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Interpretation of Results of Penetration Tests Performed on Timber Structures

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Abstract. The paper concentrates on the determination of local elastic moduli of timber in the fiber direction. To that end a single commercially produced glued timber beam was subjected to 3600 penetration measurements. The beam was first covered by a regular grid of monitoring points at which the depth of indentation was measured. We expect the measured elastic moduli to serve as an input for advanced finite element simulations on the bases of stochastic analysis. In such a case the local measured moduli represent in a given segment of each lamella an ensemble of data characterized by a selected probability distribution. These distributions are then employed in the LHS based stochastic simulation to provide probability distribution of the maximum deflection for a given load level.

Introduction

The behavior of glued lamella timber (GLT) beams loaded in bending is predominantly covered by the modulus of elasticity measured in the direction of fibers. However, for GLT beams this value is not constant. Individual segments of layered and glued lamellas are during manufacturing mutually connected by saw joints. The elastic modulus for two adjacent segments produced from the same type of wood but having different quality may considerably differ. It is therefore reasonable to consider a different modulus for each segment usually as an average value for a given region. More reliable results are expected when accepting a random nature of the material directly in numerical simulations. The analysis then typically involves finite element method (FEM) combined with the Latin Hypercube Sampling (LHS) method. Both approaches with constant segment moduli or with variable moduli represented by suitable statistical distributions are in principal independent of the number of local measurements. Nevertheless, their significant qualitative difference is evident. In the present study, 3600 penetration measurements were performed for a representative beam to directly acquire the needed moduli E to be used in simulations.

Nondestructive measurement of local moduli of elasticity

Nondestructive measurement of local moduli of elasticity was based on the determination of a depth of penetration of a pin shot into the wood. The measurement was carried out by a calibrated device Pylodyn 6J in a predefined grid of points. A regular grid of points covering both the front and back side of the timber beam is shown in Figure 1. The measuring process was design such as to easily evaluate both significant and systematic measurement errors caused e.g. by the loss of pre-stress of a string in the Pilodyn device after performing hundreds of indents. The measuring sequence considered first all central points followed by all top, bottom, left and right points, see Figure 1. The measurements were repeated on the back side of timber beam including also the measurements of local moisture at the selected central points.

