Internationales Symposion
INTERPRAEVENT 2004 – RIVA / TRIENT

DESIGN OF ROPE NET BARRIERS FOR WOODY DEBRIS ENTRAPMENT

INTRODUCTION OF A DESIGN CONCEPT

BEMESSUNG VON SEILNEZTSPERREN ZUM SCHWEMMHOLZRÜCKHALT

VORSTELLUNG EINES BEMESSUNGSKONZEPTS

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ZUSAMMENFASSUNG

In einem umfangreichen Forschungsprojekt, bestehend aus Versuchen am physikalischen Modell und in der Natur, wurden die Vorgänge und Einwirkungen auf Seilnetzsperren beim Schwemmholzrückhalt untersucht. Dabei wurden die wesentlichen Einflussfaktoren und die Kräfte auf das Netze und die Ankerseile bestimmt. Der empfohlene Anwendungsbereich und das darauf basierende Bemessungskonzept werden vorgestellt. Die wesentliche Bemessungsgröße ist die erforderliche Netzhöhe, in welche das Bachgefälle, die Holzmenge, der Abfluss, die Gerinnerauheit, der Feinanteil im Holz und die Neigung der Uferböschungen einfließt. Die Seil- bzw. Ankerkräfte errechnen sich aus der Netzhöhe und dem Stützkraftansatz.

Schlagworte: Bemessung, Schwemmholz, Netzsperre

ABSTRACT

The process and the effects of the entrapment of woody debris in rope net barriers were investigated in an large research project, containing tests in a physical model and on a prototype barrier. The main parameters of influence and the stress upon the net, the ropes and the anchors were determined. Based on these results a design concept an the limits for application were worked out and are introduced in this paper. The main design parameter is the required height of the net, which is based on the gradient of the torrent, the amount of wood, the discharge, the roughness of the torrent, the proportion of fine material and the slope of the banks. The rope and anchor forces are a result of this height and the hydrostatic water pressure.

Key words: design, woody debris, rope net barrier

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INTRODUCTION

This design concept is valid for the entrapment of woody debris and gravel in rope net barriers, not for debris flows. It is based on the results of a research project with model tests and a full-scale nature test on a prototype barrier, which is particularly described in earlier proceedings of Interpraevent and in Rimböck (2002) and Rimböck (2003).
A survey of the necessary steps in the design concept is shown in Fig 1. The most important terms and signs are detailed in Fig 2.

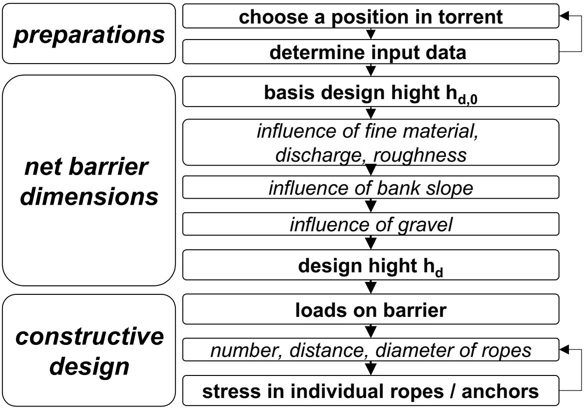

Fig 1: Survey of proceedings for the design of rope net barriers for woody debris entrapment

