

REFLECTION MEASUREMENTS AT TIMBER GLUE-LINES BY MEANS OF ULTRASOUND SHEAR WAVES

REFLEXIONSMESSUNGEN AN HOLZVERKLEBUNGEN MITTELS ULTRASCHALL-SCHWERWELLEN

MESURES DES REFLEXIONS AUX PLANS DE COLLAGE DU BOIS AU MOYEN D'ONDES DE CISAILLEMENT

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SUMMARY

In the frame of an on-going research project the feasibility of ultrasound shear wave reflection measurements at glued laminated timber (glulam) has been studied. In the applied experimental set-up the propagation direction of the ultrasound waves was parallel to the smallest dimension of the glulam beam, being the width direction perpendicular to fiber and parallel to the board edges.

In particular the presented work should answer two questions:

- Is it possible (within the frame of the used equipment and boundary conditions) to identify clear back wall reflection signals from a glued laminated beam in structural dimensions ?
- Can the reflection method be utilised for detection of boundary layers in defects of a secondary glue-line connecting two glulam blocks ?

In the paper the experimental conception and some preliminary results are presented.

ZUSAMMENFASSUNG

Im Rahmen eines laufenden Forschungsprojektes wurde die Machbarkeit von Reflexionsmessungen an Brettschichtholzbauteilen mittels Ultraschall-Schwerwellen untersucht. Beim verwendeten Versuchsaufbau wurden die Ultraschallwellen parallel zur Richtung der kleinsten Trägerabmessungen eingestrahlt, d.h. rechtwinklig zur Faserrichtung und parallel zu den Lamellenkanten.

Im Einzelnen sollte die vorgestellte Untersuchung folgende Fragen beantworten:

- Ist es (im Rahmen der zur Verfügung stehenden Geräteausstattung und der gegebenen Randbedingungen) möglich, ein klares Rückwand-Echo an Brettschichtholzbauteilen mit baupraktischen Abmessungen nachzuweisen?
- Kann die Reflexions-Methode zur Erkennung von Grenzflächen verwendet werden, wie sie im Bereich von Fehlverklebungen bei Verklebungsfugen von blockverklebten Brettschichtholz-Bauteilen auftreten ?

In dem Aufsatz werden der experimentelle Ansatz und einige vorläufige Ergebnisse dargestellt.

RESUME

Dans le cadre d'un projet de recherche en cours, une étude de faisabilité sur les mesures des réflexions des ondes ultrasonores de cisaillement dans les éléments en bois lamellé-collé a été réalisée. Dans le dispositif expérimental utilisé, la direction de propagation des ultrasons était parallèle à la plus petite dimension de la poutre, c.-à-d. perpendiculaire au fil du bois et parallèle aux arêtes des lamelles.

En particulier, l'étude vise à répondre aux questions suivantes:

- Est-il possible (dans le cadre de l'équipement disponible et des conditions aux limites) d'identifier clairement un signal réfléchi par la face arrière d'une poutre en bois lamellé-collé de dimensions usuelles?
- La méthode des réflexions peut-elle être utilisée pour détecter les surfaces de séparation, comme celles qui apparaissent à l'aboutage de deux blocs de lamellé-collé?

Cet article présente l'approche expérimentale et les premiers résultats.

KEYWORDS: Non-destructive testing, ultrasound, glued laminated timber, wood, shear waves, reflection measurements

1. INTRODUCTION

One of the important factors for the serviceability and safety of structures made of glued timber products consists in the integrity and load bearing capacity of the incorporated glue-lines. In order to develop non-destructive test methods for characterisation of the glue-line performance an applied research project on "Non-destructive detection of glue-line failures in glued timber products" has been started at MPA Otto-Graf-Institute.

In the preparation and within the frame of the on-going project several test and evaluation methods based on transmission measurements by means of longitudinal waves have been applied successfully, see for example [AICHER ET AL. 2002, AICHER ET AL. 2004, DILL-LANGER ET AL. 2005]. The methods using longitudinal waves are especially successful in the cases of a some finite gap ($> 0,1$ mm) in the area of the glue-line defect, representing for example larger air bubbles within a glue-line performed by pressure free gluing with epoxy adhesives. In those cases the advantages of longitudinal waves (for example simple coupling conditions, high input energy) overbalance the shortcomings (for example the lower sensitivity to boundary layers).

