Longitudinal prestresses in *Tilia cordata* and *Acer pseudoplatanus*

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Abstract

Growth stresses occur during cell maturation and can be considered in a technical sense as prestresses, increasing the strength of green wood. Prestresses occur in all three planes causing a tensional longitudinal prestress and compressive tangential and radial stresses in a tree´s trunk. In this paper the longitudinal prestress of 10 *Acer pseudoplatanus* grown in a forest situation at Aberdeen, Scotland and 36 *Tilia cordata* grown as avenue trees in Munich was investigated.
The prestresses measurements were carried out by using the sawing method and the single hole method for Tilia cordata (Archer,1987) and using the single hole method only for *Acer pseudoplatanus*.
The mean E-Modulus for *Tilia cordata* was 4947 N/mm² and for *Acer pseudoplatanus*. 6522 N/mm² . The compressive strength tests carried out with Instron machines were 19,7 N/mm² for *Tilia cordata* and 25,6 N/mm² for *Acer pseudoplatanus*. The highest increasement of prestress was recorded in the first 20 mm drilling/ cutting depth. For *Tilia cordata* prestress was determined with a mean value of 8,3 N/mm² and 3,6 N/mm² for *Acer pseudoplatanus*.

Therefore longitudinal prestresses increase the breaking safety of *Tilia cordata* to 40-50% in average. In the stiffer *Acer pseudoplatanus* the prestress leads to an increasment of the braking safety of 10-20% only.

SUMMARY

Growth stresses occur in all three anatomical planes within a tree trunk and are in a technical sense prestresses. They develop during cell maturation as the S_2 layer thickens causing a swelling in the radial and tangential plane and a contraction in the longitudinal plane. Longitudinal contraction leads to tensile prestress in the outer sheath of the trunk (Kübler, 1959). The swelling of cell walls causes compressive stresses in the radial and tangential plane. In the central trunk the opposite forces are active keeping a tree in its state of equilibrium.

The Statics Integrating Methods – SIM (WESSOLLY,1998) is currently used by many tree inspectors and tree consultants in different European countries. According to this method the assessment of tree safety is based on three major factors called "The

Triangle of Statics ". The most important factor in this triangle is the wind load on an exposed crown surface during a gale. However the geometry of the load bearing structure

(here: diameter of trunk, extend of hollowness) and the load resisting material properties of the individual species also have to be incorporated in all tree safety calculations.

The compressive strength of wood is significantly lower than its tensional strength. Therefore the resistance of green wood of an individual species to compression is of major significance for tree safety analyses.

The SIM calculations are based on material properties of green, but stress free wood obtained from laboratory tests at the University of Stuttgart, Germany (WESSOLLY, 1998).

Prestresses as a result of trunk growth enhance the compressive strength and can be regarded as an additional safety reserve of trunks and branches against fracture. The aim of this research is to quantify the longitudinal prestress which influences the compressive strength of a trunk under bending load.

The specimen trees used in this work are 36 *Tilia cordata* from Hanauer Straße at Munich, Germany and 10 *Acer pseudoplatanus* from Craibstone Estate and Kirkhill Forest near Aberdeen, Scotland. Unintentional wind influence on the measuring results was avoided by removing the tree crowns leaving short stumps.

In order to determine the quantity of longitudinal prestresses two methods were used: the single hole method and the sawing method (ARCHER, 1983, GRIL, 1998). Both methods released the longitudinal stresses which caused alterations in the length of the fibres. The sawing method with cuts above and below the strain gauge (elastometer) causes a fibre contraction and negative readings. By contrast the measured values using the single hole method are positive due to an extension of the fibres between the drill hole edge and the elastometer probes. The length

alterations delivered by both methods are recorded and used to calculate the quantity of prestress according to Hooke´s law

$$s = E * e$$

with

σ = stress

E = Modulus of Elasticity (E-Modulus)

ε = strain (±l/L)

The E-Modulus as one factor in the equation above was obtained from pulling tests measuring the strain in the marginal fibres of the trunks with a modified strain gauge called elastometer (measuring accuracy 1/1000mm) under a defined load (dynamometer, measuring accuracy 0,1kN).