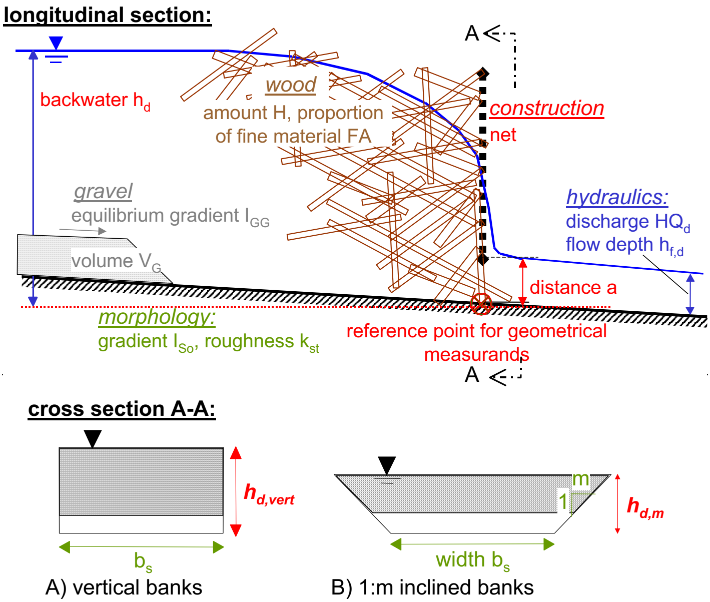

Fig 2: Terms and signs used in the text

CHOICE OF LOCATION, LIMITS FOR APPLICATION, INPUT DATA

A suitable location of a rope net barrier for woody debris entrapment fulfils the following boundary conditions:

- Straight part of the torrent: → steady-going currents, symmetrical stress on banks; radius of curves > 10 · width of torrent; distance downstream of curve > 5 · width of torrent.
- Low gradient: → large space for entrapped woody debris , low stress on net, better separation of woody debris and gravel.
- High, rocky and low inclined banks:
  - > design height h_d → no current around the barrier
  - rocky banks → anchoring easily possible
  - low inclined → with increasing backwater elevation wider cross section at net and therefore less stress; if too low inclined: problems with very long upper ropes
- Wide torrent → the specific parameters (referring to 1 m width) and therefore the forces in flow direction are lower; if too wide: the axial forces on the long ropes get too high
- Easily accessible → inspection and clearing
- Close to place which should be protected → little woody debris out of catchment area between

The limits for a sensible and tested application of rope net barriers for woody debris entrapment are shown in Tab 1. In other cases a new position for the barrier or another construction, such as rake, slit- or grid barrier, should be chosen. Fig 3 shows a recommendation for the area of use for the most common woody debris entrapment facilities dependent on the two most important design parameters: discharge and wood amount. The rakes in form of a "v" have been properly investigated by Knauss (1995).

Tab 1: Limits for the application of rope nets

width b_s	**curve-radius r**	**discharge q**	**gradient I_{So}**	**amount of wood H** (design event)	**volume of gravel V_G** (design event)
≤ 15 m	> 10 · width	≤ 5,0 m³/sm	≤ 5 %	≤ 20 m³/m	≤ 100 m³/m

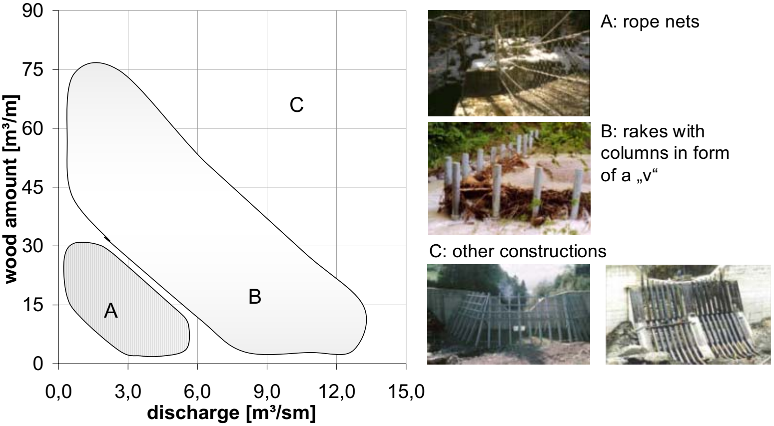

Fig 3: Recommended range of use for different woody debris entrapment constructions

The necessary input data is shown in Tab 2. It includes suggestions for methods to collect the data, in the order of decreasing quality. Many data vary a lot, e.g. amount of wood or proportion of fine material, so several calculations for different (extreme) cases should be carried out.

