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STABILIZATION OF SLOPES IN RESIDUAL SOILS WITH GEOFABRIC
STABILISATION DE PENTES AVEC DES GEOTEXTILES DANS DES SOLS RESIDUELS
BÖSCHUNGSSICHERUNG MIT GEOTEXTILIEN IN VERWITTERUNGSBÖDEN

Woven geofabric has been used successfully in Singapore to stabilize a steep slope in residual soil and weathered rock. Geofabric was wrapped around drains consisting of clean granular materials. The drains were placed in deep trenches along the slope cutting across potential sliding surfaces in the soil. The fabric will then function both as a filter around the drains and as reinforcement in the slope which will increase the stability.

The application of the method to increase the stability of a failed slope in Singapore is described in the article as well as the method that was use to evaluate the effectiveness of the drains as longitudinal reinforcement. No further movements of the slope have been observed after the installation of the drains.

In Singapur wurde ein Gewebe erfolgreich zur Stabilisierung einer steilen Böschung aus Verwitterungsgestein eingesetzt. Mit Geotextil ausgekleidete und mit grobem Kies gefüllte Dränagen wurden in tiefe, die möglichen Gleitlinien schneidende Gräben verlegt. Das Geotextil hat sowohl Filterfunktion als auch Verstärkungsfunktion, was die Böschungsstabilität erhöht.
In diesem Artikel wird das Verfahren beschrieben sowie die Bewehrungswirkung der Längsdränage rechnerisch erfaßt. Nach dem Einbau der Dräns wurden keine weiteren Bewegungen beobachtet.

INTRODUCTION

Landslides in the residual soils or weathered rocks of Singapore are generally rain induced and shallow (Ramaswamy, and Aziz, 1980, Pitts, 1983). This is also the case for landslides in residual soils and weathered rocks in general (Brand, 1984). These slopes when dry or partially saturated are normally stable at inclinations exceeding the effective angle of internal friction, ϕ', of the soil as determined by drained direct shear or triaxial tests. When partially saturated, the negative pore water pressures impart to the soil an effective stress which is higher than the corresponding total stress. The shear strength of the soil is thereby increased, enabling the slopes to remain stable even when the inclination exceeds the effective friction angle (ϕ'). After a heavy rainstorm, or a series of rainstorms, the soil becomes saturated or almost saturated because of the infiltration of the rainwater into the ground. Then the negative pore pressures originally present in the soil are eliminated or drastically reduced, causing a large reduction in the effective stress and of the shear strength. The slope may then become unstable and fail.

STABILIZATION OF SLOPES

Many methods can be used to increase the stability of a slope and to reduce the risk for landslides. These methods may be adopted singly or in combination. The choice depends primarily on the cost and the consequences of failure (Broms, 1975). The more commonly used slope stabilization methods in Southeast Asia include geometrical methods, drainage methods and restraining structures.

Geometrical methods include slope flattening, excavation at the top of the slope, toe filling and replacement of slipped material by free draining material or by recompacted slip debris. Drainage methods include installation of surface and subsurface drains and lining the slopes with a concrete apron. Restraining structures include concrete gravity or cantilever walls, gabion structures, crib walls, earth reinforcement, embankment piles and ground anchors.

USE OF GEOFABRIC FOR STABILIZING SLOPES

The use of geofabric as tensile reinforcement to stabilize built-up slopes or embankments has been described in Holtz (1985). The fabric is usually placed in horizontal layers within the slope. Where an embankment is constructed on soft ground, the geofabric is usually placed at the base of the embankment.

Another way to stabilize slopes with geofabric is described herein. With this new method the stability of existing unfailed slopes can be increased, failed slopes can be stabilized, or new steep slopes or high embankments can be constructed without exceeding the bearing capacity of the soil. In these applications, the function of the geofabric both as tensile reinforcement and as a filter is utilized. The concept is illustrated in Fig 1.

