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Instrumented Case Histories of Fabric Reinforced Embankments over Peat Deposits

Expérience pratique de la construction de talus à renfort géotextile sur des dépôts de tourbe

Two Sections of road embankments, built on soft organic deposits in Ontario, Canada were constructed by using various geotextiles for separation and reinforcement.

At the Manchester site four different fabrics were placed longitudinally at the interface of the organic peat and the base of the fill for separation. At the Bloomington site fabrics were laid in the transverse direction, partially encapsulating a layer of the embankment.

The effectiveness of the fabrics at the Manchester site was evaluated by visual examination of the geotextiles in test pits, excavated one year after installation.

At the Bloomington road the principal function of the geotextiles was reinforcement by membrane support. The stage construction of the embankment was successfully carried out by monitoring of the vertical and lateral deformations and the rate of dissipation of excess pore pressure.

Divers géotextiles ont été utilisés aux fins de séparation et de renforcement dans la construction de deux sections de talus de remblai sur des dépôts de sol organique mou, en Ontario, Canada. On a posé quatre textiles différents dans le sens longitudinal pour séparer la tourbe organique et la base du remblai au chantier de Manchester. A celui de Bloomington les textiles ont été posés dans le sens transversal, renfermant partiellement une couche du talus.

A Manchester, l'efficacité des géotextiles a été évaluée au moyen d'examen visual dans des puits d'essai, creusés une année après l'installation.

A Bloomington les géotextiles avaient la fonction principale de renforcement par support de membrane. La construction étagée du talus a été effectuée en surveillant les déformations verticales et latérales et le taux de dissipation de la pression interstitiale excédentaire.

INTRODUCTION

In constructing road embankments on highly compressible and very soft organic deposits road engineers must consider the possibility of embankment failure by the induced shear forces and the occurrence of excessive settlements. The intrusion of organic material and mixing of the soft soil with the fill will result in further aggravation of embankment stability. This paper describes two case histories where geotextiles were employed for construction of road embankments on deep organic deposits. The first, Manchester Site, describes the construction of a temporary detour using geotextiles as separators and the second, Bloomington Site, outlines the use of geotextiles as reinforcing membranes. Both sites are located near Toronto, Ontario, Canada.

MANCHESTER SITE

Highway 12 is a major two lane artery connecting Toronto and the resort area of Lake Simcoe. A detour, required to permit a bridge construction along the highway near Manchester, provided an opportunity to assess the role of geotextiles in low embankment construction over swampy lowlands. Four geotextiles, including wovens and nonwovens, were placed below the north 200 m long bridge approach fill. The south approach, over shallow peat, was constructed without fabrics. Embankment settlements and geotextile elongations were monitored over the 6 month active life of the detour.

Site Description

The detour location was relatively level but hummocky due to the cover of long reeds and 1 to 2 m tall woody shrubs. Water was at or above ground surface throughout this area. Amorphous granular peat blankets the site, underlain by sands and soft to stiff clay. South of the river, where the detour was built without geotextiles, peat depths range from 0.3-0.5 m. North of the river, the four geotextile trial sections were constructed over peat, ranging in depth from 1.5 m to 4 m (Figure 1). Physical properties of the peat are summarized in Table 1.

TABLE 1 - Properties of Peat at Manchester Site

PROPERTIES	RANGE OF VALUES
Unit weight, γ (kN/m^3)	9.7 - 11.7
Water Content, w (%)	170 - 616
Organic Content, (%)	30.4 - 82.8
Compression Index, C_c	2.4 - 8.7
Shear Strength, τ_f (kPa)	7.1 - 16.6

Design/Construction

The detour consisted of a sandy silt embankment overlain by gravelly sand and crushed stone subbase and

