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RELATIONSHIP BETWEEN GLOBAL AND LOCAL MODULUS OF ELASTICITY IN BEAMS OF ARGENTINEAN *Eucalyptus grandis**

RELACIÓN ENTRE EL MÓDULO DE ELASTICIDAD GLOBAL Y EL LOCAL EN VIGAS DE *Eucalyptus grandis* DE ARGENTINA

J.C. PITER[1];R.L. ZERBINO[2]; H.J. BLAß[3]

ABSTRACT

The present paper reports the results of an investigation regarding the relationship between the global and the local Modulus of Elasticity in sawn timber of Argentinean *Eucalyptus grandis*. For this purpose an empirical research project with 50 beams in structural sizes subjected to bending was carried out. The results obtained according to European standards show the values of both types of Modulus of Elasticity and the influence of the more important strength and stiffness reducing growth characteristics on their variation, as well as give evidence of the effectiveness of the criterion established in the American standard ASTM D 198 (1999) for correcting the influence of shear on the global Modulus of Elasticity.

Key words: *Eucalyptus grandis*, Modulus of Elasticity, stiffness, shear strains.

RESUMEN

En esta publicación se presentan los resultados de una investigación orientada a estudiar la relación entre el Módulo de Elasticidad global y el local en madera aserrada de *Eucalyptus grandis* de Argentina. Con este fin, se llevó a cabo un programa experimental con 50 vigas de tamaño estructural sometidas a flexión. Los resultados obtenidos según las normas europeas muestran los valores para ambos Módulos de Elasticidad y la influencia que sobre ellos ejercen las características que más afectan su resistencia y rigidez, así como también dan evidencia de la efectividad del criterio adoptado por la norma ASTM D 198 (1999) para corregir la influencia del esfuerzo de corte sobre el Módulo de Elasticidad global.

Palabras clave: *Eucalyptus grandis*, Módulo de Elasticidad, rigidez, deformaciones por corte.

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[1]Depto. de Ing. Civil, FRCU, UTN. Ing. Pereira 676, (E3264BTD) C. del Uruguay, E. Ríos, Argentina. ✉: piterj@frcu.utn.edu.ar
[2]Depto. de Construcciones, Fac. de Ingeniería, UNLP. 48 y 115, (1900) La Plata, Buenos Aires, Argentina. zerbino@ing.unlp.edu.ar
[3]Lehrstuhl für Ingenieurholzbau und Baukonstruktionen, Universität Karlsruhe, D-76128 Karlsruhe, Alemania. hans.blass@holz.uka.de

INTRODUCTION

Eucalyptus grandis, which is mainly cultivated in the Mesopotamian provinces of Entre Ríos and Corrientes, is one of the most important renewable species cultivated in Argentina (INTA, 1995). Up to the present neither test series regarding the comparison of global and local Modulus of Elasticity (*MOE*) nor study aimed at scrutinising the influence of the more important strength and stiffness reducing growth characteristics of this timber species on their variation were carried out.

The knowledge of the *MOE* is of great importance for designing timber structures. It is normally the most important parameter for strength grading sawn timber (Glos, 1995b). Characteristic values of *MOE*, bending strength and density allow to assign a grade/species/source combination to a strength class of the international strength class system established in the European standard EN 338 (1996), and the other characteristic strength and stiffness properties can be calculated from those basic ones (Glos, 1995a). The value of *MOE* is of great importance for estimating deformations in timber structures (Thelandersson, 1995) and for calculating timber columns (Blaß, 1995).

Numerous investigations have dealt with the determination of *MOE* by both static and dynamic methods (Glos, 1995b; Görlacher, 1984; Ilic, 2001; Pérez del Castillo, 2001). The European standard EN 408 (1996) establishes a third-point loading test for calculating the local *MOE*, free of shear, in the central third, but the Draft prEN 408 (2000) additionally allows obtaining the global *MOE*, over the whole beam span. Both types of *MOE* are considered in the American standard ASTM D 198 (1999): one is called "apparent *MOE*" and the other is "true *MOE*". In addition, ASTM D 198 recommends a formula for "shear corrected *MOE*", which is derived using simple beam theory for beams with solid rectangular homogeneous cross-section through their length. It is assumed that the beam is an isotropic elastic material with homogeneous defect distribution. ASTM D 2915 (1999) uses the shear correction concept for adjustments of apparent *MOE* between different load configurations and span-depth ratios. Typically, a single E/G is assumed for shear correction and historically a ratio of 16 has been assumed. One of the advantages of determining the global *MOE* instead of the local one is that in the former it is easier to measure deformations while testing, particularly for small beams and flatwise tested boards.