The geofabric which is wrapped around drains consisting of clean granular materials is installed along the slopes as shown in Fig 1. The drains will reduce the pore water pressure within the slopes during the rainy season. Thereby the shear strength is increased. The

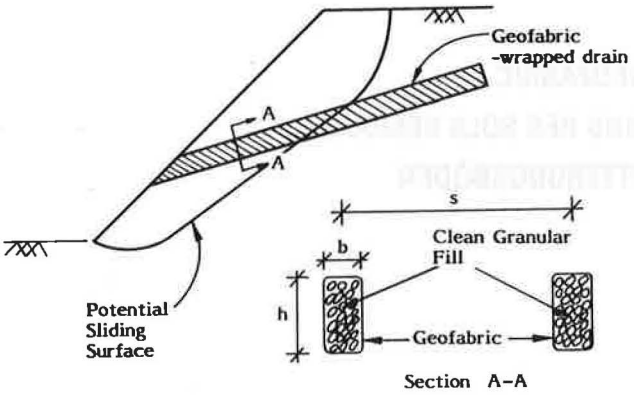

Fig. 1: Schematics of slope stabilization using geofabric wrapped drains

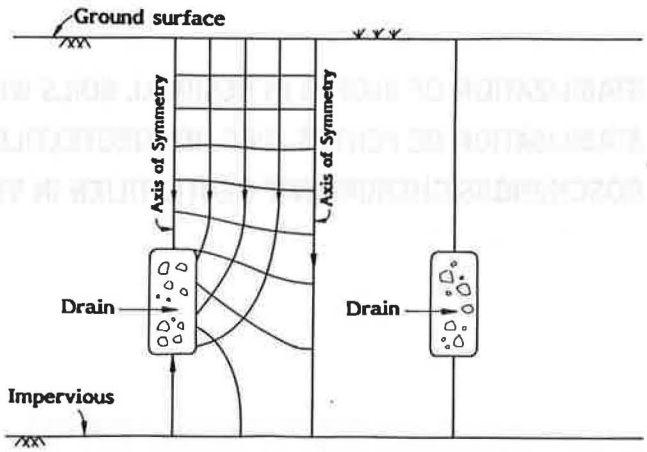

Fig. 2: Flownet showing steady state seepage

geofabric then acts as a filter around the drains which prevents the migration of soil (internal erosion) within the slope into the drains. The geofabric also reinforces the soil along potential sliding zones or planes.

One additional advantage with the new method is that the temporary decrease of the stability of the slope is only marginal during the construction of the deep trenches required for the drains. Only a limited width of the slope is affected. When concrete gravity or cantilever walls are used the stability of the slope can be reduced considerably during the construction of the walls.

Spacing of Drains

The required spacing of the drains wrapped in geofabric as well as the dimensions of the drains depend on the pore water pressures in the slope which can be evaluated by means of a flownet. An example of a flownet that corresponds to steady state seepage after a prolonged rainstorm is shown in Fig 2. The granular material in the drains has been considered to be infinitely pervious in relation to the slope material. The pore water pressure in the slope will be reduced considerably by the drains both above and between the drains as can be seen from the flownet.

For many applications, 0.5 m wide and 1.0 m high drains which are spaced 3.0 m apart would be reasonable. The flowlines above the drains will then be almost vertical as shown in Fig 2 and the excess porewater pressures will be small.

Depth of Drains

The geofabric wrapped drains can be used to increase the stability of existing unfailed slopes or as remedial stabilization of failed slopes. The drains should be located deep enough so that they intersect potential slip surfaces in the soil. The required depth of the drains depends on the difficulties of excavating trenches along the slopes with a backhoe. The maximum depth is about 4 m. For slopes in residual soils or weathered rocks this depth is usually sufficient because most slides in these materials are shallow, less than 3 to 4 m.

