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J.C. Piter · R.L. Zerbino · H.J. Blaß

Deflections in beams of Argentinean *Eucalyptus grandis* under long-term loading

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Abstract The present paper reports the results of an investigation regarding the analysis of deflections in structural-sized beams of fast-growth Argentinean *Eucalyptus grandis* under a one-year loading and in indoor climate. An empirical research project with a sample containing 16 beams was carried out. 8 pieces were free of pith and another 8 pieces contained pith. The results obtained allow to compare the creep behaviour of this timber species with those reported by other researchers for both structural-sized and small-clear specimens. The research confirms the design rules adopted by Eurocode 5 for calculating the creep deflections of this timber species under a long-term load. Results also evidence a slight influence of the presence of pith on creep, confirming similar creep behaviour for different qualities of this timber species.

Durchbiegungen von Biegeträgern aus *Eucalyptus grandis* aus Argentinien unter langer Lasteinwirkung

Zusammenfassung Dieser Beitrag fasst die Ergebnisse einer Studie zusammen, in der die Durchbiegungen von Biegeträgern aus *Eucalyptus grandis* aus Argentinien in Bauholzabmessungen unter Lasteinwirkung von langer Dauer in einem Innenklima untersucht wurden. Die Untersuchung umfasste 16 Biegeträger. 8 Prüfkörper waren ohne Markröhre und die anderen 8 Prüfkörper mit Markröhre. Die Ergebnisse der Versuche zeigen das Kriechverhalten dieser Holzart und bestätigen Angaben aus der Literatur für kleine fehlerfreien Proben und für Bauholz. Die Untersuchung bestätigt die Rechenregeln des Eurocode 5 zur Berechnung der Langzeitdurchbiegung dieses Holzes. Die Ergebnisse zeigen auch einen leichten Einfluss der Markröhre auf das Kriechen dieser Holzart, und sie bestätigen ein ähnliches Kriechverhalten für Biegeträger unterschiedlicher Festigkeit.

J.C. Piter
Departamento de Ingeniería Civil, Facultad Regional Concepción del Uruguay, Universidad Tecnológica Nacional. Ing. Pereira 676, (E3264BTD) C. del Uruguay, Entre Ríos, Argentina

R.L. Zerbino
Departamento de Ingeniería Civil, Facultad de Ingeniería, Universidad Nacional de La Plata. 48 y 115, (1900) La Plata, Buenos Aires, Argentina

H.J. Blaß (✉)
Lehrstuhl für Ingenieurholzbau und Baukonstruktionen, Universität Karlsruhe, 76128 Karlsruhe, Germany
E-mail: hans.blass@holz.uka.de

1 Introduction

The question of serviceability is very important in structural design. For many applications, elastic and creep behaviour is the most important mechanical property of wood. Particularly, in the case of beams subjected to bending under a long-term or permanent load, the requirements related to final deflections are often decisive for the cross sectional dimensions (Hunt 1999, Thelandersson 1995a, Thelandersson 1995b).

Instantaneous elastic deflections can be calculated using the standard solution based on elementary beam theory. Since the shear effect on deformations is relatively low in beams of usual structural sizes, it may normally be disregarded (Thelandersson 1995b). The creep part of the deformation begins after the instantaneous deflection and it is considered to be integrated by two independent and additive components: viscoelastic and mechano-sorptive creep, which are mainly influenced by time and moisture changes, respectively. There is also a reversible part, which is manifested during continued moisture cycling (Bengtsson 2001, Hunt 1999). Stress levels greater than 35% of the short-term strength and temperatures higher than 50 °C can also affect the creep rate, but these values are commonly not reached in normal structures and, consequently, can be disregarded as creep-influencing parameters for practical purposes (Andriamitantsoa 1995).

According to Eurocode 5, the instantaneous elastic deflection under an action should be calculated on the basis of mean values of the appropriate Modulus of Elasticity. Creep is calculated considering the combined effect of moisture content (service class) and load duration, and it is quantified for different materials by the factor k_{def}, which considers neither the size nor the quality (strength class) of the sawn timber. The creep part of deformation is equal to the instantaneous deflection multiplied by the creep factor (Arbeitsgemeinschaft Holz e. V. & Bruderverlag 1995).

