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1 Background and aim

One important property to be determined for cross laminated timber (CLT) is the shear stiffness at out-of-plane loading. The shear stiffness is governed by the lay-up of the CLT, and by the material stiffness of the individual layers. Typically, a shear flexible beam theory, such as Timoshenko beam theory (TBT), the so-called γ-method or the Shear Analogy (SA) approach, is used in evaluating test results from out-of-plane loading, see *e.g.* [1, 2].

In the product standard EN 16351, [1], one approach to test for shear stiffness is to measure the local deformation (curvature) at mid-span in a 4-point bending test (which is assumed to be independent on shear deformations) and the global deformation (which includes shear deformations), see Figure 1. By subtracting the one from the other, the shear deformations can be estimated.

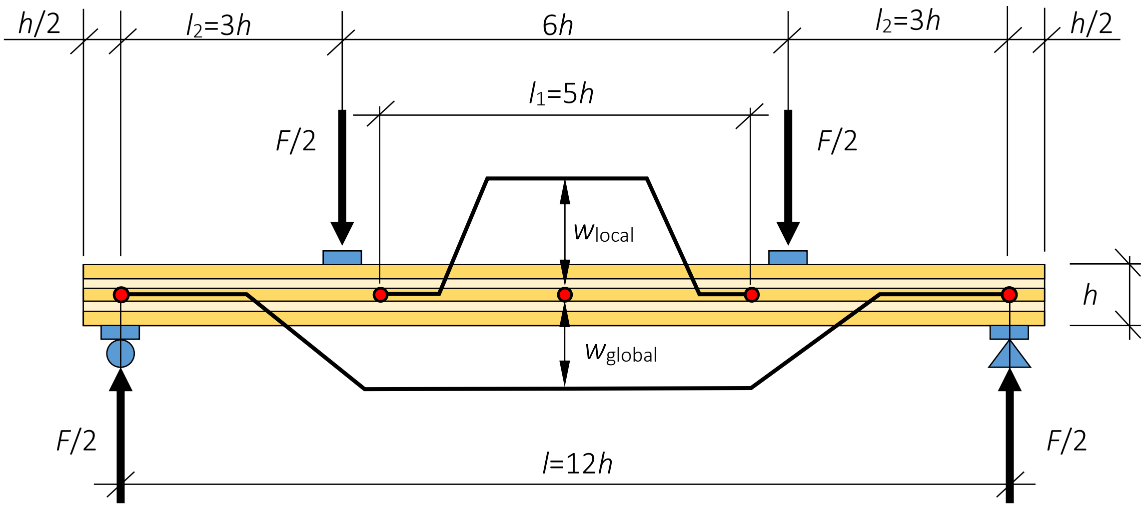

Figure 1. Test method to determine the shear stiffness at out-of-plane loading of CLT according to EN 16351.

In [3] it is stated that such a test set-up *"...does not allow for the determination of a reliable rolling shear modulus."* In recent work [4, 5] it was shown that the method of EN 16351 is indeed sensitive to small measurement errors and alternative approaches were discussed.

This paper aims at highlighting the drawbacks of the evaluation method proposed in EN 16351 [1] for determination of *shear stiffness (rolling shear) at out-of-plane loading of CLT*, corroborating the results of [4, 5] and, by additional FE-modelling work done specifically for the current paper, provide a sound basis for decision making as regards the test standard. Furthermore, this paper explains why the basic approach of the method in EN 16351 is erroneous and how it preferably should be reformulated.

Firstly, a short overview of relevant previous work is given, followed by a description of the modelling approach used herein for out-of-plane loading of CLT. The paper then highlights the consequences of using the proposed evaluation method of EN 16351 in determining the shear stiffness of CLT at out-of-plane loading. Here, two-dimensional (plane stress) FE-models are used as references. An alternative approach which apparently would substantially improve the accuracy in determining the rolling shear modulus is proposed. Finally, some suggestions for future work and closing comments as regards consequences for standardisation are given.

2 Previous work – Out-of-plane loading of CLT

2.1 Modelling approaches

As regards the description of CLT at out-of-plane loading, several different modelling techniques have been used, including shear flexible approaches based on Timoshenko beam theory (TBT) [6], the γ-method [7] and the shear analogy (SA) approach by Kreuzinger [8]. Less commonly used theories are layered beam theory (LBT) [9, 10], and several versions of so-called zig-zag theories [11]. It should be noted that according to [10] the LBT is equivalent to the use of SA.

Except for the TBT, the above-mentioned theories are implemented to analyse CLT as a beam built from a number of layers. In doing so, it is assumed that each layer is (at least piecewise) homogeneous. Consequently, variation of material directions or material stiffness in the beam axis direction, or indeed any influence of free edges in transverse layers (non-edge glued CLT) is dealt with using a smeared approach. Thus, the shear stiffness of a transverse layer represents an equivalent modulus of rigidity (shear modulus) that includes the effects of free edges and an “average” annual ring orientation.

An extensive analysis of different modelling approaches is given in the work of Bogensberger *et al*. [12] including TBT, the γ-method, and the SA, all being compared with 2D FE-analyses using plane stress elements. The cases examined involve 1-, 2- and 3-span girders with uniform loads, and the different modelling approaches are discussed in terms of stress and deformation predictions for these cases, of relevance for design practice. In the work, focus is also placed on applying realistic boundary conditions in the 2D FE-model, to mimic the behaviour of a CLT plate resting on a wall, and the influence of such modelling on the predicted stress distributions.

In the work of Blass and Fellmoser [13, 14], approaches to determine effective stiffness and strength parameters of solid wood panels are discussed, based on different modelling techniques, including SA and 2D FE-analyses.

