SMOLTCZYK, U. and MALCHAREK, K.
University of Stuttgart, Stuttgart, Federal Republic of Germany

Living Sheets on Steep Slopes

La stabilization végétal de talus très inclinés

Steep slopes covered and stabilized with natural landscaping materials in conjunction with geotextiles were constructed in order to determine their effectiveness and economy. A trial pit was dug with the sides set at steep slopes and three segments were formed for testing purposes. The first segment was left to weather normally as a control reference: the second was stabilized with geotextile bags filled with crushed limestone and strengthened with living willow shoots: the third was faced down the slope with geotextile matting staked into position and sprayed with a seeded mulch. Over a period of seasons the slopes were monitored and it was seen that the young willow shoots had grown strongly and that their segment of the slope had remained stable, whereas the other two segments had suffered weathering and surface slipping. The use of the geotextile bags in conjunction with the willows had thus enabled a significant improvement in the stability of the soil slope to be achieved. Larger tests are planned, formulae will be drawn up and further research will seek optimal aspects.

La stabilisation de talus très inclinés à partir de couverture et texture végétales se révèlerait efficace et économique. Des essais ont été effectués dans une fouille à parois très inclinées, divisées en trois tranches: la première laissée telle que, servit de témoin pour mesures de contrôle. La seconde stabilisée par des boudins de géotextile à remplissage de calcaire concassé renforcé de plants de saule. La troisième stabilisée par une couche de terre rapportée armée d'un treillis synthétique et ensemencée. A la fin du premier cycle végétal on a pu observer le bon développement des jeunes plants de saule, la tranche est demeurée stable, tandis que les deux autres tranches montraient des traces d'érosion et glissements. L'emploi de boudins géotextiles combinés avec le saule a influencé fortement la stabilité du talus. Des essais plus étendus sont prévus dans le but de déterminer avec précision les conditions optimales de mise en oeuvre.

1 SCOPE

The complexity of embankment construction projects becomes increasingly handicapped through the difficulty of proving appropriate surfaces for them. Moreover, the public is increasingly demanding that modern roads make less impact upon the environment and that, where large through streets occur, noise protection embankments or walls are provided or that the streets are set in cuttings or roofed over.

From these requirements there comes an economical demand to seek to develop the inherent strength of slopes and to achieve two objectives: to permanently stabilize the slopes without extensive building operations and to minimize the surface areas required.

It was decided to investigate the possibilities which presented themselves in Baden-Württemberg if one is required to produce steep slopes in weathered soft rock of Keuper age. Following a suggestion by the first author, the concept of a living sheet was developed. Consultations took place with engineer biologist Professor Schiechtl, Innsbruck, and Dipl.-Ing. Härle of the Highway Department, Baden-Württemberg. The authors thank both these gentlemen for their valuable suggestions.

2 PHYSICAL SOIL ASPECTS

Normal experience indicates that the Keuper - which predominantly contains clay minerals such as Illite, Corrensit and Chlorite and has a small-fissured, stratified structure with deposits of sandstone banks and Dolomite layers - will, when first cut, stand almost vertical to a height of 15 - 20 metres. However, under weathering action, strenght is lost and the material moves forward so that fractures occur in increments and screes form at the foot of the slope.

The cut face is only stable as long as the cohesion of the materials is able to resist tension forces within the soil body. Due to the horizontal relaxation of the soil following excavation of the hill, fissures are formed vertically and falling rain is allowed to enter so as to further accelerate the weakening of the material.

In order to favourably influence the maintenance of the soil cohesion through building techniques it is necessary to insulate the freshly exposed cut face against the atmosphere, as is regularly done in building excavations by means of shotcrete.

Figure 1 is a photograph of the claystone structure as is often met with. The seepage water flows out only sporadically because the material is generally impervious to water. The fissured matter has only a relatively insignificant strength and allows itself to be easily loosened and broken in the hand. The consistency fluctuates between stiff and semi-firm, the water content being predominantly below the plastic limit.

