

Short communication

Flexural behaviour of selected riparian plants under static load[☆]F.J. Sutili^{a,*}, L. Denardi^a, M.A. Durlo^b, H.P. Rauch^{c,1}, C. Weissteiner^{c,1}^a Universidade Federal de Santa Maria (Federal University of Santa Maria), Rio Grande do Sul, Centro de Educação Superior Norte, Departamento de Engenharia Florestal, BR386 km40 Linha 7 de Setembro s/n, CEP: 98400-000 Frederico Westphalen, RS, Brazil^b Universidade Federal de Santa Maria (Federal University of Santa Maria), Rio Grande do Sul, Centro de Ciências Rurais (Agricultural Center), Post-Graduation Program in Forest Engineering, Prédio 44, 2º Piso, CEP: 97105-900 Santa Maria, RS, Brazil^c Institute of Soil Bioengineering and Landscape Construction, University of Natural Resources and Applied Life Sciences, Vienna, Peter Jordan-Strasse 82, A-1190 Vienna, Austria

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ABSTRACT

Soil bioengineering techniques use plants as construction material for civil and hydraulic engineering purposes such as reinforcement of slopes and erosion control of embankments. The interactions of plants and stress from natural processes have to be quantified to assess such soil bioengineering systems from an engineering point of view.

The objective of this study is to investigate the flexural behaviour of stems and branches of four riparian species of the Southern Brazilian region, suitable for soil bioengineering purposes (*Phyllanthus sellowianus* Müll. Arg., *Sebastiania schottiana* (Müll. Arg.) Müll. Arg., *Salix humboldtiana* Willd. and *Salix × rubens* Schrank). 50 green stems of each species were collected in the surroundings of Santa Maria city (29°35'S, 53°32'W), state of Rio Grande do Sul, Brazil, and subjected to static bending tests. Specimens were tested with their bark, immediately after harvesting. The setup of the bending tests was based on the DIN standard (DIN 52186) for 3-point bending tests. Measurements were carried out to obtain characteristic stress × strain diagrams for each stems. The following data analyse resulted in characteristic parameters to describe the overall deformation behaviour (elastic – MOE and plastic – MOR). An additional parameter according to Denardi (2007) was introduced: the “angle of inflection”. This parameter describes the elastic and plastic deformation behaviour of a plant under load from an engineering point of view.

Results showed that *P. sellowianus* and *S. schottiana* are very appropriate for the protection of river banks according to the criteria of stem flexural behaviour, rupture strength, angle of inflection, growth rate and plant size. *P. sellowianus* is the most flexible species, followed by *S. schottiana*, *S. humboldtiana* and *Salix × rubens*. Therefore riparian forest stands of *S. humboldtiana* and *Salix × rubens* need more frequent maintenance in order to keep flexibility.

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1. Introduction

Natural disasters worldwide cause major damage to mankind and infrastructure. Nowadays conventional technical solutions have been complemented by ecological alternatives such as soil bioengineering approach. Different soil bioengineering methods have recently regained worldwide recognition for their use in river and civil engineering projects (Howell, 1999; Florineth et al., 2002;

Florineth, 2004; Li and Eddleman, 2002; Acharya and Florineth, 2005; Durlo and Sutili, 2005; Lammeranner et al., 2005; Cornelini and Sauli, 2005; Li et al., 2005; Petrone and Preti, 2008, 2010; Bischetti et al., 2010).

The assessment of technical and biological properties of plants from an engineering point of view provides a basement for a successful application and dissemination of soil bioengineering techniques. According to the discussion performed by Burylo et al. (2007), it is well known that vegetation efficiently mitigates erosion in two ways: by active or passive protection. Additional, Wu and Feng (2006) describe the four functions of ecological engineering: (1) improve the revival ability of ecosystem; (2) improve the protective ability of ecosystem; (3) improve the recoverability of ecosystem; (4) improve the functions of streams. Such properties include the capability of vegetative propagation, root penetration, resistance against coarse sediment deposition, tolerance of

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submersion, elasticity, bending strength, pull out resistance and compound strength.

This paper focuses on the flexural behaviour of selected riparian plants from South Brazil to provide a basis for soil bioengineering implementation work.

Wooden plants have a variable hydraulic impact dependent on the stage of succession. The morphological and material changes over time of plants have to be taken into account from engineers. Riparian plants have different impacts on hydro-morphological processes. On the one hand, they provide bank protection and are responsible for increasing of the hydraulic roughness if they have a high level of flexibility. On the other hand, they cause bank erosion when plants act as rigid elements and after breaking they are the source of hydraulic blockage.

