ROLLING SHEAR - THE ACHILLE’S HEEL IN CLT BENDING

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Rolling shear is one of the characteristics of timber which had very little consideration in NZ so far. It was considered when dealing with plywood design but was mostly overlooked in normal timber member design. However, this changed with the advent of mass timber and Cross Laminated Timber (CLT) panels.

Cross Laminated Timber panels are the engineered wood product that contributed the most significantly in the last two decades in allowing timber structures to increase in size and in height. This product allows for pre-fabrication and fast erection, making timber structures as competitive as concrete or steel.

CLT is composed of sawn timber laminations glued on their wide side and with adjacent layers at 90 degrees. The exterior laminations are usually in the longitudinal direction of the panel and the number of laminations various from even in a 3-layer panel to odd in a 5-layer panel with the transverse layers in between the longitudinal being odd and even numbers retrospectively, depending on the buildup. (see Figure 1).

CLT panel are used in floors and thus resisting loads in bending with the panel longitudinal layers in the direction of the floor span. An analog model of a CLT panel under bending is shown in Figure 2.

The “links” connecting the longitudinal layers are significantly more flexible than the longitudinal layers. These links represent the flexibility in the transverse layers under shear stresses. Those shear stresses are in this case, rolling shear stresses. The transfer in the longitudinal layer is described in mechanism a) and the transfer to the transverse layer in mechanism b) of figure 3.

Figure 1. Cross Laminated Timber panel cross-section.

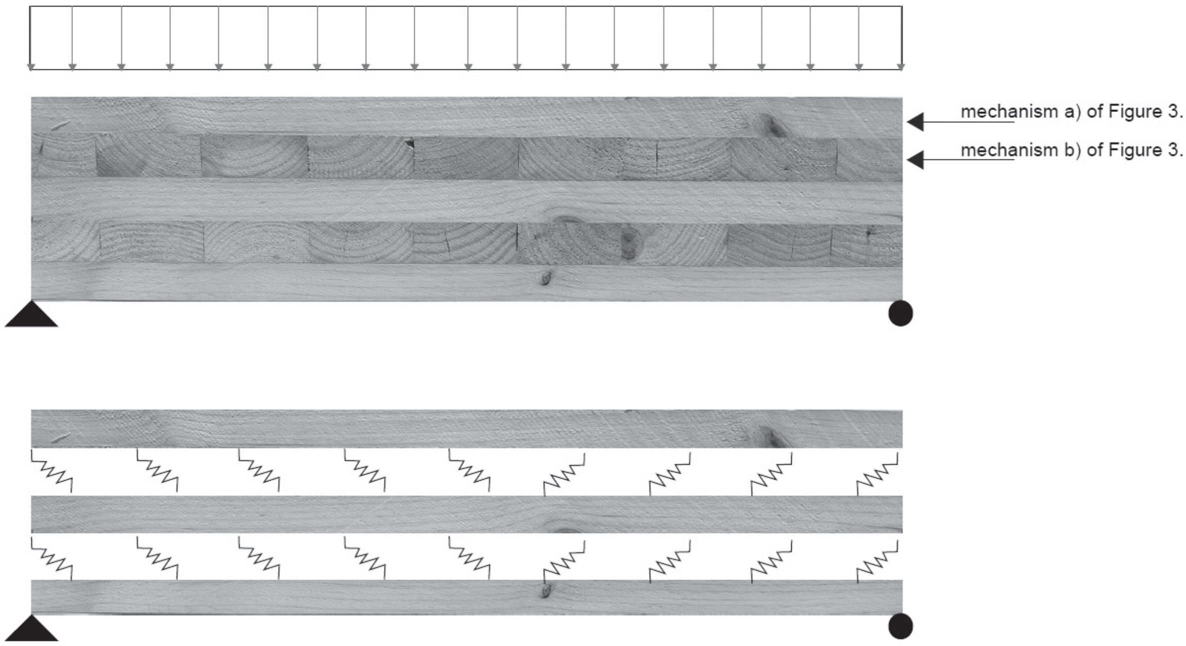

Figure 2. CLT analog model with transverse layers as flexible links between the longitudinal layers.

BUT WHAT IS ROLLING SHEAR?

Rolling shear is the shear where the force is applied in the longitudinal plane and is in the direction perpendicular to the grain. This is best explained by comparing the longitudinal shear and the rolling shear in Figure 3. In the figure to the left, we show the wood fibres and the three main fibre directions (Longitudinal (L), Radial (R) and Tangential (T)) of a generic solid timber cube.

In the middle of the figure, we show the longitudinal-radial plane. Below it, the shear is applied in the longitudinal-radial plane, and it is in the direction parallel to the grain. One can see the shear deformation that results from this longitudinal shear. In the figure to the top right, we show the radial-tangential plane. Below it, the shear is applied in the tangential plane, in this case the direction is perpendicular to the grain. The shear causes the fibres to “roll” relative to each other. This is the rolling shear direction.