The most important strength and stiffness reducing growth characteristic for sawn timber of Argentinean *Eucalyptus grandis* is the presence of pith. Although knot ratio is not highly related to the mechanical properties of this wood species, this feature must also be considered as a strength and stiffness reducing parameter (Piter et al., 2004a and b). According to ASTM D 245, the presence of fissures may affect the flexural properties, and prEN 14081-1 (2000) establishes limits for their sizes. Large sawmilling defects, such as severe reduction of width or thickness, also must be considered because they affect the strength and stiffness behaviour of the pieces.

The aim of this paper is to present the relationship between the global and the local static modulus of elasticity in bending for sawn timber of Argentinean *Eucalyptus grandis* of various quality and structural sizes. Additionally, the influence of the important strength and stiffness reducing growth characteristics and sawmilling defects on variation of *MOE* is discussed, as well as the effectiveness of the criterion adopted by the ASTM D 198 (1999) for correcting the shear influence on the global *MOE*.

MATERIALS AND METHODS

In the framework of a timber strength grading project organised by the Argentinean Timber Technological Network (RITIM), and carried out at the Argentinean *Universidad Nacional de La Plata* and *Universidad Tecnológica Nacional*, in cooperation with the German *Universität Karlsruhe*, one test sample of 50 beams with nominal sizes 50 x 150 x 3000*mm* was prepared. 25 specimens of 1984 *Eucalyptus grandis* were obtained from Virasoro, Corrientes, and an-other 25 of 1981 *Eucalyptus grandis* from Concordia, Entre Ríos. These are the main prove-nance for this species in Argentina. With the aim of obtaining a representative sample regarding the quality variation in timber, the specimens were randomly selected and taken from different locations in the log. After a period of air-drying under protected exterior conditions, they were surfaced and conditioned in a room at 25°C temperature and 65% relative humidity.

After conditioning, actual dimensions of each test piece were measured with an accuracy of 1%. Location and sizes of knots in all faces of each specimen were registered, and knot ratio was expressed according to two different criteria: i) the width of the largest knot, measured between the lines enclosing it and parallel to the edges of the piece, related to the width of the surface on which it appears. For edge knots the lower value of knot ratio on both surfaces was considered (hereafter *K*), ii) the largest area of the projection of all knots in any 150 mm of length of the specimen divided by the cross section area, without overlapping (*KAR*). No distinctions were made between different types of knots, and those with diameters less than 5 mm were ignored. Fissures were located, described and measured in all faces of each specimen. The presence of pith was registered at both ends and on all faces of each piece.

After physical measurements and features were recorded, static bending tests were carried out according to the procedures of EN 408 (1996). A loading machine Shimadzu UH 1000*KN*, capable of applying loads with adequate rate of movement of the loading head with accuracy of 1%, was used. Specimens were placed symmetrically on the supports and loaded at one-third span length, with their weakest section located in the central third and the largest growth defects in the tension zone. For determining the global *MOE*, deformations relative to the beam support were registered at the centre of the span at the centre of the tension edge. For calculating the local *MOE*, deformations were taken as the average of measurements on both faces at the neutral axis, and were measured at the centre of a central gauge length of five times the depth of the section (see Fig. 1). Three extensometers Somet, with resolution of 0,01*mm*, were used.

Global ($E_{m'g}$) and local ($E_{m'l}$) *MOE* were calculated as follows:

$$E_{m,g} = \frac{l^3 (F_2 - F_1)}{4{,}7bh^3 (\omega_2 - \omega_1)} \qquad (Eq.\ 1)$$

$$E_{m,l} = \frac{a l_1^{\,2} (F_2 - F_1)}{16I (\omega_2 - \omega_1)} \qquad (Eq.\ 2)$$

where:
l: span; F_2 - F_1: increment of load on the straight line portion of the load deformation curve; *b*: width of cross section; *h*: depth of cross section; ϖ_2 - ϖ_1: increment of deformation corresponding to F_2 - F_1; a: distance between one load and the nearest support; l_1: central gauge length of five times the depth of the section; *I*: second moment of area.