However, the transmission method exhibits some drawbacks, some of them being of practical nature, for example the need of both-sided access to the structural element. Moreover, the contrast between sound glue-lines and defects achievable from the data of transmission measurements always consists in a (small) difference of (large) numbers like differences in amplitude or time-of-flight, thereby being highly susceptible for unfavourable scatter.

In the case of very thin glue-lines ($\ll 0,1$ mm) performed by means of usual gluing pressures of about $0,6$ to $1,0$ N/mm², there is virtually no gap between the two assembly components, even within defect areas with missing glue. Thus, the compression part of longitudinal waves is transferred equally for sound glue-lines and for glue line defects and the US contrast for longitudinal waves with low frequency and thus large wave length is nearly vanishing.

Therefore, in the presented study shear waves in combination with the reflection method have been used for detection of defects in a thin glue-line. As an example, the secondary glue-line of a "block glued" member consisting of two glulam beam segments has been inspected. The shear wave reflection method has already be used successfully for detection of wood defects such as decay,

see [HASENSTAB AND KRAUSE 2005]. However, to the knowledge of the authors, the application to glue-line defect detection has not yet been studied before.

2. METHODS AND TEST CONFIGURATION

Before utilizing the shear wave reflection method for the inspection of glue-line defects, it has to be proven, that clear back wall reflection signals can be measured in the frame of the given boundary conditions (typical structural dimensions and usual quality of the glued laminated timber, available equipment, etc.). For this purpose a pair (transmitter / receiver) of US shear wave transducers has been applied to the planed surface of a glulam beam with the dimensions height \times width \times length = 600mm \times 114mm \times 1180mm.

The broad band transducers (PANAMETRICS V150) with a central frequency of 250 kHz and a nominal element size of 25 mm have been driven by a high voltage pulse generator (PANAMETRICS 5058 PR).

The propagation direction of the shear waves was mainly perpendicular to the grain in width direction of the beam. The test configuration is sketched in Fig. 1. The receiver was shifted from the transmitter by 100 mm in length direction (fiber direction). It turned out, that the best results were achieved with polarisation direction of the shear waves parallel to length direction (fiber direction). No coupling agent has been used (dry coupling) and the transducers have been pressed to the timber surfaces with a given and controlled pressure force of 1000N. The signals have been amplified by a broad band amplifier and recorded by a transient recorder (12 bit amplitude resolution, 10 MHz sampling rate).

Fig. 2 shows a typical signal, whereby two different features are clearly separated: a first peak (within about 10 to 20 μ s) resulting from a US wave propagating directly from the transmitter to the transducer near the surface of the timber beam. For sake of simplicity this part of the signal is named "surface wave", although from the measured US velocity it is assumed, that this wave component is a longitudinal wave propagating next to the surface but without the characteristics of the much slower surface wave. The occurrence of longitudinal waves in spite of nominally "pure" shear wave input results from the limited efficiency of the shear wave transducer on the one hand and from the mode conversion effects in the highly anisotropic material timber on the other hand.

Clearly separated from the first peak a much smaller second peak is observed throughout occurring within 160 to 200 μ s travel time. From literature

shear wave velocity values in the range of 1320 to 1372 m/s [Bucur, 1995] and the thickness of 114 mm this peak is clearly identified as the back wall echo of the glulam beam. In the range of 360 μs also a very small second back wall echo resulting from double reflection can be found. Although Fig. 2 shows one of the signals with relatively large signal to noise ratio the feasibility of back wall identification could be shown with all performed measurements.

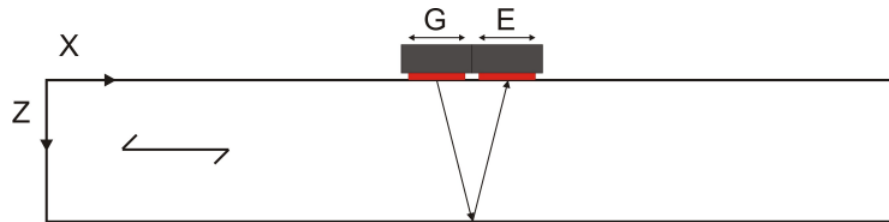


Fig. 1: Test configuration for the back wall reflection measurements at one glulam beam with propagation direction perpendicular to fiber direction and parallel to the board edges