Several studies focused on the hydraulic interaction of flow and plants such as Fathi-Moghadam and Kouwen (1997), Oplatka (1998), Gerstgraser (2000), Righetti and Armanini (2002), Meixner (2004), Rauch (2005), Musleh and Cruise (2006), McBride et al. (2007). The impact depends not only on geometrical properties (e.g. stem and branch diameter, length and leaf density), but also on the dynamic response of plants under flood conditions (stem/branch/leaf bending and reduction of plant height).

Based on the results from a previous study, which focused on the vegetative reproduction potential of suitable plants for soil bioengineering (Sutili et al., 2007), the next step involved quantifying the biomechanical behaviour of plants under specific load.

Mechanical properties such as flexural stiffness, modulus of elasticity and plastic deformation are indicators to assess the impact of plants under load.

Considering the hypothesis that younger plants (smaller diameter of the stems) are more flexible, the objective of this study is comparatively to investigate the behaviour of stems and branches of different riparian species suitable for soil bioengineering (*Phyllanthus sellowianus* Müll. Arg., *Sebastiania schottiana* Müll. Arg., *Salix humboldtiana* Willd. and *Salix × rubens* Schrank).

2. Material and methods

2.1. Over view of study area

The specimens were collected along rivers in the surroundings of Santa Maria city (29°35'S, 53°32'W; Brazil). *P. sellowianus* Müll. Arg. is part of the Phyllanthaceae family and grows up to a height of 2–3 m. It is a widely ramified bush with slender and bendable branches. *S. schottiana* (Müll. Arg.) Müll. Arg. (Euphorbiaceae) is also a shrub with a maximum height of 3–4 m. Strong branches, which are highly bendable; are typical. *Salix × rubens* Schrank originates from Europe and is a hybrid between *Salix alba* L. and *Salix fragilis* L. (Salicaceae). The plant grows very fast and reaches heights up to 16 m. *S. humboldtiana* Willd. (Salicaceae) is a tree that reaches a height up to 20 m and a stem diameter of about 90 cm. The botanical material was deposited in the Forest Herbarium of the Federal University of Santa Maria, with their numbers: 5588, 5592, 5594, 5590. All of the tested species are known to be well adapted to the environmental conditions along rivers (Denardi, 2007; Sutili et al., 2007).

The minimum diameter was defined at 10 mm and the bending test device limited the maximum diameter. For *P. sellowianus* and *S. schottiana*, no samples that exceeded a diameter of 50 mm for the former and 60 mm for the latter were found in the area under study. Specimens were tested with their bark, immediately after harvesting.

Although riparian vegetation is exposed to dynamic stress during high flood events, static bending tests are useful to identify

the bending behaviour of different plant species. 50 static bending tests of each species were carried out, using specimens of different diameters, in green condition. The results have to be considered as a relative comparison between different species.

The setup of the bending tests was based on the DIN standard (DIN 52186) for 3-point bending tests.

The testing equipment automatically recorded the parameters load F [N], center deflection f [mm] and time t [s]. Based on the collected data sets (F [N], f [mm] and t [s]) as well as on the measured diameters d [mm] of the specimens at the loading point and on the span ℓ [mm], it was possible to determine the following parameters: proportional limit load, F_{elast} [N]; ultimate (maximum) load F_u [N]; modulus of elasticity (MOE), [N/mm²]; proportional limit stress, σ_{elast} [N/mm²]; modulus of rupture (MOR) [N/mm²]; elastic strain, ε_{elast} ; plastic strain, ε_{plast} ; maximum strain, ε_u ; moment of inertia, I [mm⁴]; ultimate moment M_u [Nmm]; section modulus W [mm³].

After each bending test, a 100 mm long specimen was taken to access the following properties: moisture content, u [%]; basic apparent density, ρ [g/cm³]; thickness of bark, tc [mm]; percentage of bark, $\%c$ [%]; age of specimen, Y [years].

2.2. Calculated parameters

The ultimate load (F_u) and proportional limit load (F_{elast}) were directly taken from the load × deflection curve. The modulus of elasticity in bending (MOE) [N/mm²] is used to characterize the tendency to be deformed elastically of the stems and branches. This mechanical parameter expresses the ratio between the stress and strain under load, i.e., how much force is required for a given unit of reversible deformation. The modulus of elasticity for specimens with a circular cross-section, simply supported at ends and under action of a concentrated load at mid-span, is calculated as:

$$MOE = \frac{F_{elast} \ell^3}{48 f_{elast} I} \quad (1)$$

where F_{elast} is the proportional limit load [N], ℓ is the span [mm], f_{elast} is the deflection at proportional limit [mm], I is the moment of inertia [mm⁴].