Creep results on small clear and structural-sized beams are available for different conditions and materials, including sawn and glued laminated timber as well as wood-based products. Creep is normally smaller in structural timber than in small clear specimens under the same loading and climate conditions. This behaviour is explained by the greater and faster variation in moisture content that occurs in small clear specimens in comparison with structural timber, even though the latter may be affected by the influence of grain deviation and other defects. For this reason, results obtained from structural-size tests are very important for practical purposes and for design guidelines (Ranta-Maunus 1995).

The study of deflections has acquired more importance since the increased use of fast-growth timber, which is harvested at an early age and normally contains an important proportion of juvenile wood. Juvenile wood typically exhibits larger spiral angle for the fibres in the central layer of the secondary wall than in mature wood, and, as a consequence, it normally shows greater elastic and creep deflections than normal wood (Hunt 1999). Moreover, Bengtsson (2001) found that wood sawn near the pith has a larger propensity to creep than mature wood in test series with Norway spruce (*Picea abies*). Nevertheless, according to Bamber et al. (1982) fast-growth appears to affect the physiologically-active cells but not the mechanical cells (i.e. the fibres) of *Eucalyptus grandis*.

Argentinean *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). Results of an investigation regarding the development of a method for visually grading sawn timber of this timber species reported that the presence of pith, often associated with other defects as large fissures, significantly reduces bending strength and stiffness of this fast-growth timber species (Piter et al. 2004).

Up to the present no test series with beams of Argentinean Eucalyptus grandis in structural sizes under long-term loads has been carried out. As a consequence, the behaviour of this timber species under this load-duration class is not well known. Deflection data obtained from tests on small clear specimens of Argentinean *Eucalyptus grandis* in indoor environment under one-year load are reported by Calvo et al. (2002).

The aim of this paper is to present and discuss the results of an investigation regarding the deflections of beams in structural sizes of Argentinean *Eucalyptus grandis* under a one-year loading in indoor climate and additionally, to compare these results with the prescriptions given in Eurocode 5 and to analyse the influence of pith as an important strength and stiffness-reducing feature on deflections.

2 Material and methods

In the framework of a research project carried out at the Argentinean Universidad Nacional de La Plata and Universidad Tecnológica Nacional, in co-operation with the German Universität Karlsruhe, one test sample of 16 beams with nominal sizes 50 mm × 100 mm × 2000 mm was prepared. 8 pieces were free of pith. The specimens of 1986 *Eucalyptus grandis* were randomly selected from Concordia, Entre Ríos. This is one of the main provenances for this species in Argentina.

After a period of air-drying under protected external conditions, they were planed. Actual dimensions and measurements for each test piece were made to an accuracy of 1%. Moisture content and density were determined according to the procedures of ISO 3130 (1975) and ISO 3131 (1975), respectively, using a clear full cross section taken from one end of the beams before loading.

All beams were tested in the same room during one year. The specimens were placed symmetrically on two supports and loaded at the centre of the span with a constant load. With the aim of reproducing the usual structural conditions, a span length (hereafter l) of 1800 mm was adopted and, consequently, a span to depth ratio of 18 was registered for all pieces. With the purpose of reaching similar values for the maximum stress levels at the centre of the span ($\sigma_{m,long-term}$) to those normally adopted for beams of this timber species, concentrated-load values ranging between 1.3 kN and 1.8 kN were applied.

Instantaneous elastic deformation (u_{inst}) was registered within a period of 30 minutes after loading at the centre of the span and at the centre of the tension zone. Deflections (u) were measured during one year and creep (u_{creep}) was calculated as the difference between u and u_{inst}. After the one-year test was finished, the instantaneous elastic recovery (u_{rec}) and the residual deflection (u_{res}) were registered. Deformations were measured in all cases by means of an extensometer Somet, capable of registering 0.01 mm. Each beam was finally tested for determining its strength in bending (f_m) according to the procedures of DIN EN 408 (1996). A loading machine Shimadzu UH 1000 kN, capable of applying loads with adequate rate of movement of the loading-head and accuracy of 1% was used.