If the weathering is not prevented, then the soil deteriorates into a clay slurry with a shear angle of 15° to 20° and the effective cohesion decreases from an initial value of 50 - 100 kN/m² down to practically zero.

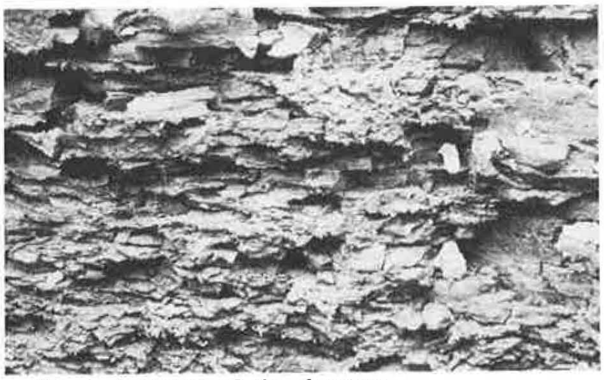

Fig. 1 Structure of the claystone

However, before reaching the minimum strength, the slope fails.

3 INVESTIGATED SOLUTIONS

In a test pit of 5 m depth, Figure 2, two 20 m long slopes with an inclination of 2:1, corresponding to a slope angle of 64°, wre formed. This appeared to be the steepest slope workable in the use of living sheets, described below. The soil succession here was a 1.7 to 2.0 m coverlayer thickness of gravelly to stoney loam, underlain by 0.3 to 0.4 m of thick chalkstone band underlain by that which was shown in Figure 1, namely stiff to semi-firm claystone (Formation: Black Jura, Lias α).

The soil mechanics parameter are:

$$w = 11 - 14\ \%,\ w_L = 32 - 37\ \%,\ w_p = 14 - 19\ \%,$$
$$\phi' = 22°,\ c' = 80\ kN/m^2$$

whereas the soil parameters of the cover layer are:

$$\phi' = 20°,\ c' = 14\ kN/m^2.$$

If a uniform layer of unit weight 21 kN/m is applied then the slope remains stable, as the effective cohesion is kept above 10.5 kN/m². The slope lengths were arranged into three segments (Figure 2): an unstabilised control segment 1, at which the pregressive weakening of the earth slope was studied; segment 2 which was stabilised with HaTe bags in a form developed by IGB; segment 3 which was stabilized by the use of Enkamat mats and green planting.

Figure 3 shows cross sections through the slope stabilised using the IGB method and demonstrates that two distinct geometrical shapes were chosen for testing. Moreover, the placing of a small berm provided advantages for access to the willow branches during trimming.