Required Tensile Strength

The required tensile strength of the geofabric can be calculated as shown in Fig 3 by considering the force polygon for the sliding soil mass above possible sliding surfaces in the soil. The sliding surface is often located at the contact between the completely weathered and the underlying partially weathered material.

For a planar sliding surface, the orientation of the geofabric and at the drains should be perpendicular to the resultant of the normal reaction force and the force that corresponds to the mobilized shear strength along the potential failure surface, as shown in Fig 3 in order to utilize the fabric effectively. For slopes where $\phi_u = 0$ the orientation of the geofabric should be parallel to the sliding surface in order to reduce the required tensile resistance. The optimal orientation of the geofabric is also governed by the maximum depth that can be obtained with the available construction equipment.

The required number of layers (N) of the geofabric in each drain can be determined as follows :

$$N = \frac{F_s R s}{a T} \qquad \ldots(1)$$

where R is the force per unit width (kN/m) to be resisted by the fabric, s is the drain spacing of the slope (m), T is the tensile strength per unit width (kN/m) of the fabric, a is the effective perimeter of the drain (m) and F_s is the factor of safety.

Deformation

The geofabrics available in the market generally require an elongation of from 14% to 50% before the ultimate tensile strength of the fabrics is mobilized. The strain required to mobilize the ultimate strength is much less for woven than for non-woven geofabrics. Only woven geofabrics should therefore be used. The brands of geofabric manufactured specifically as tensile reinforcement for soil have a rupture strain of about 14%. In view of the large strain required at failure, a factor of safety of at least three should be used in the design.

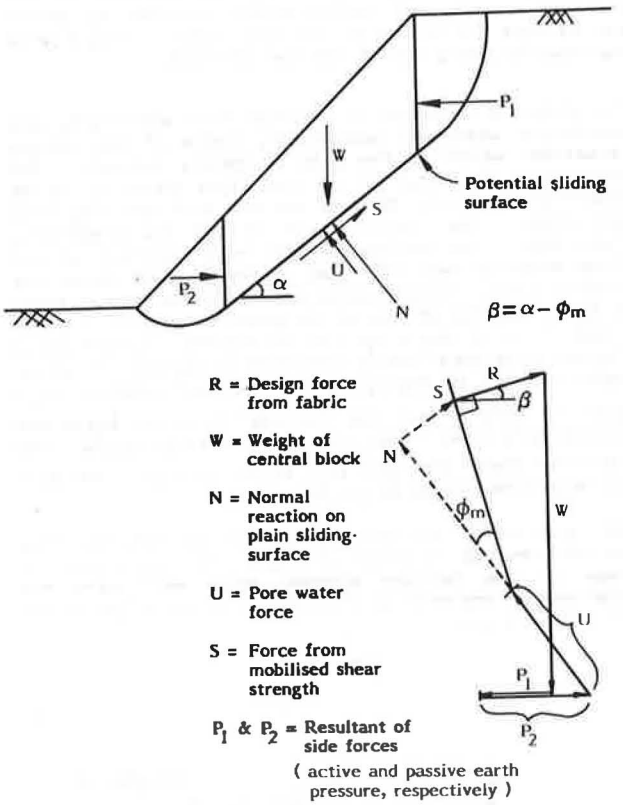

Fig. 3: Computation of design tensile reinforcement to be provided by geofabric

The length, L, which is required to transfer the load in the fabric to the surrounding soil can be calculated as follows :

$$L = \frac{R\ s}{2(hK\sigma_v' + b\sigma_v')\ \tan \phi_a'} \qquad ...(2)$$

where σ_v' is the vertical effective stress at mid height (center) of the drains, K is the lateral earth pressure coefficient for the compacted granular material in the drains, h is the height of the drains, b is the width of the drains and ϕ_a' is the friction angle between the geofabric and the soil. The transfer length will be about 1.25 m for a 0.5 x 1.0 m drain located at 3 m depth. It has been assumed in the calculations that the force in the fabric is 35 kN/m, that the unit weight of the soil is 20 kN/m³ and the friction angle ϕ_a' is 25 degrees. The required transfer length is thus relatively small.