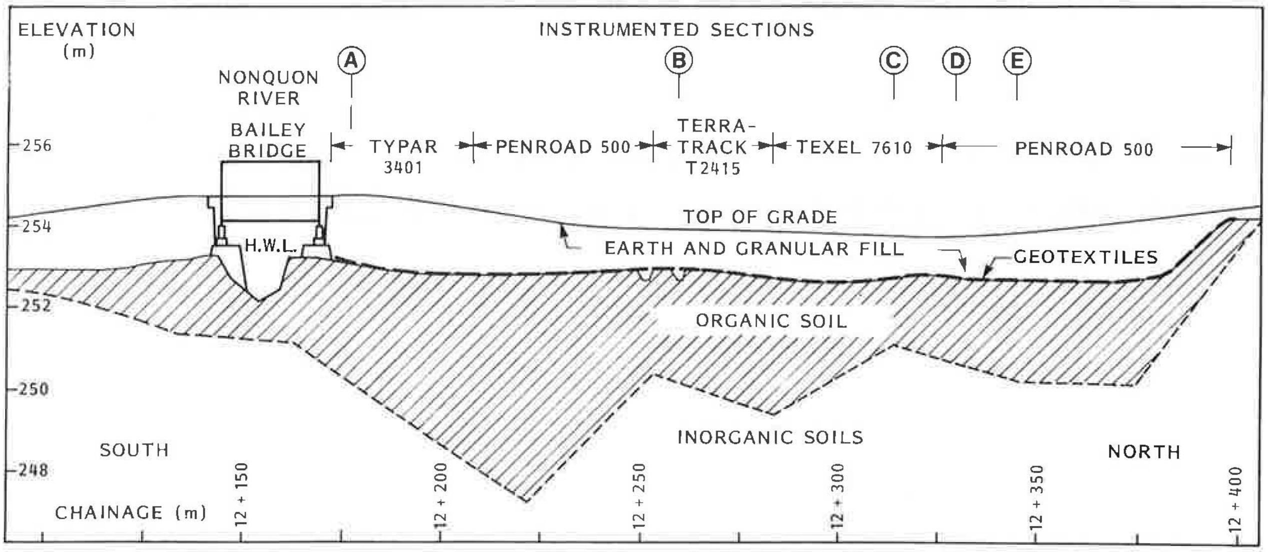


FIGURE 1 - Centre Line Profile Manchester Detour

base courses (Figure 2). Four geotextiles having similar tensile strengths were selected for trial use as separators between the embankment and the underlying peat. Properties of these fabrics are given in Table 2.

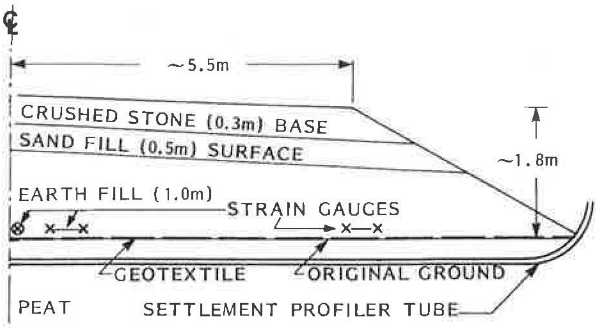


FIGURE 2 - Manchester Detour Cross Sections showing construction and instrumentation details

TABLE 2 - Geotextile Properties (2) Unaged Fabrics

PROPERTIES	PENROAD 500 Woven	TERRATRACK T-2415 Woven	TEXEL 7609 Nonwoven	TYPAR 3401 Nonwoven
Mass, μ (g/m^2)	150	120	280	136
Thickness, T_g (mm)	0.5	0.45	3.0	0.38
Breaking Force, F_G (N) Grab Test (warp)	800	485	480	600
Elongation at Rupture, E(%)	22	16	90	62
Puncture Strength, $*F_p$ (N)	1000	890	1160	750
Equiv. Opening Size, µm (US Standard Sieve)	75 (#200)	300 (#50)	150 (#100)	180 (#80)

*CGSB STANDARD 4-GP-2 11-2 (55)

The location in which each product was used is shown on Figure 1. Stability of the 1.8 m high unpaved detour embankment was not considered to be a problem due to the limited thickness of the peat and the low fill height. Settlement calculations indicated that 0.2 to 0.7 m of vertical deformation should be expected. This agreed quite closely with empirical relationships recently published, between fill height, peat thickness and settlement (1). As a rule of thumb, additional fill, amounting to half the height of the embankment (0.9 m), was provided by the construction forces to maintain final design grades after settlements. After close cutting the woody shrubs to leave stumps of less than 0.15 m height, conventional earth moving equipment was used to construct the detour. Two men in tall rubber boots hand placed the geotextiles over the peat with 1.0 m overlap of the adjacent panels, then earth fill was placed directly on the geotextiles.