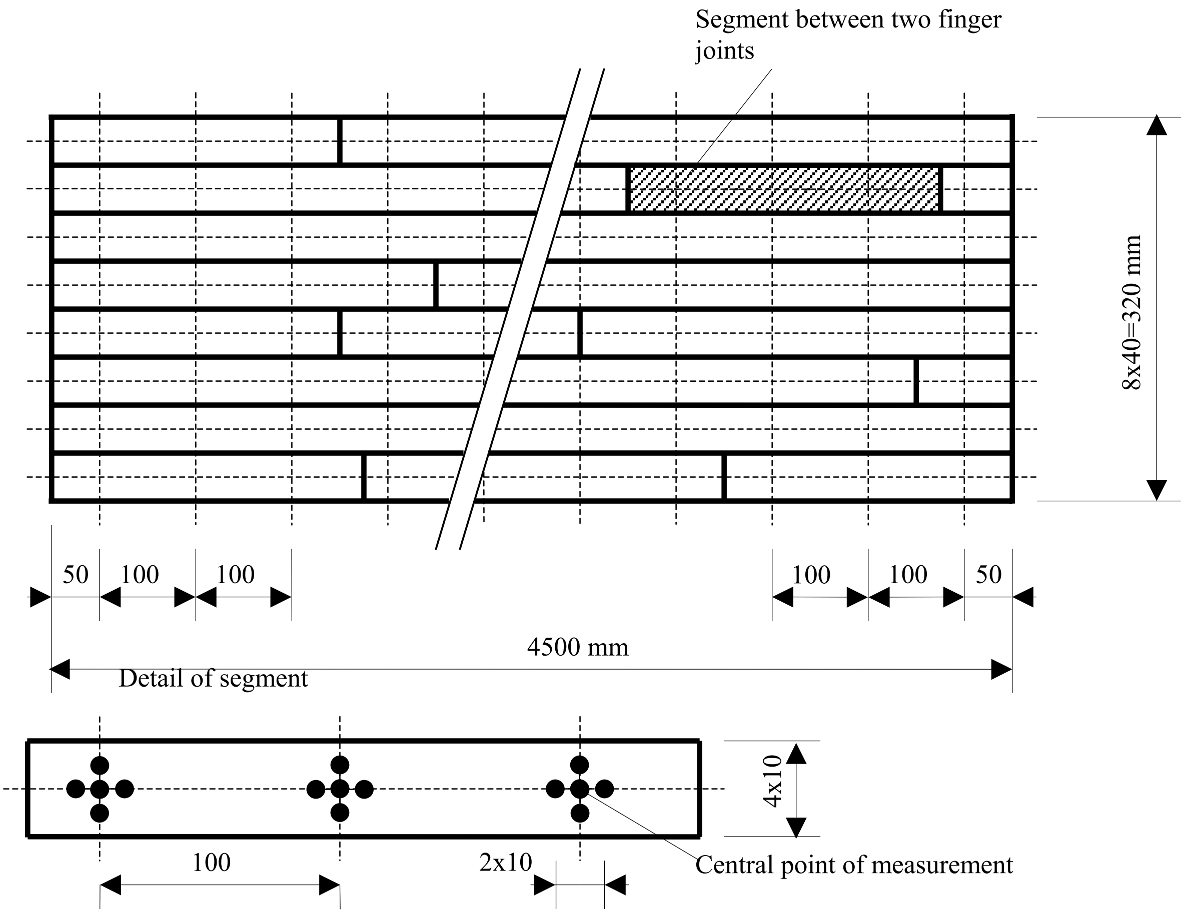

Fig. 1: Location of measuring points for the determination of local moduli of elasticity

The longitudinal modulus of elasticity in MPa can be determined from the depth of penetration of the pin (t_p) measured in millimeters adopting an empirical expression given by Eq. (1)

$$E = -564,1*t_p + 19367, \quad (1)$$

which in turn was derived from several thousands of measurements carried out under the same conditions on glued timber beams [2, 5, 6].

Statistical evaluation of local moduli of elasticity

The selected beam was manufactured from eighteen segments having a random length. The modulus E was statistically evaluated for each segment. An average value was used for the first computational model assuming constant moduli in individual segments. The second model considers apart from the mean value also the calculated standard deviation thus adopting the Gaussian probability distribution for all moduli E. The resulting distributions appear in Figue 2.

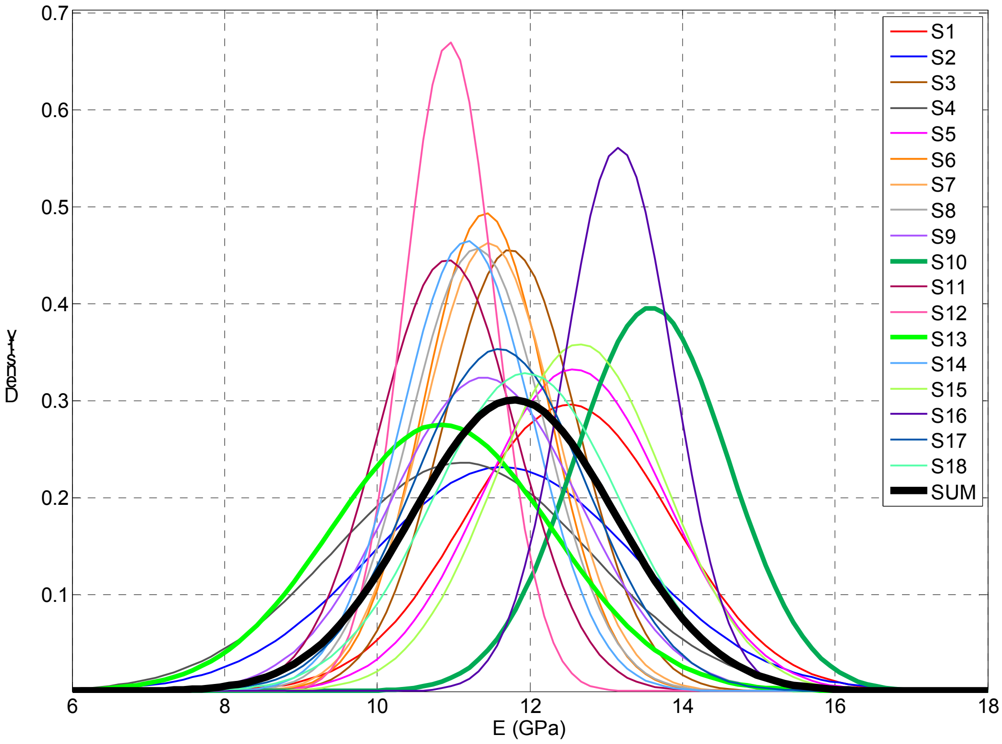

Fig.2: Probability density functions of the elastic modulus E for 18 regions, ensemble of all measurements (SUM) and distributions with the maximum and (S10) and minimum (S13) mean values are highlighted

The averages of E range from the minimum value of 10,84 (GPa) in segment No. 13 (S13) to the maximum value of 13,59 (GPa) found in segment 10 (S10). The aver all average from all measurements is 11,79 (GPa). Even if using the calculated averages of E only the differences between the maximum and minimum values from segment to segment are relatively large (approximately one quarter of the average value). Such differences thus should not be disregarded in numerical simulations.