Tab 2: Input data for the design of trope net barriers

	quantity	symbol	unit	possible method
morpholgy at net	gradient	I_{So}	%	survey, map
	width of torrent	b_s	m	survey
	inclination of bank	1:m	-	survey
	roughness	k_{St}	$m^{(1/3)}/s$	calculation, estimation
gravel	equilibrium gradient of gravel	I_{GG}	%	optical estimation / experience calculation Meyer-Peter/Müller, comparison with torrents in equilibrium
	(specific) volume of gravel	V_G	m³/m	optical estimation / experience, calculation acc. to Smart-Jäggi (1983), Meyer-Peter/Müller
hydraulic	(specific) discharge	Hq_{10} Hq_d	m³/sm	recording of water level, calculation acc. to Kölla (1986), Wundt-curve ; $HQ_{10} \approx 0{,}5 \cdot HQ_{100}$
	flow depth	$h_{f,10}$ $h_{f,d}$	m	recording of water level, calculation according to Stickler
wood	(specific) amount	H	m³/m	recordings, aerial view based estimation (Rimböck (2001)), visual estimation, estimation formulas (e.g. Rickenmann (1997))
	fine material	FA	%	recordings, visual estimation, experience

DIMENSION OF THE NET BARRIER

Basis design height $h_{d,0}$ – Parameters wood amount H and gradient I

The backwater elevation upstream of the net rises with the amount of wood H and the gradient I. Therefore the basis design height for the backwater elevation is :

$$h_{d,0} = 3{,}22 \cdot H^c \quad \text{with} \quad \begin{array}{l} c=0{,}20 \text{ for } I=1{,}0\% \\ c=0{,}25 \text{ for } I=3{,}0\% \\ c=0{,}26 \text{ for } I=5{,}0\% \end{array}$$

Other numbers can be interpolated. This number is based on: roughness $k_{st,basis} = 35\ m^{(1/3)}/s$, discharge $q_{basis} = 3{,}0$ m³/sm, proportion of fine material FA = 15 % and vertical banks. The calculation for different situations is done in the following steps.

Basis design height $h_{d,vert}$ – Parameters roughness, discharge, fine material

In rougher torrents forces can be distributed into the stream banks and the torrent bed. Therefore the backwater elevation remains lower. If the roughness $k_{st,d}$ differs from the basis value $k_{st,basis} = 35\ m^{(1/3)}/s$ it can be determined as follows:

$$f_r = 1 - \left(\frac{1}{3} \cdot \frac{k_{st,basis} - k_{st,d}}{k_{st,basis}} \right) = 1 - \left(\frac{1}{3} \cdot \frac{35 - k_{st,d}}{35} \right)$$

With rising specific discharge Hq_d the backwater elevation upstream of the net rises too, if the other parameters are not changed. This is considered with the factor f_q:

$$f_q = \sqrt{\frac{Hq_d}{q_{basis}}} = \sqrt{\frac{Hq_d}{3{,}0\ m^3/sm}}$$

Not changing the other boundary conditions, the finer the entrapped woody debris, the denser the log jam develops and the higher the water level rises upstream. Especially the percentage of the so called “green wood” (small branches with leaves, short twigs) has great influence, shown in the factor f_{FA}:

$$f_{FA} = 1{,}38 \cdot FA^{0{,}17}$$

The “vertical” design height $h_{d,vert}$ then is:

$$h_{d,vert} = f_r \cdot f_q \cdot f_{FA} \cdot h_{d,0}$$

Compared with vertical banks inclined banks also reduce the backwater elevation. If the water level rises, it also gets broader at the net and so the woody debris has more space to spread. Therefore a bank-inclination of 1:m reduces the backwater elevation to $h_{d,m}$. For some common boundary conditions (broadness 5,0m < b_s < 15 m and $h_{B,vert}/h_f > 3$) Fig 4 shows the values of $f_{bank} = \frac{h_{d,m}}{h_{d,vert}}$. For other cases it can be determined by iteration out of the following equation:

$$m \cdot h_{d,m}^3 + b_s \cdot h_{d,m}^2 - m \cdot h_u^2 \cdot h_{d,m} - b_s \cdot h_{d,vert}^2 = 0$$