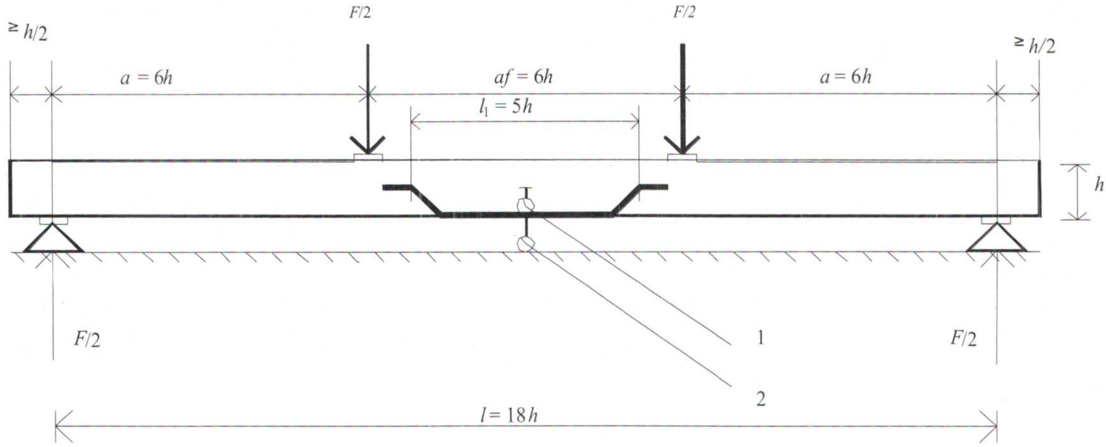

Fig. 1: Test arrangement
(1) Two extensometers, one on each side of the beam, for determining the local *MOE*; (2) One extensometer for determining the global *MOE*.

The adjustment of the global MOE for obtaining MOE free of shear influence (Em,ASTM), according to the American standard ASTM D 198 (1999), was obtained with the following formula:

$$E_{m,ASTM} = \frac{E_{m,g}}{\left(1 - \frac{l(F_2 - F_1)}{5bhG(\omega_2 - \omega_1)}\right)} \qquad (Eq.\ 3)$$

where:
G: shear modulus estimated as $E_{m,l}/16$ according to EN 384 (1996) and in line with other investigations (Thelandersson, 1995).

Moisture content was determined according to the procedure of ISO 3130 (1975), using a clear full cross section taken from the test specimen after the static test. Characteristic mean *MOE* values were determined according to EN 384 (1996).

RESULTS AND DISCUSSION

The main results for global and local *MOE* are summarised in Table 1. The mean value and the coefficient of variation of moisture content for the 50 beams were 15%, and 0,12, respectively. Since the presence of pith, fissures exceeding the maximum length established in prEN 14081 (2000) for strength classes above *C*18, and large defects, significantly reduce the strength and the stiffness of this timber species (Piter et al., 2004a and b), the values are pre-sented separately in four groups: i) the whole sample, ii) beams free of pith, iii) beams without important fissures and large defects, and iv) beams free of pith, fissures and large defects. Group iv is included in group ii and in group iii.

A detailed analysis showed that there were no important differences between the parameter and *MOE* values for the two groups of different origin. The sub-sample of Entre Ríos included 13 beams without pith, 11 without important fissures and large defects and 8 free of all these features. The global *MOE* mean value for these 25 specimens was 12703N/mm^2 and the local one was 13634N/mm^2. The corresponding numbers for the sub-sample of Corrientes were 11, 11, 7, 12606N/mm^2 and 13410N/mm^2, respectively.

All *MOE* mean values increase for timber of better quality, which confirms the above mentioned defects as reducing stiffness features, but in all cases mean values are greater for the local *MOE* than for the global one. The difference between both types of *MOE* ranges between 6% and 7% for all timber qualities. Hermoso Prieto (2001) reported mean values for global *MOE* up to 7% smaller than for the local one for *Pinus sylvestris* L. from Spain when deformations were registered on the neutral axis and even greater differences when deformations were measured on the inferior tension edge. The correlation between the defects and local and global *MOE* can be explained by interaction of several variables: i) local stiffness reducing characteristics located in the middle third of the span, ii) local *E/G* ratio in the middle third of the span, iii) global stiffness reducing characteristics, and iv) global *E/G* ratio. While concentrations of defects near the mid-span may lead to reduction of local *MOE*, it is counteracted by the absence of shear deformation component in this measurement. On the contrary, the global stiffness represents the average *MOE*, which may be higher than the local *MOE* but it is reduced by the effect of shear deformation.