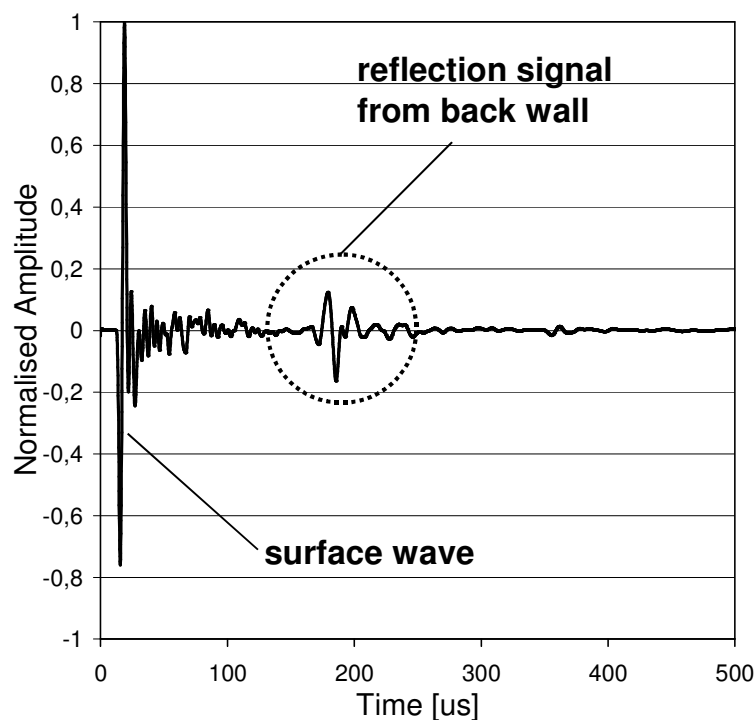


Fig. 2: Typical back wall echo of a glulam beam in transmission perpendicular to fiber direction and parallel to width direction (for test configuration see Fig. 1)

The test specimen for detection of glue-line defects has been manufactured by two stages of gluing:

1. First the timber lamellas are bonded together resulting in a usual glulam cross-section (primary gluing).
2. Two glulam cross-sections are then connected by a secondary gluing process, whereby the two components of the assembly are bonded flat-wise resulting in a so called "block glued" member. The resulting cross-section is depicted in Fig. 3.

In the following only the secondary or "block" glue-line will be inspected by means of non-destructive testing. The primary glue-lines have been produced by usual industrial means and exhibit virtually no defects. For sake of simplicity the term "glue-line" in the following always refers to the secondary glue-line.

The secondary gluing has been performed by means of a PRF adhesive at a gluing pressure of $0,8 \text{ N/mm}^2$ in a hydraulic veneer pressing device. The faces of the two glulam components have been planed directly before gluing. The resulting glue-line thickness was smaller than $0,1 \text{ mm}$. In the center of the interface no adhesive has been applied at an area of 400 mm length and 300 mm width. At the edge of the artificial glue-line defect a sealing inside a millcut of 1 mm depth and 14 mm width prevented penetration of adhesive to the defined defect area.

The lay-up of the block-glued specimen resulted in a sound glue-line with a defined glue-line defect. Due to the surface quality and the applied gluing pressure there is virtually no gap between the two glulam components in the area of the defect.

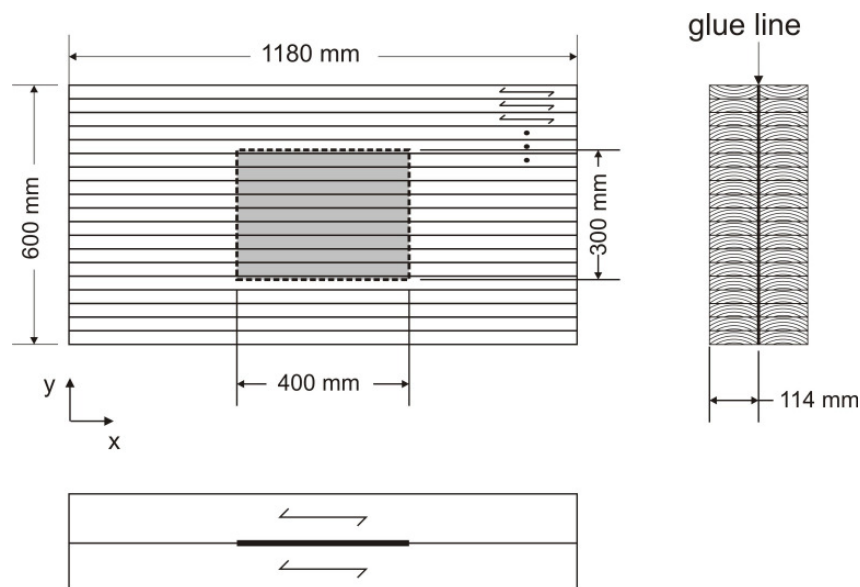


Fig. 3: Lay-up and dimensions of the glulam specimen with secondary "block" glue-line

