

Short Note

A numerical study of the effects of stresses induced by moisture gradients in steel-timber dowel joints

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Introduction

This study considered moisture-induced stresses in timber dowel-type joints. It has previously been shown that moisture variations and gradients can affect the load-bearing capacity of structural timber elements (Aicher et al. 1998; Gustafsson et al. 1998; Jönsson and Thelandersson 2005). The explanation is that the moisture-induced stresses interact with the stresses generated by mechanical loading (Figure 1). Typically, the tensile stresses perpendicular to the grain are of prime concern. The aim of the study was to investigate to what extent the load-bearing capacity of steel-timber dowel joints can be affected by moisture gradients. The joint was loaded parallel to the grain (Figure 2a). In Figure 2b, two typical failure modes are presented (Schmid et al. 2002). Jorissen (1998, 1999) has described the influence of tensile stresses perpendicular to the grain and shear stresses on these failure modes. In the present study, only the effect of tensile stresses perpendicular to the grain was evaluated because of their great importance.

Numerical analyses

Two types of 3D analyses based on the finite element method were performed. One type considered the stress distribution for a mechanical load case, and the other considered the stress distribution induced by moisture gradients. For the latter, the effects of both drying and moistening were investigated. The humidity conditions chosen were similar to those likely to occur during construction and during the service life of a timber structure containing such joints.

The element subdivisions used are shown in Figure 3. For both cases, 8-node linear brick elements were

employed. Linear elastic behaviour was assumed for the wood in all cases. The elastic constants were set to $E_l=15,160$, $E_r=505$, $E_t=505$, $G_{lr}=950$, $G_{rt}=950$ and $G_{lt}=95$ MPa, with E denoting the modulus of elasticity and G the shear modulus. The indices l , r and t denote the longitudinal, radial and tangential directions of the timber, respectively (Figure 3). The Poisson ratios were set to $\nu_{lr}=0.50$, $\nu_{rt}=0.50$ and $\nu_{lt}=0.70$.

Linear elastic behaviour was also assumed for the steel plates and the steel dowels. The modulus of elasticity and Poisson's ratio were set to $E=210,000$ MPa and $\nu=0.3$, respectively. The interaction between steel and wood parts was simulated by a contact algorithm, with the coefficient of friction set to 0.4 for contact between the dowels and the timber, and 0.6 for contact between the dowels and the steel plate.

For the mechanical load case, the load was applied as uniform deformation (u) of the steel plates (Figure 3). The load applied was 45 kN, which equals 90% of the esti-

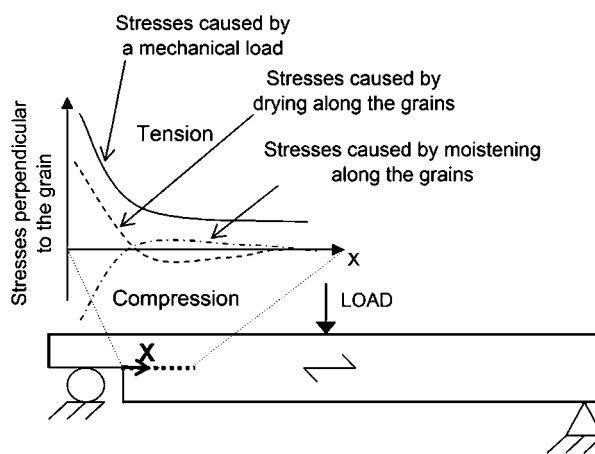


Figure 1 Stress distributions in a notched beam if load is applied perpendicular to the grain.

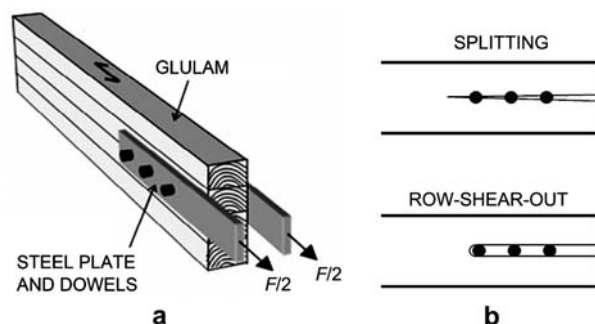


Figure 2 (a) The joint type studied and (b) typical failure modes if load is applied parallel to the grain.

