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GEOTEXTILE REINFORCED SOIL STRUCTURES ON WHICH VEGETATION CAN BE ESTABLISHED
OUVRAGES DE SOUTENEMENT VEGETABILISABLES EN TERRE ARMEE PAR DES GEOTEXTILES
BEGRÜNBARE STÜTZKONSTRUKTIONEN AUS GEOTEXTILARMIERTEM ERDMATERIAL

Using a combination of retaining mesh, non-woven vegetation fabric and reinforcing geotextile (special non-woven fabric), reinforced soil retaining structures can be simply constructed and subsequently completely vegetated. The system, for which a patent under the name TEXTOMUR has been applied for, offers distinct advantages in terms of dimensional stability during construction, vegetation, and subsequently in maintenance (machine mowing of the embankment slopes). Design is carried out using the STRU stability calculation method developed by P. Steiner and R. Rüegger which utilises circular slip planes to calculate the tensile loads in and the corresponding length of the geotextile reinforcement.

1. THE CONCEPT OF THE TEXTOMUR SYSTEM

The TEXTOMUR system offers the following possibilities which have not, or at best partially, been fulfilled by geotextile reinforced constructions used to date:

- over-steep slopes capable of supporting vegetation over their entire surface area
- use of local subgrade soil as principal construction material
- dimensionally stable, flat slope surface for easy maintenance (machine mowable)
- flexibility in use

The TEXTOMUR system consists of three main elements:

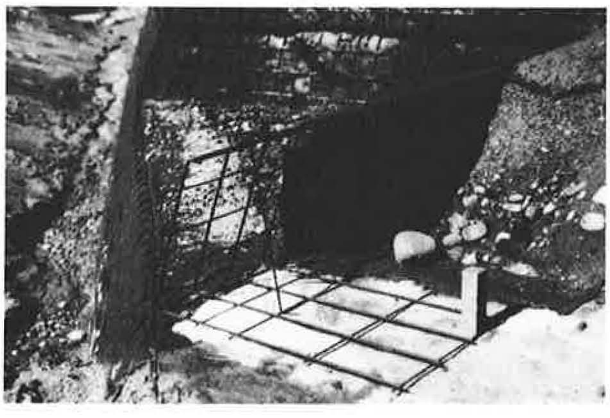

Photo no. 1: Construction elements

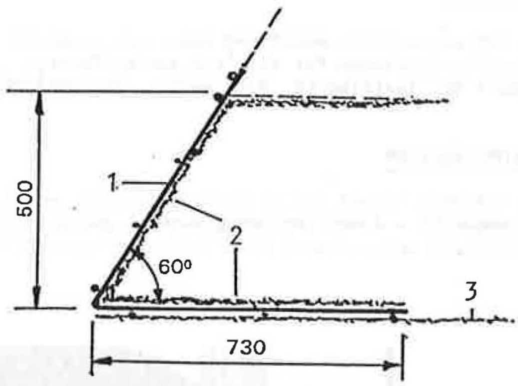

Figure 1: Section through standard construction

(1) The TEXTOMUR retaining mesh (standard mesh)

Length of unit	5.0 m	Height of unit	0.5 m
Width of unit	0.73 m	Mesh width	0.15 m
Transverse rod dia.	10 mm	Longitud. rod dia.	6/10 mm

During construction the retaining mesh (1) performs the function of a sacrificial shuttering and guarantees the dimensional stability. It must provide local surface support until a root layer is sufficiently established. The roots then provide adequate reinforcement to ensure that long term corrosion of the mesh can be accepted.

(2) The FLN vegetation fabric

Open-pored non-woven with polyester carrier mesh

Area mass	μ = 400	g/m2
Tensile strength	α_f = 20	kN/m
Embedded length in soil (top and bottom)	L = 0.7	m

The vegetation fabric (2) is laid ount into the retaining mesh (1) and fulfils a number of roles due to its special construction:

- protection of the fill material against wind and water erosion
- support and carrier fabric for the seeding (Hydroseed)

(3) The FLN non-woven reinforcing fabric

Mechanically-bonded (needle-punched) polyester non-woven fabric

Aerea mass	μ =	300	g/m2	
Tensile strength	α_f =	40	kN/m	
Extension at break	ε_f =	40	%	(approx.)
Working load	z(adm.) =	13	kN/m	
Extension at z(adm.)	ε_z =	10	%	(approx.)