The test configuration for the reflection measurements are analogous to the echo measurements of the single glulam segment described above: A pair of shear wave transducers is pressed to one surface of the block-glued member. Ultrasound shear waves are applied by the transmitter and the resulting signal is measured by the receiver and recorded by a amplifier / transient recorder system. The coupling conditions, the orientation and distance of the two transducers, the polarisation direction and the data of the US equipment conform to those mentioned above. The whole specimen surface (apart from some centimeters at the edges) has been scanned by shifting the transmitter / receiver pair of transducers within a grid of 50 mm in fiber direction and 32 mm in direction perpendicular thereto. In total $21 \cdot 17 = 357$ signals have been recorded. The test configuration is sketched schematically in Fig. 4.

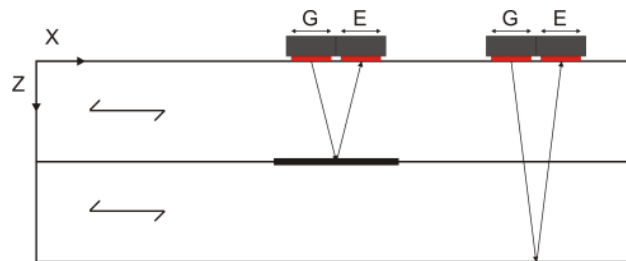


Fig. 4: Test configuration for glue-line defect detection by means of reflection measurements

First preliminary results and evaluations are given below.

3. PRELIMINARY RESULTS

Figure 5 shows a typical signal recorded at a location within the section of sound glue-line. The comparison with the signal recorded at the single glulam cross-section (Fig. 2) yields some similarities and some deviations:

- The maximum peak resulting from direct wave propagation between transmitter and receiver is found in the same time domain as for the signal obtained in case of the single glulam cross-section.
- In the time domain corresponding to the location of the glue-line the amplitudes are quite low compared to the case of a single glulam cross-section.

- Some small, but reproducible amplitudes are observed in the time domain which corresponds to the back wall reflection of the composite block-glued cross-section.

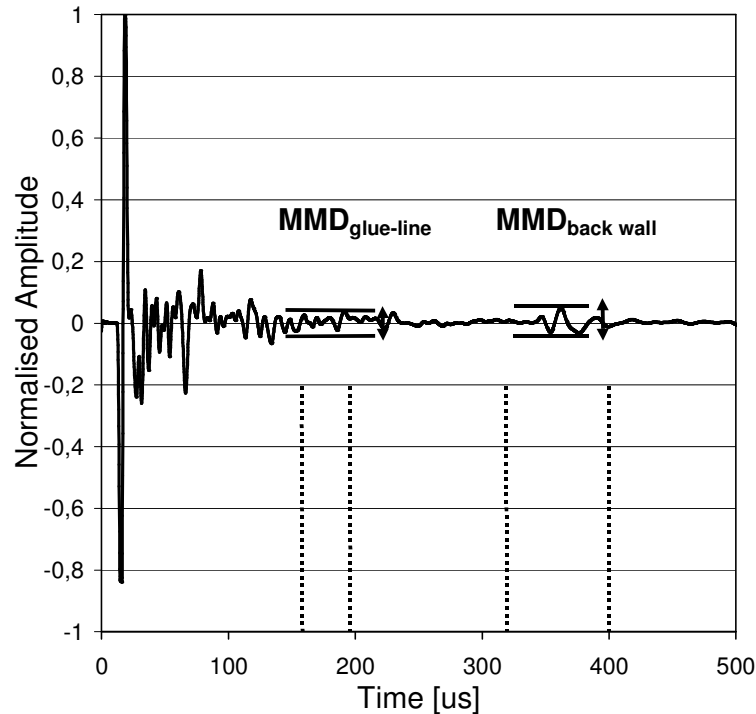


Fig. 5: Typical US signal (A-scan) of a glulam block with one secondary glue-line perpendicular to US propagation direction (for test configuration see Figs. 3 and 4): signal recorded in a section with **sound glue-line**