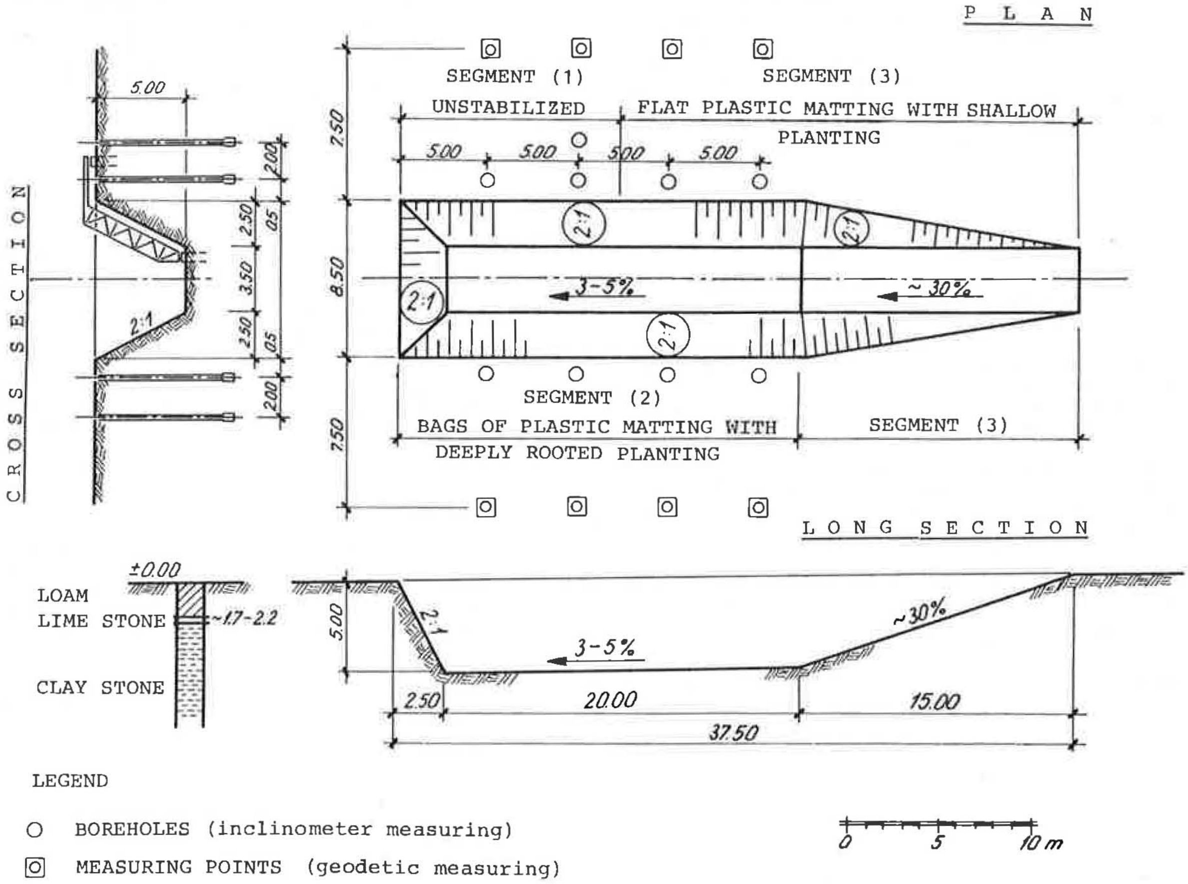

Fig. 2 Test pit

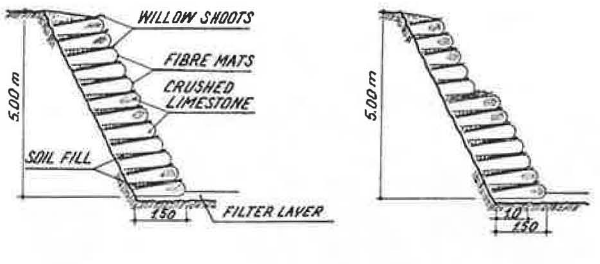

Fig. 3 Slope stability in cross sections

Figure 4 shows as cross section of the construction in greater detail whilst Figure 5 is a photograph of the matting. 4.0 m wide mats were arranged to form courses of 1.5 m width, each course being filled to a depth of 40 cm with size 0 - 45 mm crushed limestone. The upper surface of each course was laid to a slope of about 10° to the horizontal (required by the living sheets) and was covered with about 10 cm of bedding soil in which the willow shoots were laid at 0.1 m centres in April 1980.

The installation procedure is illustrated in Figures 6 to 8. Formation of the bag shape was facilitated by use of a piece of half section pipe. Consolidation was effected by four passes of a small vibrator.

To stabilize the ENKA mats, Figure 9, a 20 mm thick plastic fabric was hung over the slope and spiked and was then sprayed with a mexture of straw mulch, adhesive and grass seed. The method of installation is well known and simple and was able to be done by the Institute people themselves.

