

Zeitschrift: Veröffentlichungen des Geobotanischen Institutes der Eidg. Tech. Hochschule, Stiftung Rübel, in Zürich

Herausgeber: Geobotanisches Institut, Stiftung Rübel (Zürich)

Band: 101 (1989)

Artikel: Mechanische Belastbarkeit natürlicher Schilfbestände durch Wellen, Wind und Treibzeug = Mechanical impacts on natural reed stands by wind, waves and drift

Autor: Binz-Reist, Hans-Rudolf

Register: Liste of figures

DOI: <https://doi.org/10.5169/seals-308911>

Nutzungsbedingungen

Die ETH-Bibliothek ist die Anbieterin der digitalisierten Zeitschriften auf E-Periodica. Sie besitzt keine Urheberrechte an den Zeitschriften und ist nicht verantwortlich für deren Inhalte. Die Rechte liegen in der Regel bei den Herausgebern beziehungsweise den externen Rechteinhabern. Das Veröffentlichen von Bildern in Print- und Online-Publikationen sowie auf Social Media-Kanälen oder Webseiten ist nur mit vorheriger Genehmigung der Rechteinhaber erlaubt. [Mehr erfahren](#)

Conditions d'utilisation

L'ETH Library est le fournisseur des revues numérisées. Elle ne détient aucun droit d'auteur sur les revues et n'est pas responsable de leur contenu. En règle générale, les droits sont détenus par les éditeurs ou les détenteurs de droits externes. La reproduction d'images dans des publications imprimées ou en ligne ainsi que sur des canaux de médias sociaux ou des sites web n'est autorisée qu'avec l'accord préalable des détenteurs des droits. [En savoir plus](#)

Terms of use

The ETH Library is the provider of the digitised journals. It does not own any copyrights to the journals and is not responsible for their content. The rights usually lie with the publishers or the external rights holders. Publishing images in print and online publications, as well as on social media channels or websites, is only permitted with the prior consent of the rights holders. [Find out more](#)

Download PDF: 31.01.2026

ETH-Bibliothek Zürich, E-Periodica, <https://www.e-periodica.ch>

LIST OF FIGURES

Section I

- 1.1. Left: View of a reed plant (drawing A. HEGI). R = Rhizom; W = stem below water level; Ls = stem above water level; HS = shoot; JS = young sprouts; AW = adventitious roots; Bl = leaves; Ä = panicle.
Right: Panicle (from HESS et al. 1967). p. 13.
- 1.2. Rhizome (from: RODEWALD-RUDESCU 1974). in = internode; n = node; ra = adventitious roots; r = roots; m = bud; t = stem; l = shoot; lt = terminal shoot. p. 14.
- 1.3. Rhizome layer of *Phragmites*. I = top, II = middle and III = lower layer. a = upper top layer with roots of other species; b = lower top layer only with rhizomes of reed; 1+4 cross sections of the rhizomes (from RODEWALD-RUDESCU 1974). p. 15.
- 1.4. Cross sections of internodes (sectors), somewhat simplified. a = rhizome; b = stem (from HÜRLIMANN 1951). p. 16.
- 1.5. Section through the shoot (50 cm above soil surface) of a plant growing under "normal" conditions. Note the vascular bundles and the strongly developed sclerenchym (dark shades) (from KLÖTZLI 1971). p. 17.
- 1.6. Internode of a reed stem (from RODEWALD-RUDESCU 1974). p. 18.
A: internode with leaf-sheaths; 1 = internode; 2 = leaf-sheat; 3 = hairs; 4 = insertion point of the leaf-sheet on the node;
B: internode without leaf-sheet; 1,2 as A; 3 = bud; a = outer diameter of the internode;
C: longitudinal section through node and internode; 5 = node; 6 = external cylinder; 7 = inner parenchym; 8 = remainders of medullary parenchym; a = total diameter; a' = diameter of the big lumen; a'' = diameter of the small lumen;
D-F: Development of a leaf.
- 1.7. Length of internodes of a series of reed stems from Altenrhein (Bodensee-Obersee). p. 19.
- 1.8. Structure and zones of a natural lake shore (from GRÜNIG 1980). p. 24.
- 2.1. Aspects of reed stands, schematic; elevation and ground-plan (from KLÖTZLI and GRÜNIG 1976). p. 30.
a normal reed;
b "*Schwanenschilf*" ('swan-reed'): reed belt divided into individual bushes by waterfowl and eutrophication (directly by algae and drift);
c secondary reed: stems broken by waves and drift, to some extent formation of secondary shoots.
Horizontal line in the elevation sketches: mean water level during summer time
Wavy line passing through: mean shore line during summer time
1 small density, single shoots, mostly 5 - 10/m²;
2 normal density, mostly about 20 - 60/m² (cf. HÜRLIMANN 1951);
3 high density, local or within bushes, mostly about 60 - >100/m²;
4 heavily matted by broken of stems and formation of secondary shoots.
- 2.2. Comparison between some criteria of eutrophication and decline of reed (according to LEHN 1972, modified and completed, from GRÜNIG 1980). p. 31.
PO₄-P: phosphate phosphorus concentration
NO₃-N: nitrate nitrogen concentration
Algen: Concentration of cells of plankton algae in 0+10 m water depth
Crust: plankton crayfish beneath 1 dm² of water surface
Fische: total yield of fishery of the Bodensee
O₂: remainig content of oxygen in maximum depth