Instrumentation

Five sections of the detour were instrumented to monitor embankment settlement and geotextile elongation as shown on Figure 2. Settlements were measured by pulling an electronic pressure transducer through a water filled profiling tube, placed under the geotextile at each instrumented section. Geotextile elongations were measured by gauges resembling miniature hydraulic pistons. The piston body was clamped to the geotextile at a point 200 mm distant from the actuating point for the piston arm. Elongation in the geotextile caused withdrawal of the piston and resulted in lowering of the water level in a sight tube remote from the embankment but connected to the piston body. Three of these strain gauges were installed at each of the instrumented sections. (A,B,C,D and E in Figure 1).

Installation of Geotextile and Observation of Instrumentations

The high grass and reed cover and the roughly 0.3-0.4 m deep water, covering parts of the site made the geotextile installation rather difficult. The Texel fabric, a needle punched polyester, having relative densities higher than water and quick water absorption, became very heavy and unwieldy in open water installation. (3).

The heavy construction equipment readily rutted the earth fill over the fabrics, prestressing the geotextiles.

Settlement monitoring indicated that most of the vertical deformation occurred very soon after fill placement, as expected. Settlements some 140 days after construction are shown on Figure 3. Maximum settlements at each section ranged from 0.2 to 1.0 m.

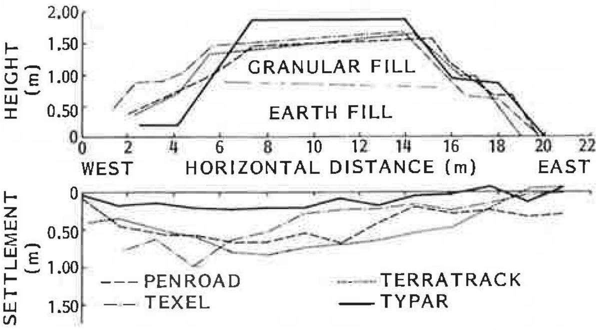


FIGURE 3 - Manchester Embankment Cross Sections, showing fill height and settlements

The elongation of the fabrics during and after construction was monitored by strain gauges as mentioned earlier. In Figure 4 typical values of elongation versus time are plotted. The maximum observed elongation was somewhat less than 10% in both the longitudinal and the transverse directions. The strain gauges registered a gradual decrease in elongation during the months following construction.

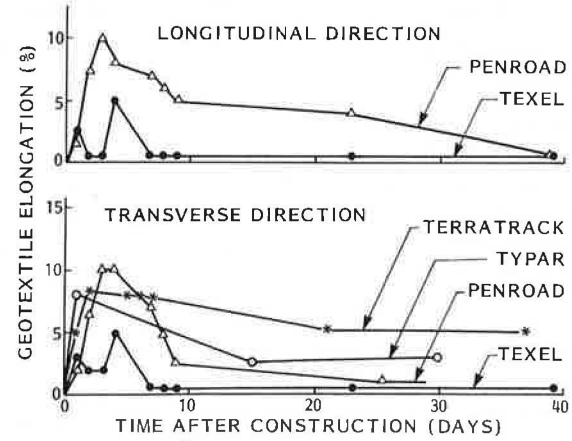


FIGURE 4 - Typical Geotextile Elongations at the Manchester Site

Discussion

Geotextiles used under the detour embankment provided superior separation between the fill material and the underlying organic soil. The fabrics were also very useful in bridging local depressions and soft spots.

Trenches excavated through the fill and down to the organic deposit one year after construction clearly showed that the geotextiles produced a sharp, smooth line of separation, with absolutely no subgrade intrusion and no mixing of the two soils (Figure 5). Similar trenches through the fill with no fabrics revealed an irregular fill-peat interface with layers of intermixed soils of some 0.15-0.2 m thickness (Figure 6).