3 Results and discussion

The mean value of moisture content was 14.1% with a standard deviation (S) of 0.05% and a coefficient of variation (COV) of 0.04. These results confirm similar moisture content for the 16 beams. The minimum (Min), mean and maximum (Max) values for density were 408 kg/m^3, 580 kg/m^3 and 822 kg/m^3, respectively, with $S = 105$ kg/m^3 and $COV = 0.18$, which are congruent with earlier results reported for this timber species (Piter et al. 2004). Table 1 shows the results obtained for parameters normally influencing deflections in wood. The relation between the span length and the instantaneous deflection ranged between 191 and 364, with a mean value of 288. These values are congruent with those recommended by Eurocode 5 for structural design (Arbeitsgemeinschaft Holz e. V. & Bruderverlag 1995). Since the maximum stress level was produced only at the central cross section during the one-year test, and the bending strength, determined according to DIN EN 408 (1996), reached maximum values throughout the central third, the ratio $\sigma_{m,long-term}/f_m$ is presented for both the centre of the span and the one-third span

Table 1 Summary of results for instantaneous deflection and stress levels. (1) ratio corresponding to the centre of the span; (2) ratio corresponding to the one-third span length

Tabelle 1 Ergebnisse für die Anfangsdurchbiegung- und Beanspruchungsniveaus. (1) in der Trägermitte; (2) im Trägerdrittel

	Min	*Mean*	*Max*	*S*	*COV*
l/u_{inst}	191	288	364	50	0.17
$\sigma_{m,long-term}$(N/mm^2)	10.0	13.0	15.7	2.1	0.16
f_m (N/mm^2)	18.2	58.2	102.8	24.9	0.43
$\sigma_{m,long-term}/f_m$	$0.15^{(1)} - 0.10^{(2)}$	$0.27^{(1)} - 0.18^{(2)}$	$0.65^{(1)} - 0.43^{(2)}$	$0.13^{(1)} - 0.09^{(2)}$	$0.49^{(1)\,(2)}$

length. A particular analysis indicates a maximum value of 0.65 at the centre of the span (0.43 at the one-third span length) for only one beam and another piece showed a value of 0.45 (0.30 at the one-third span length). These values were exhibited by specimens with pith, which presented the lowest values for the instantaneous resistance (f_m). The other 14 pieces presented ratios not greater than 0.35 at the centre of the span (0.23 at the one-third span length). The presence of 8 beams with pith and the same amount of specimens free of this important strength and stiffness reducing characteristic for this timber species (Piter et al. 2004) may explain the high values of COV found for f_m (0.43) and $\sigma_{m,long-term}/f_m$ (0.49).

Table 2 summarises the main results for the instantaneous as well as for the one-year deflections of the test sample. After unloading, the instantaneous elastic recovery showed similar results to the instantaneous elastic deflection and the residual deflection exhibited similar behaviour to the creep part of deformation. The ratio u_{rec}/u_{inst} amounts to 0.95 for the corresponding mean values and the same relation for $u_{res}/u_{creep,1\,year}$ reaches 1.10.

Taking into account the load duration classes established in Eurocode 5 (Arbeitsgemeinschaft Holz e. V. & Bruderverlag 1995), Table 3 presents a summary of results for the relative deflections corresponding to three periods of time after loading for service class 1: i) the limit between short-term and medium-term load duration classes: 1 week, ii) the limit between medium-term and long-term load duration classes: 6 months, and iii) 1 year.

The mean values of the relative deflection (u/u_{inst}) corresponding to 1 week, 6 months and 1 year are 1.13, 1.36 and 1.46, respectively, with increasing COV values ranging from 0.07 to 0.12. Results of a research carried out with small clear specimens of Argentinean *Eucalyptus grandis* (Calvo et al. 2002), tested in similar conditions to the present structural beams, show mean values of 1.48, 2.25 and 2.25, for the same relation and the same periods of time after loading. The great difference found between these results may be explained by the influence of variation in moisture content, which is greater and faster in small-scale specimens than in structural timber. Nevertheless, the mean value of 1.46 for the ratio after one-year loading is in line with earlier reports regarding the level of creep in structural-sized timber after the same period of time in indoor environment (Ranta-Maunus 1995).

