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Construction and analysis of a fabric reinforced low embankment

Construction et étude d'un remblai construit sur du muskeg et armé en textile non-tissé

RESUME

Un remblai armé en textile a été utilisé sur un substratum de muskeg dans la construction d'une route forestière en Alaska du Sud-est, aux U.S.A. Celui-ci était composé de tout-venant, sur une tourbe de texture fibreuse, épais de 2.5 à 3.4 mètres. La quantité de remblai et les tassements furent surveillés pendant et après la construction de portions comportant ou non une armature en textile. Une économie de 28 % a été réalisé sur les materiaux de remblai par l'utilisation de textile de polypropylène, non tissé et à fibres continus. Des analyses par la méthode des differences finies furent réalisés sur les remblais armés pour prévoir les tensions éxercés sur le textile et pour établir, en fonction de la résistance du textile, les déformations du remblai et l'amplitude des tensions éxercés sur le textile. Il en ressort que les tensions éxercés sur le textile s'accroissent avec les déformations du remblai et la resistance du textile. Avec les qualités mécaniques du textile employé ici, la presence de textile n'influence pas substantiellement les déformations du remblai, évalués au préalable par la méthode des differences finies. L' action positive du textile, constaté sur le chantier, résulte certainement de ce que la présence d'un textile assure dans le remblai, la continuité qui est p'hypothise fondamental de cette analyse.

INTRODUCTION

Road construction in Southeast Alaska involves extensive crossings of muskeg terrain. As almost all roads are constructed using overlay techniques and "shot-rock" embankments, the costs involved in crossing such weak deposits often become excessive. Any method of reinforcement, bridging or floating over the muskeg may be feasible depending on the particular peat deposit, rock cost and construction technique used. Because of the relative low costs of fabrics, this type of reinforcement appears desirable.

This paper describes a field test of fabric reinforced roads across muskeg and presents the results of a finite element analysis of the test section.

FIELD TEST

The test section is located on the Tongass National Forest, approximately 20 miles south of Petersburg, Alaska, U.S.A. The road is a typical timber sale road, constructed of pitrun quarry rock for the purposes of supporting logging traffic. The muskeg is about 700 feet long, running from station 29+00 to 36+00. The peat consists of the fine-fibrous type (sphagnum).

The muskeg was probed and a two-inch diameter vane shear device used to determine shear strength of the in-place peat. Depths ranged from 8 to 11 feet with the average being about 10 feet. The shear strengths ranged from 50 to 350 lb/ft^2. The average value was about 250 lb/ft^2. The saturated water content of the peat was about 960 percent.

The fabric used was a nonwoven, needle-punched, spunbonded polypropylene (Fibretex) of 420 g/m^2 weight. This fabric has a tensile strength of 800 to 900 lb/ft for 100 to 200 percent elongation.

Instrumentation on this project consisted of very simple strain devices and settlement plates. The strain gages consisted of a simple electrical circuit with a coupling which breaks the circuit when the fabric strains more than the circuit has been set to accommodate. Periodic readings could be taken to determine whether the fabric had stretched beyond the gage's capabilities. A level was used to monitor elevation changes and a portable core drill was used to supplement the embankment thickness data after construction. The devices worked very satisfactorily; however, only limited information was obtained due to the time and available manpower.

The section was planned to illustrate the differences in rock embankment thicknesses, if any, with and without fabric matting. The various sections were constructed to show the effects of the fabric. Basically they consisted of rock placed directly on muskeg and rock on both a single and a double layer of fabric. The sections are indicated in Table 1.

Table 1. Test Sections and Fill Thickness Data.

		Fill Thickness (ft)		
Station	Fabric	Left Shoulder	Center	Right Shoulder
30+25	None	6.25	7	3.75
30+59	None	6.5	8	6.25
30+78	Double	5.5	6	4.25
31+00	Double	3	5.75	3.75
31+25	Double	4	5.7	2.5
31+75	Double	2		3
32+25	Single	2.75	3.1	2.25
32+60	None	4	5	3.5
33+00	Single	2	3.6	2.25
33+50	Single	2.25		3.75
33+75	Single	3.5		
34+00	Single	2.5	4.2	2.25
34+20	None	3	4.5	2.75

Construction began in April 1975. Normal timber sale construction techniques were used, whereby the rock fill was placed by end-dumping and then spread by a Cat. Figures 1 and 2 show the road during and immediately after construction. No special provision was made to carefully handle the fabric as one of the results desired was how the fabric performed under existing construction procedures. The shot-rock was highly variable, ranging from four feet to coarse sand or gravel sizes.