- Sicht: sighting depth measured with Secci-discs
Schilf: surface of the reed stand near Altenrhein
- 2.3. Influence of a sea-wall (from BINZ 1980). *p. 36.*
Top: In a natural state the wave is attenuated gradually within the reed stand (dashed line —). Floating matter is deposited behind the reedswamp.
Bottom: The wall prevents wave attenuation. The waves are reflected and superposed on the new arriving waves. This increases the total wave height (dotted line). Furthermore the floating matter is prevented from being transported away and is repeatedly thrown back on the reed.
- 2.4. Effect of dredging in the nearshore zone (from BINZ 1980). *p. 38.*
Top: Situation of a natural beach: The wave-induced water particle motion reaches from the still water level down to the depth d_1 (large wave) and d_2 (small wave) respectively. When the water depth is smaller, friction between water and soil causes dissipation of energy. At the critical depth d_{1k} wave 1 is breaking, whereas the critical depth for wave 2 is reached only far behind the reedswamp (outside the figure). Until that point, this already smaller wave will be reduced sufficiently to cause no damage to the reed when breaking.
Bottom: The dredging hole (not in scale in the figure) has no influence on wave 2, because soil influences water particle motion only where the water depth is less than d_2 . With regard to wave 1, there is no wave-reflecting beach and wave 1 reaches the landside of the dredging hole completely undamped. Here the water depth becomes abruptly less than d_{1k} : wave 1 is breaking. Reed stands on this site are greatly stressed.
- 2.5. Factors influencing shore vegetation (from GRÜNIG 1980). *p. 41.*
2.6. Possible influences of eutrophication on a reed stand (from GRÜNIG 1980). *p. 42.*
2.7. Stubble-field of dead reed plants in front of a reed stand at Altenrhein (Bodensee-Obersee). Note also the stems partly or completely pressed down by heavy of algae-mats. (winter 1977/78). *p. 49.*

Section II

- 1.1. Effect of mechanical factors on reed. The thick arrows mark connections simulated by the mathematical model of the present study (after BINZ 1981). *p. 55.*
2.1. Definition sketch for the mathematical approach of KLÖTZLI (1974). *p. 58.*
3.1. Decrease of wind velocity in a reedswamp according to data from RUDESCU (1965). The filled area within the rectangles corresponds to the local relative wind velocity based on the wind velocity u_0 outside of the reed stand. x [m] is the distance from the front line, h is the height above water level. *p. 64.*
3.2. Definition sketch of equation (31.1). *p. 65.*
3.3. Drag coefficient c_l (air) = c_w (water) of a cylinder in steady flow versus Reynolds number (from BURKHARDT 1967). *p. 66.*
3.4. Measurement of wind force on reed in the wind channel. Schematic view of the experimental layout. *p. 68.*
3.5. Experiments with reed in the wind channel. *p. 69.*
A. 10 stems, increasing wind velocity
B. 3 stems in a line, increasing wind velocity
C. 3 stems side by side, decreasing wind velocity. Note that the leaves remain in the wind direction, even when there is no more wind ($u_l = 0$).
3.6. Hold for 3 stems in the wind channel. *p. 70.*
3.7. Hold for 10 stems in the wind channel. *p. 73.*
3.8. Drag coefficient c_l vs. wind velocity, from experiments on 17.10.79. *p. 78.*
3.9. Drag coefficient c_l vs. wind velocity of 10 and 3 stems respectively (cf. 3.1.2.2), from experiments on 17.10.79 and 11.10.79 respectively. *p. 79.*

