INFLUENCE OF SPECIMEN GEOMETRY ON STRESS DISTRIBUTIONS IN PULL-OUT TESTS OF GLUED-IN STEEL RODS IN WOOD

EINFLUß DER PRÜFKÖRPERGEOMETRIE AUF SPANNUNGSVERTEILUNGEN BEI AUSZUGSVERSUCHEN VON IN HOLZ EINGEKLEBTEN GEWINDESTANGEN

INFLUENCE DE GEOMETRIE DE L'EPROUVETTE SUR LA DISTRIBUTION DES CONTRAINTES AUX ESSAIS DE TRACTION DES GOUJONS METALLIQUES COLLES EN BOIS

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SUMMARY

It is reported on some numerical investigations concerning the influence of specimen geometry on the stress distribution in a joist like glulam specimen with two steel rods glued-in axially parallel to fiber at the two opposite end faces. Hereby the question arises to what extent the intermediate distance between the two opposite glued-in rod ends affects the stress distribution in the specimen. The concern is on the tension stresses in the wood and especially on the stresses in the contact area between steel rod and wood along anchorage length.

The parameter study was conducted in an approximation with an axial symmetric finite element model. The computation showed that intermediate distances of more then two times of anchorage length have no influence on the regarded stress distributions in the nearfield of the rod. Distances between the two opposite rods smaller then the anchorage length result in increasing changes of the stress distributions.

ZUSAMMENFASSUNG

Es wird über rechnerische Untersuchungen zum Einfluß der Prüfkörpergeometrie auf die Spannungsverteilung in stabförmigen Prüfkörpern aus Brettschichtholz, in die an den gegenüberliegenden Querschnittsenden Gewindestangen axial faserparallel eingeklebt sind, berichtet. Es erhebt sich hierbei die Frage, in welchem Maße der Abstand zwischen den beiden gegenüberliegenden eingeklebten Stahlstangenenden die Spannungsverläufe im Prüfkörper beeinflußt. Von Interesse sind die Zugspannungen im Holz und insbesondere die Spannungen im Kontaktbereich von Gewindestange und Holz längs der Verankerungslänge.

Die Parameterstudie wurde in einer Näherung mittels eines axialsymmetrischen Finite Element Modells durchgeführt. Die Berechnungen zeigten, daß ab Zwischenabständen mit doppelter Einbindelänge kein Einfluß auf die betrachteten Spannungsverteilungen im Nahbereich der eingeklebten Stangen vorliegt. Abstände zwischen den beiden gegenüberliegenden Stangenenden kleiner als die Einbindelänge ergaben zunehmend deutliche Spannungsveränderungen.

RESUME

Une étude numérique est présenté sur l’influence de la géométrie aux distribution des contraintes dans une éprouvette parallélépipède de lamellé-collé avec deux tiges filetés collés parallèlement au fil de bois a chaque extrémité de l’éprouvette. Le problème posé est a quelle distance l’influence des goujons collés devient négligeable sur la distribution de contraint de l’éprouvette. L’étude concerne les contraintes de traction dans le bois et spécifiquement les contraintes dans la surface du contact entre le goujon métallique et le bois le long de l’ancrage.

L’étude paramétrique a été simplifiée par une modélisation par éléments finis axisymmetriques. Les résultats ont montré si la distance séparant l’extrémité des goujons est supérieure a deux fois la longueur de l’ancrage elle n’a plus d’influence sur les contraintes au voisinage du goujon métallique. Si ce distance est inférieure a une fois la longueur de l’ancrage la résultat est une augmentation du changement.

KEYWORDS: Wood, glulam, glued-in steel rod, specimen geometry, stress distribution, axialsymmetric FE-analysis

1. INTRODUCTION

In the framework of the European Research Project „Glued in rods in timber structures“[1] one of several work items consists in the derivation of an empirical data base on the withdrawal resistance of axially loaded glued-in threaded steel rods in pull-out tests [JOHANSSON ET AL., 1998]. For assessment of the influences of anchorage length l_a, rod diameter d and adhesive type (Phenolic Resorcinol, Polyurethane, Epoxy), a number of 270 short term and 130 DOL tests are to be performed with rods glued-in parallel to fiber direction centrally into glulam specimens of square cross-section. This test configuration is regarded subsequently. It should also be mentioned that additionally to the above test configuration further 85 pull-out tests are performed with different angles between load and grain direction.

After evaluation of several possible solutions for the lay-out of the specimens (i.a. [AICHER AND HERR, 1997]) it was decided to use a test set-up as shown in Fig. 1 with two rods, one being the actual test rod (l_a = anchorage length, d = nominal diameter), the other one being the support rod.