Fabric survivability and field workability must be assessed prior to any installation as suggested by Haliburton (4). On the basis of subgrade strength and vegetation cover the field workability criterion was not considered to be critical. Considering the construction equipment, the prerutting of the fill over the fabrics and soil conditions, moderate to high survivability requirements were specified. Strength parameters of all the installed geotextiles met these requirements.

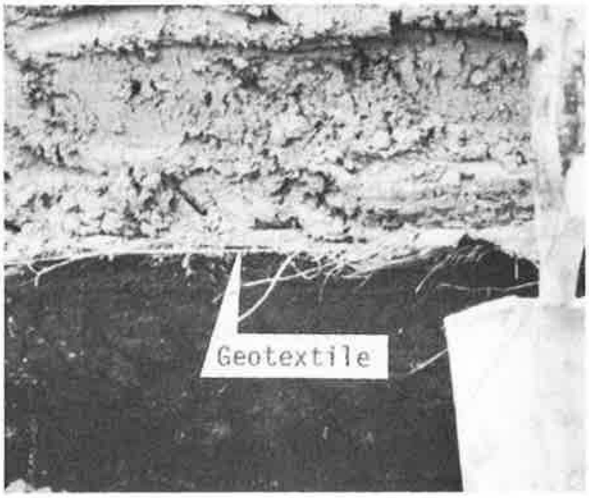


FIGURE 5 - Fill, Peat interface with Geotextile

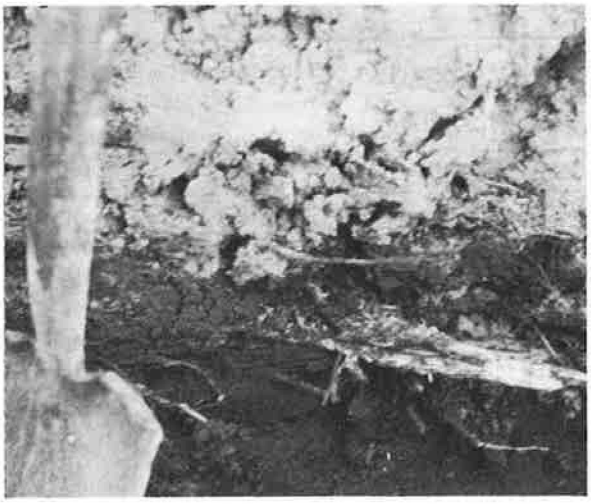


FIGURE 6 - Fill, Peat interface without Geotextiles

BLOOMINGTON SIDE ROAD

Bloomington Side road, a two lane highway corridor is located some 16 km north of the city of Toronto. The construction started in early 1981, and at the time of writing this report, part of the 2 km road is still under construction. In the vicinity of the road there are numerous undrained organic deposits. The road traverses one of these deposits, having a maximum thickness of 7.6 m and a length of 300 m. Construction of the approximately 1.5 m high road embankment across the organic deposit utilized geotextiles for separation and reinforcement.

Soil Conditions

A thorough field investigation, consisting of 11 sampled boreholes, was carried out at the site of the organic deposit, prior to design. The soil stratigraphy revealed by the borings is shown on the soil profile in Figure 7. The organic deposit was identified to be a highly organic peat (Pt), extending to maximum depths of 6 m and 7.6 m in the west and east of the swamp with considerably shallower peat in the middle. The consistency of the peat was very soft Properties of the peat are recorded in Table 3. The groundwater level was either 0.2-0.3 m above or at the general ground surface. Underlying the peat an inorganic layer of silt and sand (SP & ML) was found, having compact density.