Obviously, several authors have already approached the topic of accurately predicting/model the behaviour of CLT at out-of-plane loading although surprisingly little is reported on the use of such methods in evaluating test procedures. Two studies dealing with this are [4] and [5]. For the present work, especially the study of Lind [5] is of interest. In that work, one CLT-lay-up was investigated: 5×20 mm C24 CLT. By performing 2D FE-analyses and evaluating the FE-results in the same way that would be done with results obtained from a laboratory test, it was concluded that the proposed evaluation method of EN 16351 does not give reliable results, in general. However it worked quite well for the reference case investigated in that study (5×20 mm, E_0=11 000 MPa, E_{90}=370 MPa, G_0=690 MPa, G_{90}=50 MPa, where E denotes the modulus of elasticity and G denotes the shear modulus, indices *0* and *90* denote the longitudinal and transverse directions, respectively), but the results were extremely sensitive to changes of input data: *"… if the rolling shear modulus is 50 MPa and the shear correction factor is set to 0.25 the testing method provides quite accurate results for this particular beam. The output/input-ratio was approximately 1.08 meaning that the result is 8 % larger than the actual rolling shear modulus, used as input in the FE-model."*. However, it was at the same time concluded that if the theoretically correct value of the shear correction factor (0.193) is used instead, and/or if other rolling shear modulus values are used as input in the FE-model, the predicted rolling shear modulus from the EN 16351-approach gives unreasonable values, differing from the input value by a factor of up to almost 10.

3 Test evaluation according to EN 16351

3.1 Approach

The test situation as given in EN 16351 is shown in Figure 1 and the related expressions used to evaluate the test results are given below. In EN 16351 it is stated that the shear correction factor for five-layer CLT may be assumed to be equal to 0.25. Consequently, in the current investigation, the shear correction factor, κ, has been set either to the proposed fixed value of 0.25 or has been calculated using the expression given in [15]

$$\kappa = \frac{1}{\kappa_z}; \qquad \kappa_z = \frac{\sum G_i \cdot A_i}{\left(\sum (E_i I_i + E_i A_i a_i^2)\right)^2} \cdot \int_h \frac{\left(E(z)\int A \cdot z\,dz\right)^2}{G(z)\cdot b} dz \qquad (1)$$

where E, G, A and I are the modulus of elasticity, shear modulus, area and second area moment of inertia, respectively, of the layers, i and where a denotes the distance from the centre of gravity of the cross section to the centre of gravity of a layer.

The shear stiffness of CLT is determined using the following expression:

$$(GA) = \kappa \sum_{i=1}^{n} G_i \cdot A_i = \frac{24(EI)_{local} \cdot (EI)_{global}}{(3l^2 - 4l_2^2)((EI)_{local} - (EI)_{global})} \tag{2}$$

with

$$(EI)_{local} = \frac{l_2 l_1^2}{16}\left(\frac{\Delta F}{\Delta w_{local}}\right) \tag{3}$$

and

$$(EI)_{global} = \frac{3l_2 l^2 - 4l_2^3}{48}\left(\frac{\Delta F}{\Delta w_{global}}\right) \tag{4}$$

and where l, l_1, l_2, F, w_{local} and w_{global} are all defined in Figure 1. Finally, EN 16351 states that (for symmetric five-layer CLT) the effective shear stiffness is calculated as

$$\sum_{i=1}^{n}\left(G_i \cdot A_i\right) = b \cdot (t_1 \cdot G_0 + t_2 \cdot G_{90} + t_3 \cdot G_0 + t_4 \cdot G_{90} + t_5 \cdot G_0) = b \cdot t_{lay}(3 \cdot G_0 + 2 \cdot G_r) \tag{5}$$

where the last equality holds for constant layer thickness, t_{lay}, and where G_{r} is the rolling shear modulus. Now, if Equation (5) is inserted into Equation (2), a closed form expression for G_{r} is obtained. However, to determine G_{r}, the longitudinal shear modulus G_0 and the shear correction factor need to be known. In EN 16351 it is mentioned that the value of G_0=650 MPa can (should) be used. Its influence on the results is, however, expected to be limited. The shear correction factor can according to EN 16351, as already mentioned, be assumed to be 0.25.

3.2 The problem(s)

Applying the above equations effectively means using an approach based on Timoshenko beam theory, aiming at backwards calculating the shear deformations. Following this, the rolling shear modulus of the transverse layers are calculated from Equation (5).

Since the evaluation involves quantifying the difference between measured values, it could be that the approach is very sensitive to small measurement errors. Furthermore, it could be questioned to what extent the fixed value of κ would influence the results, and, finally, the influence of the assumed value of longitudinal shear modulus on the results is unknown and should be investigated.

However, from the investigation in [5] it is clear that the approach of EN 16351 does not work even when applying it for the idealised conditions of a FE-analysis and that the problem seems ill-conditioned. Therefore, the choice of shear correction factor (κ-value) and of shear modulus of the longitudinal layers could potentially influence the results considerably. In [5] it is also shown that the strain distribution found from the 2D FE-analyses, deviate quite considerably from the strain distribution assumed when using beam theory, and that this deviation could also add to inaccurate predictions of G_r.

4 Methods and cases analysed

4.1 FE-modelling

Two-dimensional, plane stress models have been used in the present study. All models are based on small strain, linear elasticity and the influence of annual ring orientation and influence of free edges (non-edge-glued CLT) have not been explicitly taken into consideration. The reason for doing this is to simplify the evaluation and interpretation of the results. It also facilitates the comparison with (layered) beam theory. A discussion on these parameters is given at the end of the paper.

The set-up has been modelled with boundary conditions mimicking the conditions for a laboratory test, involving the use of stiff plates at the support and at the load introduction point, their length being set to 60 mm, see Figure 2. The stiff plates were modelled by the use of coupling constraints and no slip between the CLT and the plate is allowed.