A detailed analysis shows that in all cases the maximum value for u/u_{inst} corresponds to the beam with the highest ratio $\sigma_{m,long-term}/f_m$, which was above mentioned (see also Table 1). The maximum values exhibited for this piece are 19%, 20% and 25% higher than the mean value for the three periods of time presented in Table 3, respectively. No particular relation was found between the level of stress and the rate of creep for the other 15 pieces, in line with other experimental results reported by Andriamitantsoa (1995).

With the aim of checking the design rules established in Eurocode 5 for calculating the creep deflections of this timber species, the mean values presented in Table 3 were compared with the corresponding creep-factor values given in the Standard. Since a linear relation between u and u_{inst} is assumed, and final deflections may be calculated with the equation $u = u_{inst}\ (1 + k_{def})$, the results presented in Table 3 are equal to $1 + k_{def}$. According to Eurocode 5, the creep factor k_{def} amounts to 0, 0.25 and 0.5 for short, medium, and long-term load duration classes, respectively, and for both service classes 1 and 2. It may be appreciated, that the mean values of 0.13 and 0.36 registered in the present research for 1 week and 6 months, which are the upper

Table 2 Summary of results for the instantaneous and one-year deflections

Tabelle 2 Ergebnisse für die Durchbiegungen zu Beginn und nach einem Jahr

	Min	*Mean*	*Max*	*S*	*COV*
u_{inst} (mm)	5.0	6.4	9.4	1.2	0.19
$u_{creep,1year}$ (mm)	1.1	3.1	7.8	1.7	0.55
u_{rec} (mm)	4.6	6.1	9.4	1.3	0.22
u_{res} (mm)	1.7	3.4	7.8	1.7	0.48

Table 3 Summary of results for relative deflections (u/u_{inst}) corresponding to different periods of time after loading

Tabelle 3 Ergebnisse der relativen Durchbiegungen (u/u_{inst}) für verschiedene Zeiträume nach der Belastung

	Min	*Mean*	*Max*	*S*	*COV*
1 week	1.04	1.13	1.34	0.08	0.07
6 months	1.12	1.36	1.63	0.15	0.11
1 year	1.20	1.46	1.83	0.17	0.12

time limits for short and medium-term load duration classes, respectively, are slightly higher than those of k_{def} adopted by this European standard. Moreover, the value of 0.46 registered in the present study after one year of loading is similar to k_{def} corresponding to the long-term load duration class, which extends from 6 months to 10 years. The results confirm the design rules adopted by the Eurocode 5 for calculating deflections in beams of this timber species under a long-term load, even though it is necessary to extend the analysis of its creep behaviour up to 10 years.

The relative deflection as a function of time is presented in Fig. 1, where it is possible to appreciate separately the mean values of u/u_{inst} for i) the whole sample, ii) the beams free of pith and iii) the pieces with pith. In relation to the whole sample, and in line with other reports (Andriamitantsoa 1995, Calvo et al. 2002), a relatively rapid increase of u/u_{inst} at the beginning of the test can be found. The creep rate goes on with a significant slope up to 2 months, although its slope is smaller than the one registered during the first week. After 2 months begins a range approaching stabilization with a constant creep rate, which slightly increases after 6 months and till the end of the test.

A particular analysis shows that, even though with modest differences, the beams with pith exhibit a higher rate of creep than the pieces free of it. The greatest difference between the corresponding mean values appears after 2 and 3 weeks, with an amount of 16%. Then, this percentage decreases, reaching a level of 3% after 2 months and 0% after 6 months. Finally, the difference increases gradually, exhibiting a value of 7% after 1 year. These results show a moderate influence of pith on creep rate and, consequently, this important strength and stiffness reducing feature may be disregarded as creep-influencing parameter for practical purposes. The creep behaviour found in the present research for this fast-growth timber species appears to be more in line with the report of Bamber et al. (1982) than with the one produced by Bengtsson (2001), and it is congruent with the criterion established in Eurocode 5, which ignores the influence of timber quality on creep factor k_{def}. The results confirm that the method adopted by this European standard is equally suitable for different qualities of this timber species for practical purposes.