The deformation δ of the geofabric to mobilize therequired tensile force can be calculated from the following equation :

$$\delta = L \times \frac{e}{100} \qquad ...(3)$$

where e is the percent elongation needed to mobilize the required tensile resistance of the geofabric and L is the transfer length. In the case the strain required to mobilize the required tensile force in the fabric is 5% then the elongation will be 63 mm at a transfer length of 1.25 m. It has been asumed that the strain in the fabric increases linearly within the anchor zone. Thus the elongation required to develop the tensile force is relatively small.

Compaction

During the construction of the granular fill drains it is important to compact the fill carefully. The compaction will increase the lateral earth pressure and therefore the friction between the fabric and the soil. Thus the transfer length is then reduced. For a well compacted fill a value of k equal to at least 1.0 can be used in the calculations of the transfer length. The lateral earth pressure is highly dependent on the degree of compaction of the granular fill.

A second important point with respect to the compaction of the granular fill drains is that the compaction should be done in the downhill direction in order to pretension the fabric. In this way, the elongation of the fabric which is necessary to mobilize the required tensile force will be reduced as well as the required displacement of the slope.

STABILIZATION OF A LANDSLIDE AT NTI

In the following sections, the remedial works for the stabilization of a landslide on the campus of the Nanyang Technological Institute (NTI) in Singapore is described.

The landslide occurred in early 1984, during a period of heavy rainfall, on the NTI campus in the western part of Singapore. One student dormitory, Block E, was located at the toe of the slope. At the crest were two other dormitories. An existing rubble wall which had been constructed along the whole length of the slope with height varying from 1.70 m to 3.50 m failed during the landslide as can be seen in Fig 4. The average

Fig. 4: Slide at NTI block E showing backscar

height of the slope was about 7 m. The inclination of the slope was 37° prior to the failure. A scupper drain at the toe of the rubble wall was damaged and closed up as a result of the movement of the slope. The ground immediately in front of the displaced rubble wall heaved about 200 mm.

The whole sliding soil mass continued to move at a slow rate during the rest of 1984. Large cracks appeared on the displaced rubble wall. The total displacement of the wall was approximately 700 mm in the end of 1984. The toe had moved about 300 mm.

Site Investigation

The failed slope was investigated using both weight and ram sounding tests. In addition, undisturbed block samples were taken to determine the shear strength and other properties of the soil in the laboratory such as water content, liquid and plastic limits.

The weight penetrometer is the most commonly used penetration testing method in the Scandinavian countries (Broms and Bergdahl, 1982). It is also used extensively in Japan as described by Fukuoka (1974) and in the Philippines. Because of its light weight, the weight penetrometer has been found to be particularly useful for investigations of the stability of existing slopes and of failed slopes which are not conveniently accessible to conventional soil investigation equipment such as drilling rigs and cone penetrometers.

Ten weight soundings (WST) were carried out at two sections through the failed slope in order to locate the failure surface (Lim and Yau, 1985). Fig 5 show the results along one of the two sections.

The slope is composed of residual soil and highly and completely weathered sedimentary rocks of the Jurong Formation, which at the site is mainly mudrock. The grain size distribution of the slope material is 9% gravel (lateritic), 7% sand and 84% silt and clay size particles. The liquid limit is 56% and plasticity index 29%. The average natural water content of the slide material was 33%, just a few percent above the plastic limit. Consolidated drained direct shear tests on block samples of the slide material gave c' = 0 and a peak friction angle (ϕ') of 26 degrees. Consolidated drained ring shear tests indicated a residual friction angle (ϕ'_r) of 16 degrees and a residual cohesion (c'_r) equal to zero. Thus the residual friction angle was considerably lower than the peak friction angle. The undrained shear strength (c_u) which is highly variable was determined to be 50 to 100 kPa.