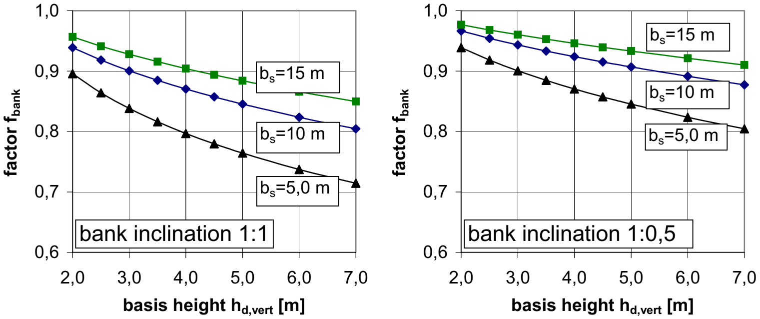

Fig 4: Factor for bank inclination in common situations

Effect of gravel entrapment

After entrapping woody debris a small impounded lake develops in which gravel sediments. Normally the woody debris arrives within a short time during the flood event, whereas with transportation and sedimentation of gravel the time is much longer. If the volume of gravel V_G reaches $V_{G,1}$ it starts to influence the log jam (comp Fig 5). For $V_{G,1} < V_G < V_{G,2}$ the log jam gets denser, which causes higher backwater and higher forces. It the volume of sediment V_G exceeds $V_{G,2}$ the gravel dominates and the woody debris in no longer important for the design. The threshold volumes $V_{G,1}$ and $V_{G,2}$ can be determined by the following equations:

$$V_{G,1} = \frac{1}{2}\frac{(h_{G,1})^2}{I_{So} - I_{GG}} \quad \text{with } h_{G,1} = h_{d,m} - I_{So} \cdot 5 \cdot h_{d,m} - h_{GG} \text{ ; } h_{GG} \text{ see Fig 5}$$

$$V_{G,2} = \frac{1}{2}\frac{(h_{d,m} - h_{GG})^2}{I_{So} - I_{GG}}$$

Thus for the estimated gravel volume V_G the following conclusions can be drawn and the design height is:

(a) $V_G < V_{G,1}$ $\Rightarrow$ woody debris decisive $h_d = h_{d,m}$

(b) $V_{G,1} < V_G < V_{G,2}$ $\Rightarrow$ woody debris and gravel $h_d = \max(h_{d,m}; h_{d,G}) + 1{,}0\text{m}$

(c) $V_G > V_{G,2}$ $\Rightarrow$ gravel decisive $h_d = h_{d,G} = \sqrt{2 \cdot V_G \cdot (I_{So} - I_{GG})} + h_{GG}$

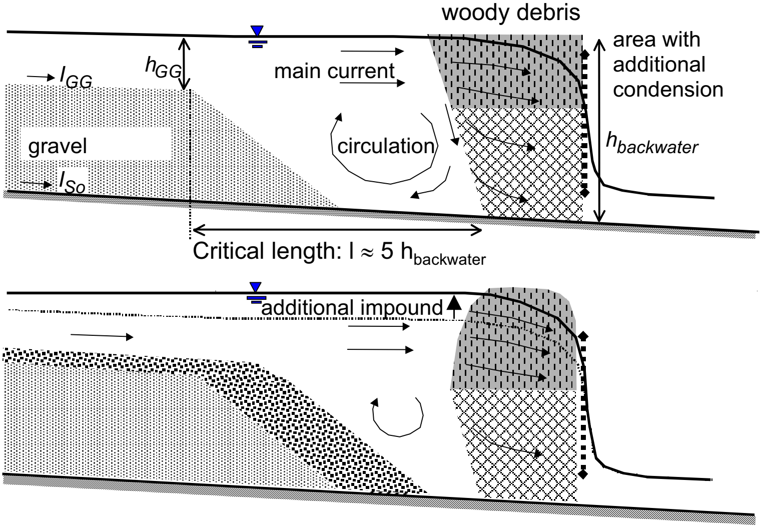

Fig 5: Effect of sedimentation on log jam and backwater elevation

Barrier height h_d

The above calculated design height is the required height of the net barrier or the distance of the uppermost rope to the torrent bed. To get an idea of the influence of the main design parameter on the barrier height h_d some calculations have been done, which are shown in Fig 6.

Distance a, torrent bottom to net base

For each individual net barrier the distance a (comp Fig 2) of the lowest rope to the torrent bottom has to be determined by careful consideration of the required security level downstream of the barrier and the flow conditions at the barrier. If it is chosen too low, the entrapment process starts very early (mainly with fine material) and possibly the barrier is filled up too quickly. If it is chosen too high, large logs can pass beyond the net and can cause log jams in the downstream torrent bed.