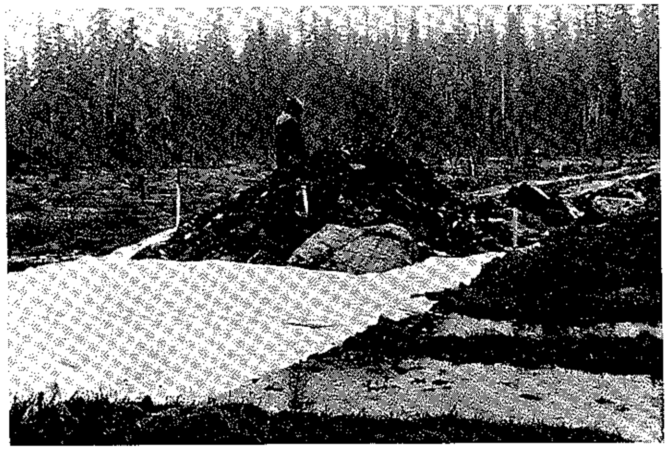

Figure 1. Road during construction.

Figure 2. Immediately after construction.

As the contractor started construction across the muskeg, excessive upheaval of the muskeg in front of the embankment occurred as the result of a typical bearing failure. The embankment depth through this first section was 7 to 8 feet. Since this initial section was requiring excessive amounts of rock, it was decided that a small section of fabric would be installed sooner than planned. A 30 ft length of double fabric was placed from station 30+70 to 31+00 and immediate results were obtained. The fill thickness required was decreased to a maximum of 5 1/2 to 6 ft.

Once construction was well within the double fabric section the initial fill thickness required decreased to 3 to 4 ft. A maximum fill thickness of 3 ft was also adequate when the section changed to a single layers of fabric (station 32+00 to 32+43). However, the first rock truck to back over the unreinforced section from station 32+43 to 32+77 caused a bearing capacity failure in the muskeg. Additional loads of rock were required to compensate for the failure displacement, and the fill depth for this section was approximately 5 feet. At stations 32+77 to 34+06, a section with a single fabric layer reduced the fill depths to 3 1/2 to 4 ft. From 34+06 the rock was placed on bare muskeg and the one measurement taken indicated a maximum fill depth of 4 1/2 ft.

The settlement plates were used both to determine the depth of fill and settlement of the fill. The plate at station 30+51 indicated that a subsidence of approximately 7 to 8 ft occurred in the first day. Within the next two days, the fill only settled another half foot and within another three months only an additional one-half foot.

When there was no obvious bearing capacity failure, such as at station 31+25, the fill settled 1 1/2 ft within the first day. By the end of three months this section had settled an additional 3 1/2 ft, for a total settlement of slightly less than 5 ft. Additional fill thickness data were obtained approximately one year after construction by drilling through the fill. They include rock added for maintenance during the first year. These data are presented in Table 1. Eight strain gages were installed at various locations to indicate fabric strain. The gage capacities ranged from 5 to 50 percent. None of the gages reached capacity within the three day monitoring period immediately after construction. However, after a three month period the gages were again checked and all but one had strained to capacity. This suggested the fabric had undergone slow strain (creep) up to 50 percent. From the performance of the road, however, it is felt the fabric did not rupture.

Using the test section data, it can be estimated that if no fabric had been used, the rock depths would range from 5 to 7 1/2 ft, resulting in a total rock volume of 2330 yd^3. With fabric the maximum rock depths would range from 3 1/2 to 5 1/2 ft, yielding a total rock volume of 1670 yd^3. These figures indicate a 28 percent savings in rock due to the fabric.

ANALYSIS

The data from the field test afforded the opportunity to make a theoretical analysis of a fabric reinforced embankment on a soft foundation to evaluate the tension in the fabric and to study the effects of fabric stress-strain properties on performance.

For analysis, the granular embankment was considered to be 4.5 ft high, 12 ft wide, with side slopes inclined at 1 horizontal to 1 vertical. The unit weight of the embankment was assumed to be 120 lb/ft^3. A fabric reinforcing layer was considered between the base of the embankment and the muskeg; the muskeg was taken as a homogenous layer 9 ft thick. Bedrock was assumed to be rough and rigid.