The mean E-Modulus for *Tilia cordata* was found to be 4949 N/mm² and that for *Acer pseudoplatanus* 6522 N/mm².

Prestress measurements were carried out on standing trunks using the single hole method and the sawing method (ARCHER, 1983) for *Tilia cordata*. For *Acer pseudoplatanus* at Aberdeen locations the single hole method was used only.

The cutting geometry of each method is influenced by the anisotropy of wood. Therefore it is important to incorporate a factor of correction (GRIL, 1998) into all prestress calculations.

$$s = \triangle l * f * E \quad (3.3)$$

σ stress	in N/m²
△l length alteration related to base length	in 10-6 m
E modulus of elasticity (c.f chapter 3.2.1)	in N/m² from pulling tests
ϕ factor of correction	in 1/m.

Directly after finishing the measurements of the E-moduli and the prestress values all sample trees were felled and disks of 100 mm thickness were cut from various heights up the stem. To avoid moisture loss the specimens were immediately sealed up on site in airtight plastic bags and deep frozen at a temperature of -20° Celsius.

The frozen wood disks were cut with a bench saw parallel to the grain to specimens of 2x2x3 and 2/2/6 (*Acer pseudoplatanus*) [cm] size. The specimens obtained from disks of 1 m and 0,8 m trunk height were used for compressive tests carried out with Instron machines at the Institut für Holzforschung, Munich and at the University of Aberdeen. The remaining disks from 0,6 m trunk height were used for density and moisture tests.

All specimens used for compressive stress tests had an moisture content well above the fibre saturation point. For *Tilia cordata* the mean compressive strength was 9,7 N/mm² and for *Acer pseudoplatanus* 25,6 N/mm².

The density values (ρ12) of all specimens showed only little variation. *Tilia cordata* had a density of 0,49 g/cm³ and *Acer pseudoplatanus* 0,56 g/cm³, both with a standard deviation of only 0,01%.

The mean prestress value for *Tilia cordata* obtained from both methods is 8,3 N\mm² showing a steep increase of measured strains in the first 10 mm cutting depth.

The mean prestress value for *Acer pseudoplatanus* (single hole method only) is 3,58 N/mm² showing a higher scattering of data but also confirming the trend of steep increase of strains in the first 10 mm drilling depth.

For both *Tilia cordata* and *Acer pseudoplatanus* the strain measurement trends show that between 10 and 20 mm cutting depth the values still increased steeply but beyond the 20 mm depth level to the final cutting depth the values plateauxed or even decreased. From the data obtained it can be concluded that the highest prestresses occur in the marginal fibres near the cambium.

Statistical analysis of the data showed that the influence of density and prestress on the modulus of elasticity were significant but not linearly related. The evaluation of the e-modulus data derived from leaning trunks compared to those from straight, upright trunks gave no evidence for a significant influence on the elastic properties.

One way and two way analysis of variance (c.f. App. A, Table 24 and 25) allow the conclusion within set limits that prestress (measured as strain) and modulus of elasticity are independent from each other which allowed for a better differentiation of cutting depth values and further prestress calculations (cf. p. 45, formula 3.3).

Tilia cordata and *Acer pseudoplatanus* are common street trees in many European countries. They are exposed to trunk and root damage which leads to decay and reduced breaking safety. Tree inspectors and tree consultants using the SIM should consider the additional safety reserve prestress when assessing the safety of *Tilia cordata* and *Acer pseudoplatanus* (cf. Fig. 52 and 53).

The results of this study allow the conclusion that longitudinal prestresses increase the breaking safety by 50% on average for Tilia cordata (cf.Fig. 51) and only 20% for *Acer pseudoplatanus*).