4 Conclusions

Deflections in structural-sized beams of fast-growth Argentinean Eucalyptus grandis under a one-year load, in indoor climate, were analysed. Normal structural conditions were reproduced during the one-year test, which was carried out with 8 pieces free of pith and the same amount containing it. The instantaneous resistance was determined according to the procedures of DIN EN 408 (1996). After the one-year test was finished, the instantaneous elastic recovery showed similar results to the instantaneous elastic deformation and the residual deflection exhibited similar behaviour to the creep part of deformation. It was found a rate of creep significantly smaller than the one reported for a research carried out with small clear specimens of the same timber species, but similar to those found for structural timber. The design rules adopted by Eurocode 5 for calculating the creep deflections under a long-term load were checked for this timber species, and results demonstrated that it is suitable for practical purposes, even though it is necessary to analyse the creep rate up to 10 years. In line with the assumption of the European standard, the research also showed a slight influence of the presence of pith on creep, confirming similar creep behaviour for different qualities of this timber species.

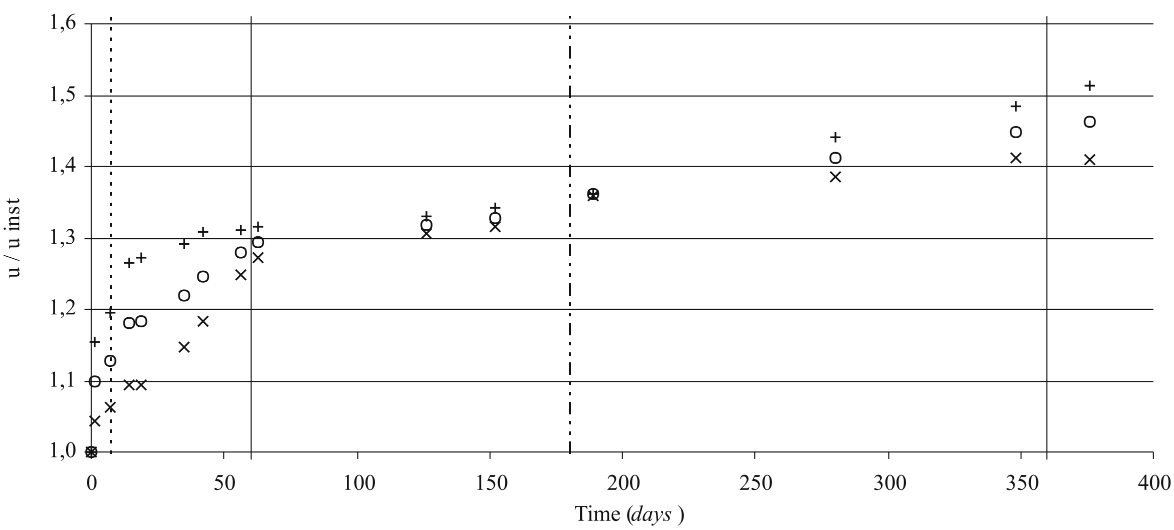

Fig. 1 Relative deflections (u/u_{inst}) as a function of time. (o): mean values for the whole sample; (x): mean values for the beams without pith; (+): mean values for pieces with pith; vertical lines indicate 1 week, 2 months, 6 months and 1 year

Abb. 1 Relative Durchbiegungen (u/u_{inst}) in Abhängigkeit von der Zeit. (o) Mittelwerte für die gesamte Probe; (x) Mittelwerte für die Biegeträger ohne Markröhre ; (+) Mittelwerte für die Biegeträger mit Markröhre; vertikale Geraden zeigen 1 Woche, 2 Monate, 6 Monate und 1 Jahr

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