Computational models of GLT beams

The considered beam was subjected to a four-point bending test. The maximum deflection at the center of the beam together with the local moduli measured at selected points using strain gauges were recorded. The loading was represented by two concentrated forces applied at one third of the beam span equal to 4,2m. Based on the previously performed extensive experimental study on twenty GLT beams the maximum load level the beam can reliably sustain was set equal to 24 (kN) for each force [4]. This loading scheme was adopted for both computational models. The two models were compared on the basis of central beam deflection. Unlike the second computational model, the first model considers constant moduli only and as such it is essentially deterministic providing only a single value of the deflection equal to 18,9 mm.

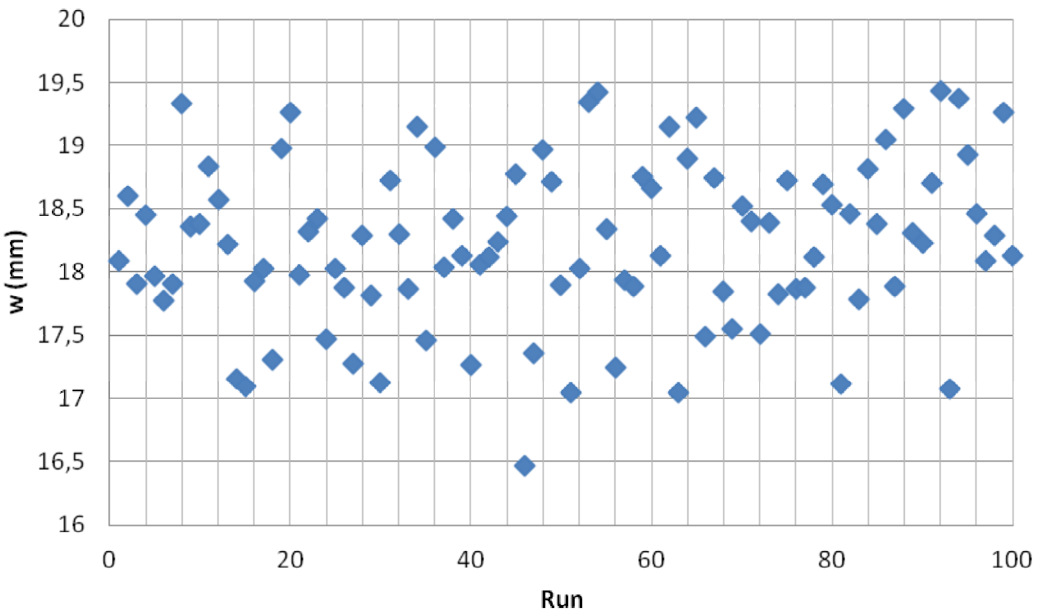

Fig.3: Deflection provided by 100 simulations of the LHS method.

In the more advance (stochastic) model, which draws on the application of LHS simulation method, the actual deflection depends on the selected probability distribution function and number of simulations to acquire its statistical parameters [1]. Figure 3 plots the resulting deflections derived from one hundred simulations. The corresponding probability density function and the distribution function appear in Figures 4 and 5. The analysis was performed for both Normal (Gaussian) and Log-normal probability distributions. The results provided by the two distributions are, however, almost negligible. Thus only the results pertinent to the Gaussian distribution are presented.