Two conditions of live loading were investigated, termed "normal" and "construction" live loads. The normal load was a 36,000 lb dual tandem axle corresponding to a legally loaded truck. The construction load was a 72,000 lb dual tandem axle from an oversized dump truck in the process of end dumping.

Plane strain conditions were used in the analysis, so the live loads were reduced to equivalent infinitely long line loads parallel to the longitudinal axis of the embankment. Four line loads, two on each side of the embankment centerline, were positioned to simulate dual wheels. The load equivalency was based on elastic theory, with the requirement that equal compressive stresses occur at the base of the embankment for both the actual wheel loads and the line loads. Such an equivalency can only be satisfied at certain discrete points, and is therefore only approximate. The resulting line loads for the normal and construction conditions were 1000 and 2000 lb/ft, respectively.

A nonlinear, large deflection finite element program, NONSAP (1) was used in the analysis. Only one-half of the assumed embankment was analyzed in this model. The discretization, relative dimensions and boundary conditions of the model are also shown in Figure 3.

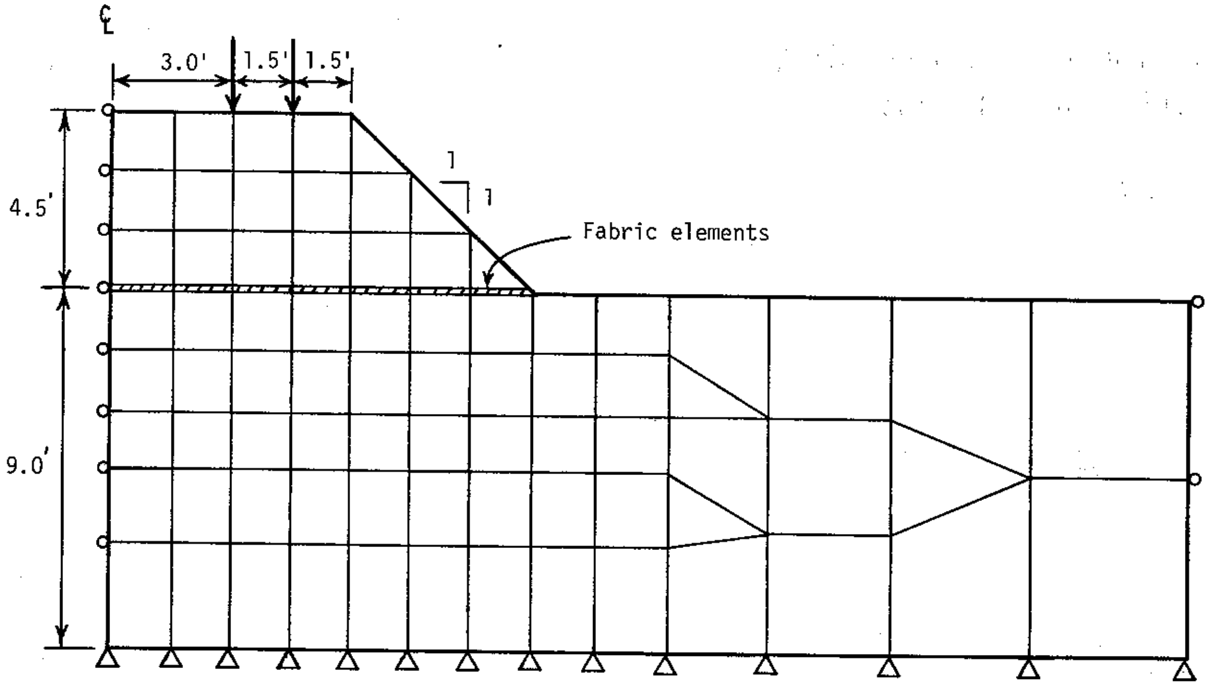

Figure 3. Finite element discretization.

Since granular soil is a "no tension" material, the use of an isotropic elastic material in the model would cause very large errors in the computed fabric tensions. If a granular soil were assumed to have the same modulus in tension as in compression it would be stronger in tension than the fabric and very low fabric tensions would be estimated. To simulate a "no tension" material, the embankment was assumed to be a linear orthotropic elastic material with Poisson's ratio equal to zero, elastic modulus in the vertical and horizontal directions of 600,000 and 600 lb/ft^2 respectively, and a shear modulus of 240,000 lb/ft^2.