To put things in perspective, it is best to look at the stiffness and strength of the wood fibres in the different

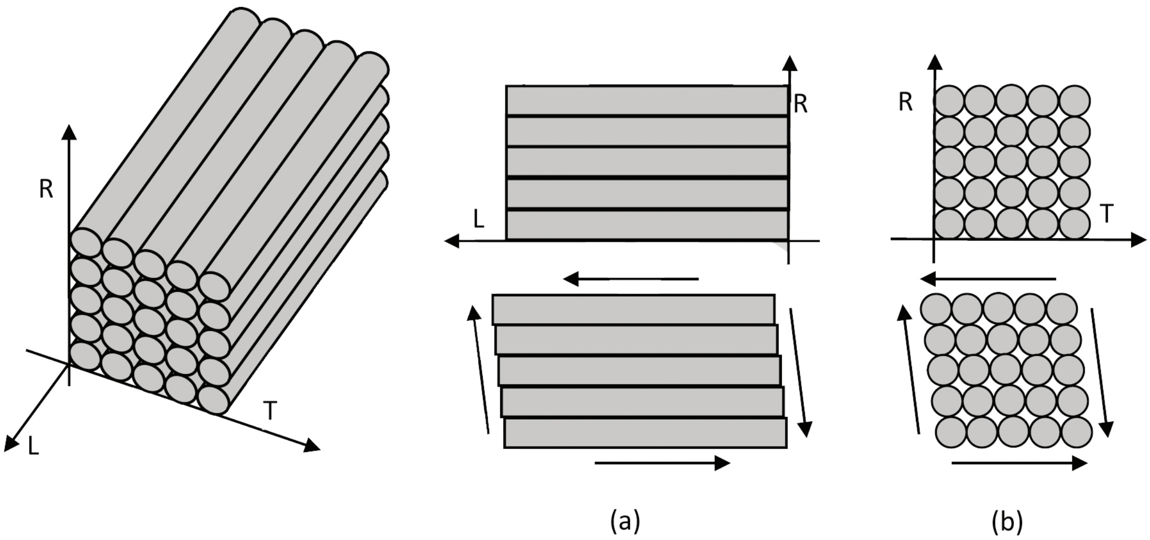

Figure 3. Shear in a generic timber section/cube. Longitudinal shear (a) and rolling shear (b).

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directions as this is important in understanding the behavior of CLT panels.

The strongest direction is longitudinal and the stiffer one. For the sake of comparison, let us use a SG8 piece of timber. The E in the longitudinal direction is 8000 MPa (note, this is the average value). The characteristic compression strength in this direction is 18 MPa and the characteristic tension strength is 6 MPa (NZS AS 1720.1:2022, 2022). The shear modulus G in the longitudinal direction (direction (a) in Figure 3), is E/15, thus 533 MPa FPI Innovations CLT Handbook (Popovski et al., 2019).

In the transverse directions of the CLT panel, the E of the fibres is the one about the Radial or Tangential directions. This E_{90} is about E/30. The values of the E and the E_{90} influence the stiffness of the CLT panel. Moreover, the rolling shear stiffness G_R is approximately 10 times smaller than the longitudinal shear stiffness G, thus we have G_R = E*150, or 53 MPa. (Popovski et al., 2019)

Referring to figure 2, the stiffness of the 3 longitudinal layers would be 8000 MPa and the stiffness of the links between the longitudinal layers would be 53 MPa.

The strength in rolling shear of timber is also lower and about 1/3 of the shear strength fs in the longitudinal direction, thus about $f_{s,r}$ = 3.8 MPa/3 = 1.2 MPa for SG8 piece of timber as described in the proHolz CLT Structural Design Guide (Wallner-Novak, DI Dr. Markus, 2014). 1.2 MPa is being referenced by most New Zealand and Australian manufacturer of CLT. Research suggests the rolling shear strength is linked to a function of the laminate depth and dependent on the individual lamella aspect ratio (Ehrhart, M-4-10/2014) with a limited number of tests for Radiata pine (Pinus radiata) in CLT carried out so far (Li, 2017).

This low resistance in rolling shear can govern the bending resistance of CLT panels. There are many observations in the literature where a rolling shear failure in the CLT panel transverse layer was the first failure to occur in a panel bending test, as shown in Figure 4 .

In conclusion, because of the nature of CLT (having transverse laminations transferring normal stresses in rolling shear), it is now impossible to not be aware of rolling shear characteristics. With its low stiffness and strength, rolling shear is causing significant deformations and failures in CLT if not carefully considered by the designer . At the moment NZ specific testing is still limited to only a few tests and further research and testing is required. The referenced values are an approximation based on international guidelines and should only be considered as best practice until further NZ specific data is available. This tech note encourages NZ industry to undertake further research with regards to rolling shear stiffness and rolling shear strength for timber and all mass timber products utilized in NZ.

NOTATION AND FACTORS

Symbol	Definition
G	Shear modulus
GR	Rolling shear modulus
E	Elastic modulus parallel
E90	Elastic modulus perpendicular
fs	Characteristic shear strength
fs,r	Characteristic rolling shear strength

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