- 3.10. Comparison of drag coefficient c_l of 10 stems with c_l of 3 stems in a line and with the mean value c_l of 5 single stems, as a function of wind speed (at higher velocities only 4 and 3 stems respectively considered, see text). *p. 80.*
 Top: values of c_l computed with eq. (31.8).
 Bottom: values of c_l^* computed with eq. (31.11).
- 3.11. Superposition of 7 elementary waves from 15 sources (points). The circles represent the wave crests. The superposition creates parallel fronts travelling to the right and left hand side respectively. *p. 83.*
- 3.12. The principal dimensions of a wave. *p. 84.*
 L = wave length $z_s(x,t)$ = height of water surface above ground
 H = wave height $\zeta(x,t)$ = water surface elevation
 d = water depth T = wave period
 x, z = coordinates t = time
- 3.13. Sample record of the water level of a wave train, and discrimination of the individual waves according to the crest-to-crest method (top) and to the zero-crossing method (bottom) (from SCHÜTTRUPF 1973). *p. 89.*
- 3.14. Spectrum of a periodic and an aperiodic oscillation. *p. 93.*
 Left: Composition of a periodic oscillation with three harmonics and spectrum (without considering a phase lag).
 1 + 3 harmonics
 4 superposition of the three harmonics
 5 spectrum of amplitudes
 Right: aperiodic oscillation and spectrum
- 3.15. Definition sketch to eqq. (32.42) and (32.43). *p. 99.*
- 3.16. Comparison of computed and measured amplitudes of a plastic stem. Diameter = 1 cm, wave height = 12 cm (top) and 16 cm (bottom) respectively. *p. 103.*
 "Totale Bewegung" (total amplitude) = sum of positive and negative amplitude of the oscillation.
 ----- measured ——— computed with variable drag coefficient c_w .
- 3.17. Definition sketch for computing the effective fetch in a given place *A*. *p. 106.*
 f_i = length of a given direction vector (free water surface)
 β_i = angle between the vector f_i and the wind direction
- 3.18. Propagation of a (supposed) elementary wave influenced by blowing wind. *p. 107.*
- 3.19. Air pressure on an inclined plane. *p. 108.*
 p_0 = dynamic pressure of the wind
 p_β = wind pressure on a plane inclined at β to the orthogonal of the wind direction
- 3.20. Division of the fetch into zones with equal wind velocity and direction, for the calculation of the effective fetch with eq. (32.49). *p. 109.*
- 3.21. Reduction of the direction vector by the ineffective part, if the opposite shoreland is inclined at more than 10° . *p. 109.*
- 3.22. Direction vectors of the fetch in front of the investigation area at Altenrhein. The reference direction is north, i.e. θ_i equals the azimuth of the direction vector i . *p. 111.*
- 3.23. Nomogramm for computing wind velocity at different levels above ground: vertical distribution of relative wind velocity, based on u_{10} at the reference level of 10 m above ground. Curve parameter is u_{10} (after PRANDTL and CHARNOCK). The curves according to eq. (32.66) with the exponents n mentioned in the text are also plotted. *p. 117.*
 $n = 1/4$ ($z \leq 15$ m), and $n = 1/5$ ($z > 15$ m)
 $n = 1/7$
- 3.24. Group of waves (dashed line) as a superposition of two waves with similar frequencies (full line). *p. 127.*
 L = length of an individual wave
 C = wave speed (velocity of propagation) of the individual wave
 C_g = velocity of propagation of the wave group (group velocity)

- 3.25. Wave height, group velocity and local wave length as a function of relative water depth, based on deep water wave length L_0 . *p. 129.*
 H/H_0 local wave height/deep water wave height
 C_g/C group velocity/wave velocity
 d/L local water depth/local wave length
- 3.26. Parameters α and kl of 3rd order sinusoidal theory (Stokes III), as a function of relative water depth d/L_0' and relative wave height H/L_0' ($L_0' = g T^2/2\pi$). *p. 131.*
- 3.27. Relation between the spectrum of fully arisen sea and that of developing sea (small figure on top) and partly arisen sea because of limitation of fetch or duration of wind (bottom). *p. 137.*
- 3.28. Estimation of frequency f_k of partly arisen sea. $f_k = g X/(\pi \cdot u_i)$
 (after KINSMANN 1965, from BRUSCHIN and FALVEY 1975/76). *p. 138.*
- 3.29. Change in wave form and direction due to an abrupt change of water depth d . *p. 139.*
- 3.30. Refraction on slopes with straight, parallel contours. *p. 140.*
- 3.31. Stepwise construction of an orthogonal vector to wave crests on a slope with non-parallel contours (the wave crests themselves are not plotted). The deep water wave direction (α_0) is determined by other factors, e.g. wind direction.
 In this figure the construction of the orthogonal vector between contour 1 and contour 2 is shown (after SILVESTER 1974). *p. 141.*
- 3.32. Water particle motion induced by a deep water wave with small amplitude. The wave is plotted at time t_1 and t_2 (e.g. 1/2 s later). The water particle paths (orbits) are closed circles. The thick part of the circles represents the motion of some water particles between t_1 and t_2 (from BINZ 1980). *p. 150.*
 (N.B.: The drawings in this and the following figures 3.33-3.35 are not in scale, wave height and diameter of the orbits are too large.)
- 3.33. Wave in transitional depth (water depth is less than the half of the wave length). The orbits are no longer circles but ellipses. On the ground, the particles oscillate horizontally. *p. 151.*
- 3.34. Shallow water wave (water depth is less than 1/25 of wave length). The ellipses are flatter, the amplitude of the horizontal motion is almost uniform between ground and water surface. *p. 151.*
- 3.35. Steeper waves, predominating in the nearshore zone, cause a nonperiodic drift (the orbits are not closed). *p. 151.*
- 3.36. Situation of a supposed observer, travelling with the wave in point B . The choice of B is arbitrary, in this figure a wave crest has been chosen. *p. 153.*
- 3.37. Form of a wave ($T = 3,3$ s; $d = 1$ m; $L = 10,6$ m; $H = 0,66$ m, $C = 3,2$ m/s) and profile of horizontal particle velocity under the crest, according to linear or first order theory (Airy-Laplace) and third order sinusoidal theory (Stokes III). *p. 155.*
 The figure shows that in this case the values given by linear theory for maximum surface elevation and maximum water particle velocity under the crest are too small, whereas the particle velocity on the ground is almost the same from either theory.
- 3.38. Rigid floating matter (drift-wood and broken reed stalks) in a reed stand (Photo: F. Klötzli). *p. 164.*
- 3.39. Algae mats in reed stands. *p. 165.*
 Top: floating algae mat in reed stand near Küßnacht ZH (Photo: Amt für Gewässerschutz des Kantons Zürich).
 Bottom: The algae rest on the inclined reed stems and pull them further down, when the water level falls. Because of the low water level during winter time the remains of dead reed plants become visible.
- 3.40. Schematic diagram of a reed stand stressed by floating matter (water side) (from BINZ 1978). *p. 167.*
- 3.41. Several phases of a reed stem being broken down by drift-wood (schematic; for sim-