The fabric elements were simple "truss" members, capable of transmitting axial force only. The fabric material was modeled as a nonlinear (multi-linear) elastic material capable of sustaining tension only. Two sets of fabric properties were considered, termed Fabrics "A" and "B" in the analysis. The force-strain curves for both fabrics are shown in Figure 4. Fabric A corresponds to the fabric used in the Alaska test. Fabric B has a tangent modulus three times as great as Fabric A.

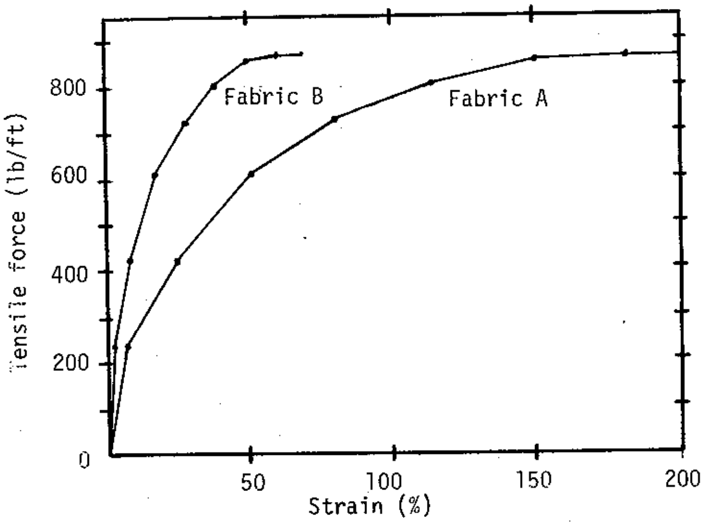

Figure 4. Assumed Fabric Properties.

The load-deformation behavior of muskeg has been investigated using finite element techniques by Hollingshead and Raymond (2). Although muskeg is markedly anisotropic due to layering of organic matter during formation, they have shown that little improvement in undrained (immediate) settlement estimates is obtained by utilizing this fact. They advocate modeling muskeg as an isotropic elastic-perfectly-plastic material. For one peat they tested, with water content of 558% and vane shear strength of 150 lb/ft^2, they obtained a modulus of elasticity of 3000 lb/ft^2. A Poisson's ratio of 0.25 fit their field data better than a Poisson's ratio of 0.5, and was thus recommended.

They performed finite element analyses assuming the muskeg was a perfectly plastic material upon yielding; yielding was defined by the unconfined compressive strength. An empirical increase of 47% in laboratory unconfined compressive strength was needed to bring their calculated values into agreement with field data.

The muskeg foundation was assumed to be a homogeneous, isotropic elastic-perfectly-plastic material as recommended by Hollingshead and Raymond. Modulus of elasticity, E, Poisson's ratio, ν, and yield strength σ_f, were taken as $E = 3000\ lb/ft^2$, $\nu = 0.25$, and $\sigma_f \doteq 440\ lb/ft^2$. Settlements calculated with this model, therefore, include some drained settlement, and would be greater than totally undrained settlements calculated with $\nu = 0.5$. The vane shear strengths at the test site were similar to those measured by Hollingshead and Raymond; thus, their recommendations appear appropriate for use in an analytical model of this field installation.

Three cases were analyzed. Case 1 was an embankment without fabric, Case 2 included fabric, and Case 3 also included live loads.

The predicted deflections of the natural ground surface under the embankment are shown in Figure 5. The deflections are nearly identical for no fabric, Fabric A, or Fabric B (Cases 1, 2A, and 2B). For two 1000 lb/ft live loads, the deflections increased to about 1.9 ft for both fabrics (Cases 3A and 3B). Doubling the live loads resulted in 2.7 feet of settlement (Cases 3A2 and 3B2). In all cases the differences between deflections for Fabric A and Fabric B were too small to be shown at the scale of the figure.