The location of the sliding surface as inferred from the WST results is shown in Fig 5. The depth and the shape of the failure surface agree well with the locations of the scar at the crest and the bulge at the toe of the slope.

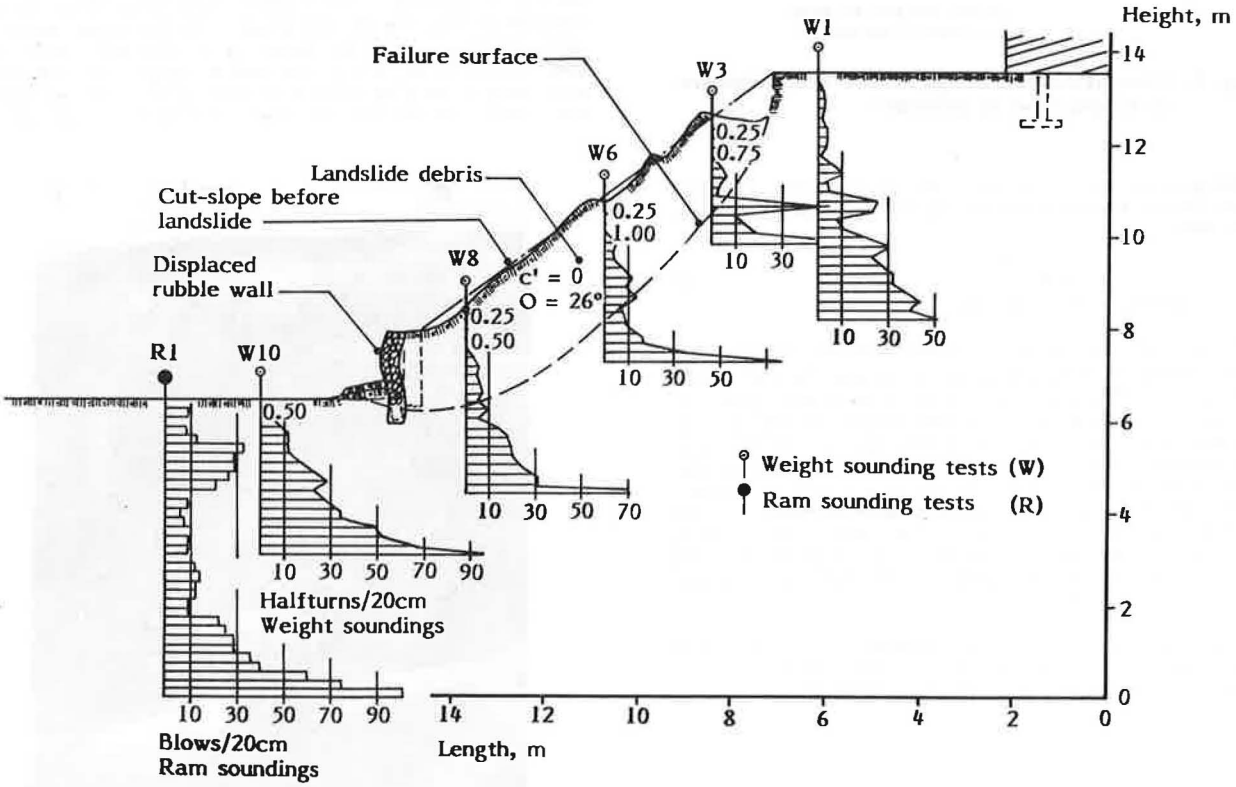

Fig. 5: Weight sounding test results and failure surface - Profile 1, NTI block E Slide

Remedial Stabilization Works

The remedial stabilization works at the Block E slope consisted of the installation of eight fabric-wrapped crushed rock drains. The drains, 0.5 m wide and 1.0 m high, are spaced 3.0 m apart. Based on the sliding surface shown in Fig 5, and a residual friction angle for the soil (ϕ_r') of 16°, the required tensile force of the geofabric is 85 kN per m of the slope or 255 kN per drain. For each drain, four layers of 3.4 m wide FOV polyester fabric with a ultimate tensile strength of 70 kN/m (238 kN per layer) at 14% elongation were used. The fabric was wrapped around the two sides and the bottom of each drain. A cross section of the slope with the drains is shown in Fig 6.