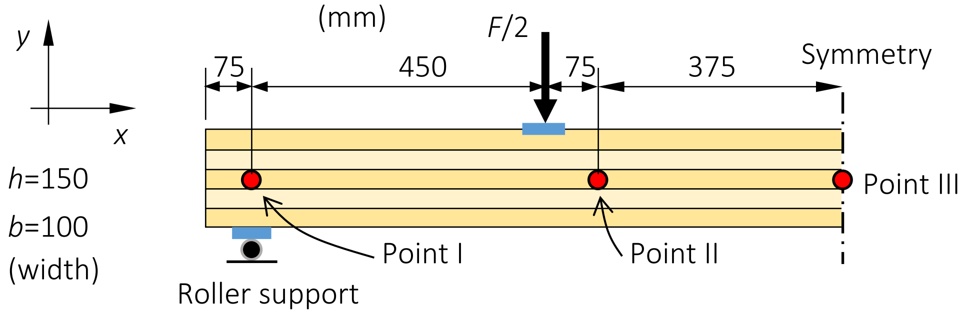

Figure 2. Model used for FE-analyses with steel plates indicated in blue and points for evaluation of displacements in red.

The FE code ABAQUS [16] has been used for the analyses, which are based on a mesh using square, 8-node second order elements. Since the problem is analysed in 2D, the mesh size was not an issue in terms of computer resources. Based on a convergence study (see Table 1), it was decided to use the finest mesh, with an element size of 1.25 mm, which gave in total 93 600 elements. Thanks to symmetry, only half of the test set-up needs to be modelled. The model analysed is 100 mm wide. The material data used in the analyses is summarised in Table 2.

Table 1. Convergence study. The deformations refer to Figure 2, measured in the FE-model according to the provisions of EN 16351.

Element size	Global deformation $u_{y,\text{III}}-u_{y,\text{I}}$	Difference (%)	Local deformation $u_{y,\text{III}}-u_{y,\text{II}}$	Difference (%)
10 mm	−12.7410	-	−1.8610	-
5 mm	−12.7510	0.079%	−1.8593	−0.091%
2.5 mm	−12.7561	0.040%	−1.8585	−0.043%
1.25 mm	−12.7584	0.019%	−1.8580	−0.027%

Table 2. Material data used in FE-analyses.

Symbol	Quantity	Value	Unit	Remark
E_0	MOE along grain	12 000	MPa	-
E_{90}	MOE across grain	400	MPa	$E_0/30$
G_0	Longitudinal shear modulus	750	MPa	$E_0/16$
G_{90}	Rolling shear modulus	75	MPa	$G_0/10$
$\nu_{0,90}$; $\nu_{90,0}$	Poisson's ratio	0.50	-	-

The provisions of the standard EN 16351 have been adhered to as regards the specimen lay-up in all cases studied herein. Thus, *only five-layer* CLT has been investigated, and in addition, the *outer laminations are oriented with the grain in the x-direction*. All face bonds are assumed rigid, and the influence of non-edge bonding has not been included here but is briefly discussed in the discussion section. For additional details on the influence on this, see *e.g.* [5].

The reference case is a 150 mm thick CLT plate with equal layer thicknesses, *i.e.*, the lay-up is 30-30-30-30-30 (lay-up A). In addition, four alternative lay-ups B–E have been investigated, all with the same total thickness of 150 mm, see Table 3. The reason for introducing layups B–E is to investigate the performance of the evaluation method for a broader range of shear-to-bending stiffness ratios ($\kappa GA/EI$) of the cross section.

Table 3. Lay-ups studied. Values of cross section bending stiffness (EI) and shear stiffness (κGA, see Equation (1)) are based on assuming the transverse modulus of elasticity being E_{90}=400 MPa.

Lay-up	Thickness of layers [mm]	EI [$\text{Nm}^2\cdot 10^5$]	Shear correction factor, κ	κGA [$\text{N}\cdot 10^6$]
A	30-30-30-30-30	2.6964	0.2430	1.7497
B	20-40-30-40-20	2.1145	0.2662	1.5571
C	20-45-20-45-20	2.0961	0.2672	1.3829
D	40-20-30-20-40	3.0695	0.2535	2.1671
E	45-20-20-20-45	3.1739	0.2388	2.0417

As already mentioned, only linear elastic behaviour has been considered. Bearing in mind that the purpose is establishing stiffness values, this is considered reasonable. In the results shown from the FE-analyses, all stress and strain values are given for a total load of F=30 000 N. This means that the average shear stress at any point between the support and the load point is 1.0 MPa. Likewise, for a homogeneous beam cross-section the maximum bending stress, at any point between the two loads, would be 18 MPa.

5 Results

5.1 Overview of FE-results

Below, the main results from the FE-analyses are summarised in terms of stress- and strain contours and plots of stress distributions across the specimen height direction, making comparison to beam theory easier. To keep the number of plots limited, only cases A, C and E are shown in detail.

For each case, three contour plots are shown (shear strain E12, shear stress S12 and axial stress S11), followed by stress distribution plots. The stress distributions show the shear stress and axial stress at four different sections along the specimen. The locations of the sections are at the quarter- and mid-points of the distances from the support to the load, and from the load to the centre of the specimen, see Figure 3.