The embedment length l_s and diameter d_s of the support rod were chosen as $l_s = 1{,}2\ l_a$ and $d_s = 1{,}5\ d$ in order to definitely achieve a failure at the test rod where the load displacement measuring devices are mounted. One of several reasons for choosing a test configuration with unequal rods was to create a highest possible degree of conformity in test layout of ramp load and related DOL tests. In case of the DOL tests, due to limited number of available LVDT’s, only one rod per specimen can be equipped with deformation measuring devices.

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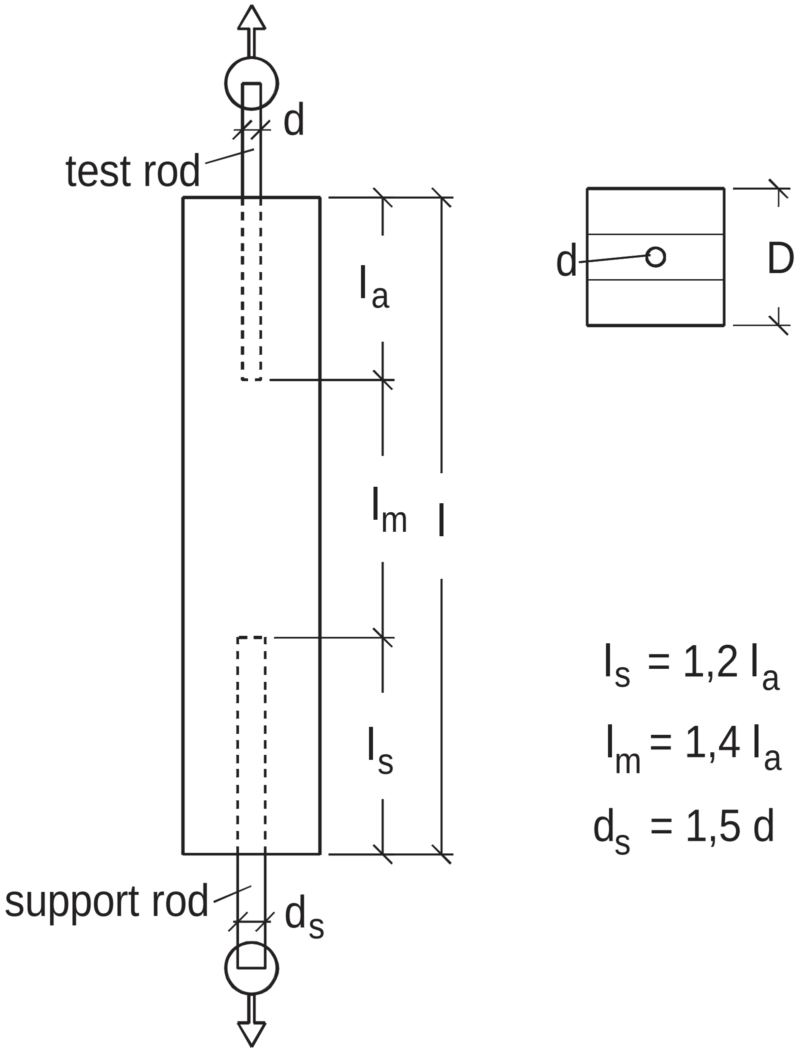


Fig. 1: *Schematic view of employed specimens in axial pull-out tests with threaded steel rods glued into glulam parallel to fiber*

The dimensions of the specimens, covering a very large range of rod slenderness ratios $\lambda_a = l_a/d = 5$ to 40, had to be chosen as a sound compromise between material resp. manufacturing effort and avoidance of falsifying boundary conditions. With respect to the latter the specimen ratios D/d and L_m/l_a were of primary interest ($L_m = l_m/2$). The ratio of cross-sectional width D to rod diameter d was chosen in the range of 7 - 7,5 - 8,75, what at a first view could seem rather small (7 resp. 7,5) with respect to splitting failures. However, testing of more than 50% of the specimens so far revealed only very rare cases of splitting failure modes. This issue shall not be deepened here. In the following the implications of the length between test and support rod $l_m = 2L_m$ resp. the ratio L_m/l_a is discussed in more detail.