A clue for the distance is the flow depth for which significant transport of woody debris or larger logs starts. An estimation therefore is the flow depth of a 5 to 20 year flood. If this is not known, take between 0,50 and 1,0 m. If there is a low danger for log jams downstream (wide steady torrent bed) it can be enlarged to allow more fine material to pass in the beginning. With a high danger potential a lower height a should be chosen.

Important: with loading of the net, the distance between the torrent bottom and the rope can increase! Without loading the rope hangs down due to its weight. With the beginning of the entrapment process the horizontal load of the water pressure causes a deflection into the flow direction. Due to the influence of the neighbouring net a vertical component occurs, which causes even a vertical deflection (comp Fig 7). If necessary this effect can be reduced by columns, which then have to be designed for impact forces. and the vertical component due

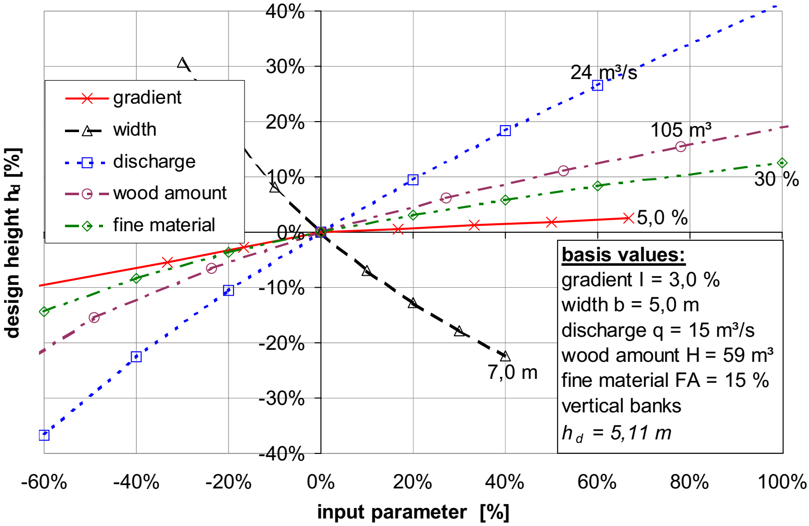

Fig 6: Effect of changing input parameters on design height

CONSTRUCTIONAL DESIGN

Net loading

For the cases (a) and (b) (woody debris decisive) the loads onto the net are determined by the the design height h_d considering the hydrostatic water pressure and the momentum. If gravel is predominant (case (c)) the active earth pressure under assumption of the wet density of the material is sufficient.

Dimensions of the individual ropes

This step of the net barrier design is an iterative process: after choosing a rope diameter and rope distances the loads on the individual ropes are determined. If necessary the diameters and distances are adapted and a new computation is carried out.

The total load onto the net (based on the design height h_d) is distributed among the individual ropes according to the run of the water pressure. The influence height for the loads onto a single rope is the sum of half of the distance between the considered rope and the two neighbouring ropes at a time. For the lowest and highest rope the influence height extends from half the distance to the next rope to the torrent bottom or to the water level respectively (comp. Fig 7).

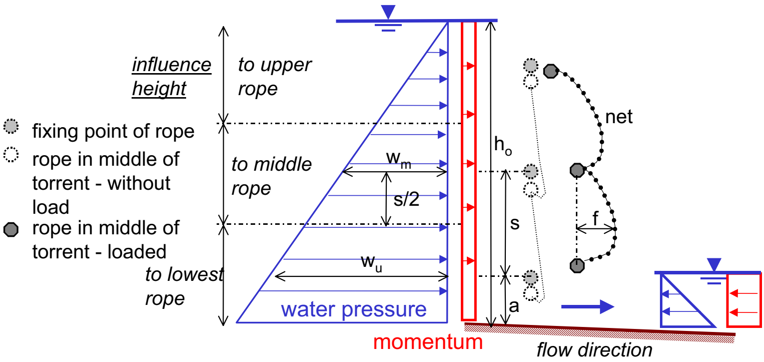

Fig 7: Load distribution to the individual ropes (cross section of barrier)