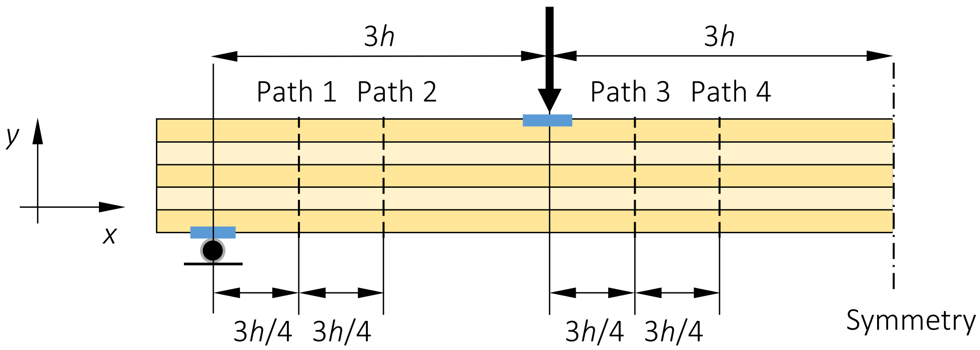

Figure 3. Stress distributions are evaluated at four sections, shown as dashed lines in the figure.

5.2 Results for cases A, C and E

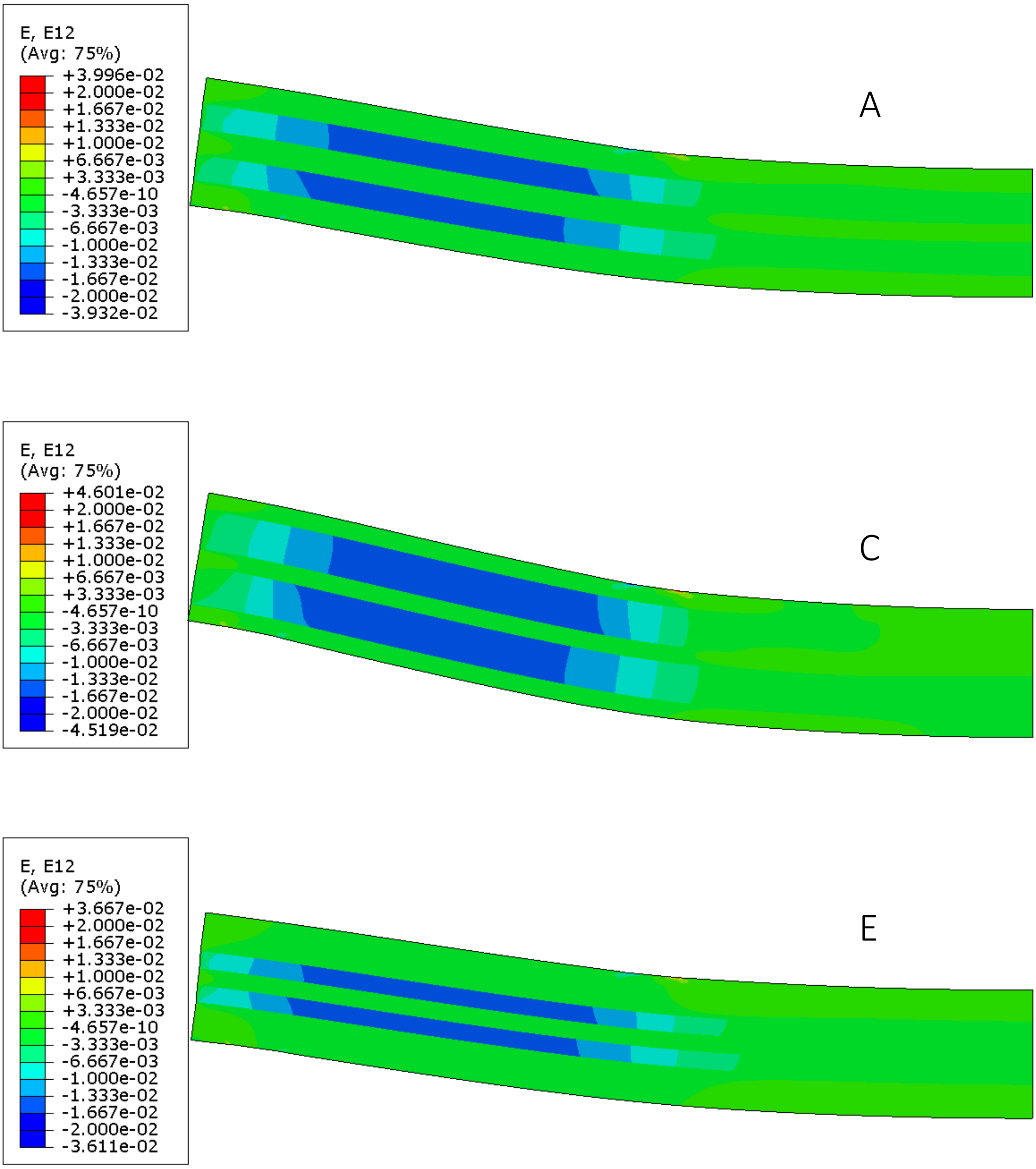

Figure 4. Top to bottom: Shear strain for cases A, C and E. Deformations are scaled a factor of 7.5.