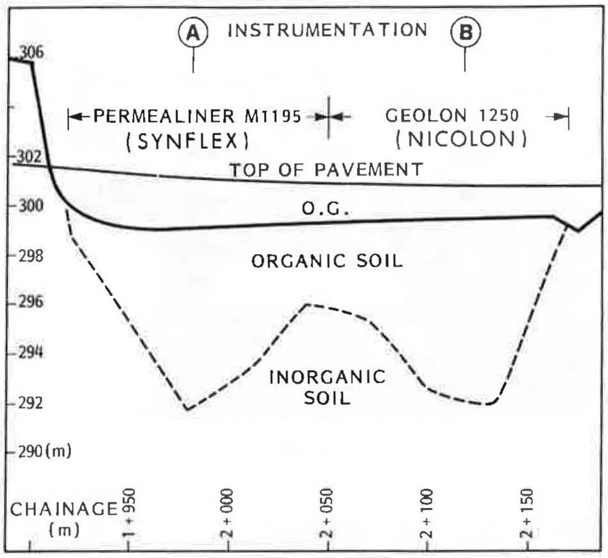


FIGURE 7 - Centre Line Profile Bloomington Side Road

TABLE 3 - Properties of Peat at Bloomington Site

PROPERTIES	RANGE	AVERAGE
Unit Weight, γ (kN/m^3)	9.2 - 11.5	10.0
Water Content, w (%)	291 - 1041	595
Organic Content, (%)	17 - 80	53
Liquid Limit, w_L (%)	216 - 324	275
Plastic Limit, w_p (%)	138 - 255	690
Plasticity Index, I_p (%)	20 - 78	46
Intial Void Ratio, e	7.0 - 18.6	12.6
Compression Index, C_c	3.9 - 10.1	5.6
Shear Strength, τ_f (kPa)	6 - 38	18
Sensitivity, S_t	1 - 3	

Design Considerations

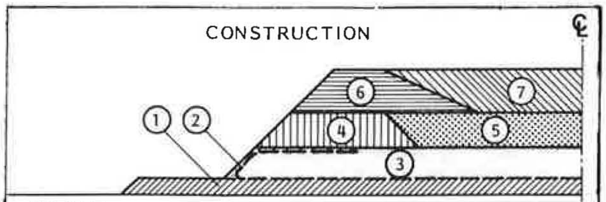
In designing the 1.5 m road embankment over the organic terrain, total or partial excavation of the peat and replacement with inorganic soils was considered. On account of the depth of the deposit and the sloping swamp bottom these methods were found uneconomical. Since a full year was available for the completion of the road it was decided to build the fill in stages. The first stage construction called for "floating" the embankment on the peat surface. It was estimated that the dissipation of excess pore pressures under the fill would take about three months. After this period the embankment could be reconstructed, with an additional surcharge load. Construction of the base, subbase and asphalt pavement courses would follow after another six months of consolidation. Total stress stability analyses of the fill were carried out using remoulded shear strengths of the peat, as suggested by some authors (5). The analyses indicated that shear failures along circular arcs may occur under the designed 1.5 m high fill. The use of berms to minimize the possibility of such failures was not possible at this site due to the width of right of way available. It was therefore decided to place fabrics under the embankment in order to prevent slip failures. Accordingly it was proposed to install woven geotextiles having high tensile strengths and high moduli. A twisted polypropylene, anisotropic, slit film Nicolon woven product was chosen for half the length, for the other half a monofilament polypropylene woven fabric manufactured by Synflex was used. Properties of the geotextiles are listed in Table 4.

TABLE 4 - Geotextile Properties (2) Unaged Fabrics

PROPERTIES	GEOLON 1250	PERMEALINER 1195
Mass, μ (g/m^2)	730	225
Thickness, T_g (mm)	2.26	0.4
Breaking Force, F_G (kN) Grab Test (warp)	5.56	1.78
Elongation at Rupture, E (%)	18	30
Mullen Bursting Pres., (MPa)	11.0	3.5
Equivalent Opening Size,(μm) (US Standard Sieve)	425 (#40)	212 (#70)

Sequence of Construction and Instrumentation

The first stage of embankment construction across the swamp took place in the spring of 1981. After clearing the site a working platform, consisting of a 0.3 m layer of silty sand, was placed on the ground to eliminate placing the geotextiles under water. The fabrics were laid transverse to the road alignment, overlapping the adjacent strips by 0.7 m. A toe to centreline sequence of fill construction was carried out, modified somewhat from the method described by Haliburton (4). Secure achorage was accomplished by folding back the 3 m extra lengths of the fabrics over the first lift of fill, and placing a second lift over the fabric near the toes. These toe fills were compacted prior to filling the middle portion of the embankment. The sequence of construction is depicted in Figure 8.