(Extensions measured in strip test)

This reinforcing fabric is a special non-woven in which high strength at low extension is achieved by means of special fibres laid anisotropically in stress direction.

The FLN geotextiles mentioned above are products specially developed for this end use by Messrs. Landolt AG, Textilwerke, 8752 Näfels, Switzerland.

2. CONSTRUCTION

The TEXTOMUR system can be constructed with a minimum of labour (3 - 4 men including machine operators) and machines (tractor shovel plus roller for compaction).

Photo no. 2: Placing the initial layer

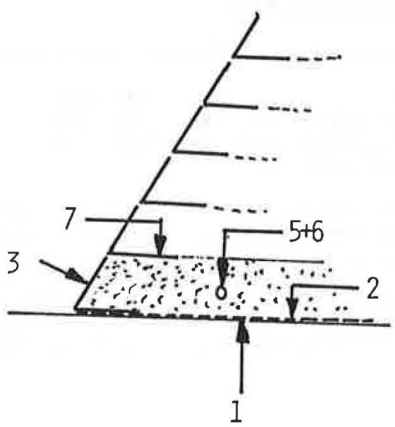

Fig. 2: Construction sequence

Construction sequence (Fig. 2)

1. prepare formation
2. roll out non-woven reinforcing fabric
3. place retaining mesh
4. lay vegetation fabric
5. place fill material
6. compact layer
7. new formation
8. repeat steps 1 to 7 until final height

3. DESIGN

The design is carried out by means of a stability analysis using slip circles. For the project described here, P. Steiner and R. Rüegger (the author) developed the STRU method which, when compared with the well known methods of BISHOP or JANBU, offers the same degree of accuracy with the following advantages:

- direct safety factor calculation without iteration
- applicable to all polygonal slip surfaces (i.e. not only circular shapes)
- can also be used for very steep failure planes
- for linear slip planes, the method is identical to Coulomb earth pressure measurement

The method uses single slices.

The basic principle involves setting up the stability along the failure plane, without regard as to whether the overall component stability or moment stability is fulfilled. The safety factor is defined as the ratio along the slip plane of the forces causing sliding to those resisting it (Fig. 3)

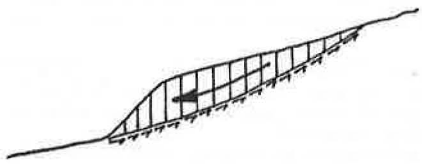

Fig. 3: Model of STRU method

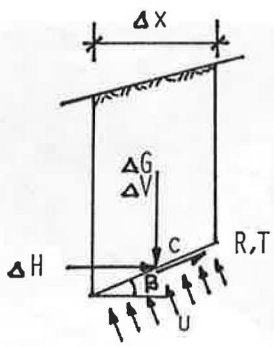

Fig. 4: Individual slice - STRU method

Key fig. 4:

- ΔG = wt. of slice
- $\Delta H, \Delta V$ = internal or external forces resolved into horizontal and vertical components (e.g. anchor forces, geotextile force, hydraulic pressure)
- Δx = width of slice
- β = angle of slip plane to horizontal
- u = pore water pressure
- R = "opposign shear force"
- T = "driving shear force"

Calculation formula:

$$\text{Safety } FS = R / T \tag{1}$$

$$FS = \frac{\sum \left[\frac{c \cdot \Delta x}{\cos\beta} + \left((\Delta G + \Delta V)\cdot\cos\beta + \Delta H\cdot\sin\beta - \frac{u\cdot\Delta x}{\cos\beta}\right)\cdot tg\varphi\right]}{\sum \left[(\Delta G + \Delta V)\cdot\sin\beta - \Delta H\cdot\cos\beta\right]} \tag{2}$$

Three steps are necessary in the design of a geotextile-reinforced retaining structure:

a) Calculation of required tensile force:

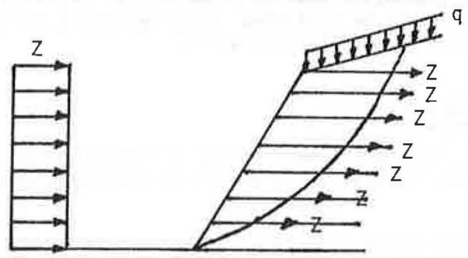

Fig. 5: required tensile force z

Using the stability analysis STRU already described, the tensile force z required of the reinforcing fabric is calculated. The minimum factor of safety required is usually FS = 1.30.