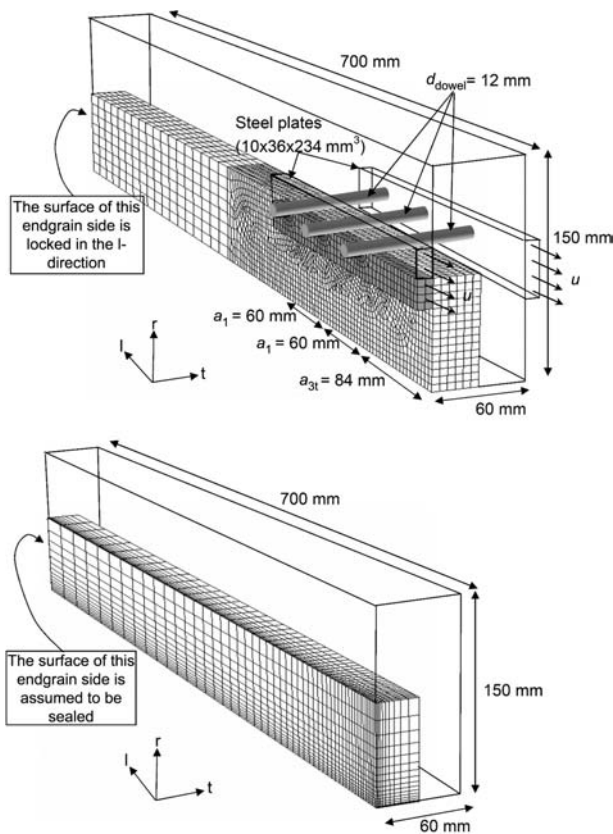


Figure 3 Element subdivisions for the mechanical load case (top) and for the moisture load case (bottom).

mated load-bearing capacity of the joint according to EN 1995-1-1.

The moisture load case involved the simulation of transient moisture flow and moisture-induced deformations and stresses. In the moisture flow simulation, moisture distributions were calculated. The timber was assumed to have an initially uniform moisture content (MC) of 12% (corresponding approx. to a climate of 65% RH at 20°C) and was then subjected to climates of 30% and 90% RH for the drying and moistening cases, respectively. The MC of the timber surface was assumed to be in equilibrium with the surrounding air. The surface of one of the end-grain sides was assumed to be sealed (Figure 3). The diffusion coefficients were set to $D_r = D_t = 4 \times 10^{-10} \text{ m}^2 \text{ s}^{-1}$ in the cross-grain directions and $D_l = 13 \times 10^{-10} \text{ m}^2 \text{ s}^{-1}$

in the longitudinal direction (Eriksson 2005). These correspond to values typical for Norway spruce at 20°C. For further details of these simulations, see Sjödin (2004).

In the simulation of the moisture-induced deformations and stresses, constant shrinkage coefficients (α) for the timber were used. The values chosen were $\alpha_l = 0.0001$ in the longitudinal direction and $\alpha_t = 0.002$ in the cross-grain direction. These data are typical for Norway spruce, as presented in timber handbooks (Carling 2001).

Results and discussion

For the mechanical load case, the largest tensile stresses were found in areas close to the steel plate ($x=0$) (Figure 4). Along the y -direction (Figure 4), the tensile stresses reach extreme values close to the steel dowels and in the area located close to the end grain. These findings verify the observations made by Jorissen (1998, 1999).

Figure 5a shows the moisture distribution for the drying case. With this moisture distribution as input, deformations and stresses were calculated. The results in terms of stresses perpendicular to the grain are shown in Figure 5b. Note that the stresses, especially in parts close to the steel plate ($x=0$), interact with the stress field generated in the mechanical load case shown in Figure 4b.

For the case of moistening, the results are not presented in detail here, but reveal that moistening of the joint results in stresses counteracting the stresses due to mechanical loading. Figure 6 illustrates the interaction of stresses between the load cases for both drying and moistening. Here the moisture-induced stresses on day 7 are used for comparison.

The elastic stiffness decreases with increased MC (Dinwoodie 2000). This fact, in combination with the assumed linear elastic material behaviour of the wood, leads to calculated stresses being greater than in practice. However, the general validity of the calculations presented in this study are not affected by this.