The moment of inertia (I) [mm⁴] for a circular section:

$$I = \frac{\pi d^4}{64} \quad (2)$$

where d [mm] is the cross section diameter of the specimen measured at the point of load application.

Replacing I in Eq. (1), the equation changes to:

$$MOE = \frac{F_{elast} \ell^3}{3 f_{elast} (\pi d^4 / 4)} \quad (3)$$

The strain ε is a dimensionless variable:

$$\varepsilon = f \frac{6d}{\ell^2} \quad (4)$$

where f is the center deflection [mm], d is the diameter of specimen at the point of load application [mm], ℓ is the span [mm].

Eqs. (3) and (4) used for the analysis of MOE and ε are based on the assumption that the segment of the specimen has a constant diameter and shear stress is neglected. Tree stems are generally tapered, but in our case, the diameters of the specimens were approximately constant, therefore the tapering effect is negligible. Usually bending resistance of wood is determined with a 4-point bending test. The results of the used 3-point bending test are influenced by shear stress, but for wood, it is conventionally neglected if $\ell/d > 14$.

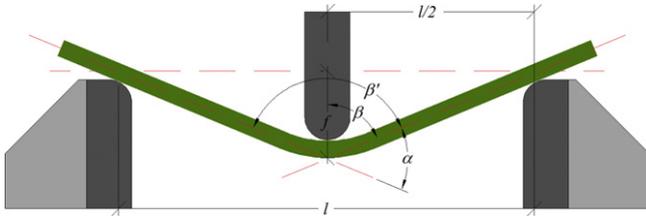


Fig. 1. Bending diagram, indicating the variables used in calculating the angle of inflection (α).

However, the applied equations are considered as approximations and results are highly appropriate to compare the species with each other.

The modulus of rupture MOR [N/mm²] for the specimens with a circular cross-section was obtained from:

$$MOR = \frac{M_{max}}{W_{max}} = \frac{F_u(\ell/4)}{\pi d^3/32} = \frac{8F_u\ell}{\pi d^3} \quad (5)$$

where M_{max} is the maximum bending moment [Nmm], W_{max} is the section modulus [mm³], F_u is the ultimate load [N], ℓ is the span [mm], d is the diameter of specimen at the point of load application [mm].

The stress up to the proportional limit σ_{elast} [N/mm²] can be obtained by the formula (5), replacing the ultimate load F_u [N] by the load up to the proportional limit F_{elast} [N] or by “Hooke’s Law,” which determines:

$$\sigma_{elast} = MOE \cdot \varepsilon_{elast} \quad (6)$$

where MOE modulus of elasticity [N/mm²], ε_{elast} deformation in the elastic region.

Additionally, for each samples branches mechanical test, was calculated the moisture content (%), percentage of the bark (%) and the basic apparent density of the wood (g/cm³).

After preparation and staining of histological sections, a microscope was used to determine the age of the samples.

An additional parameter according to Denardi (2007) has been used. It describes the whole deformation process of plants under load: angle of inflection at proportional limit, α_{elast} [°] and angle of inflection at ultimate load, α_u [°].

At the original non-inflected position (dashed horizontal line in Fig. 1), the bending point divides the specimen into two equal parts with an angle of zero to the horizontal and 180° between the two. The levels of proportional limit and ultimate load are characterized by the parameters of ℓ (span) and f (deflection) for each individual specimen and used to calculate the angle of inflection (α), respectively α_{elast} and α_u (Fig. 1).

$$\tan \beta = \frac{\ell/2}{f}; \quad \tan \beta' = 2 \tan \beta \quad (7)$$

$$\text{Internal angle } (\beta') = \arctan \beta' \quad (8)$$

$$\text{Inflection angle } (\alpha) = 180 - \arctan \beta' \quad (9)$$

3. Results and discussion

3.1. Basic apparent density, moisture content and dimension of bark

The basic apparent density and the moisture content affect the material properties on the bending conditions. In general, *P. sellowianus* showed, independently of the moisture content (figure not showed), higher values of the basic apparent density (0.51 g/cm³) when compared with all other species (<0.4 g/cm³). The slower

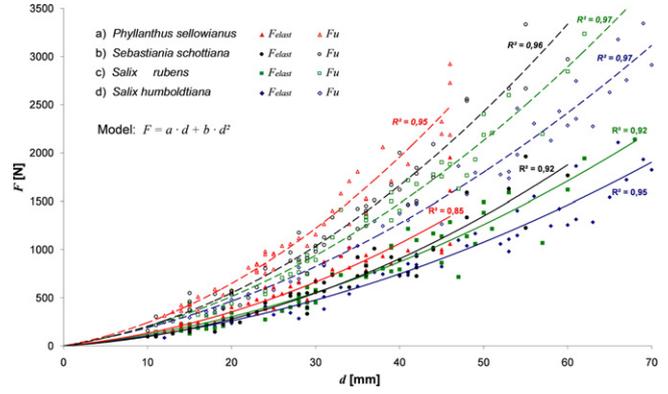


Fig. 2. Relationship between diameter (d) and load (F). Solid line: at the proportional limit, F_{elast} ; dashed line: at the ultimate load, F_u .

growth and the higher average age of the specimens of *P. sellowianus* are possible causes.