The reconstruction of the slope was carried out in May and June 1985. Fig 7 and 8 show the progress of the construction. The up to 4 m deep trenches for the drains were easy to excavate using a backhoe at the top of the slope (Fig 7). A temporary bench was cut at the middle of the slope so that the lower part of the trench next to the crib wall could be reached and excavated. The granular material in the trench was compacted using a plate vibrator (Fig 8). Temporary supports (struts) are recommended in the trench for safety during the construction. Horizontal strips were placed in the slope to prevent shallow slides during the backfilling. Geofabric was also placed behind the crib wall as a filter. Figure 9 shows the completed stabilized slope. The reconstruction of the slope was completed in June 1985. The slope has since then withstood several heavy rainstorms. No further movements of the slope or of the crib wall have been observed except on one side beyond the stabilized part of the slope where a minor slip has occurred after a heavy rainstorm. The crib wall has therefore been extended in order to stabilize also this part of the slope.

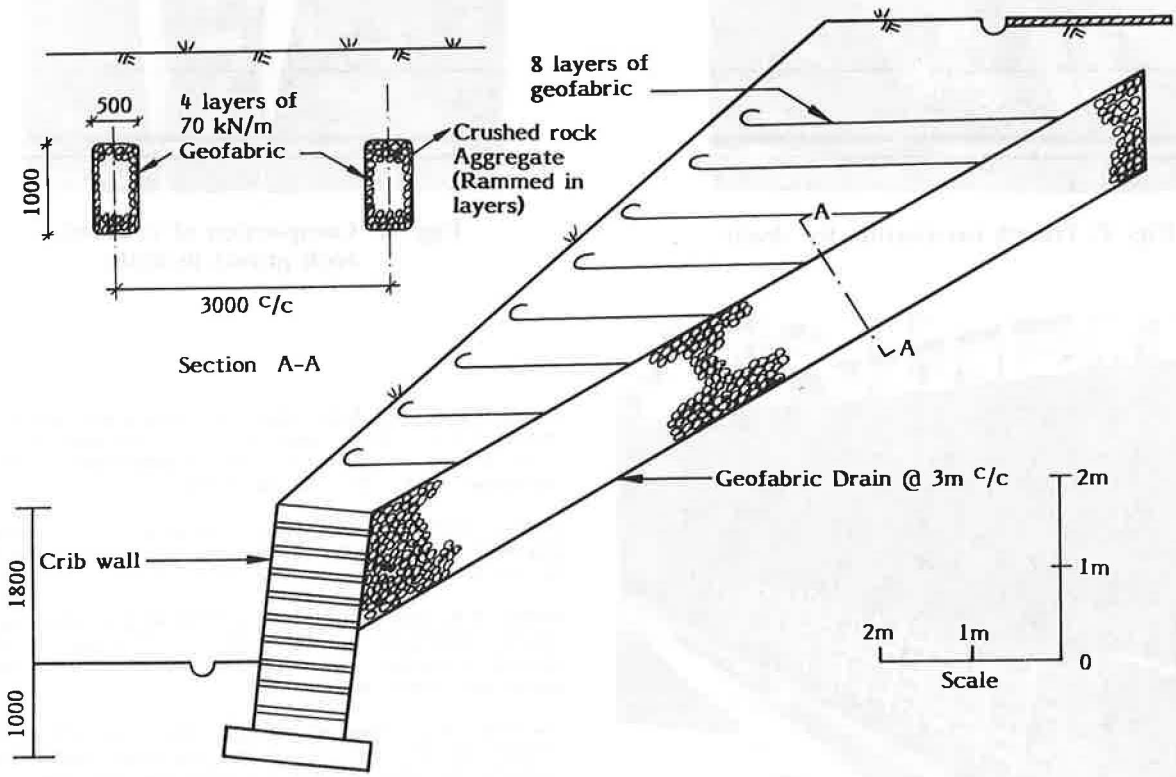

Fig. 6: Slabilization scheme - NTI block E slide

The drains are connected to the crib wall at the lower end of the slope for drainage. The crib wall was filled with crushed rock to allow discharge of the water from the transverse drains.