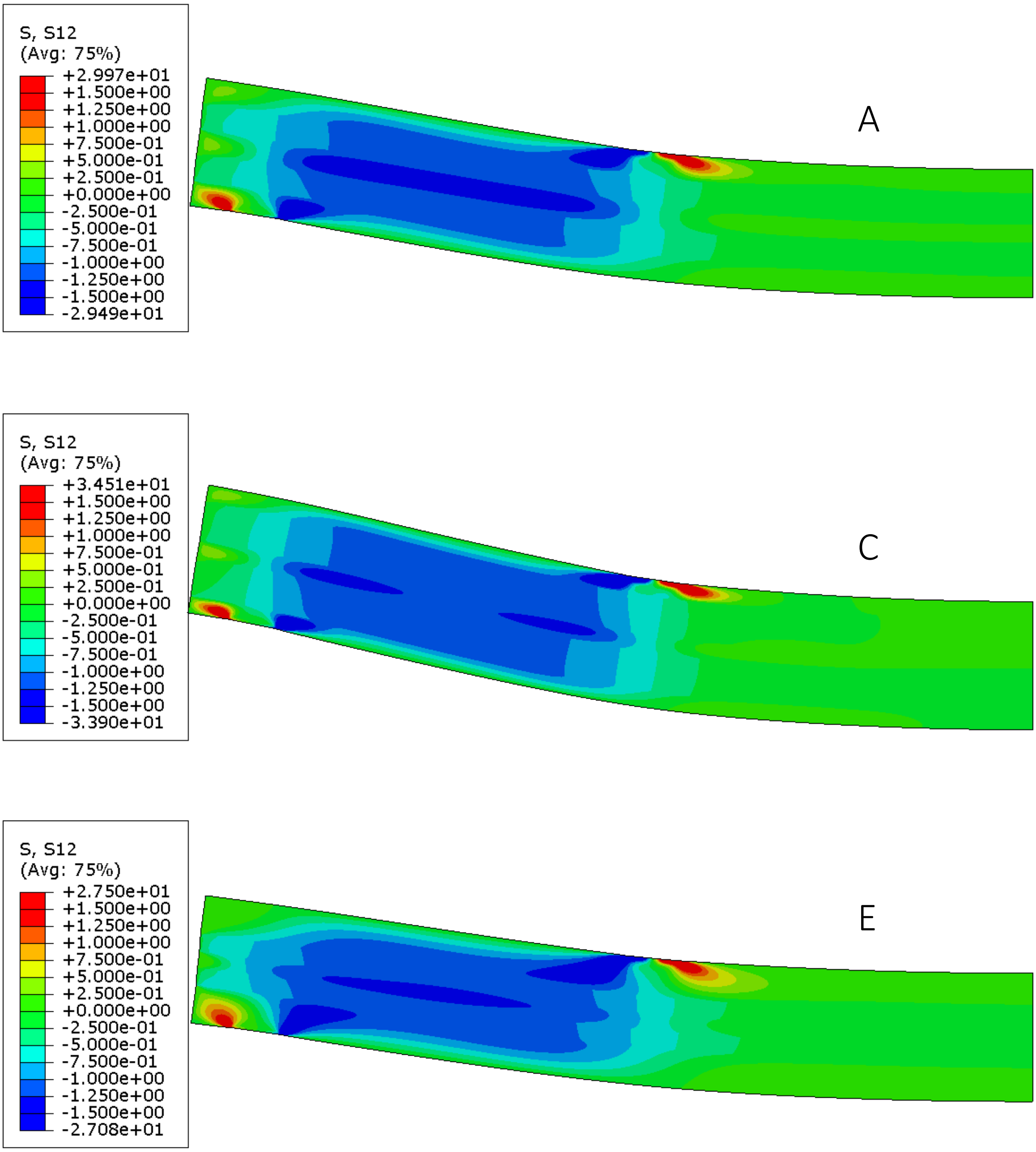

Figure 5. Top to bottom: Shear stress for cases A, C and E. Deformations are scaled a factor of 7.5.

As a short comment at this stage, it is obvious that the shear strain distribution in parts close to the support and close to the load application point, is quite affected by the boundary conditions, which is of course to be expected. The distance from the support/load to an undisturbed distribution (as compared to the one predicted by TBT) is in the range of approximately $h/4$–$h/2$ for the present case. On the following page the axial stress contours for cases A, C and E are given.