As expected, the thickness of the bark strongly correlates with the diameters and maintains a relatively constant percentage up to the highest diameters used in this study. The two species with a lower average bark thickness – *P. sellowianus* and *S. schottiana* – consequently show a more discrete increase in bark thickness with increasing diameter. *S. humboldtiana* represents the thickest bark from 5 mm up to 7 mm for stem diameters between 60 and 70 mm. Brüchert et al. (2003) found that the higher initial bark/wood ratio and its decline with the development of the branch may be a cause of the initial variations regarding the modulus of elasticity (MOE). All specimens have been tested in bending, with bark.

4. Modulus of elasticity

Fig. 2 indicates the force (F) for different diameters, which is required to reach the proportional limit – F_{elast} (solid line) and the ultimate load – F_u (dashed line).

P. sellowianus is the most stiff species in bending, whereas *S. humboldtiana* is the most flexible one. This means that for *P. sellowianus* a higher amount of load is necessary to reach the proportional limit and the ultimate load respectively.

Table 1 shows the moduli of elasticity for the different species classified into diameter classes. The standard deviation and the coefficient of variation [%] are shown in brackets. The last column contains the coefficient of determination between the modulus of elasticity and the stem and branch diameter. It can be concluded from the low coefficients of determination that there is in fact no correlation.

The calculated moduli of elasticity are visually lower than those determined by Vollsinger et al. (2000) for green stems and branches of five European species (*Alnus glutinosa* (L.) Gaertn. *Fraxinus excelsior* L., *S. alba* L., *Salix caprea* L. and *Acer pseudoplatanus* L.). The authors obtained values between 6900 and 10,200 N/mm² for the different species (with diameters of 40–100 mm). Based on parameter MOE , the tested southern Brazilian species are visibly less rigid.

The moduli of elasticity (Table 1) appeared to decline with increasing diameter. However, this suggestion of an inverse correlation between the modulus of elasticity and the stem diameter must be considered with caution due to the small number of tested specimens, the high coefficients of variation and the low coefficients of determination (R^2). Perhaps the distribution of stems and branches diameters could be useful to understand this behaviour. Vollsinger et al. (2000) found similar results. Brüchert et al. (2003) conducted tests on *A. glutinosa* (L.) Gaertn and *Alnus viridis* (Chaix) DC. at an age of 1–24 years and found a slight increase in the

Table 1
Average values of the modulus of elasticity at green state [N/mm²] for the different diameter classes of each species. Standard deviation and coefficient of variation [%] are shown in parentheses.

Species	Modulus of elasticity [N/mm ²] per diameter class						R ²
	10–20 mm	20–30 mm	30–40 mm	40–50 mm	50–60 mm	60–70 mm	
<i>Phyllanthus sellowianus</i>	4.513 (889;20)	3.793 (1173;31)	3.329 (835;25)	3.028 (825;27)	–	–	0.27
<i>Sebastiania schottiana</i>	4.615 (1188;26)	3.930 (1126;29)	4.104 (1273;31)	3.485 (432;12)	3.114 (575;18)	–	0.14
<i>Salix × rubens</i>	4.940 (1726;35)	4.562 (1312;29)	4.296 (1054;25)	3.555 (1208;34)	3.625 (766;21)	3.031 (331;11)	0.19
<i>Salix humboldtiana</i>	4.084 (1590;40)	3.347 (630;19)	3.254 (388;12)	2.822 (925;33)	2.419 (285;12)	2.155 (446;24)	0.35

modulus of elasticity up to the fifth year. In older samples, the modulus of elasticity remained relatively constant. Niklas (1992) noted that young cell walls are ductile, while older cells walls tend to be much more elastic and resilient.

4.1. Proportional limit and ultimate load

Fig. 3 shows the stress × strain curve up to the proportional limit (solid line) and then to the ultimate load (dashed line). The first part of the diagram showing a linear behaviour, where the modulus of elasticity and the proportional limit can be determine from. From this point, the deformation becomes plastic and continues up to the ultimate load in a non-linear behaviour.

The variation of the deformation behaviour between the species is much higher at the plastic range compared to the elastic one. Apparently, *S. schottiana* and especially *P. sellowianus*, resist large deformation and stresses up to the ultimate load, while *S. humboldtiana* withstands slightly less stress than *Salix × rubens*. However, *S. humboldtiana* exhibited bigger flexural deformations in comparison to *Salix × rubens*.