2. FINITE ELEMENT ANALYSIS OF SPECIMEN GEOMETRY

2.1 Modelling aspects

The effect of the mentioned geometry ratios was investigated by means of a linear elastic finite element analysis. In an approximation of the real geometry the 3D problem was analysed as an axial-symmetric problem with the rotation axis coinciding with the rod axis. In this approach the specimen diameter $D^*=(4D^2/\pi)^{0,5}$ was determined from the equivalent square area. The material properties of the glulam were assumed to be homogeneous in the cross-section, i.e. radial and tangential stiffness quantities were smeared. For the parameter study the following stiffness values were employed for glulam (l = longitudinal = parallel to fiber, r = radial, t = tangential):

$E_{ll} = 12000$, $E_{rr} = E_{\varphi\varphi} = 600$,
$G_{rl} = G_{l\varphi} = 680$, $G_{r\varphi} = 45$
$\nu_{rl} = 0,45$, $\nu_{l\varphi} = 0,056$, $\nu_{r\varphi} = 0,31$.

All given E_{ii}, E_{ij} values are in N/mm^2. In case of ν_{ij} first and second index denote deformation and stress direction, respectively. The glue line was not explicitly modelled as it was verified that this approximation is of minor influence. In the parameter study on the influence of intermediate length l_m the dimensions of the support rod were assumed equal to the test rod, so only one quarter of the length section of the approximate axial symmetric specimen was modelled (Fig. 2). Figure 3 shows the employed finite element mesh.

With respect to the conditions at the embedded end of the rod $\xi= l_a$, the following has to be considered. Depending on the type of adhesive there can be a well bonded connection between both areas, but for other adhesives the bond can be very poor, if existent at all. In the lower loading range this bond, if existent, will contribute to load transfer, however for strength considerations a tension cut-off zone should be assumed. In the presented calculations an element layer of 1 mm thickness representing the adhesive was arranged between the rod end face and the end grain face of the bottom of the drilled hole; the MOE of the isotropic adhesive layer was set to 2000 N/mm^2.