4 ACCOMPANYING SURVEY

The question of which accompanying survey - apart from the laboratory soil mechanics tests - was reasonable for the control of the work was not easy to answer, because appearance was the only real control. In addition to the geodetic measuring (see Figure 2), 10 measurement points were chosen for inclinometer measuring, in order to follow possible movements of the slope. Of course, continuous meteorological data were recorded. To our knowledge, there were no testing procedures known for the control of progressive weakening of an unsafe earth

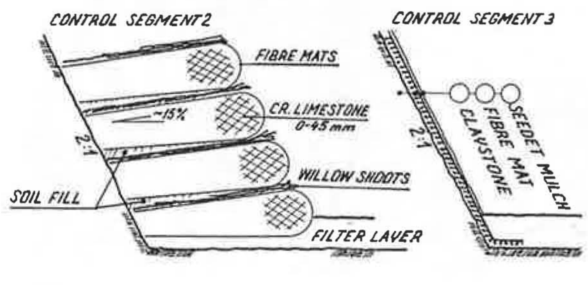

Fig. 4 Details of the slope stability in control segments 2 and 3

wall. We therefore built ourselves a travelling framework, as seen in Figure 10, to enable us to take point soundings on the slope.

TYPE 43.144 α_f = 39 kN/m²

TYPE 30.143 α_f = 35 kN/m²

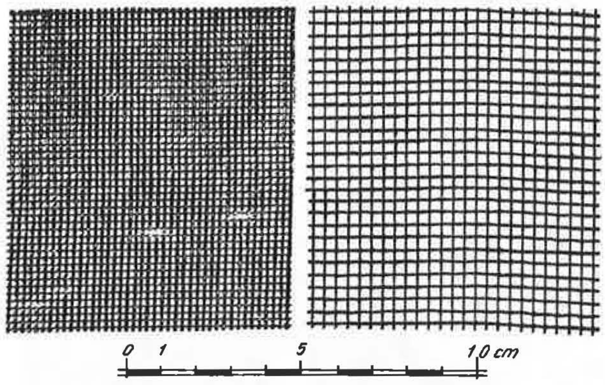

Fig. 5 Structure of the HaTe mats

Fig. 6 IGB stability slope, partly constructed

Fig. 7 IGB stability slope, partly constructed

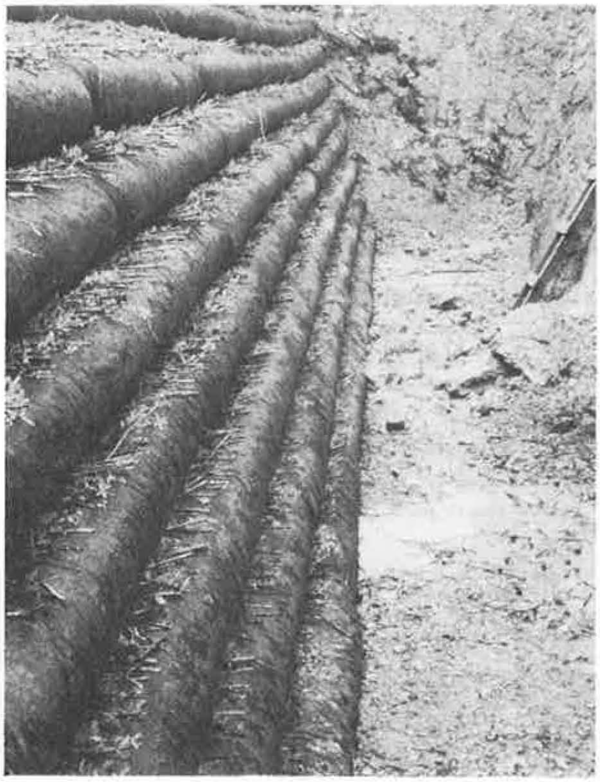

Fig. 8 IGB stability slope, partly constructed

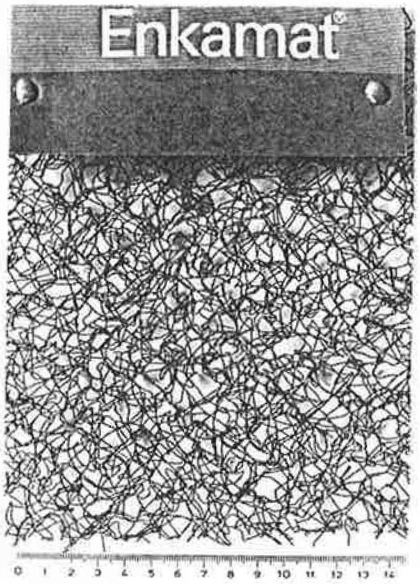

Fig. 9 Structure of the Enkamat mat

Fig. 10 Travelling framework for control measurements on the slope

5 RESULTS TO DATE

In spite of the fact that the planting was not carried out in the optimum season, the plants grew satisfactorily and after only two months had reached the stage shown in Figure 11, where generally the plastic fabrics were not visible outwardly.