Conclusion

Stresses induced by moisture gradients can interact with (in the drying case) or counteract (in the moistening case) the stresses that contribute to the failure modes of steel-

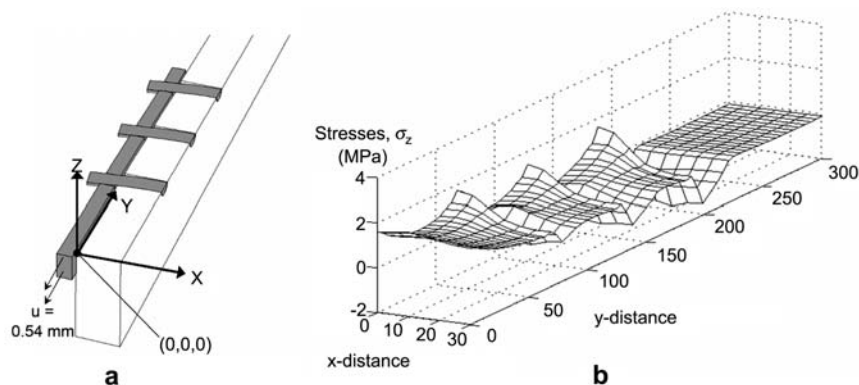


Figure 4 (a) Deformed joint for the mechanical load case (deformations are scaled by a factor of 20). (b) Stresses perpendicular to the grain on the symmetry surface in the mechanical case.

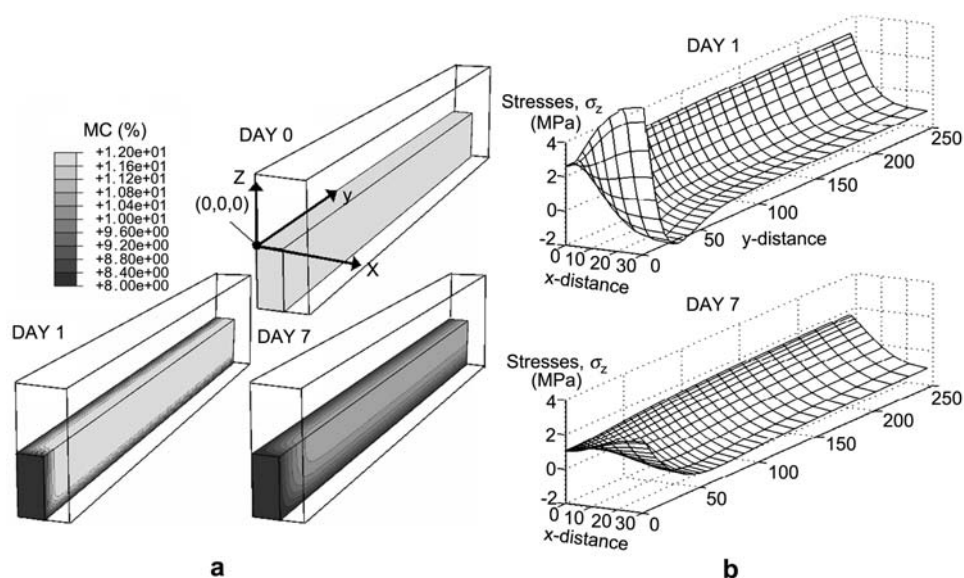


Figure 5 (a) Changes in MC for the drying case and (b) stresses perpendicular to the grain on the symmetry surface for the drying case.

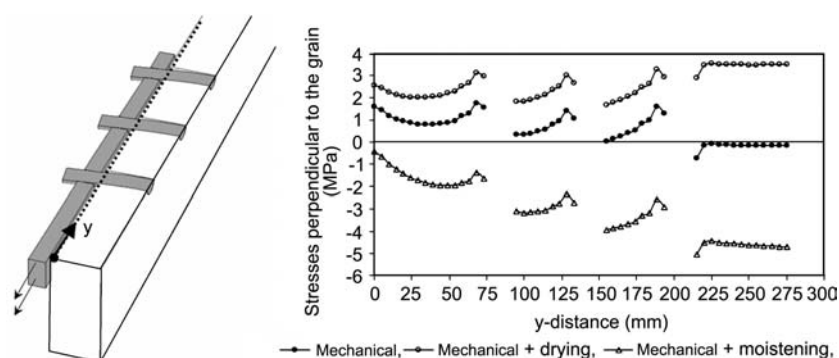


Figure 6 Stress distribution perpendicular to the grain on the 7th day for: 1) mechanical load; 2) mechanical load in combination with drying; and 3) mechanical load in combination with moistening.

timber dowel joints loaded in tension parallel to the grain. It thus appears reasonable to assume that the load-bearing capacity of dowel-type joints can be either negatively or positively affected by moisture changes in the joint area. Experimental work is in progress to verify the numerical results presented here. The results obtained raise the important question as to how moisture-induced stresses can be avoided by design. The alternative question is whether it is possible to effectively consider the moisture load case in design codes.

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