Table 1: Main results for global and local MOE
(1) fissures exceeding the maximum length established in prEN 14081-1 (2000) for strength classes above *C*18; (2) large defects; *n* is the number of specimens; *Min*, *Mean* and *Max* are the minimum, mean and maximum values respectively; *S* and *COV* are the standard deviation and the coefficient of variation respectively; *MOE* values adjusted to a reference moisture content of 12% according to EN 384 (1996).

	Whole sample		Without pith		Without fiss(1) and ld(2)		Without pith, fiss(1) and ld(2)	
	$E_{m,g}$ N/mm² (n = 50)	$E_{m,l}$ N/mm² (n = 50)	$E_{m,g}$ N/mm² (n = 24)	$E_{m,l}$ N/mm² (n = 24)	$E_{m,g}$ N/mm² (n = 22)	$E_{m,l}$ N/mm² (n = 22)	$E_{m,g}$ N/mm² (n = 15)	$E_{m,l}$ N/mm² (n = 15)
Min	9039	9621	10994	10650	11311	10690	12013	10690
Mean	12655	13522	13388	14277	13622	14459	13965	14850
Max	16990	19048	16990	19048	16990	19048	16990	19048
S	1547	1940	1504	2101	1501	2167	1425	2224
COV	0,12	0,14	0,11	0,15	0,11	0,15	0,10	0,15

The values of both types of *MOE* for each beam are displayed in Fig. 2, where it is possible to appreciate that the local *MOE* was greater than the global one in 44 of the 50 tested beams (88%). This detailed analysis confirms that the values in Table 1 represent a general tendency in the present investigation for the relation between local and global *MOE*.

Knot ratio must also be considered as a strength and stiffness reducing parameter for this timber species (Piter et al., 2004a and b). The mean values of *K* and *KAR* were 0,35 and 0,21 for the 25 beams of Entre Ríos. The results for the 25 specimens of Corrientes were 0,34 and 0,17, respectively. In order to evaluate the influence of knot ratio on both types of *MOE* without the interference of other parameters, the relation between local and global *MOE* is presented in Fig. 3 as a function of *K* and *KAR* for the 15 beams free of the analysed defects (see also Table 1). The mean ratio of local and global *MOE* was 1,063, and it was not possible to find a relationship between the analysed variables. This observation suggests that the dif-ference between both types of *MOE* is independent of the timber quality. Since the significance of shear deformations varies with the load arrangement and the depth to span relation (Thelandersson, 1995), these results cannot be generalized for other load conditions.

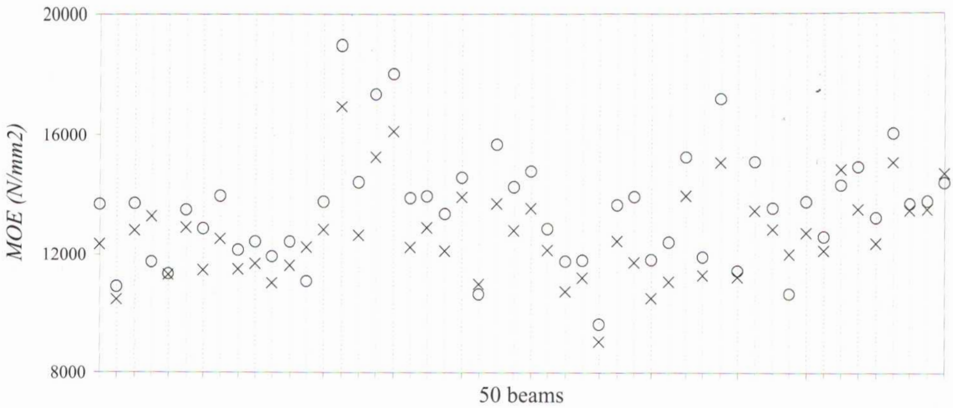

Fig. 2: Global and local *MOE* values for each beam
(x) global *MOE*; (o) local *MOE*; values adjusted to a reference moisture content of 12% according to EN 384 (1996).