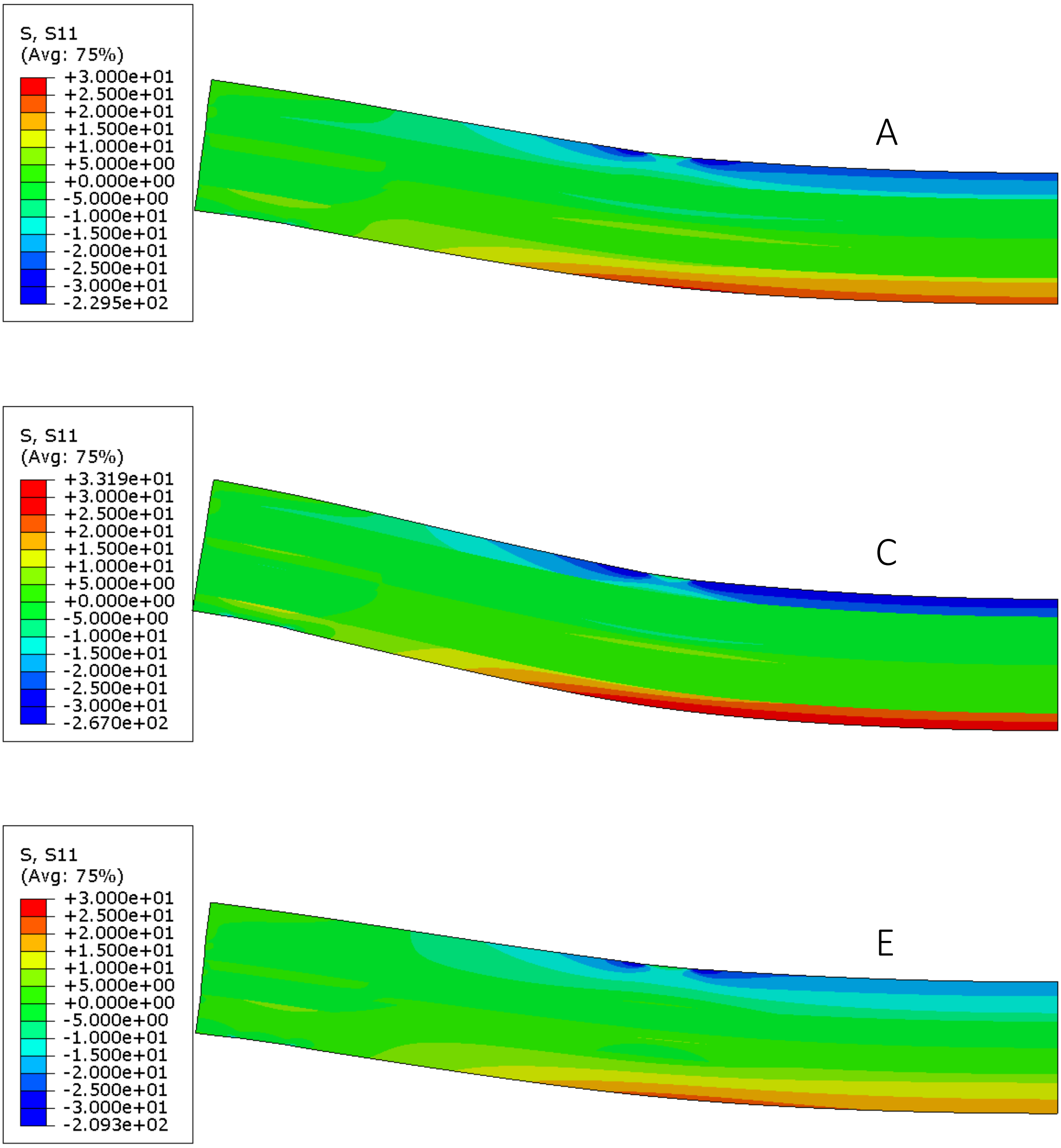

Figure 6. Top to bottom: Axial stress for cases A, C and E. Deformations are scaled a factor of 7.5

Below are shown the shear stress plots and the axial stress plots for cases A, C and E, along the paths mentioned above and depicted in Figure 3. Paths 1 and 3 are located at $3h/4$ from the support and the load point, respectively, while paths 2 and 4 are located at $3h/2$.

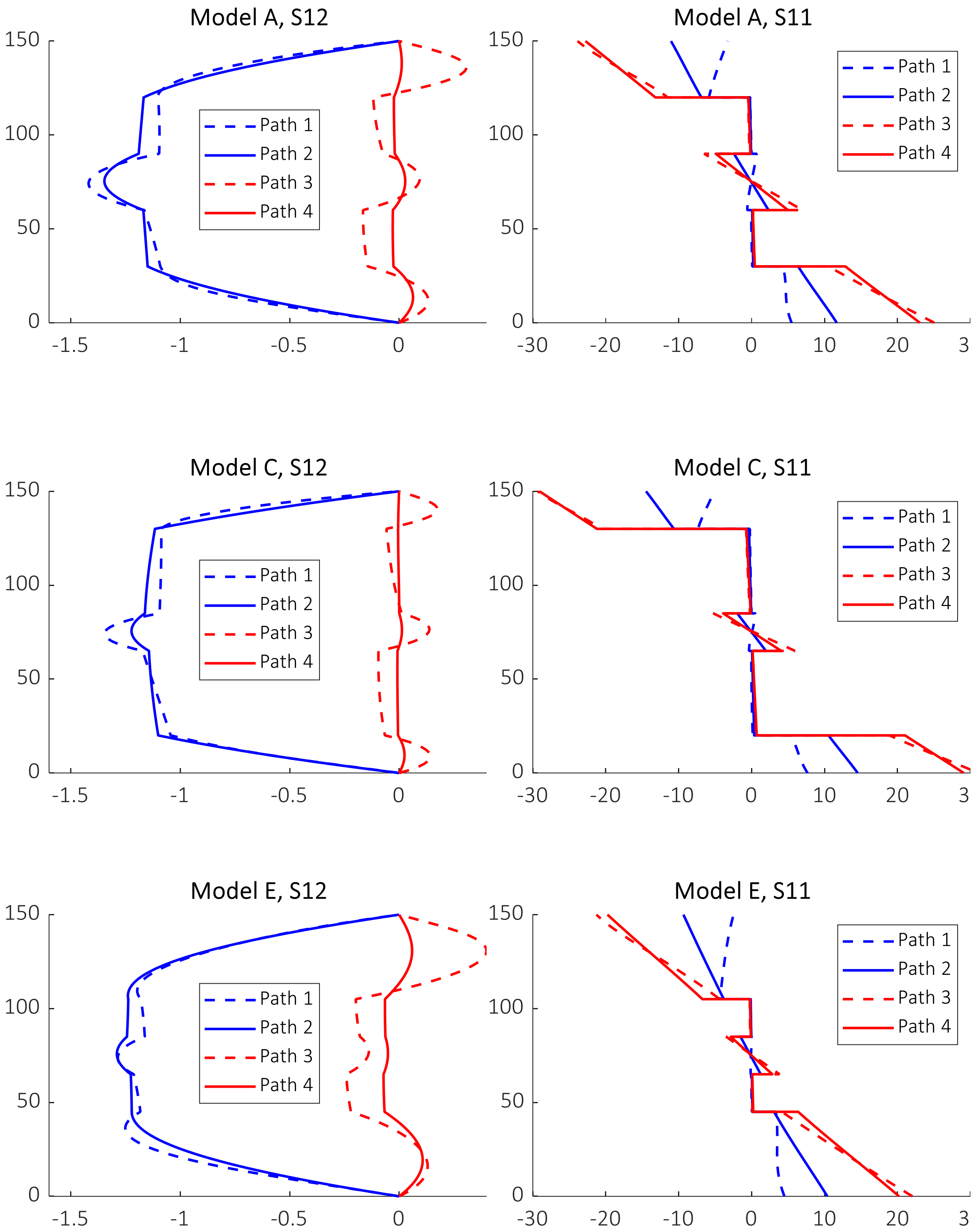

Figure 7. Shear stress and axial stress for cases A, C and E along Paths 1–4, see Figure 3.