Large differences were exhibited in the stability of the construction types. whist in the IGB segment no measurable slips were recordet and the slope remained unchanged over a full summer-winter period, the surface of segment exhibited slipping and an example of this is shown in Figure 12. It became loosened through the considerable rainfall experienced in 1980. We see here a clear advantage of the solution using bags, which hold a sufficient volume of water for the use of the plants yet allow seepage to prevent the development of eccessive water pressures behind the vegetation.

A drainage system was installed in the valley floor to collect run-off.

6 FURTHER WORK

According to the way that the IGB procedures showed satisfactory practical results, the following matters have yet to be investigated.

6.1 In ggreement with the Highway Department of Baden-Württemberg the method will be used to construct a 10m high slope over a length of about 100m.

6.2 In order to gain further information prior to the construction of 6.1, a test load will be carried out on the crest of the existing slope to study the conditions of failure under the actions of loads greater than self weight.

Fig.11 Condition of the IGB stability slope after two months

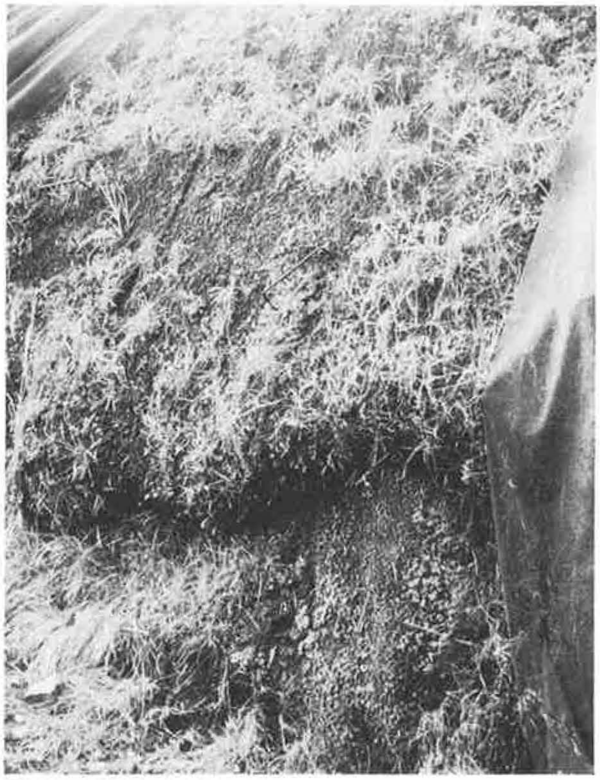

Fig. 12 Slips in control segment 3

6.3 The support frame for the installation of the bags will be extendet to be applicable for any slope height between 3 and 20m.

6.4 Technical improvements will be examined whereby possible optimisation and increased use of mechanisation can be used in the construction.

6.5 Fot the new construction type a soil static stabiloiy verification will be produced.

6.6 Tests will be made of other plant types:essentially, thewillow was chosen for its resistance to salts and its ease of maintenance, for the construction of higher slopes, however, there are possibly other suitable plant types.