Assuming a rectangular distribution of tensile force, the slip circle requiring the greatest tensile force is found. The justification for the rectangular force distribution based on static and kinematic considerations can be found in the chapter "Embankments and Retaining Structures" in literature ref. [1].

b) Width of reinforced zone:

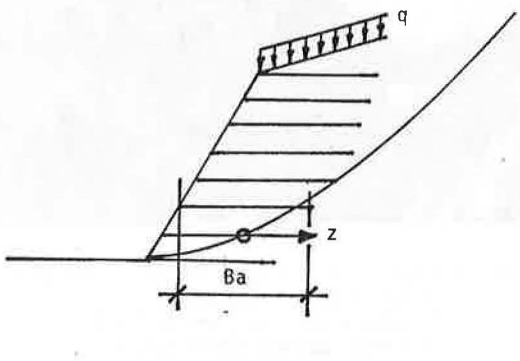

Fig. 6: Width of reinforced zone Ba

The stability of every potential slip circle containing the reinforced zone must be investigated. In each case, the lowest slip circle is the critical circle, and determines the length of the reinforcement in the last layer considered in the calculation (usually FS = 1.30)

c) Anchor length

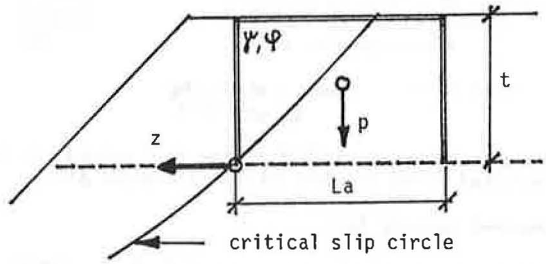

Fig. 7: Anchor length

Behind the critical slip circle calculated in a), the minimum anchor length calculated from the soil pressure and the friction between geotextile and fill material must be complied with.

Calculation formula: $La \geqslant \frac{f \cdot z}{p \cdot tg\varphi_g} \quad p = \gamma \cdot t$ (3)

where:

z	= geotextile tensile force	[kN/m]
La	= anchor length	[m]
p	= vertical earth pressure	[kN/m2]
φ_g	= soil-geotextile friction	[°]
φ_g	= 0.6 - 1.0 * soil friction φ	[°]
FS	= safety factor	[-]
γ	= soil density	[kN/m3]
φ	= soil friction	[°]

*) 0.6 for very fine-grained, clayey soils
1.0 for granular soils

The design method described is generally applicable (see also ref. [1] and is not restricted to the TEXTOMUR system.

The method has been used to develop design diagrams for simple cases (see ref. [1])

a) Input data:

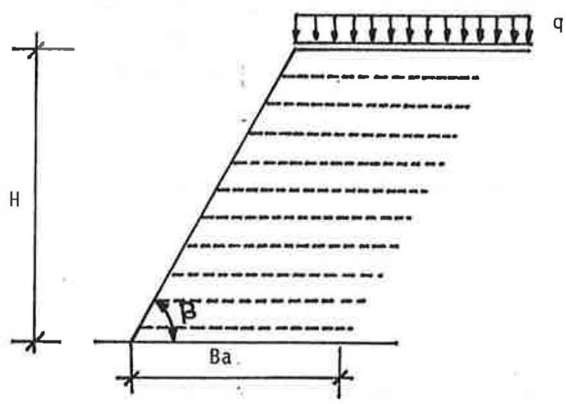

Fig. 8: geometry of retaining structure

Geometry :	H	= height of structure	[m]
	β	= angle of slope	[°]
	Ba	= width of reinforcement	[m]
Fill material:	γ	= density	[kN/m3]
	φ	= angle of friction	[°]
Surcharge:	q	= area load	[kN/m2]
Geotextile:	α_f	= tensile strength	[kN/m]
	z(adm.)	= working load	[kN/m]
	ε_z	= extension at z	[%]

Condition: $z(adm.) \leq 0.3 \cdot \alpha_f$
$\varepsilon_z \leq 10\ \%$

Surcharges of less than 20 % of the fill weight can be approximated using an additional fill height ΔH.