Horizontal layers of fabric were also placed in the slope between the ground surface and the transverse drains to increase the stability of the slope with respect to shallow slides above the transverse drains. The far end of each fabric strip was anchored in the crushed rock drain. Another layer of the fabric was placed along the drains between the horizontal strips as a filter to prevent the soil above from being washed (eroded) into the drains.

CONCLUDING REMARKS

Woven geofabric has been used successfully in Singapore to stabilize a steep slope in residual soil and weathered rock. Geofabric was wrapped around drains consisting of clean granular materials. The drains were placed in deep trenches along the slope cutting across potential sliding surfaces in the soil. The

Fig. 7: Trench excavation for drain

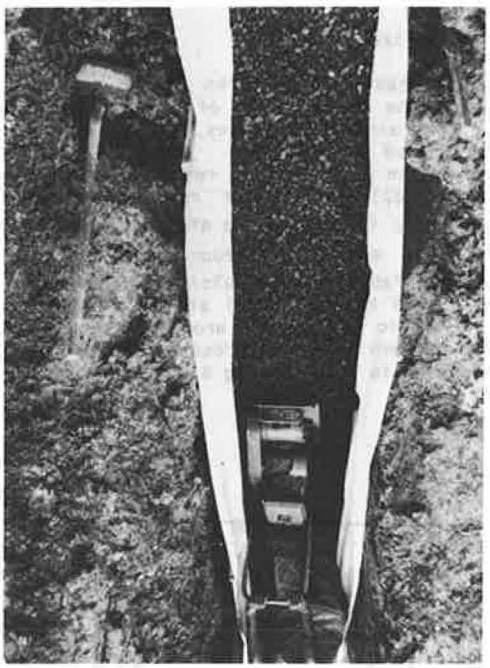

Fig. 8: Compaction of crushed rock gravel in drain

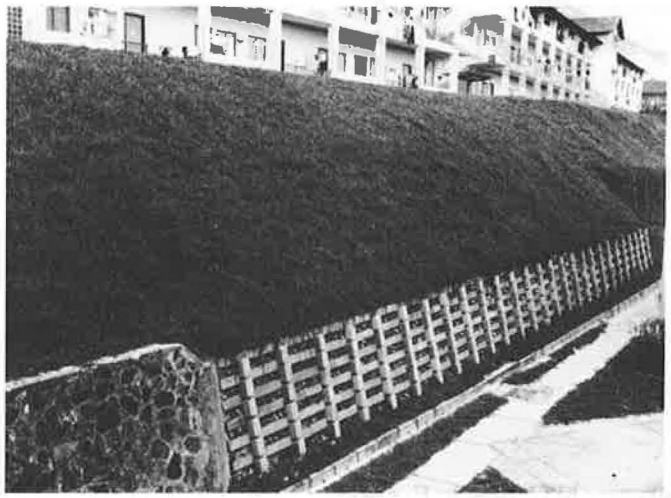

Fig. 9: Completed reconstruction of the slope

fabric will then function both as a filter around the drains and as reinforcement in the slope which will increase the stability.

The application of the method to increase the stability of a failed slope on the NTI campus in Singapore is described in the article as well as the method that was use to evaluate the effectiveness of the drains as longitudinal reinforcement. No further movements of the slope have been observed after the installation of the drains.

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