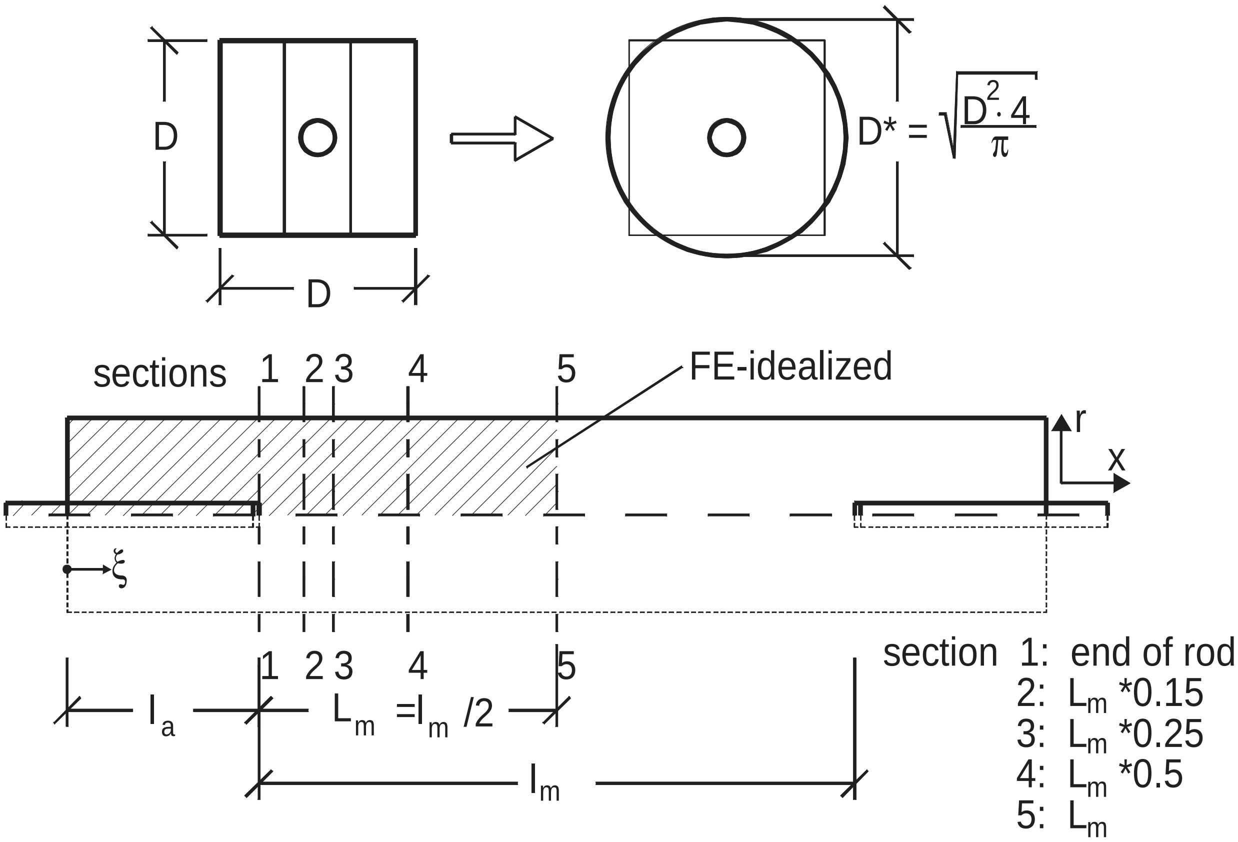


Fig. 2: *Dimensions of finite element discretized part of the specimen and locations of sections for stress evaluation*

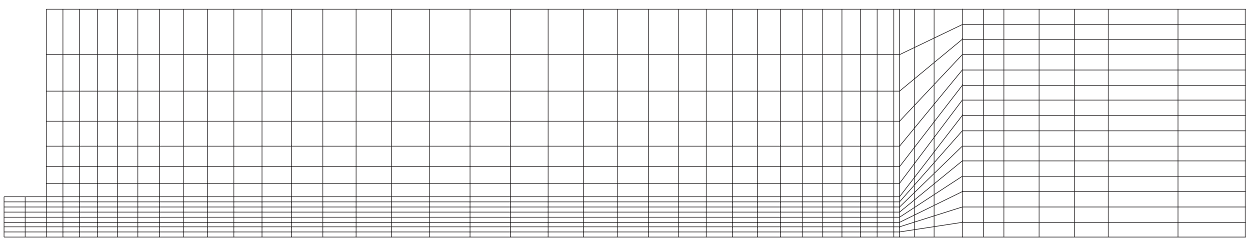


Fig. 3: *Finite Element discretization of the axial symmetric model*

2.2 Simulation results

The specimen geometry was analysed in general for six different intermediate length ratios L_m/l_a = 0,05; 0,125; 0,25; 0,5; 1 and 2 at constant ratios D/d and l_a/d. Two slenderness ratios l_a/d = 10 and 20 and two ratios D/d = 5 and 7,5 were investigated. All results presented here strictly apply to D/d = 7,5 and L_a/d = 10; they apply qualitatively very well to the other parameter configurations, too.

2.2.1 Axial normal stresses in the wood

Figure 4 depicts the cross-sectional distribution of the normal stress in the wood in axial direction of the specimen in four sections 2-5 with increasing relative distance (see Fig. 2) from the embedded end of the glued-in rod; the stresses are given for intermediate length ratios of L_m/l_a = 0,25; 0,5; 1 and 2.

Generally speaking the graphs reveal the following: In case of a large distance between the two rods a very even stress distribution occurs in the middle part of the intermediate length l_m. With gradual approach of the regarded cross-section to the embedded end of the rod the normal stress distribution becomes increasingly uneven due to the high stiffness of the rod attracting the stress flow. In section 1, right at the rod end, a high stress peak occurs close to the rod. In case of small intermediate distances between the rods the normal stress distribution in the wood is never even; the stress flow is throughout highly concentrated in the interior of the cross-section.

