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SHORT NOTICES

SPAN-TO-DEPTH RATIO FOR SHEAR FREE DEFORMATIONS IN STATIC BENDING OF SMALL WOOD SPECIMENS

Stergios Adamopoulos
Technological Educational Institute of Larissa, Department of Forestry and Management of Natural Environment
Karditsa, Greece

Marina Chavenetidou, Costas Passialis
Aristotle University of Thessaloniki, School of Forestry and Natural Environment, Laboratory of Forest Utilization
Thessaloniki, Greece

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ABSTRACT

Disregarding shear effects is a principal defect in predicting the bending strengths of small clear specimens of timber according to standards. The present study proposes a method to determine spans of 2 x 2 cm wood specimens of black locust and chestnut for shear free deformations in static bending. It was found that for both ring-porous species, spans of at least 40 cm in a bending test would ensure a negligible influence of shear on modulus of elasticity.

KEYWORDS: Static bending, span/depth ratio, modulus of rigidity, pure modulus of elasticity, black locust, chestnut.

INTRODUCTION

Besides the deflection of wood specimens subjected to static bending due to the elongation and compression of fibers from axial stresses, there is a further deflection due to shear stresses. The shear influence on the deflection of wood specimens depends on the span-to-depth ratio and on the ratio of pure modulus of elasticity in bending to that of rigidity of the specimens (Biblis 1965, Harrison and Hindman 2007).

Neglecting the deflection due to shear might lead to errors in determining the elastic properties of a wood specimen (Wangaard 1964, Dong et al. 1994, Lam et al. 1997). The static bending tests are made on 2 x 2 x 36 cm specimens with a span length of 30 cm (15:1 span-to-depth ratio) according to DIN 52186 (ISO 3133) standard and on 5 x 5 x 76 cm specimens with a span length of 70 cm (14:1 span-to-depth ratio) according to ASTM standard D143-94 (2000).

MATERIAL AND METHODS

The study material comprised 66 and 125 defect-free and straight-grained mature wood specimens with approximate dimensions 2 x 2 x 34 cm from black locust (*Robinia pseudoacacia* L.) and chestnut (*Castanea sativa* Mill.), respectively. The specimens were stored in a conditioning room at 20 ± 1 °C and 65-66 % relative humidity until constant weight was achieved.

Once conditioned, each specimen was tested in static bending over 18 cm (9:1 span-to-depth ratio) and 30 cm (15:1 span-to-depth ratio) spans. The load applied to each span was only one-third of the estimated proportional limit load for each specimen and was based on previous tests. Specimens were supported freely at the ends and centrally loaded alternately on radial and tangential surfaces, using a Shimadzu testing machine. Loading speeds used for each span were according to DIN 52186 standard.

Load-deflection curves were obtained to permit determination of experimental MOE (E´) at the two span-to-depth ratios in radial (E'_{18r}, E'_{30r}) and tangential planes (E'_{18t}, E'_{30t}) as follows:

$$E' = PL^3/4bd^3y \tag{1}$$

where:
E´ - experimental modulus of elasticity ($N.mm^{-2}$)
P - load in the region of proportionality (N)
L - length between beam supports (mm)
b - width of beam (mm)
d - height of beam (mm)
y - mid span deflection of beam at load P (mm)

The experimental modulus of elasticity E'_{30t} at 15:1 ratio when specimens loaded on radial surfaces (tangential plane) corresponds to MOE determined according to DIN 52186 standard.

Pure modulus of elasticity (E), free from shear stresses, was determined for the radial (E_r) and tangential plane (E_t) by a method described by Wangaard (1964) according to the following equation:

$$(L/2d)^2/E' = 0.3/G + (L/2d)^2/E \tag{2}$$

where:
E´ - experimental modulus of elasticity at a specified span-to-depth ratio (L/d) ($N.mm^{-2}$)
G - modulus of rigidity ($N.mm^{-2}$)

When data for E´ determined at the two span-to-depth ratios are plotted on rectangular coordinates, the intercept of the Y axis is equal to 0.3/G and the slope of the line is equal to 1/E.

RESULTS AND DISCUSSION

The average values of static bending properties (pure MOE determined at radial and tangential planes, experimental MOE determined for span-to-depth ratios 9:1 and 15:1 at radial and tangential planes) of black locust and chestnut specimens are shown in Tab. 1. In both species and in the two directions of load application the calculated values of pure moduli of elasticity were much higher compared to experimental moduli of elasticity. This finding was to be expected due to the shear deformations that were caused by the short 9:1 and 15:1 span-to-depth ratios (Biblis 1971, Passialis and Adamopoulos 2002).

Tab. 1: Static bending properties of black locust and chestnut small wood specimens1.