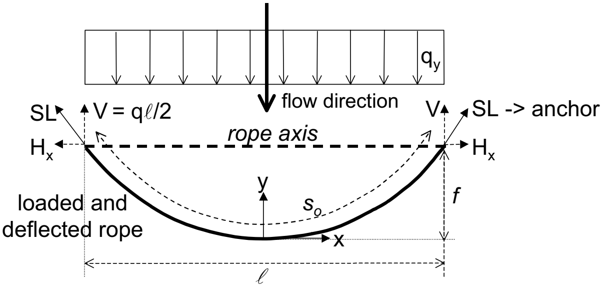

Fig 8: Signs to determine rope and anchor forces (layout of rope)

The pressure and this influence height leads to the rope load q_y. To determine the horizontal component H_x of the longitudinal rope load the Newton iteration is used to solve the universal rope equation, whereas the temperature is neglected (comp. Palkowski (1990)). For all signs see Fig 8. As starting value $H_{x,1}$ for the iteration choose EA -> ∞ and determine:

$$H_{x,1} = q_y \cdot \ell \cdot \sqrt{\ell / (24 \cdot (s_0 - \ell))}$$

with s_0 = total length of the installed rope: $s_0 = \ell \cdot \left(1 + \frac{8}{3} \cdot \left(\frac{f}{\ell}\right)^2\right)$

The following steps i+1 of the iteration are calculated out of the value for the step i as follows:

$$H_{x,i+1} = \frac{2 \cdot H_{x,i}^3 + EA \cdot \left(1 - \frac{\ell}{s_0}\right) \cdot H_{x,i}^2 + \frac{EA \cdot q_y^2 \cdot \ell^3}{24 \cdot s_0}}{3 \cdot H_{x,i}^2 + 2 \cdot EA \cdot \left(1 - \frac{\ell}{s_0}\right) \cdot H_{x,i}}$$

Normally after three or four steps the result is sufficiently exact. Finally the longitudinal rope force resp. design force for the anchors SL is:

$$SL = \sqrt{H_x^2 + (q_y \cdot \ell / 2)^2}$$

The security factor for the ropes should be at least 1,1 and for the anchors higher, e.g. 1,3. This considers the fact, that the ropes can be changed easily, whereas anchoring is costly.

In vertical direction the net can be regarded as a rope to simulate the load distribution to the main carrying ropes. Thus vertical load components onto the carrying ropes result. In the middle ropes the two vertical loads resulting from the lower and the upper part are almost in balance. For the lowest and highest rope due to the vertical loads the longitudinal rope force increase about 10 %, for very taut nets even more.
The lowest rope is decisive for the whole construction, as it is very exposed and receives high loads. For security reasons only a small distance should be chosen between this rope and the next higher one (up to about 0,5 m). The effect of several varying rope and construction sizes on the longitudinal rope force in the lowest rope is shown in Fig 9.

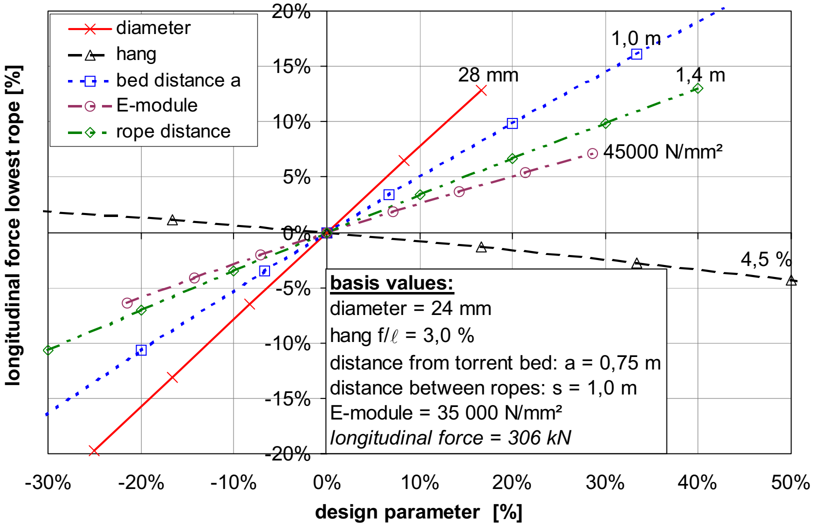

Fig 9: Effect of several rope and construction sizes on the longitudinal force in the lowest rope