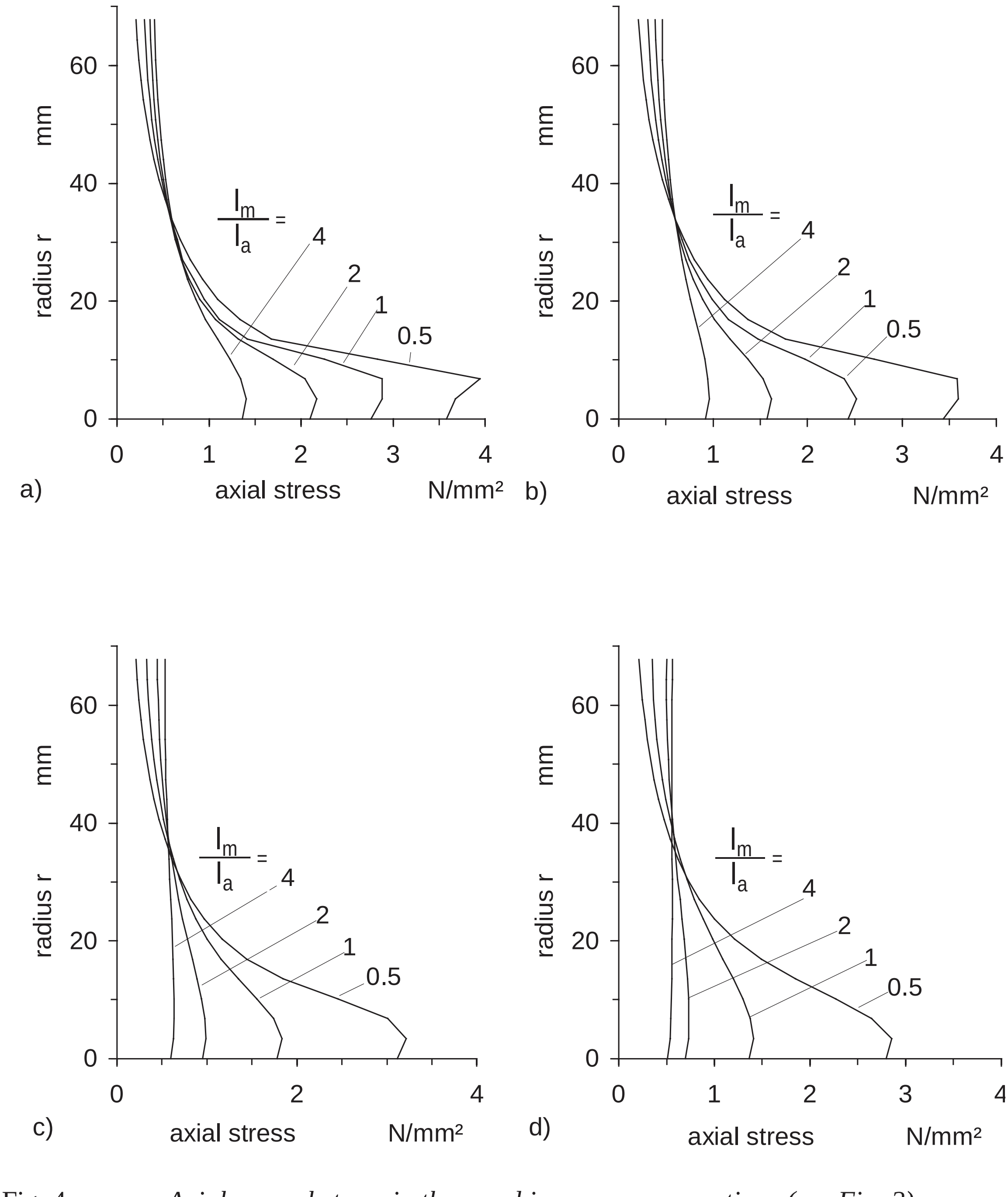


Fig. 4: *Axial normal stress in the wood in some cross-sections (see Fig. 2) of intermediate length l_m for different ratios l_m/l_a*
a) section 2 *b) section 3*
c) section 4 *d) section 5*