A short comment at this stage on the stress distributions is that it is noticeable that the shear stress S12 at $3h/4$ from the support (Path 1) is affected as compared to beam theory (≈Path 2). Note especially that compared to the stress distribution along Path 2, stress levels along Path 1 are higher in longitudinal laminations and lower in transverse laminations. Note also that even though the average shear stress is zero in the mid-part of the specimen (Paths 3 and 4), the shear stress (and shear strain) is in general not.

5.3 Evaluation of FE-results according to EN 16351

For all cases A–E the FE-results were evaluated following the procedure of EN 16351. Thus, the vertical displacements at the three points I–III, see Figure 3, were extracted and the procedure of Equations (1)–(5) was followed. In addition, when backwards calculating the rolling shear modulus, a "best guess" variant was also tested. This best guess consisted of using the actual value of the shear correction factor (see Table 3), instead of using the proposed value of κ=0.25. Furthermore, when applying Equation (5), the actual input value to the FE-model was used for this "best guess" (*i.e.,* G_0=750 MPa instead of the proposed 650 MPa). The results from this evaluation are presented in Table 4. As mentioned, the rolling shear modulus used in the FE-analysis was 75 MPa. The closest estimation is obtained for case C and using the "best guess" approach—and still the resulting modulus is overestimated by a factor of 2.4. EI_{local}, is 2%–9% lower than *EI* according to beam theory, and the total shear stiffness *(GA)* is 20% –50% higher than *κGA,* see Table 4.

Table 4. Results from evaluation of FE-results using Equations (1)–(5). Values in italics are repeated from Table 3, for convenience. G_r should be (close to) 75 MPa, the input value for the FE-models.

Lay-up	*EI* [$Nm^2 \cdot 10^5$]	EI_{local} [$Nm^2 \cdot 10^5$]	EI_{global} [$Nm^2 \cdot 10^5$]	*κGA* [$N \cdot 10^6$]	*(GA)* [$N \cdot 10^6$]	$G_{r,16351}$ [MPa]	$G_{r,best\ guess}$ [MPa]
A	*2.6964*	2.5544	1.9641	*1.7497*	2.2895	551	445
B	*2.1145*	2.0536	1.5921	*1.5571*	1.9084	385	240
C	*2.0961*	2.0463	1.5303	*1.3829*	1.6346	293	180
D	*3.0695*	2.8697	2.2900	*2.1671*	3.0534	1266	949
E	*3.1739*	2.8990	2.3106	*2.0417*	3.0663	1279	1148

5.4 Alternative approaches

As the test set-up in EN 16351 is well-defined in terms of specimen lay-up, it is quite straightforward to define an approach that clearly outperforms the approach currently suggested. The key lies in determining the resulting (effective) shear modulus of the cross section and, in doing so, using a consistent approach.

EN 16351 assumes that a five-layer CLT with outer longitudinal layers is tested. Thus, assuming that the CLT is symmetric, it is reasonable to assume that:

a) Shear *deformation* takes place only in the transverse layers or at least these layers are the main contributors (layer number 2 and 4)
b) Shear *stress* is equal in layer 2 and 4 due to symmetric lay-up
c) Shear *stress is constant* in layers 2 and 4, since $E_{90} \ll E_0$

Effectively, a), b) and c) mean that a series coupling of the two shear compliant layers 2 and 4 is a reasonable mechanical model. Here series coupling should be interpreted in the sense that both layers experience the same stress and addition of their respective compliances results in the total compliance of the cross section, since layers 1, 3 and 5 are assumed not contributing. Noting that the compliances of layers 2 and 4 are the only contributors we can write for the compliance of the cross section:

$$\frac{h}{G_{eff}} = \frac{t_2}{G_2} + \frac{t_4}{G_4} = 2\frac{t_2}{G_r} (= 2\frac{t_4}{G_r}) \quad (6)$$

where indices refer to the layer numbers and the transverse layers 2 and 4 are assumed to be equal (regarding thickness and shear modulus), and where G_{eff} refers to the effective shear modulus of the entire cross section "(κGA)/(A·5/6)".

Compare now Equation (6) with the expression given in EN 16351, see Equation (5), which assumes a parallel coupling of the shear stiffnesses of the layers. Now, obviously, the real situation is neither series coupling, nor parallel coupling, but it is nevertheless of interest to compare what the outcome is using Equation (6) on the FE-results. Note also that using Equation (6) instead of Equation (5) has the advantage of not needing to guess the value of G_0 (it is assumed to be infinite).

Equation (6) represents the extreme case where all shear deformation takes place in the transverse layers and the longitudinal layers do not contribute to shear deformation. Another approach can be established assuming that all layers are experiencing the same shear stress (which is obviously not true) and including shear strain contributions from *all* layers. Doing so, the following equation can be found:

$$\frac{h}{G_{eff}} = \frac{t_1}{G_1} + \frac{t_2}{G_2} + \frac{t_3}{G_3} + \frac{t_4}{G_4} + \frac{t_5}{G_5} \quad (7)$$

where, in the present case G_1=G_3=G_5=G_0=750 MPa and G_2=G_4=G_r=75 MPa.