4.2. Angle of inflection

The strain ϵ can be understood as an expression of how the material behaves under load. The angle of inflection up to the proportional limit (α_{elast}) and specifically up to the ultimate load (α_u) is another possibility to express its behaviour.

The angle of inflection at the proportional limit did not correlate with diameter. The α_{elast} area in Fig. 4 represents the range of the inflection angle at the proportional limit for any species and diameter. The angle of inflection at the ultimate load represents the maximum angle to which a stem or branch of a particular species and diameter can be bent before it fails. The results have to be

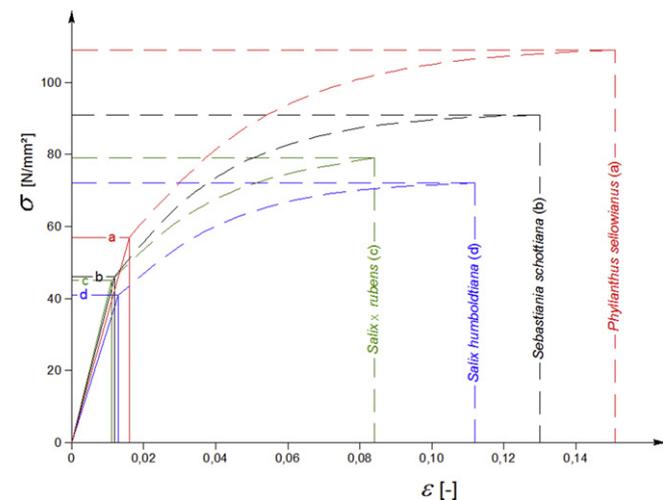


Fig. 3. Average trend stress/strain curves up to proportional limit (solid line) and further to ultimate load (dashed line) for the four species.

considered as a base to compare the bending behaviour of the tested species.

The diagram shows that *P. sellowianus* exhibited a larger angle of inflection at the ultimate load than the other species. For example, while a branch ($d = 20$ mm) of *P. sellowianus* exhibited a maximum angle of 45° inflection before failure, a branch of *Salix × rubens* of the same diameter reached a maximum angle of 25° at ultimate load.

The relationship between the angle of inflection at rupture (α_u) and the ultimate load (F_u) for the four species and seven selected diameters (Fig. 5). The nomogram shown in Fig. 5 cannot be used to derive the values at the proportional limit due to the lack of a relationship between the inflection angle and the diameter at this limit (Fig. 4).

The load required to reach the failure increased with larger diameters, whereas the angle of inflection at the ultimate load decreased. For example, a branch of *P. sellowianus* with a

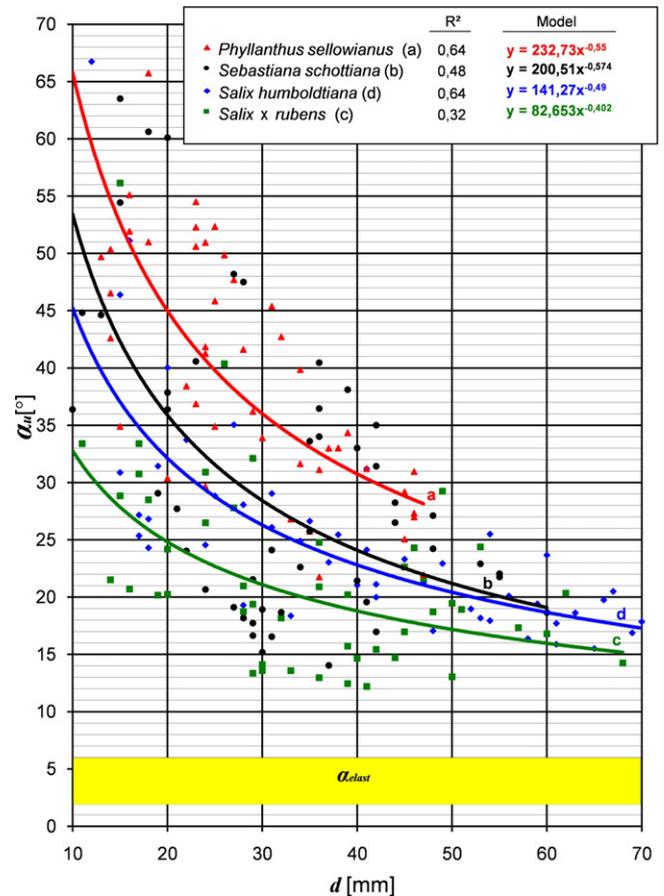


Fig. 4. Relationship between the diameter (d) and the angle of inflection at failure (α_u). The band at the bottom of the graph shows the area of distribution of the angles of inflection at the proportional limit (α_{elast}).