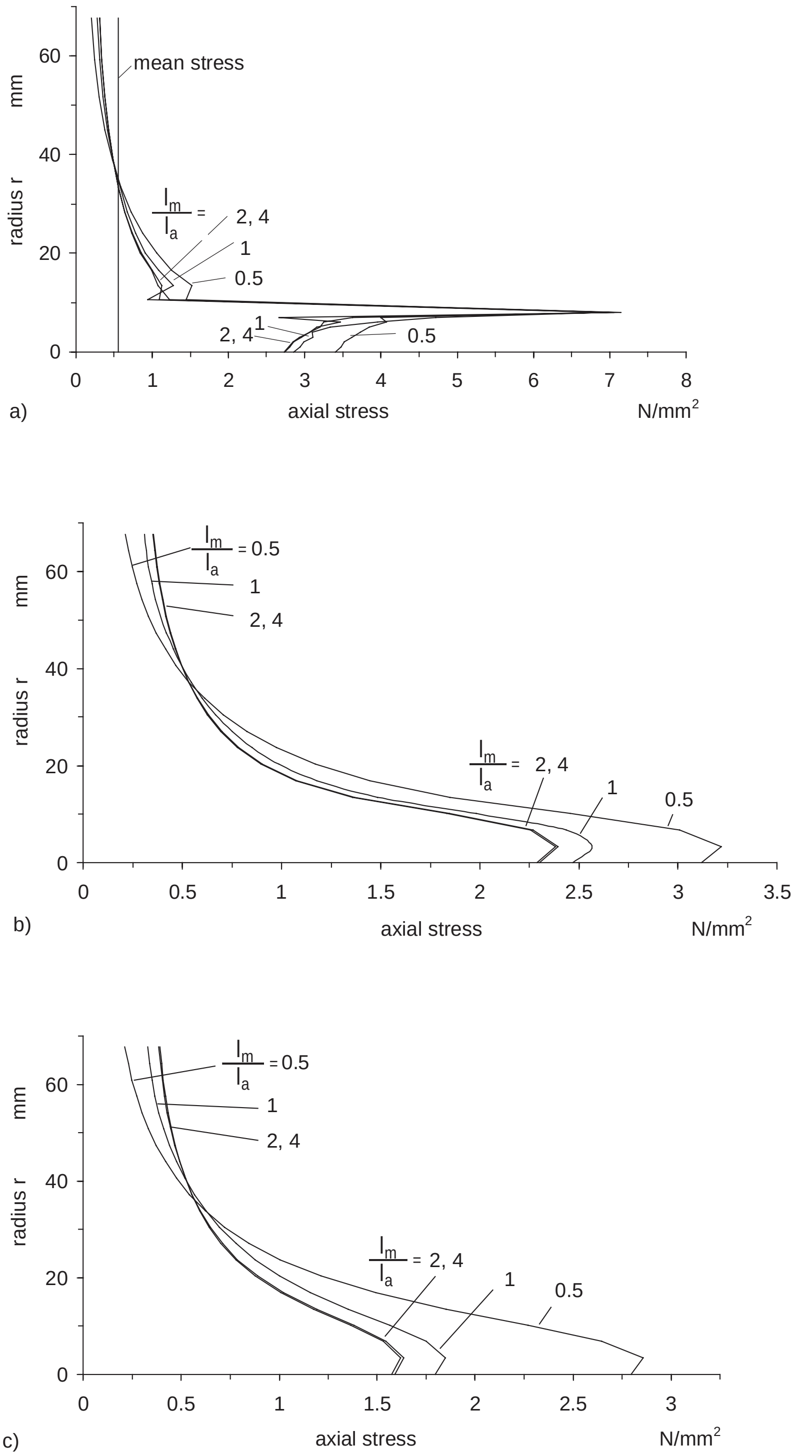
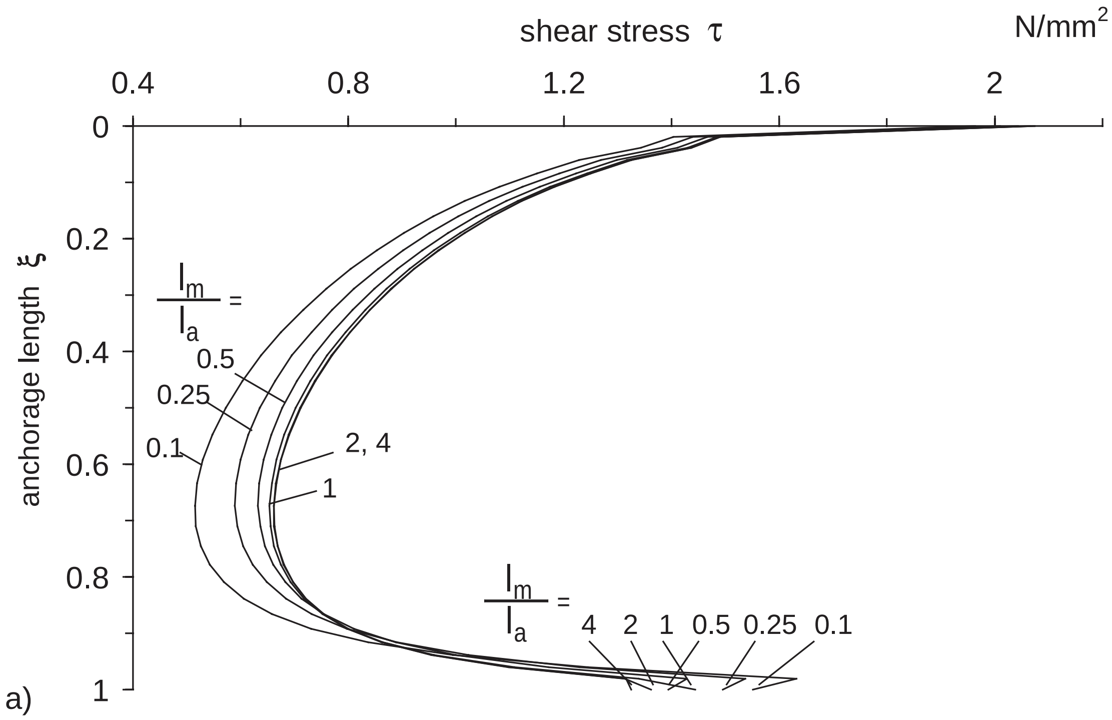