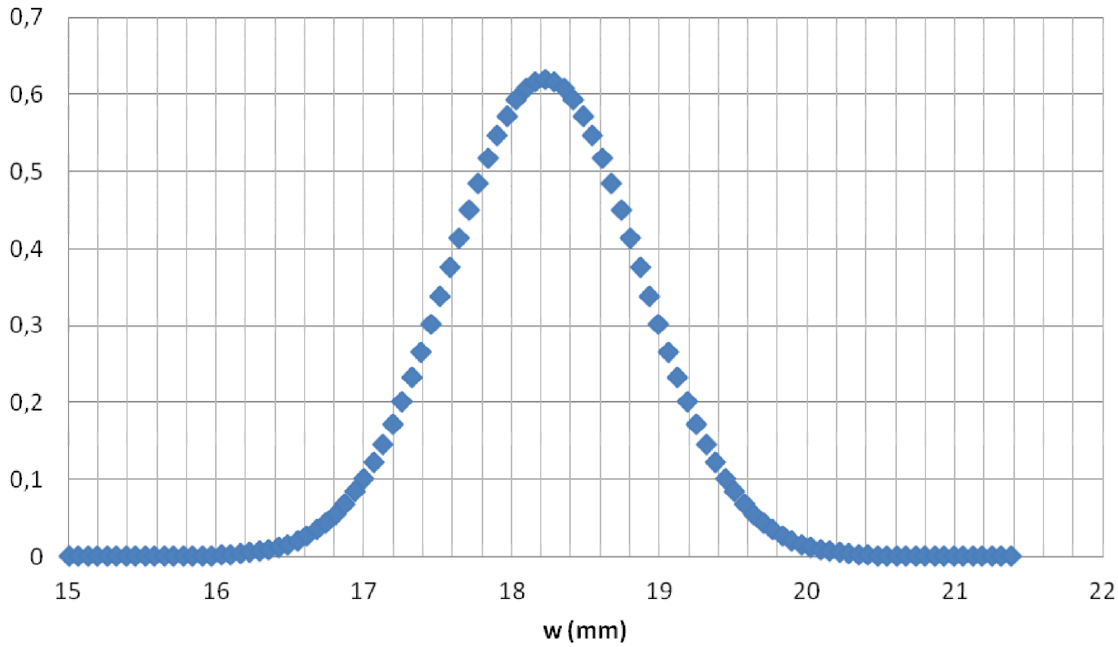

Fig.4: Probability density function of the deflection for 24(kN) loading

The mean value was found equal to 18,22 mm and the standard deviation equal to 0.644. In comparison to the deterministic model the average deflection is by 0.7mm smaller, which is a significant accuracy improvement. Even higher proportional improvement can be expected for extreme loading close to the beam failure. This, however, goes beyond the present scope.

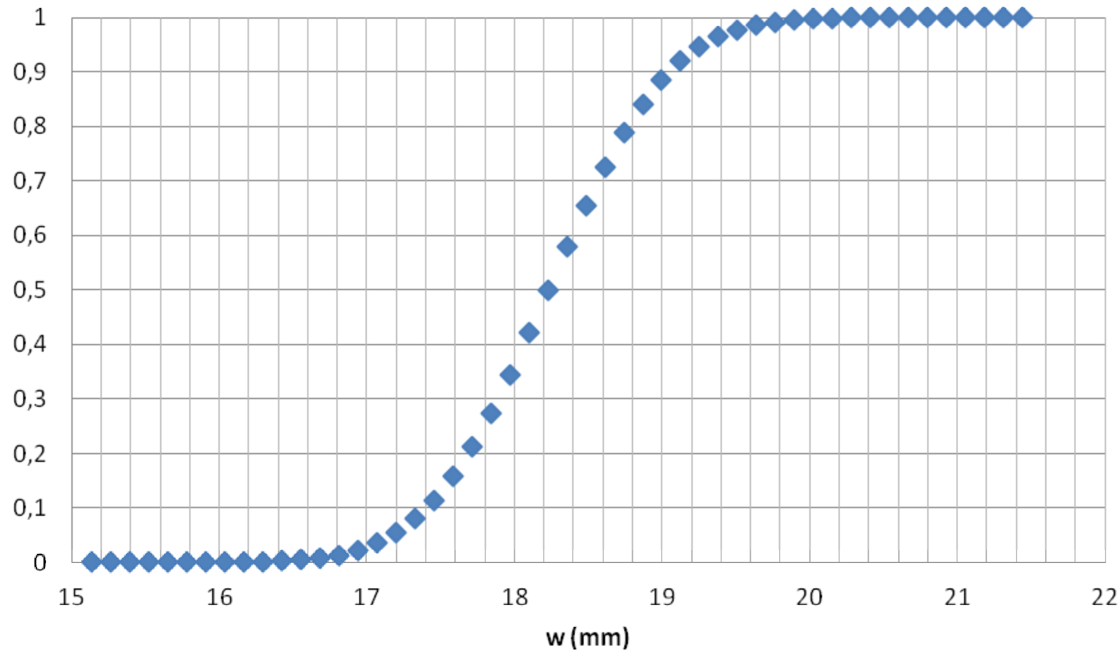

Fig.5: Distribution function of the deflection for 24(kN) loading

The stochastic computational model may further exploit the knowledge of correlation between moduli corresponding to individual segments. The manufacturing process typically adopts wood from the same source. It is therefore expectable that segment properties will not be entirely independent. This statistical dependence can be reflected in our case by 18x18 correlation matrix.

Conclusion

A lamella glued timber beams were subject of investigation. Considerable attention was accorded to the determination of local moduli of elasticity in the fiber direction. The adopted method is non-destructive and well suitable for the present class of timber beams allowing also for a simultaneous measurement of moisture important particularly for exterior beams. The numerical analysis adopted two computational models, the deterministic one and the stochastic one based on the LHS simulation method. The resulting comparison promoting importance of properly accounting for timber variability in its local properties was performed on the basis of maximum deflection only. Nevertheless, other quantities such as local stresses and strains can also be investigated both experimentally and numerically [3].

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