- plicity, only one stem has been drawn). In reality, the different phases are not clearly distinct from each other. *p. 167.*
- 3.42. Several phases of reed stem destruction by floating algae mats (schematic). Depending on the actual wave climate, there can be more or less time between the different phases. If the stem is more inclined, falling water level has a similar effect (cf. fig. 3.39.). *p. 170.*
- 3.43. Definition sketch of the differential equations describing drift motion. *p. 172.*
- 3.44. Definition sketch of the floating drift and its momentary immersion. (For practical reasons the water line has been drawn in this figure as a simple horizontal line.) *p. 175.*
- 3.45. Wave generator at the hydraulic laboratory of the Swiss Fed. Inst. of Technology (VAW). The vertical plate (top) acts as a piston and produces the waves. It is driven by two arms connected to independent Scotch yokes which are in turn driven through a pulley system by a variable speed motor with driver (bottom). *p. 179.*
- 3.46. Wave tank at VAW. Top view and longitudinal section. Cf. the following figures. *p. 180.*
- 3.47. Hold for the plastic stems in the wave tank of VAW. Top: top view and longitudinal section. Bottom: view through the lateral window. *p. 182.*
- 3.48. Experimental drift-wood. Top: Cross section and top view. Bottom: Photo taken through the lateral window of the wave tank. *p. 183.*
- 3.49. Running experiment with plastic stems in the wave tank. *p. 184.*
 Top: photograph of an experiment without drift-wood (cf. chap. 3.2.1.4.). For better visibility in the photos, every second stem has been coloured white.
 Bottom: Exposure time = 1 s (wave period = 0.92 s). The camera is installed at the height of the still water level. The tops of the three white stems are clearly visible.
- 3.50. Calculated positive amplitudes of plastic stems under the effect of waves and drift-wood (same situation as in the experiments) as a function of drag coefficient G_d and inertia coefficient G_m . Wave period $T = 0.92$ s, wave height $H = 16$ cm, mass of drift-wood $M_T = 5.99$ kg. *p. 189.*
 Δ maximum amplitude during the whole period considered (23.5 s)
 \square maximum amplitude during the last 3 1/2 wave periods (3.3 s)
 \circ Average amplitude and number of considered oscillations during the last 3.3 s.
 ∞ Instability of the algorithm (this signifies that the drift-wood is thrown over the stems).
- 3.51. Calculated amplitudes as in fig. 3.50. with $T = 0.92$ s, $H = 12$ cm, $M_T = 5.99$ kg. *p. 190.*
- 3.52. Calculated amplitudes as in fig. 3.50. with $T = 0.92$ s, $H = 12$ cm, $M_T = 4.90$ kg. *p. 192.*
- 4.1. Reed stem with deflections $\delta(z)$ caused by load. $\delta'(z)$ is the tangent of the angle φ . *p. 195.*
- 4.2. Model of reed stem by a system of rigid bars (4 in this fig.) interconnected by elastic joints. The external forces F_i correspond to the load by wind, waves, drift-wood etc. *p. 195.*
- 4.3. Relation between the angle of two model bars and the mean curvature of the corresponding part of the real stem. *p. 196.*
- 4.4. Model of a reed stem with several bars; drawn in are the velocities of the centroid and the top of each bar. The external force F (divided in x - and z -components) need not necessarily act upon a joint. All linear components are positive in the direction of the plotted x - and z -axis, angles are positive in clockwise direction. *p. 200.*
- 4.5. Displacement of the external forces F due to a (small) elementary displacement $\delta\varphi_i$ (in this fig.: $\delta\varphi_2$). *p. 205.*
- 4.6. Definition sketch of the interaction of drift-wood and stem (in this example the q -th bar is the 3rd, the b -th is the 4th). *p. 209.*

4.7. Forces acting upon stem and drift. *p. 211.*

Left: Forces exerted on the drift by the stem.

G_T''	weight of the drift occasionally reduced by buoyancy
W_x, W_z	dynamic water pressure
C	Coriolis force
Z_x, Z_z	driving force
N	normal force
R	friction

Right: forces exerted on the stem by the drift.