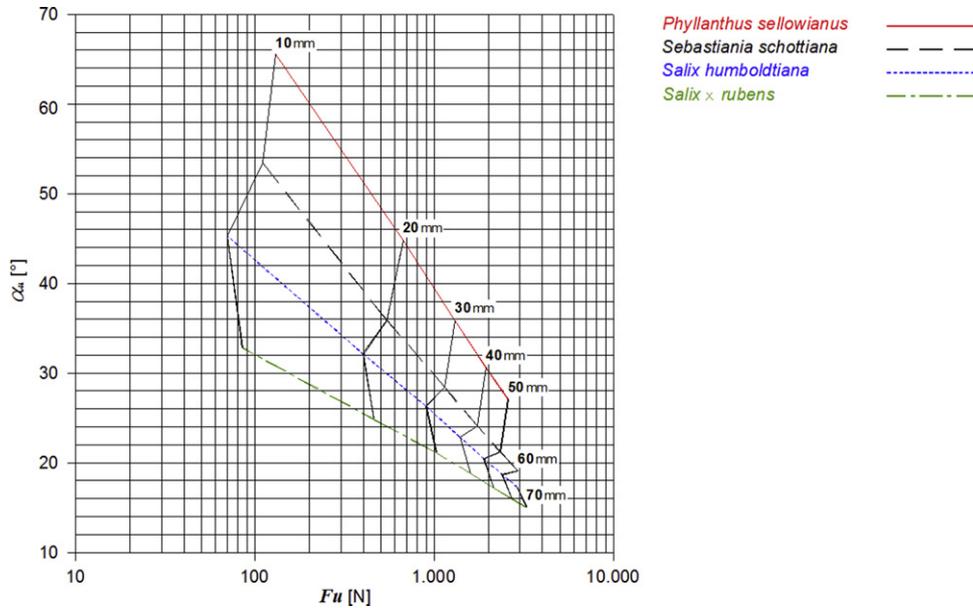


Fig. 5. Relationship between angle of inflection α_u at rupture and $\log F_u$ (ultimate load) dependent from the diameter for the four species.

diameter of 20 mm had to be stressed up to a load of 670 N to reach the angle of rupture and formed a 45° angle of inflection. A branch of *S. schottiana* of the same diameter, with a load of 550 N, broke at 36°. *S. humboldtiana* formed a smaller inflection angle (32°) and required a load of 400 N to reach the failure. For the same diameter, *Salix x rubens* – despite having an angle of inflection at failure that is even lower than the previous species – needed a higher load (460 N) than *S. humboldtiana* to reach a maximum 25° angle of inflection.

As shown in Fig. 5, the inflection angle gradually declined with the increasing in diameter. *P. sellowianus* is the species that apparently supports the greatest stress and can be bent to higher angles of inflection up to the ultimate load. Moreover, its growth rate is the lowest of all species investigated.

The relationship between age of the stems or branches and their diameter was conducted. This relationship exposed the different local environmental growing conditions and can be taken

as reference values for the growth rate of the species according to temporal period of consideration of the specimens.

In a following step, the growth rate (diameter and age) is related to the angle of inflection at ultimate load (α_u) and shown in Fig. 6.

The relationship between age and stem diameter can be seen directly on the x- and y-axes respectively. The angle of inflection is characterised by means of the marked areas. For example, in order to know the diameter of an specific stem at an age of 4 years, a straight line parallel to the y-axis at the 4 years age is traced. At the point where this line crosses the straight line that defines the relations for *P. sellowianus*, one will get a diameter of 16 mm and an inflection angle at failure of 50°. At the same age, *S. schottiana* has a diameter of 23 mm and a 33° inflection angle (interpolated between the lines of 30° and 35°). *Salix x rubens* at 4 years shows a diameter of 32 mm and can be bent till it reaches angles of inflection of 21°, while *S. humboldtiana*, reaching a larger diameter (39 mm),