b) Required tensile force

Z(tot)= reqd. tensile force over height H [kN/m]

$$Z(tot) = \lambda \cdot \frac{\gamma \cdot H^2}{2} \quad (4)$$

where λ = design coefficient from Fig. 9 [-] for FS = 1.30
z = specific tensile force = Z/H [kN/m2] (5) (provided by geotextile)
d = spacing of geotextile layers [m]
d = z(adm.) / z (6)

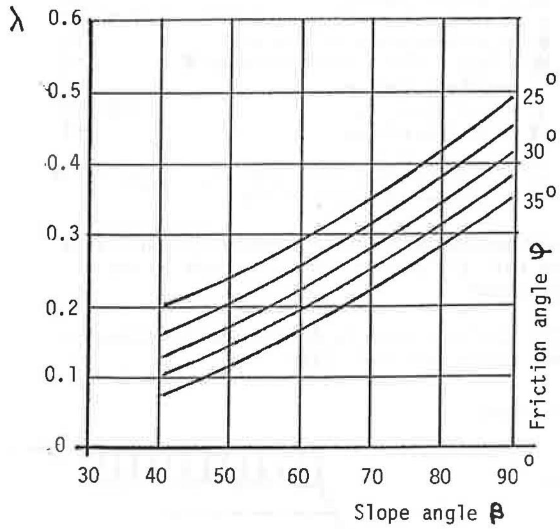

Fig. 9: Coefficient λ for required tensile force Z

c) Width of reinforcement Ba

The required width Ba can be determined as follows:

$$Ba = \nu \cdot H \quad [m] \quad (7)$$

ν = design coefficient from Fig. 10 [-] for FS = 1.30

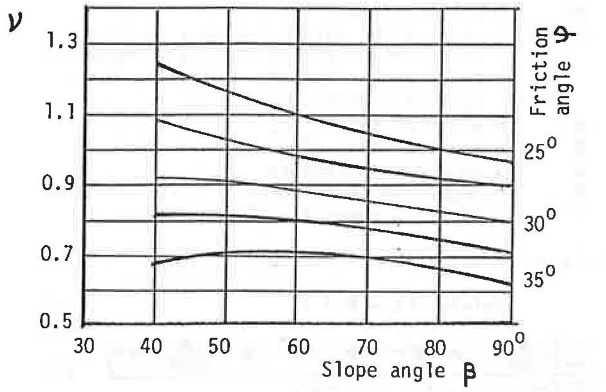

Fig. 10: design coefficient ν for reinforcement width

Structure design using the method outlined assumes adequate foundation bearing capacity. In critical cases this must be confirmed using methods similar to those for gravity retaining walls.

4. VEGETATION

The most important aspect of the TEXTOMUR system described here is that it is easily covered with vegetation.

Total plant cover is only possible on such steep slopes if the so-called Hydroseed technique is used (Fig. 11), whereby slopes with high insolation and poor or no irrigation from the fill mass require usually a two layer spray application.

Photo no. 3: Grassed and mowed reinforcing structure 4 months after completion
Location: Herisau, Switzerland
altitude approx. 800 m a.s.l.
SW exposition of main slope.

The system permits bush and shrub layers to be incorporated (Fig. 12,13) as the structure is being built.

Plant types must be very carefully selected according to the climatic conditions prevailing at the site, and experienced specialists should be involved from the design stage on.

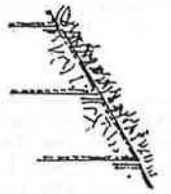

Fig. 11: Hydroseed

- grass appropriate to locality sprayed on in 2 layers (carrier and seed layer)
- machine mowable
- grassing normally done with special low growing blends for minimum maintenance (1 - 2 mowings / year).