4.8. Air and water pressure acting directly upon the stem. In the model they are transformed to equivalent concentrated forces W . *p. 219.*

4.9. Local deflection of the bar resulting from the collision of the drift wood with the stem. *p. 221.*

4.10. Comparison of stem properties and parameters of the model with e.g. 3 bars. In this example, the stem properties are known at 7 measuring points. *p. 223.*

4.11. Definition sketch for the calculation of spring stiffnesses. They are determined in such a way that the joints of the model lie on the real deflection line (i.e. the displacements of the joints under a given load are equal to the deflection of the stem in the corresponding points under the same load). Note that the figure is distorted in x -direction. *p. 226.*

4.12. Flow chart of the computer program for simulating the motions of a reed stem (explanation see text). *p. 234.*

4.13. to 4.25.: Computed oscillation of a reed stem stressed by waves, wind and drift-wood. The horizontal motion (x -direction) of the top of the model bars is plotted as a function of time (points 1 - 4). The position of the drift-wood is marked by T, the intersection of stem and water surface by W. Lines are drawn for the motion of the stem top (point 4) and the drift-wood (T) respectively. The asterisks (*) show the undisturbed water particle motion at stillwater level. See the small definition sketch within fig. 4.13.

4.13. Example ST811, wave height $H = 10$ cm, wave period $T = 1,25$ s. *p. 267.*

4.14. Example ST811, wave height $H = 15$ cm, wave period $T = 1,53$ s. *p. 268.*

Note that at first, the drift-wood does not touch the stem. The first strike happens at about $t = 12$ s and causes an amplitude of singular magnitude. The same is true in all cases, where the wave height does not exceed 25 cm, i.e. also for fig. 4.13., 4.15. and 4.16.

4.15. Example ST811, wave height $H = 20$ cm, wave period $T = 1,76$ s. *p. 269.*

4.16. Example ST811, wave height $H = 25$ cm, wave period $T = 1,97$ s. *p. 270.*

4.17. Example ST811, wave height $H = 30$ cm, wave period $T = 2,16$ s. *p. 271.*

4.18. Example ST811, wave height $H = 35$ cm, wave period $T = 2,33$ s. *p. 272.*

4.19. Example ST811, wave height $H = 40$ cm, wave period $T = 2,49$ s. *p. 273.*

4.20. Example ST811, wave height $H = 45$ cm, wave period $T = 2,65$ s. *p. 274.*

4.21. Example ST811, wave height $H = 50$ cm, wave period $T = 2,79$ s. *p. 275.*

4.22. Example ST711, wave height $H = 20$ cm, wave period $T = 1,76$ s. *p. 276.*

4.23. Example ST731, wave height $H = 20$ cm, wave period $T = 1,76$ s. *p. 277.*

The weaker stems of plot 4.3 (in comparison with the stems of plot 1.2, ex. 711) show stronger motion under the same external conditions; however, the resulting forces (bending moment) are smaller (cf. tab. 4.4.).

4.24. Example ST721, wave height $H = 20$ cm, wave period $T = 3,0$ s. *p. 278.*

The wave period in fig. 4.24. ($T = 3$ s) is almost twice as long as the wave period in fig. 4.22.; the amplitudes, however, are almost equal.

4.25. Example ST741, wave height $H = 20$ cm, wave period $T = 3,0$ s. *p. 279.*

The wave period in fig. 4.25. ($T = 3$ s) is almost twice as long as the wave period in fig. 4.23.; the amplitudes, however, are almost equal.

4.26. Lateral view of computed stem oscillations (according to the definition sketch in fig.

- 4.13.). The same series of cases as in fig. 4.13. - 4.21. (example ST811) has been chosen. The vertical dashed lines mark time spaces approximately equal to one wave period. p. 280.
- 4.27. to 4.32.: Computed oscillation of plastic bars influenced by waves and drift-wood. The situation corresponds to the experiments executed in the wave tank at VAW (cf. chap. 3.3.4.). Different oscillations are obtained by varying inertia coefficient G_m . The drag coefficient is $G_d = 1,25$ in all of the 6 following figures. The mass of the drift-wood is $M_T = 5,99$ kg, the wave height $H = 16$ cm and the wave period $T = 0,92$ s. The drawings are analogous to those in fig. 4.13. - 4.25.
- 4.27. $G_m = 1,0$ p. 282.
 4.28. $G_m = 1,25$ p. 283.
 4.29. $G_m = 1,5$ p. 284.
 4.30. $G_m = 1,75$ p. 285.
 4.31. $G_m = 2,0$ p. 286.
 4.32. $G_m = 2,5$ p. 287.
- 4.33. to 4.38. Computed bending moment at the foot of the stem vs. wave height, from the examples dealt with in the text.
- Top: maximum value of the whole period considered (25 s).
 Bottom: mean square value σ_M .
- 4.33. Influence of (missing) drift-wood. Stems from plot 1.2 at 27. 6. p. 288.
 ----- (SO751): without drift-wood — (ST711): drift-wood of 6 kg
 ----- (ST751): drift-wood of 12 kg
- 4.34. Influence of (missing) drift-wood. Stems from plot 4.3 at 27. 6. p. 289.
 ----- (SO731): without drift-wood — (ST731): drift-wood of 6 kg
- 4.35. Influence of (missing) drift-wood. Stems from plots 1.2 (ST771, SO761) and 4.3 (ST791, SO781) at 13.6. p. 290.
 ----- (SO761, SO781): without drift-wood — (ST711, ST791): drift-wood of 6 kg
- 4.36. Influence of (missing) drift-wood. Stems from plots 1.2 (ST811, SO801) and 4.3 (ST831, SO821) at 23.7. p. 291.
 ----- (SO801, SO821): without drift-wood — (ST811, ST831): drift-wood of 6 kg
- 4.37. Influence of wave period T . Stems from plots 1.2 (ST711, ST721) and 4.3 (ST731, ST741) at 27.6. p. 292.
 — (ST711, ST731): increasing wave period according to tab. 4.4.2., from 1,25 s ($H = 10$ cm) to 2,65 s ($H = 45$ cm)
 ----- (ST721, ST741): constant wave period $T = 3$ s irrespective of wave height
- 4.38. Influence of bending stiffness and season. Stems from plots 1.2 (ST711, ST771, ST811) and 4.3 (ST731, ST791, ST831). p. 293.
 ----- (ST771, ST791): at 13.6. —
 (ST711, ST731): at 27.6.
 ----- (ST811, ST831): at 23.7.
- 4.39. Diameter D , stiffness $E \cdot J$, critical moment M_{Gr} and breaking moment M_{Br} vs. time of the stems dealt with in the examples. p. 294.
 Top: plot 1.2 Bottom: plot 4.3
 ----- diameter D ----- stiffness $E \cdot J$
 — critical moment M_{Gr} (lower line) and breaking moment M_{Br} (upper line)
- 4.40. and 4.41. Wave heights producing the same moment without drift-wood (H_0) and with a piece of drift-wood of 6 kg (H_T) respectively, as a function of wave height H_0 .
 ----- curve based on the mean square value
 ----- curve based on the maximum value
 stems are run over by drift-wood
- 4.40. stems from plot 1.2 . p. 295.
 4.41. stems from plot 4.3 . p. 296.