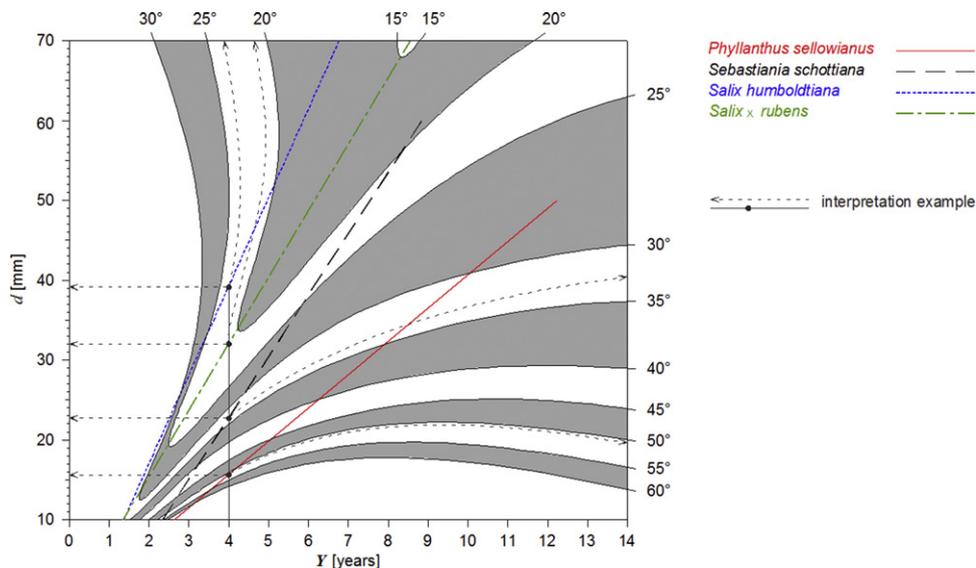


Fig. 6. Relationship with the diameter (d) and angle of inflection at ultimate load (α_u), for different ages (Y).

show approximately 24° angle of inflection at rupture. The same procedure can be applied starting from any diameter (d), age (Y) or angle of inflection (α_u), for each species. Even the relationship between the different parameters is variable due to specific local growing conditions. Fig. 6 provides a useful tool for planning and managing local soil bioengineering work.

5. Conclusions and final remarks

The modulus of elasticity (MOE), as a single parameter, does not satisfactorily explain the flexural behaviour of live stems or branches for the assessment of soil bioengineering structures, on river banks.

The angle of inflection is a useful criterion to identify a plant's capacity to stabilise river banks under hydraulic stress. High flexibility means that stressed plants are able to bend down reducing turbulence effects and acting as a protection layer against bank erosion. Additionally, this property improves the free stream flow along the river cross-section.

Based on the parameters inflection angle α_u , ultimate load F_u and age Y , it can be affirmed that plants of a smaller diameter (younger shoots) are more flexible, and better suitable for river banks stabilization, regardless of species. The results showed that the flexibility of the stems and branches decrease over the time, but not equally or proportionally for each of the species studied.

It was found that *P. sellowianus* and *S. schottiana* are very appropriate for the protection of river banks according to the criteria of inflection angle, rupture strength (stem breakage), growth rate and plant size. Riparian forest stands of *S. humboldtiana* and *Salix × rubens* need more frequent maintenance (systematic stem cutting procedure) in order to preserve its “flexibility function”. According to the literature, any of the four species studied can excellently withstand and respond well to the branch pruning and trunk or stem coppicing.

Furthermore, more studies about the influence of the bark and the anatomical characteristics of the wood can be helpful to clarify additional biomechanical characteristics of the riparian vegetation.