A final simple refinement would be to assume a more realistic stress distribution across the CLT, and with that as a basis weight the different layers' contributions to the shear stiffness (compliance). One such stress distribution involves a constant shear stress across layers 2, 3 and 4 and assuming that this stress decreases linearly to zero at the edges, across layers 1 and 5 at the two faces, respectively. With this, the weighted stiffness (compliance) could be found by using:

$$\frac{h}{G_{eff}} = \frac{t_1}{2G_1} + \frac{t_2}{G_2} + \frac{t_3}{G_3} + \frac{t_4}{G_4} + \frac{t_5}{2G_5} \quad (8)$$

As reported in *e.g.* [4], the effective shear modulus of a transverse layer will vary with the lamination's pith position, a factor of at least 2 times higher than the local modulus G_r, can be expected. Indeed, experimental values corresponding to an effective shear modulus in the range of 110–184 MPa, with an average of 159 MPa, were reported by Olsson *et al.*, [17], for a material that had a local modulus G_r of 59 MPa. In addition, the layer shear stiffness is expected to vary depending on lamination width-to-thickness ratio and depending on whether laminations are edge bonded or not.

In light of the above, a simplified approach to investigate the influence of the effects of annual ring orientation (pith location) and edge bonding, is to assume a higher rolling shear modulus of layers 2 and 4. Consequently, the FE-model for case A was used in an analysis where the only change to input data was setting the rolling shear modulus in the transverse layers to 150 MPa, instead of the previously reported 75 MPa.

Table 5 reports all results from the above FE-analyses, evaluated according to the use of the provisions of EN 16351 and according to the above proposed alternative expressions (Equations (6)–(8)). The case with higher rolling shear modulus in the transverse layers is here denoted A2.

Table 5. Results from evaluation of FE-results with according to EN 16351 (Equations (1)–(5)) and according to proposed alternatives of Equations (6)–(8). Deviation percentages are relative the used input value of G_r in the FE-models (75 MPa for cases A–E and 150 MPa for case A2).

Lay-up	EI_{local} [$Nm^2 \cdot 10^5$]	EI_{global} [$Nm^2 \cdot 10^5$]	(GA) [$N \cdot 10^6$]	$G_{r,16351}$ [MPa]	$G_{r,eq(6)}$ [MPa]	$G_{r,eq(7)}$ [MPa]	$G_{r,eq(8)}$ [MPa]
A	2.5544	1.9641	2.2895	551	73.3 (−2,3%)	85.8 (+14%)	81.2 (+8.3%)
B	2.0536	1.5921	1.9084	385	81.4 (+8.6%)	90.0 (+20%)	87.4 (+16%)
C	2.0463	1.5303	1.6346	293	78.5 (+4.6%)	84.3 (+12%)	82.3 (+9.7%)
D	2.8697	2.2900	3.0534	1266	65.1 (−13%)	85.6 (+14%)	76.8 (+2.4%)
E	2.8990	2.3106	3.0663	1279	65.4 (−13%)	86.1 (+15%)	76.2 (+1.6%)
A2	2.6548	2.2502	3.9769	1676	127 (−15%)	171 (+14%)	153 (+2.0%)

6 Discussion, conclusions, and outlook

6.1 Discussion and conclusions

The proposed method to evaluate the transverse shear modulus of CLT, as given in EN 16351 was used on FE-data simulating a test situation. It was already known from previous work that at least for a specific case (5×20 mm CLT) the EN 16351-method did not give reliable results. In the current work those conclusions have been further strengthened by investigating a number of CLT lay-ups. As it turns out, there seems to be only very few cases where the EN 16351-method would give reliable estimates of the rolling shear modulus. Based on the findings, and based on a very simplistic mechanical analogy, alternative equations to extract the desired value of the rolling shear modulus, G_r, were proposed. Using the proposed Equation (6) on the same FE-data the accuracy for prediction of G_r was considerably improved, deviating at most 15% from the input value to the FE-model. Another proposal, Equation (8), gave an overall better prediction.

However, one must keep in mind a number of very crude estimations done in obtaining the results presented in Table 5. Firstly, the proposed Equations (6)–(8) are simplistic engineering approaches. Secondly, there was no attempt to make use of the knowledge of the strain distribution as seen in Figure 4. One way to do so could be to reduce the length l_2 when applying Equations (2)–(4). As a final remark, it is interesting to note that the use of Equation (7) seems to give an upper bound for the estimate of G_r. As it seems from Table 5, the prediction is always overestimating G_r, quite consistently.

6.2 Outlook

6.2.1 Future work

The work presented here has been a first study on a new proposal for evaluating test results according to EN 16351. Thus, several questions would be of interest to investigate further. A reasonable additional refinement of the approach could be to consider the shear deformation in the longitudinal layers in a more detailed manner than by using Equations (7) or (8). However, it should be emphasised that the main drawback of *not* using Equation (6) is that the (unknown) longitudinal shear modulus enters the expression. Additional CLT-lay-ups should be investigated, and it should be established in which cases Equations (6), (7) and (8) give reasonable results. It is probable that at least the proposed approach according to Equation (6) does not work well for very stiff transverse layers. Also, the effect of annual ring orientation and the effect of edge gluing/non-edge gluing on the predictive capabilities of the proposed approach should be further analysed.

6.2.2 Consequences for standardisation

Based on the finding from this (and previous studies) it can be concluded that:

- The approach in EN 16351 to backwards calculate the rolling shear modulus of CLT, is not useful. It is based on assumptions, as regards the cross layers' contributions to the shear deformation, which are not representative for typical lay-ups.
- Candidate approaches for upcoming revisions of EN 16351 are presented in this paper, see Equations (6)–(8).
- Before any of those are include in the standard, additional investigations should be performed to fully understand the limitations of the proposed equations.

7 References

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