- 3.2. Schematic view of the experimental facilities for laboratory experiments at EMPA (cf. fig. 3.3.). *p. 357.*
- 3.3. Photo of the facilities schematically shown in fig. 3.2. *p. 358.*
The metal plates between the supporting cylinders and the small wooden pieces on the stem have proven to be unnecessary and therefore were later omitted.
- 3.4. Influence of the date of testing on the characteristics of strength, viz. ideal breaking stress (left hand line at every date), ideal critical stress ("yield stress"; middle line) and ideal Young's modulus (right hand line). The specimens were gathered on 13. 7. 77 from "Großes Loch" (cf. fig. 3.6.), tests were carried out on 13. 7., 19. 7. and 28. 7. respectively. *p. 361.*
- 3.5. Diameter D , wall thickness t and moment of inertia of cross section area J vs. height above the first node of a "thin" and of a "thick" stem respectively (measured by EMPA). *p. 363.*
- 3.6. Plan of the reed stand at Altenrhein SG on Bodensee-Obersee, with sample sites (scale about 1 : 3350). *p. 365.*
 - "Großes Loch Nord": preliminary experiments for measuring solidity and stiffness and the influence of testing date.
 - plots 1.2, 4.1, 4.3, 5.1, Z and G: bending experiments for measuring solidity and stiffness
 - C_1 , C_2 : measuring the degree of fixation in the ground (cf. chap. 5.)The denomination of sector D* originates from earlier investigations (KLÖTZLI and ZÜST 1973 a,b)
- 3.7. Ideal Young's modulus of the stems from Altenrhein on 13. 6. 79. *p. 374.*
The lines belonging to every plot correspond, from left to right, to the first, second and third cut above ground respectively (this remark is also valid for fig. 3.8.-3.10.).
- 3.8. Ideal Young's modulus of the stems from Altenrhein on 27. 6. 79. *p. 375.*
- 3.9. Ideal Young's modulus of the stems from Altenrhein on 23. 7. 79. *p. 376.*
- 3.10. Ideal Young's modulus of the stems from Altenrhein on 12. 8. 79. *p. 377.*
- 3.11. Ideal Young's modulus of the stems from Altenrhein vs. diameter, 1st cut above ground, on 23. 7. 79. *p. 378.*
- 3.12. Ideal Young's modulus of the stems from Altenrhein vs. diameter, 1st cut above ground, on 12. 8. 79. *p. 379.*
- 3.13. Ideal Young's modulus of the stems from Altenrhein vs. diameter, 2nd cut above ground, on 23. 7. 79. *p. 380.*
- 3.14. Ideal Young's modulus of the stems from Altenrhein vs. diameter, 2nd cut above ground, on 12. 8. 79. *p. 381.*
- 3.15. Ideal Young's modulus of the stems from Altenrhein on 13. 6. 79.
Single cuts taken at water level. *p. 382.*
- 3.16. Ideal Young's modulus of the stems from Altenrhein on 27. 6. 79.
Single cuts taken at water level. *p. 383.*
- 3.17. Ideal Young's modulus of the stems from Altenrhein vs. diameter, individual cuts taken at water level on 13. 6. 79. *p. 384.*
- 3.18. Ideal Young's modulus of the stems from Altenrhein vs. diameter, individual cuts taken at water level on 27. 6. 79. *p. 385.*
- 3.19. Ideal breaking stress of the stems from Altenrhein on 13. 6. 79. *p. 386.*
The lines belonging to every plot correspond, from left to right, to the first, second and third cut above ground respectively (this remark is also valid for fig. 3.20.-3.22.).
- 3.20. Ideal breaking stress of the stems from Altenrhein on 27. 6. 79. *p. 387.*
- 3.21. Ideal breaking stress of the stems from Altenrhein on 23. 7. 79. *p. 388.*
- 3.22. Ideal breaking stress of the stems from Altenrhein on 12. 8. 79. *p. 389.*
- 3.23. Ideal breaking stress of the stems from Altenrhein vs. diameter, 1st cut above ground, on 23. 7. 79. *p. 390.*