Fig. 5 a-c: *Axial normal stresses in the wood in three cross-sections close to the embedded end of the rod*
a) at end of rod *b) 20 mm from the rod* *c) 40 mm from the rod*

All mentioned aspects were anticipated qualitatively. With respect to very short distances before the embedded end of the rod it is necessary to look at sections with discrete absolute distances to the rod end. Figures 5a-c show the normal stress distribution for different L_m/l_a ratios in three sections with equal absolute distances of 1, 20 and 40 mm to the embedded rod end. It is interesting to note that the stress peak in front of the rod end remains quasi constant in all three sections for intermediate length $l_m \geq 2\ l_a$. Contrary, for values $l_m \leq l_a$ the stress concentration increases significantly, and these differences remain also in the cross-section of the rod end. So, it can be stated that for intermediate length ≤ 2, quantity l_m has a non neglectible influence on the normal stress distribution in the wood at the location of the embedded rod end. More important with respect to falsifying boundary conditions is the question whether intermediate distance l_m has a significant impact on the bond stresses along anchorage length.

2.2.2 Bond stresses along anchorage length

Figures 6a,b and 7a,b depict the shear and axial stresses resp. the stresses in radial and tangential direction in the steel-wood-interface along anchorage length for a large parameter span l_m/l_a = 0,1 to 4. The following conclusions can be drawn from the given stress distributions. The shape of the stress distribution is only marginally affected by intermediate length ratio. Intermediate length has a certain influence on the peak values of the stresses at both ends of the anchorage length. Shorter intermediate lengths result in higher peak values what conforms to above presented axial normal stress distribution in the wood. The interface shear stresses in the wood, as anticipated, show the highest sensitivity to a reduction of intermediate length. Significant changes in the shear stress distribution however are confined to ratios of $l_m/l_a < 1$.



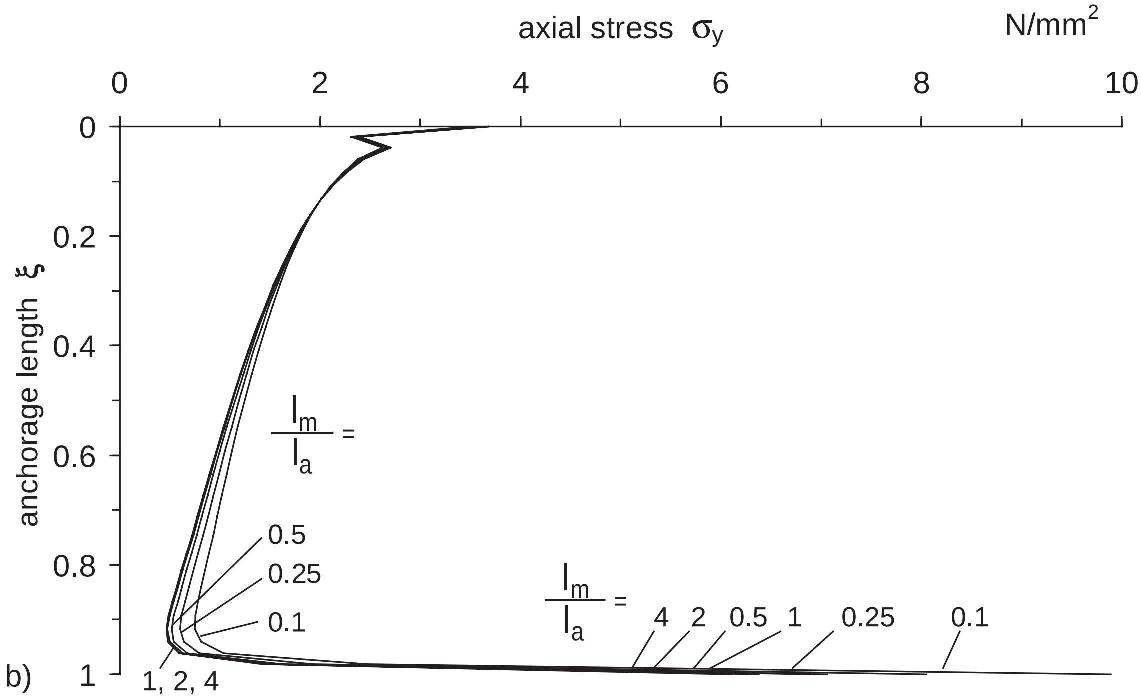


Fig. 6 a-b: *Stresses of wood in the steel-wood-interface along bond line depending on intermediate timber length lm for D/d = 7,5 and l_a/d = 10*
a) shear stress *b) axial stress*