Figure 6 shows a typical signal recorded at a location within the section of the glue-line defect (missing adhesive). The following features can be stated:

- Analogously to the single glulam cross-section and to the compound cross-section with sound glue-line the maximum peak from direct "surface" wave propagation is visible at the beginning of the signal.
- In the time domain corresponding to the location of the (adhesive free) boundary between the two glulam blocks a clear echo signal with significantly higher amplitude as compared to the case of sound glue-line is observed.
- Some small amplitudes are visible in the time domain corresponding to the location of the back wall reflection of the composite block-glued cross-section. This feature is comparable to the case of sound glue-line.

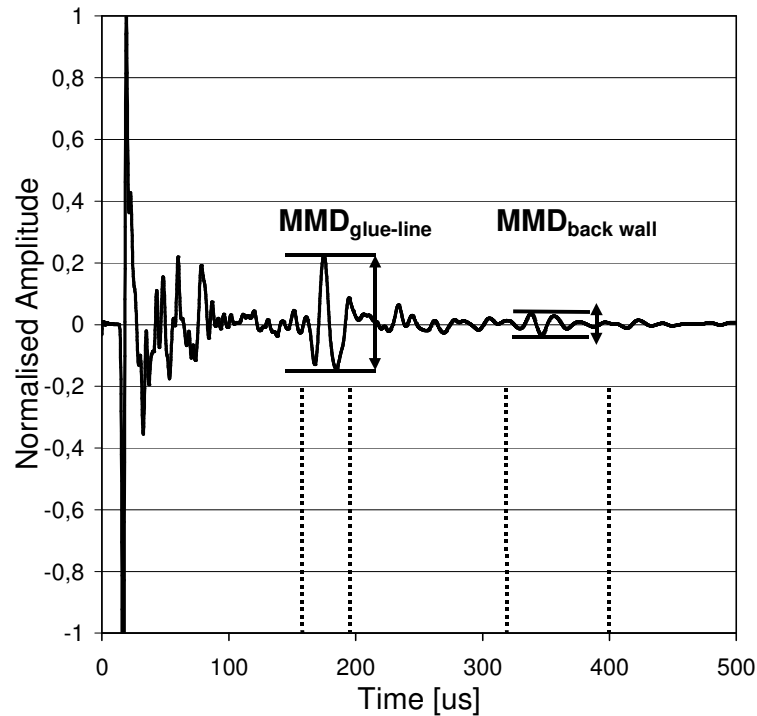


Fig. 6: Typical US signal (A-scan) of a glulam block with one secondary glue-line perpendicular to US propagation direction (for test configuration see Figs. 3 and 4): signal recorded in a section with **glue-line defect (missing glue)**

From the presented two A-scans it can be assumed that one promising parameter for a C-scan evaluation is the maximum-minimum difference amplitude (MMD) in a time window corresponding to the location of the glue-line, i.e. $MMD_{\text{glue-line}}$. In order to reduce scatter due to the coupling influence or due to different US attenuation of different boards the $MMD_{\text{glue-line}}$ is normalised with respect to the "surface" wave amplitude MMD_{surface} , in all cases being identical to the global MMD of the signal.

In Fig. 7b the results of the reflection measurements are given as a 3dimensional C-scan representation, i.e. the parameter normalised reflection amplitude = $MMD_{\text{glue-line}} / MMD_{\text{surface}}$ is plotted vs. the location (co-ordinates parallel and perpendicular to fiber direction) of the measurements. For better comparison the location and the dimensions of the glue-line defects are depicted in Fig. 7a in a graphical similar representation, whereby the z-axis has only the meaning to differentiate between sound and defect glue-line sections.

The normalised reflection amplitudes show the maximum values within the area of the glue-line defect. The minimum values are found in the section of sound glue-line. Although there is a high amount of scatter within the defect

area, a clear contrast between the sections of sound and defect glue-lines can be observed.