- 3.24. Ideal breaking stress of the stems from Altenrhein vs. diameter, 1st cut above ground, on 12. 8. 79. *p. 390.*
- 3.25. Ideal breaking stress of the stems from Altenrhein vs. diameter, 2nd cut above ground, on 23. 7. 79. *p. 392.*
- 3.26. Ideal breaking stress of the stems from Altenrhein vs. diameter, 2nd cut above ground, on 12. 8. 79. *p. 393.*
- 3.27. Ideal breaking stress of the stems from Altenrhein on 13. 6. 79.
Individual cuts taken at water level. *p. 394.*
- 3.28. Ideal breaking stress of the stems from Altenrhein on 27. 6. 79.
Individual cuts taken at water level. *p. 395.*
- 3.29. Ideal breaking stress of the stems from Altenrhein vs. diameter, individual cuts taken at water level on 13. 6. 79. *p. 396.*
- 3.30. Ideal breaking stress of the stems from Altenrhein vs. diameter, individual cuts taken at water level on 27. 6. 79. *p. 397.*
- 3.31. Ideal critical stress of the stems from Altenrhein on 13. 6. 79. *p. 398.*
The lines belonging to every plot correspond, from left to right, to the first, second and third cut above ground respectively (this remark is also valid for fig. 3.32.-3.34.).
- 3.32. Ideal critical stress of the stems from Altenrhein on 27. 6. 79. *p. 399.*
- 3.33. Ideal critical stress of the stems from Altenrhein on 23. 7. 79. *p. 400.*
- 3.34. Ideal critical stress of the stems from Altenrhein on 12. 8. 79. *p. 401.*
- 3.35. Ideal critical stress of the stems from Altenrhein vs. diameter, 1st cut above ground, on 23. 7. 79. *p. 402.*
- 3.36. Ideal critical stress of the stems from Altenrhein vs. diameter, 1st cut above ground, on 12. 8. 79. *p. 403.*
- 3.37. Ideal critical stress of the stems from Altenrhein vs. diameter, 2nd cut above ground, on 23. 7. 79. *p. 404.*
- 3.38. Ideal critical stress of the stems from Altenrhein vs. diameter, 2nd cut above ground, on 12. 8. 79. *p. 405.*
- 3.39. Ideal critical stress of the stems from Altenrhein on 13. 6. 79.
Single cuts taken at water level. *p. 406.*
- 3.40. Ideal critical stress of the stems from Altenrhein on 27. 6. 79.
Single cuts taken at water level. *p. 407.*
- 3.41. Ideal critical stress of the stems from Altenrhein vs. diameter, individual cuts taken at water level on 13. 6. 79. *p. 408.*
- 3.42. Ideal critical stress of the stems from Altenrhein vs. diameter, individual cuts taken at water level on 27. 6. 79. *p. 409.*
- 3.43. Critical curvature of the stems from Altenrhein on 13. 6. 79. *p. 410.*
The lines belonging to every plot correspond, from left to right, to the first, second and third cut above ground respectively (this remark is also valid for fig. 3.44.-3.46.).
- 3.44. Critical curvature of the stems from Altenrhein on 27. 6. 79. *p. 411.*
- 3.45. Critical curvature of the stems from Altenrhein on 23. 7. 79. *p. 412.*
- 3.46. Critical curvature of the stems from Altenrhein on 12. 8. 79. *p. 413.*
- 3.47. Plan of sewage purification plant at Othfresen BRD, with sample plots. *p. 415.*
- 3.48. Reed culms harvested for bending experiments. Each sheaf originates from one of the sample plots 0 - 5 respectively (from left to right). The higher portion of already yellowed leaves of the plants from plots 3 - 5 is not clearly visible on this black and white reproduction of the photo. The person measures about 1.60 m. *p. 416.*
- 3.49. Length of the stems used for experiments from Othfresen. *p. 417.*
- 3.50. Ideal Young's modulus of the stems from Othfresen tested in laboratory. *p. 422.*
The lines belonging to every plot correspond, from left to right, to the first, second and third cut above ground respectively (this remark is also valid for fig. 3.51.).
- 3.51. Ideal breaking stress of the stems from Othfresen tested in laboratory. *p. 423.*