According to ASTM D 198 (1999), Appendix X2, it is possible to correct the shear influence on the global *MOE* (see *Eq.* 3). The results obtained by applying this formula to the whole sample indicate the minimum, mean, and maximum values of 9414N/mm^2, 13199N/mm^2 and 17699N/mm^2, respectively. The standard deviation is 1614N/mm^2 and the coefficient of variation 0,12. The ASTM shear correction is essentially a constant in this case, the 50 values ranging between 1,035 and 1,053. For this reason, the coefficient of variation for the adjusted values is similar to the corresponding for the global *MOE* (see Table 1). The mean value of 13522N/mm^2 for the local *MOE* (see Table 1) obtained by the static test is only 2% greater than the one of 13199N/mm^2 obtained by correcting de global values of *MOE* according to the above mentioned equation. This difference is not relevant and is mostly caused by the effect of defects on the deformation of the tested beams. Since the results were obtained with a representative sample of specimens in usual structural sizes, the effectiveness of the criterion adopted by the American standard for correcting the shear influence on bending deformations is confirmed for this wood species for practical purposes.

The results indicate that the utilisation of global *MOE*, without shear correction, instead of the local one, increases safety for this wood species. Therefore, decisions related to strength grading and the allocation of a grade of this wood species to a strength class of the international system established in EN 338 (1996) are situated on the conservative side if the global *MOE* is considered. The structural design according to both ultimate and serviceability limit states is also situated on the safe side if characteristic values of global *MOE*, without shear correction, are employed instead of the corresponding local ones.

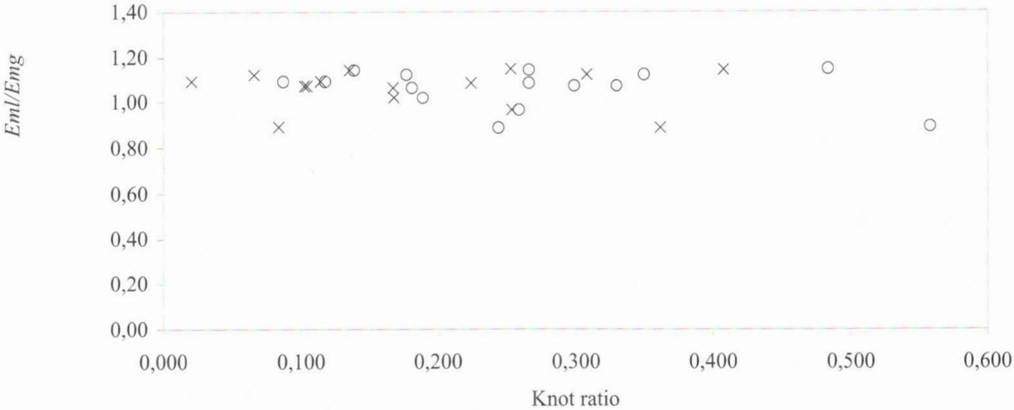

Fig. 3: Relation between local and global *MOE* as a function of knot ratio
Beams free of pith, fissures[(1)] and large defects; (o) knot ratio according to *K* criterion; (x) knot ratio according to *KAR* criterion; (1) fissures exceeding the maximum length established in prEN 14081-1 (2000) for strength classes above *C*18; *MOE* values adjusted to a reference moisture content of 12% according to EN 384 (1996).

CONCLUSIONS

Global and local Modulus of Elasticity of Argentinean *Eucalyptus grandis* according to the European standards were determined on a test sample of 50 beams in structural sizes subjected to bending. Results showed that the local *MOE*, free of shear influence, exhibited mean values 6% to 7% greater than the corresponding global ones. It was not possible to establish correlation between the ratio of the local and global *MOE* and the presence of strength and stiffness reducing growth features such as pith, knots, fissures and large defects. The effectiveness of the criterion adopted by the American standard ASTM D 198 (1999) for correcting the shear influence on the global *MOE* was checked. Results confirm that the utilisation of global *MOE*, without shear correction, instead of the local one, situates decisions related to strength grading this wood species as well as to the structural design on the conservative side.

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