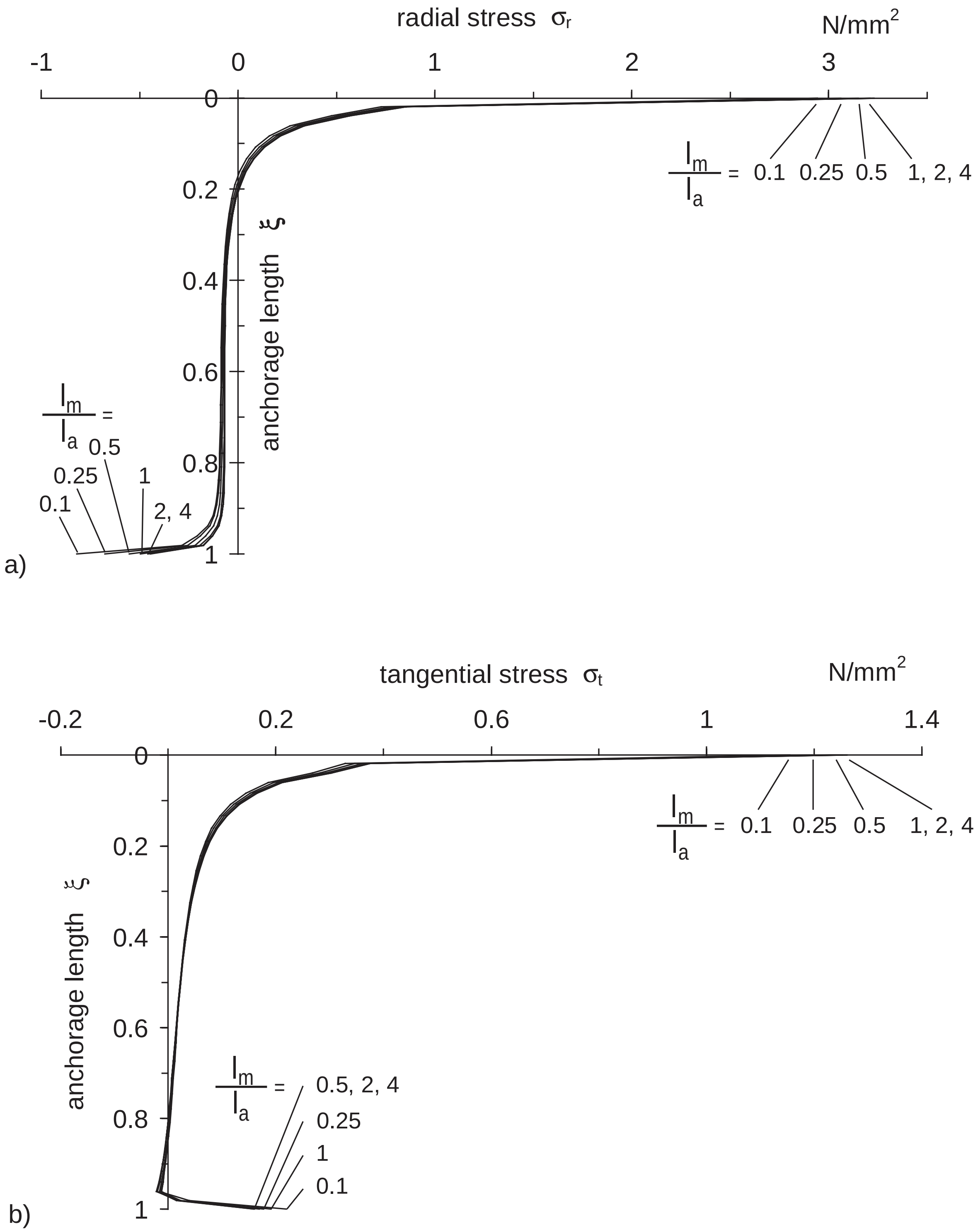


Fig. 7 a-b: *Stresses of wood in the steel-wood-interface along bond line depending on intermediate timber length l_m for D/d = 7,5 and l_a/d = 10*
a) radial stress *b) tangential stress*

3. CONCLUSIONS

The parameter study on the effect of intermediate length of two steel rods glued parallel to fiber into the end grain faces of a glulam joist was conducted in an approximation with an axial symmetric finite element model. The computation showed that intermediate distances of more than two times of anchorage length have no influence on the regarded stress distributions in the nearfield of the rod. Distances between the two opposite rods smaller than the anchorage length result in increasing changes of the stress distributions.

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