Properties	Black locust		Chestnut	
	Radial[2]	Tangential[3]	Radial[2]	Tangential[3]
Density (air-dry) ($g.cm^{-3}$)	0.75 (0.05)	0.75 (0.05)	0.63 (0.03)	0.63 (0.03)
Bending strength				
Pure MOE – E ($N.mm^{-2}$)	19.147 (3.221)	18.434 (2.690)	17.006 (2.912)	19.002 (4.407)
Exper. MOE – E´18 ($N.mm^{-2}$)	12.157 (1.106)	11.877 (1.178)	7.751 (1.064)	6.807 (796)
Exper. MOE – E´30 ($N.mm^{-2}$)	14.728 (1.240)	14.307 (1.282)	11.712 (1.402)	11.342 (947)
Length between beam supports for shear free MOE (cm)	41.1 (2.9)	41.0 (2.1)	45.1 (3.9)	49.3 (6.0)

[1]mean values and standard deviations in parenthesis
[2]specimen loaded on tangential side
[3]specimen loaded on radial side

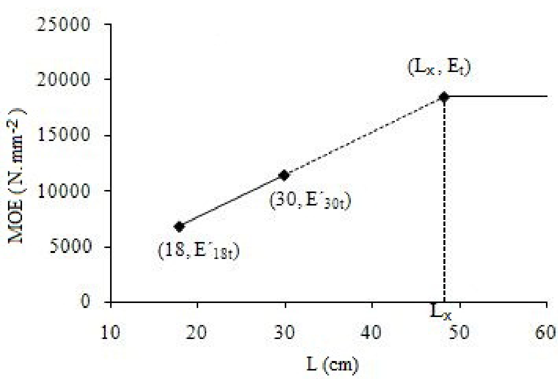

Fig. 1: Determination of span (L_x) for shear free MOE in static bending.

Data for E'_{18} and E'_{30} for each specimen at the two directions of load application (radial and tangential) were plotted on coordinates with Y-axis being MOE and X-axis being L. Fig. 1 shows an example for a chestnut specimen with load applied to the tangential direction. The line through the distinct points (18, E'_{18t}) and (30, E'_{30t}) can be described algebraically by the linear equation:

$$Y = E'_{18}t + [(E'_{30t} - E'_{18t}) / (30 - 18)] \cdot (L - 18) \tag{3}$$

As shown in Fig. 1 the changing pattern of E_t (theoretically the modulus at infinitive span-to-depth ratio) with L may represented by a parallel line to X-axis starting at a span L_x and written as:

$$Y = f(L) = E_t,\ L \geq L_x \tag{4}$$

From equations (3) and (4) we get:

$$L = [(E_t - E'_{18t}) \cdot (30\text{-}18) + (E'_{30t} - E'_{18t}) \cdot 18] / (E'_{30t} - E'_{18t}) \tag{5}$$

Equation (5) implies that lines (3) and (4) intersect at the point (L_x, E_t) and its solution gives the length L_x between beam supports that ensures calculation of modulus elasticity free from shear stresses.

The results in both species demonstrate that the span-to-depth ratio 15:1 suggested by DIN 52186 standard (conforming with ISO 3133) includes a component of shear deformation that contributes to the deflection of wood specimens loaded at this particular span and depth. This finding is of particular importance for the ring-porous species that contain zones of earlywood with low strength. In calculating shear free deformations of 2 x 2 cm wood specimens of the species larger spans could be used, 40 cm at least (Tab. 1), implying a 20:1 span-to-depth ratio.

In bending, the measured properties are greatly influenced by the span-to-depth ratio. According to existing standards, the span-to-depth ratio ranges might be determined so as to restrict the influence of deflection caused by the shearing force. However, previous research has shown that the bending properties are often not measured properly by the span-to-depth ratio determined in several major standards. The values of bending properties obtained in the standardized span-to-depth ratio ranges varied largely depending on the span-to-depth ratio because the specimen is greatly influenced by the anomalous stress distribution near the loading points as well as the deflection caused by the shearing force (Yoshihara et al. 1998, Yoshihara and Matsumoto 1999, Yoshihara et al. 2003). This limitation was also confirmed by our results in the small span-to-depth ratio range. Without any doubt, the 15:1 and 14:1 span-to-depth ratios in DIN and ISO, and ASTM standards respectively are generally accepted compromises between test piece preparation and result. For obtaining the bending properties as quantitative indices, however, it is desirable to minimize the influence of span-to-depth ratio. Our study suggests larger spans of 2 x 2 cm wood specimens of black locust and chestnut for shear free deformations in static bending than those determined in the major standards mentioned above.

CONCLUSIONS

When measuring the MOE of small wood specimens using static bending tests, a shear contribution to total deflection exists. However, the effect of shear on the load-deflection relation is small and generally acceptable when specimens have a small depth/span ratio as in standard methods (DIN 52186). In this study we suggest a span-to-depth ratio of about 20:1 for shear free MOE in two ring-porous species, black locust and chestnut.

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Stergios Adamopoulos
Technological Educational Institute of Larissa
Department of Forestry and Management of Natural Environment
431 00 Karditsa
Greece
Corresponding author: adamopoulos@teilar.gr
Phone: + 302441064706

Marina Chavenetidou, Costas Passialis
Aristotle University of Thessaloniki
School of Forestry and Natural Environment
Laboratory of Forest Utilization
541 24 Thessaloniki
Greece