- 3.52. Ideal Young's modulus vs. diameter of the stems from Othfresen tested in laboratory, first cuts above ground. *p. 424.*
- 3.53. Ideal Young's modulus vs. diameter of the stems from Othfresen tested in laboratory, second cuts above ground. *p. 426.*
- 3.54. Ideal breaking stress vs. diameter of the stems from Othfresen tested in laboratory, first cuts above ground. *p. 428.*
- 3.55. Ideal breaking stress vs. diameter of the stems from Othfresen tested in laboratory, second cuts above ground. *p. 430.*
- 3.56. Ideal critical stress of the stems from Othfresen tested in laboratory. *p. 432.*
The lines belonging to every plot correspond, from left to right, to the first, second and third cut above ground respectively (this remark is also valid for fig. 3.57.).
- 3.57. Critical curvature of the stems from Othfresen tested in laboratory. *p. 433.*
- 3.58. Ideal critical stress vs. diameter of the stems from Othfresen tested in laboratory, first cuts above ground. *p. 434.*
- 3.59. Ideal critical stress vs. diameter of the stems from Othfresen tested in laboratory, second cuts above ground. *p. 436.*
- 3.60. Critical curvature vs. diameter of the stems from Othfresen tested in laboratory, first cuts above ground. *p. 438.*
- 3.61. Critical curvature vs. diameter of the stems from Othfresen tested in laboratory, second cuts above ground. *p. 440.*
- 4.1. Field measurements of bending strength. Schematic view of the testing facilities. *p. 443.*
- 4.2. Improvised measuring facilities at Othfresen. The two vertical tent poles were attached at the metallic shelf and served as supports. The samples were held in back of the poles as shown in fig. 4.1. The friction caused by the supporting force prevented the stems from falling down. *p. 443.*
- 4.3. Diameter of the tested reed stems at Othfresen, lowest cuts. *p. 447.*
The left hand line of every plot represents the laboratory tested stems (chap. 3.4.2.), the right hand line was obtained from the stems used for spring-balance experiments (this remark is also valid for fig. 4.4.).
- 4.4. Diameter of the tested reed stems at Othfresen, second cuts above ground. *p. 448.*
- 4.5. Ideal breaking stress of the stems tested with a spring-balance at Othfresen. *p. 449.*
The lines belonging to every plot correspond, from left to right, to the first and second cut above ground respectively.
- 4.6. Ideal breaking stress of the stems tested with a spring-balance at Othfresen vs. diameter, lowest cuts. *p. 450.*
- 4.7. Ideal breaking stress of the stems tested with a spring-balance at Othfresen vs. diameter, second cuts above ground. *p. 452.*
- 4.8. Comparison of mean ideal breaking stress of reed stems from Othfresen tested in laboratory and with the spring-balance respectively. The numbers 0 - 5 in the figure represent the sampling plots 0 - 5. Each number is plotted twice, representing the lowest cuts (start of the arrow) and the second cuts above ground (arrow-head) *p. 454.*
- 4.9. Portable testing device for measuring the bending stiffness of reed stems. *p. 456.*
- 4.10. Bending stiffness of the samples from plot 1 at Othfresen measured in the laboratory vs. bending stiffness of the same specimens measured with the portable testing device. *p. 458.*
- 4.11. Comparison of the bending stiffness of the samples from plot 1 measured with both methods. From left to right: lowest, second and third cuts above ground, all specimen. The left hand line of each case shows the values obtained by laboratory experiments, the right hand line stands for the values obtained with the portable testing device. *p. 459.*
- 5.1. Displacement of the stem at the water level due to the elastic fixation of the stem in the ground, under the load of a horizontal force F . *p. 461.*

- $M_E = h_F \cdot F$ = fixed end moment due to the force F
 α_E = inclination of the stem foot
 δ_F = displacement due to the force F
 δ_α = displacement due to the inclination of the stem foot
- 5.2. Schematic view of the testing facilities for measuring the degree of fixation c_E of reed stems in the field. *p. 463.*
 5.3. Measuring the degree of fixation in the field. *p. 463.*
 5.4. Inclination α of the stem foot by increasing (points 1...4) and subsequently decreasing load (points 4...6). *p. 464.*
 G_i : loading weights
 P_i : force exerted on the stem
 R_i : friction
 α_i : inclination of the stem foot
- 5.5. Degree of fixation vs. bending stiffness of the approximately 60 cm long lowest part of the stem. The regression line according to eq. (5.10) is drawn, whereas the line according to (5.11) lies so closely to the former, that it could not be plotted. Numbers 1 - 16 are samples from within the stand, the numbers 51 - 62 were taken at the water side front of the stand. *p. 467.*
 5.6. Mean bending stiffness EJ of the approximately 60 cm long lowest part of the stems vs. diameter. *p. 469.*
 Regression lines $\ln y = a + b \cdot \ln x$ are drawn:
 ----- stems from within the stand (no. 1+16)
 ----- stems from the front side of the stand (no. 51+62)

Section IV

- 2.1. Reed-fence after SUKOPP (1973). *p. 486.*
 2.2. Floating reed-fence at Altenrhein SG. Situation plan see part III, fig. 3.6. ("Schutzhag"). Top: cross section. Bottom: view of one element. *p. 488.*
 2.3. Wattle in front of the reed stand at Seefelder-Aach Mündung (Bodensee Obersee). (Construction by WASSERWIRTSCHAFTSAMT RAVENSBURG 1988, fig. according to DITTRICH and WESTRICH 1988.) *p. 492.*