Examination of dynamic forces

Normally the dynamic forces can be neglected, because the static loads are very high and decisive for the design. With high flow velocities v in the torrent ($v > 3{,}0$ m/s) and very large transported logs ($L > 7{,}5$ m) with the mass m, it should be examined if the rope force due to the impact is decisive in the lowest rope:

$$SL = \sqrt{\frac{EA \cdot m \cdot v^2}{\ell}} \qquad \text{EA: rope}$$

Further suggestions for net construction

Ring nets are recommended because of their good load distribution and elasticity. They should be installed quite limp to allow large deformations under load and reduce the vertical stress. Like the distance from the torrent bottom, the width of the mesh should be chosen according to the required security level downstream. For example take: ring diameter 0,30 m for smaller barriers and 0,50 m for barriers with more than 7,0 m width. To allow an early entrapment of woody debris and to ensure enough spare entrapment volume for large logs and gravel in later stages of the process it is also possible to choose a net with small width of the mesh in the lower part and a larger width in the upper part of the barrier. The anchors should have an inclination of about 10 to 20 degrees towards upstream of the net plane.

It is very important to protect the torrent bed from erosion in the vicinity of the net barrier. Because of the high water level upstream of the net and the currents beyond the log jam, at least twice the length of design height h_d up- and downstream of the net plane should be paved. For full energy dissipation a special calculation and design is necessary. The up- and downstream end of the pavement needs to be reliably secured.

If the layout of the rope net barrier has the form of an “v” (point downstream) like the rakes (comp. Fig 3 and Knauss (1995)), the backwater level can be reduced by about 10% compared to straight nets perpendicular to the direction of flow.

Brake elements, which are used for rockfall barriers, are not recommended because the loads onto woody debris barriers are mainly static. Furthermore the lengthening of the ropes due to brake elements can enlarge the distance between rope and torrent bed, allowing a lot of woody debris to pass beyond the net.

Concluding points

In every case the design has to be carefully adapted to the danger potential downstream and the individual boundary conditions. The erected barriers have to be well observed. After an entrapment they must be cleared quickly and all construction parts must be checked.

Example

In the following a design example is introduced for some typical boundary conditions.

boundary conditions:

torrent: gradient I = 3,0 %; discharge q = 3,8 m^3/sm; roughness k_{st} = 25 $m^{(1/3)}/s$
woody debris: amount H = 8,2 m^3/m; percentage fine material: 15 %
gravel: V_G = 150 m^3/m; I_{gg} = 2,0 % -> not decisive; only woody debris
ropes: ø 22 mm; E = 32 500 kN/mm²

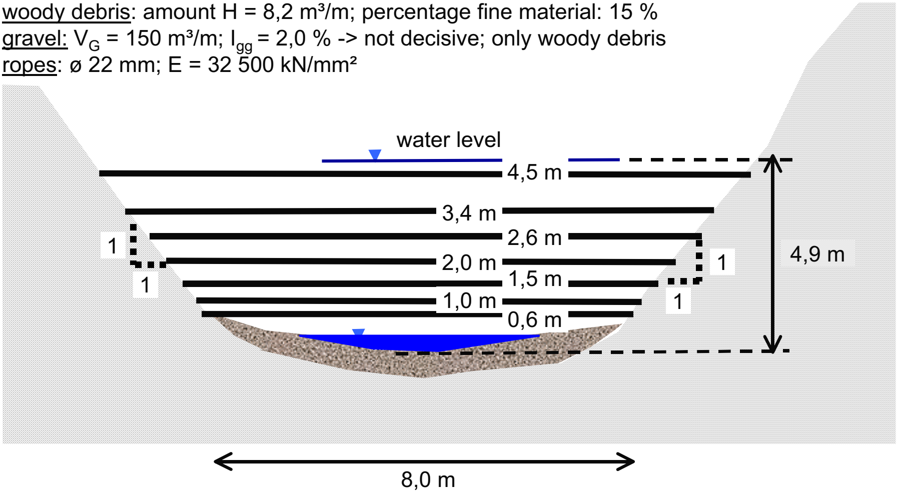

Fig 10: Example for a rope net barrier according to the design concept

If a rope diameter of 26 mm is chosen, 5 ropes in the heights of 0,6 m, 1,2 m, 2,0 m, 3,0 m and 4,5 m are enough.

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