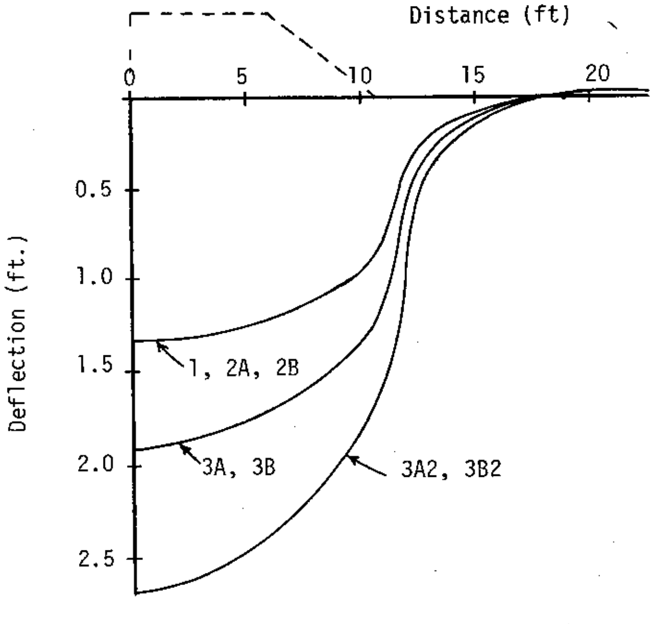

Figure 5. Calculated surface deflections.

The maximum computed fabric tensions are presented in Table 2. The magnitude of the tension is greatly influenced by fabric type.

Table 2. Maximum Fabric Tension.

Case	Maximum tension (lb/ft)	Location (ft from ℄)
2 A	125	0
B	304	0
3 A	197	2.5
B	357	2.5
A2	290	4
B2	454	4

The shear stresses on a horizontal plane near the top of the muskeg were also computed and found to be only slightly reduced by the fabrics.

The deflections calculated for construction live load on the embankment agree with the field data. The finite element model predicted 2.7 ft of settlement and the immediate settlements in the field were 3 ft under conditions similar to those assumed in the model.

The presence of fabric had little effect on the predicted deflections in the finite element model; however, they had a marked effect in the test section. This suggests that in the field, local shear failures are more likely to occur without fabric present as the fill material is dumped onto the muskeg. On the other hand, a fabric layer provides reinforcement against these local failures, the embankment then performs more as a unit, and decreased settlements result. In the finite element model, however, local failures are precluded; continuity at all points within the model is required. Thus the model embankment must "hold together" even without a fabric layer; therefore, little improvement is noted by adding fabric in the model.

The fabric stiffness had little effect on predicted deflections or foundation stresses in the finite element model. No field data exists with which to compare this result.

The calculated tension is directly dependent on deflections. Time dependent settlements were not included in this investigation, but may increase tension in the fabric. Primary and/or secondary consolidation would be significant in this regard. In the field fabric strains increased with time. During the same period, additional settlements up to 3.5 ft were observed. The data suggest that fabric tension increased with settlement or creep occurred in the fabric. Critical fabric conditions may therefore occur later in the life of the embankment. However, the strength of the foundation is also increasing as it consolidates.

Predicted fabric tension also depends directly on fabric stiffness. The stiffer Fabric B had significantly higher calculated tensions than did Fabric A for the same embankment deflections. Thus, for equal ultimate strengths, the high modulus fabric would possess a lower factor of safety with respect to ultimate strength than would the low modulus material. This result may be very significant in temperature and fabric creep considerations not investigated here.

The susceptibility of fabrics to creep at constant load and accumulated strain under repetitive load is not well defined presently. It might be predicted that higher relative stress levels in the fabric would increase creep; however, would a low modulus material with a low relative stress level creep more or less than a high modulus material with a higher relative stress level? Also, for the conditions investigated here the dead load stresses are quite low; therefore, is fatigue under repeated live loads more important than creep? Other questions not answered here are what are the effects of temperature on modulus and how do the results of laboratory tests relate to stress-strain relations in the field?

CONCLUSIONS

As is often the case, this study has asked more questions than it answers; however, it has shed some light and some conclusions appear justified for very low fabric reinforced embankment roads over very soft foundations.

1. The main function of the fabric is to prevent local bearing failures.
2. When shear failures do not occur, the embankment settlement is essentially the same with or without fabric and independent of fabric type.
3. Other conditions being equal, the tension in the fabric depends on the modulus of the fabric, with tension increasing as modulus increases.
4. Much more information about the mechanical properties of fabrics must be available before rational designs are possible.

ACKNOWLEDGEMENTS

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