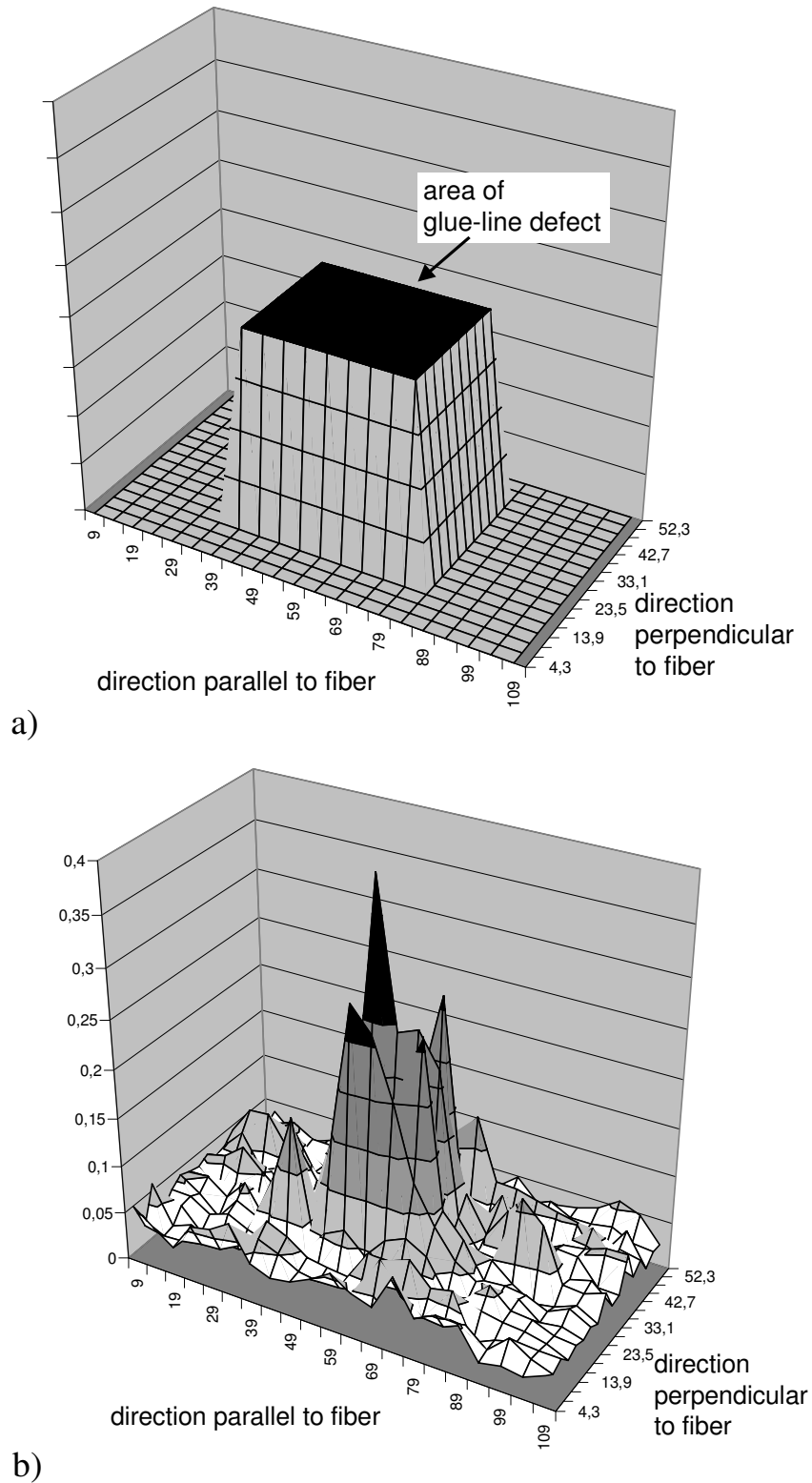


Fig. 7: Results of reflection measurements at a secondary glulam glue-line in C-scan representation:

a) Location and dimensions of the glue-line defect

b) Normalised reflection amplitude ($MMD_{reflec} / MMD_{surface}$)

4. CONCLUSIONS

The reported study on reflection measurements at structural sized glue-laminated timber beams shows

- the feasibility of back wall reflection measurements on glulam with a thickness of 114 mm
- the potential of the reflection method to detect glue-line defects in block members with a depth of 228 mm and one secondary glue-line, even if the glue-lines are thin ($< 0,1\text{mm}$) and high gluing pressure has been applied.

The presented results are part of an on-going research project and have to be verified with more specimens and different specimen configurations concerning dimensions and timber quality. One of the problems consists in the relatively high amount of scatter which makes it difficult to establish a clear threshold value to differentiate between sound and defect glue-lines. In order to further reduce scatter it may be necessary to simultaneously measure additional non-destructive parameters for advanced normalization of the reflection data.

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