References

- Acharya, M.S., Florineth, F., 2005. Bamboo crib wall—a sustainable bioengineering method to stabilise slopes in Nepal. In: International Symposium “Landslide Hazard in Orogenic Zone from the Himalaya to Island Arc in Asia, 25–26 September 2005, Kathmandu, Nepal, pp. 235–244.
- Bischetti, G.B., Chiaradia, E.A., D'Agostino, V., Simonato, T., 2010. Quantifying the effect of brush layering on slope stability. *Ecol. Eng.*, 258–264.
- Burylo, M., Rey, F., Delcros, P., 2007. Abiotic and biotic factors influencing the early stages of vegetation colonization in restored marly gullies (Southern Alps, France). *Ecol. Eng.* 30, 231–239.
- Brüchert, F., Gallenmüller, F., Bogenrieder, A., Speck, T., 2003. Stem Mechanics, Functional Anatomy and Ecology of *Alnus viridis* and *Alnus glutinosa*, vol. 114. Feddes Repertorium, Berlin, pp. 181–197.
- Cornelini, P., Sauli, G., 2005. Manuali di indirizzo delle scelte progettuali per interventi di ingegneria naturalistica. Ministero dell'Ambiente e della Tutela del Territorio/Ministero dell'Economia e delle Finanze. Progetto Operativo Difesa Suolo.
- Denardi, L., 2007. Anatomia e flexibilidade do caule de quatro espécies lenhosas, para o manejo biotécnico de cursos de água. Tese (Doutorado em Manejo Florestal) – Universidade Federal de Santa Maria (UFSM), Santa Maria, 113 pp.
- DIN 52186, 1978. Prüfung von Holz – Biegeversuch. Deutsches Institut für Normung, Berlin.
- Durlo, M.A., Sutili, F.J., 2005. Bioengenharia – Manejo biotécnico de cursos de água. Editora EST, Porto Alegre, 189 pp.
- Fathi-Moghadam, M., Kouwen, N., 1997. Nonrigid, nonsubmerged, vegetative roughness on floodplains. *J. Hydrogen Eng.* 123 (1), 51–57.
- Florineth, F., Rauch, H.P., Staffler, H.P., 2002. Stabilization of landslides with bioengineering measures in South Tyrol/Italy and Thankot/Nepal. In: Interpraevent 2002 in the Pacific Rim (Ed.), Interpraevent 2002 in the Pacific Rim, vol. 2. Congress publication, Matsumoto/Japan, pp. 827–837.
- Florineth, F., 2004. Pflanzen statt Beton. Handbuch zur Ingenieurbiologie und Vegetationstechnik. Patzer Verlag Berlin, Hannover, 282 pp.
- Gerstgraser, C., 2000. Ingenieurbiologische Bauweisen an Fließgewässern. Grundlagen zu Bau, Belastbarkeiten und Wirkungsweisen. Band 52, Dissertation, Universität für Bodenkultur, Wien.
- Howell, J., 1999. Roadside Bio-engineering. Dept. of Roads. His Majesty's Government of Nepal, Kathmandu.
- Lammeranner, W., Rauch, H.P., Laaha, G., 2005. Implementation and monitoring of soil bioengineering measures at a landslide in the Middle Mountains of Nepal. *Plant Soil* 278, 159–170.
- Li, M.-H., Eddleman, K.E., 2002. Biotechnical engineering as an alternative to traditional engineering methods. A biotechnical streambank stabilization design approach. *Landscape Urban Plan.* 60, 225–242.
- Li, M.-H., Landphair, H.C., Arnold, M.A., Mullin, K., Eddleman, K.E., 2005. A dormancy extension technique for biotechnical streambank stabilization in warm regions. *Landscape Urban Plan.* 71, 223–231.
- Meixner, H., 2004. Grundsätze zum Management von Ufervegetation. *Ingenieurbiologie. Mitteilungsblatt für die Mitglieder des Vereins für Ingenieurbiologie*, Nr. 2, pp. 14–18.
- Musleh, F.A., Cruise, J.F., 2006. Functional relationships of resistance in wide flood plains with rigid unsubmerged vegetation. *J. Hydraulic Eng.* 132 (February (2)), 163–171.
- McBride, M., Hession, W.C., Rizzo, D.M., Thompson, D.M., 2007. The influence of riparian vegetation on near-bank turbulence: a flume experiment. *Earth Surf. Process. Landforms* 32 (13), 2019–2037.
- Niklas, K.J., 1992. Plant Biomechanics—an Engineering Approach to Plant Form and Function. University of Chicago, Press Chicago & London, 607 pp.
- Oplatka, M., 1998. Stabilität von Weidenverbauungen an Flussufern. Mitteilung 156, Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie, ETH-Zürich.
- Petrone, A., Preti, F., 2010. Soil bioengineering for risk mitigation and environmental restoration in a humid tropical area. *Hydrol. Earth Syst. Sci.* 14, 239–250.
- Petrone, A., Preti, F., 2008. Suitability of soil bioengineering techniques in Central America: a case study in Nicaragua. *Hydrol. Earth Syst. Sci.* 12, 1241–1248.
- Rauch, H.P., 2005. Hydraulischer Einfluss von Gehölzstrukturen am Beispiel der ingenieurbiologischen Versuchsstrecke am Wienfluss. Dissertation an der Universität für Bodenkultur Wien, 222 pp.
- Righetti, M., Armanini, A., 2002. Flow resistance in open channel flows with sparsely distributed bushes. *J. Hydrol.* 269, 55–64.
- Sutili, F.J., Rauch, H.P., Durlo, M.A., Florineth, F., 2007. Investigations on the Selection of Plants for Soil Bioengineering Measures in South Brazil (Poster). European Geoscience Union Assembly, Vienna.
- Vollinger, S., Doppler, F., Florineth, F., 2000. Ermittlung des Stabilitätsverhaltes von Ufergehölzen in Zusammenhang mit Erosionsprozessen an Wildbächen. Universität für Bodenkultur, Wien. Studie in Auftrag des Bundesministeriums für Land- und Forstwirtschaft, 107 pp.
- Wu, H.L., Feng, Z., 2006. Ecological engineering methods for soil and water conservation in Taiwan. *Ecol. Eng.* 30, 333–344.