STAGE I

1. Place working platform
2. Place Geotextile transverse to alignment
3. Place 0.3 m granular and fold back Geotextile
4. Place and compact earth to anchor Geotextile
5. Place and compact embankment core

STAGE II

6. Place and compact earth to profile grade at edges
7. Place and compact earth to profile grade at core

STAGE III

Remove preload and place pavement structure

FIGURE 8 - Construction Sequence

In order to control stage construction and to observe fabric performance some field instruments were installed at both of the deep peat locations. A sketch of the instrumentation is presented on the cross-section of Figure 9. The excess pore water pressure and the rate of dissipation was observed by Geonor type brass piezometres installed beneath the centreline and beneath the shoulder of the fill. Vertical movements were measured by settlement profilers, as previously described. Elongation in the geotextiles was monitored both in the longitudinal and transverse direction at the centreline and near the slopes. Two independent sets of gauges were installed, one operated hydraulically the other by electric current. The former was already described, the latter consists of a set of wire coils encased in plastic, affixed to the fabric some 200 mm apart. The distance between the coils is determined by running an electric current through one and measuring the induced current in the other. Lateral displacements were determined by inclinometers, installed vertically at both sides of the fill adjacent to the toes.

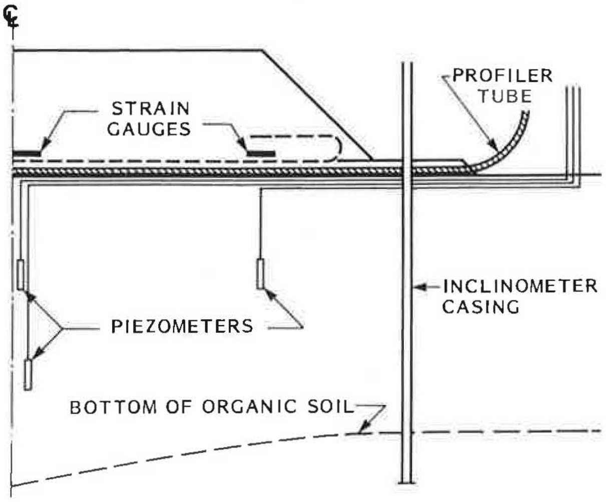


FIGURE 9 - Sketch of Instrumentation Locations

Discussion and Results

The first stage of construction was carried out successfully without any sign of prospective rotational failure. It is postulated that this type of failure was prevented by the membrane effect of the geotextiles.

In the middle 80 m portion of the peat the depth of the deposit was less than 3 m. Settlements predicted along this section were in the order of 0.3 m. Actual settlements observed during and immediately after the first stage construction were about 0.4 m. Floating of the embankment as planned, within this section, was thus achieved.

Under section A and B (See Figure 7), where the depth of the organic deposit was considerably deeper than in the middle, much larger settlements were observed than predicted. The magnitude of the vertical deformation was 94% of the total height of the fill. The corresponding excess pore pressure beneath the centre of the embankment was measured to be up to 90% of the applied effective stresses. The excess displacement was due to lateral shear deformation of the peat under undrained conditions. This fact was confirmed by movements of inclinometers indicating an outward lateral force located below mid-depth of the deposit. Field vane tests carried out 60 days after construction resulted in no appreciable increase in the undrained shear strength of the peat, substantiating the above hypothesis.

During the first stage of construction the geotextiles were subjected to elongations of 2% to 5% as measured by the strain gauges. Elongations of similar magnitudes were observed in both the transverse and longitudinal directions, as at the Manchester Site. Strains induced in the longitudinal direction imply that plane strain conditions may not fully apply to low embankments constructed on highly compressible organic materials on account of surficial variations (soft areas, tree stumps, etc.). All the strain gauges registered a decrease in strain with time, as also observed at the Manchester Site. While it is not suggested that a decrease in observed strain corresponds to a decrease of fabric elongation, the observed phenomenon might have been caused by stress re-orientation due to continuing deformation.

During the planned three month waiting period following the first construction stage excess pore pressures dissipated and the rate of settlement considerably slowed down so that construction of the second stage was deemed feasible. The geometry of Stage II construction with the corresponding settlement profile is shown in Figure 10.