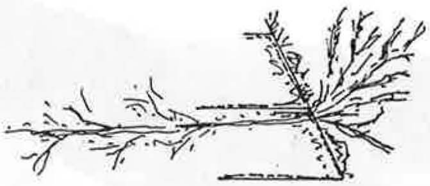

Fig. 12: Bush layers

- direct planting of young branches combined with Hydroseed
- main plant types: locality-appropriate willow sorts
- good additional reinforcing and drainage function

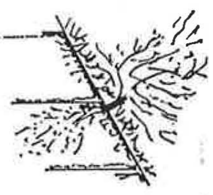

Fig. 13: Shrub layers

- direct planting of rooted plants combined with Hydroseed
- depending on plant type, may be used in dry embankments (e.g. acoustic protection walls)
- plant selection depends on locality, usually sorts such as:

elder	alder	willow
hazel	honeysuckle	mountain ash

Photo no. 4: Bush layers approx. 4 months after planting

5. AREAS OF APPLICATION

The TEXTOMUR system has many applications. The main areas are:

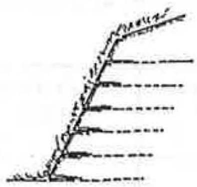

Fig. 14

End slopes
Embankments/cuttings
Alternative to retaining walls

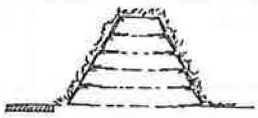

Fig. 15

Acoustic protection walls
Embankments protecting against falling stones or avalanches

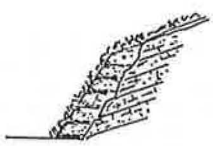

Fig. 16

Screen walls in front of rock faces

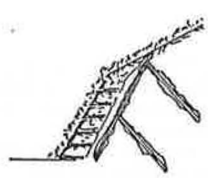

Fig. 17

Screen walls combined with soil stabilisation (infiltration anchors)

6. TRIAL STRUCTURE

A steep slope 20 m long and 4 m high was constructed in July 1985 as part of a programme to investigate the deformation behaviour and establishment of vegetation.

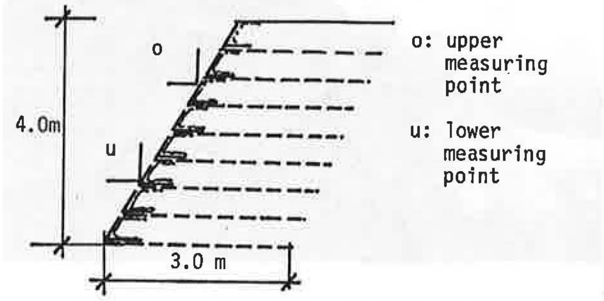

Fig. 18: Section through test slope

The fill material used was a silty sand (USCS classification SM) which was installed in 0.5 m thick layers and compacted using a 1.5 tonne vibrating roller.

The following average deformations in mm were measured:

Time	at 1/3 final height H	V	at 2/3 final height H	V
Between reaching measuring point & completion of construction	20	10	30	20
Deformation 1 month after completion	35	20	55	35
Deformation 3 months after completion	35	20	55	35

H = horizontal displacement
V = vertical displacement

The deformations occurred in part stepwise after rainfall had led to complete wetting of the fill. Three months after completion, no further movement in either horizontal or vertical planes was to be observed. The total displacements correspond to approx. 1.4 % of the height of the structure. They are thus in line with displacements recorded in rigid retaining structures designed with active earth pressure.

The measurements confirm practical experience which has indicated that geotextile reinforced structures exhibit significantly lower deformations than would be expected from the strip tensile behaviour of the geotextile at the equivalent of the design load in the structure.

This also highlights the questionability of applying properties measured in isolation to geotextile reinforced structures.

In the author's opinion it is perfectly permissible to design geotextile reinforcement using classical equilibrium state design methods which do not take account of deformation. Geotextiles with relatively high extensions - measured in laboratory strip tests - can be used at working loads of 10 - 15 % even in low deformation structures.

The vegetation selected was a success (see Photos nos 3 - 6). The bush and shrub layers planted during construction have both flourished, and the Hydroseed provided a complete grass cover after about two months despite a hot, dry July and August and the south-west exposition of the main slope.

Photo no. 5: Test slope immediately after construction

ACKNOWLEDGEMENTS

The following participated in the development of the TEXTOMUR system:

Peter Steiner, c/o Rüegger AG, 9013 St. Gallen (Idea, Design calculation)
Eugen Schwitter, c/o Landolt AG, 8752 Näfels (Geotextiles)
Anton Eberle, c/o Eberle AG, 9100 Herisau (Vegetation)

REFERENCES

[1] Das Geotextilhandbuch (The geotextile Handbook), Swiss association of Geotextile Specialists, c/o Empa, 9001 St. Gallen, 1985