Further reading" slide of the Powerpoint pdf file). A novel application using double-angled inclined screws across butt joints in CLT can be found here:

> Hossain, A., Danzig, L., & Tannert, T. (2016). Cross-laminated timber shear connections with double-angled self-tapping screw assemblies. *Journal of Structural Engineering,142* (11).

Q: How do inclined screw connections fare in terms of constructibility? (Are connections typically built with enough precision to ensure the proper angle of inclination?)

Achieving the proper angle of inclination is important. Getting the angle right promotes even load sharing and also ensures that accidental through-penetration of the member does not happen. An acceptable level of tolerance should be within the range of a few degrees.

We recommend the use of jigs and pilot holes to establish the precise placement of inclined screws (especially when using 45 degree washers in steel to wood connections). More information can also be found here:

http://www.my-ti-con.com/knowledge-base/pre-drilling-requirements-inclined-screw-applications