Most of the additional settlements occured during construction of the second stage. In the four months following construction, settlements of 0.1 m only were measured.

The piezometers registered excess pore pressures equal to 40% of the newly applied stresses. Elongations of the geotextiles in the transverse direction approached the failure elongation at some locations. The maximum longitudinal elongation was observed to be 8% beneath the centre of the fill.

Some mud waves with tension cracks developed near the toe of the embankment, on account of the additional load confirming lateral shear deformation.

No tension cracking or horizontal deformation was observed within the body of the embankment demonstrating the ability of the geotextile to contain and restrain the embankment thus preventing lateral spreading.

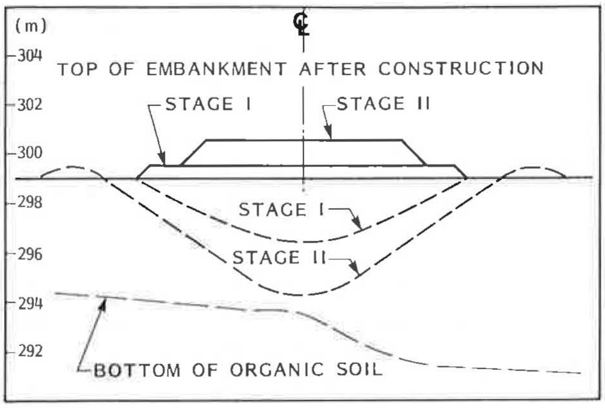


FIGURE 10 - Sketch showing deformation of Original Ground immediately after Stage I and Stage II construction

CONCLUSIONS

From the field studies reported in this paper several useful and practical lessons can be learned and conclusions drawn. These are summarized as follows.

(a) Regardless of the differences in the base polymers of the fibers and in fabric construction, all the geotextiles used at the Manchester fill performed the separation function well. The actual construction experience appears to confirm Haliburton's finding that if a fabric survives the abuse during placement and construction it will provide adequate separation, provided that the opening size and permeability of the textile is within acceptable limits. If drainage along the plane of the fabric is not required then thin woven or bonded nonwoven fabrics will be more suitable than thick needle punched ones, based on economics and the ease of placement. Fabrics manufactured of polypropylene are easier to handle in open water installation than polyester and nylon products, since the relative density (specific gravity) of the former is less than one, with hardly any water absorption.

Except one woven polypropylene fabric, all the geotextiles recovered one year after construction lost some 25% to 36% of their original tensile strengths. The loss of strength did not seem to have any adverse effect on their performance.

(b) While it is not an engineering necessity, building of a thin non-cohesive soil working platform on very soft, rough and uneven swamp surface will facilitate placement and prestressing of the fabric. The additional construction expenditure will be offset by the much speedier placement, and the more even distribution of loads on the fabric.

(c) For the Bloomington site stability analysis in terms of total stresses was carried out prior to construction, using the proposed height of the embankment of 1.5 m. The resulting safety factor of 1.0 indicated a potential rotational shear failure of the fill without the geotextile. By using the critical slip circle and adding a fabric tensile strength of about 30 kN/m, the resisting moment was increased sufficiently so that a safety factor of 1.2 was obtained. During construction the fabrics were subjected to elongation on account of vertical deformations. On the basis of laboratory stress strain curves it was estimated that under the measured elongation the geotextiles mobilized tensile strengths in the order of 35 kN/m. It is therefore postulated that the membrane effect of the geotextile was fully utilized in preventing rotational failures.

(d) At the Bloomington site considerable vertical deformation occurred by lateral displacement of the peat. Such large lateral movements of the foundation soil could have resulted in embankment failure by horizontal splitting (4). There were no tensile cracks observed within the embankment whereas several were observed outside the geotextiles involving the working platform. It may be concluded that the mobilized tensile strength of the geotextiles and the soil fabric friction assisted in restraining the fill from lateral sliding.

ACKNOWLEDGEMENT

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Festigkeitsverluste der Geotextilien, 36%
Vorspanneffekt erwünscht, Vergleichmäßigung der Lastverteilung
Messungen bestätigen Aufnahme von Zug-kräften