FOWLER, J.
U.S. Army Waterways Experiment Station, Vicksburg, Mississippi, U.S.A.

Theoretical Design Considerations for Fabric-Reinforced Embankments

Les considérations théorétique de dessein pour des remblais armé avec tissu

The development and verification of embankment design, construction criteria, and theoretical consideration for fabric-reinforced embankments provide basic information necessary for estimation of the unbalanced forces to be carried by geotechnical fabric for known foundation conditions, embankment material properties, embankment heights, and side slopes. Two case histories of fabric-reinforced embankment construction are analyzed and presented. The paper discusses the theoretical design considerations for successful design and construction of fabric-reinforced embankments constructed on soft foundations and correlates the measured fabric elongation and strength with the theoretical computation for each embankment. Nomographic design curves, equations, and design criteria for successful test sections and prototype design and construction are also presented.

Le développement et vérification de dessein des remblais, des critère de la construction, et des considérations théoretique pour des remblais armé avec tissu se prémuni des renseignements de base indispensable pour l'estimation des forces non équilibré a été porté par un géotextile pour des conditions de fondation connu, des proprietes materiele des remblais, l'hateur des remblais, et des pentes du talus. Deux dossiers historique de la construction des remblais armé avec tissu sont analysé et presenté. Ce papier discute des considérations théoretique de dessein pour dessein et construction avec succès des remblais armé avec tissu constructé sur des fondations mou et mis en correlation la mesurage de l'elongation et la force du tissu avec la calcul théoretique de chaque remblai. Des courbes de dessein abaque, des equations, et des critère du dessein avec succès des sections d'essai et du dessein et construction des prototypes sont présenté aussi.

INTRODUCTION

In the past, conventional construction of embankments across extremely soft foundations have principally been displacement sections that contained two to three volumes of material below the surface for one volume above grade. This ratio could easily be much greater even when the embankment base widths are very large. Therefore attempts have been made to design fabric-reinforced embankments that float on these soft foundation materials. Geotechnical fabrics alleviate many soft ground embankment construction problems because they provide equipment mobility, allow expedient construction, and also temporarily suspend several laws associated with foundation bearing failure, allowing construction to design elevation without failure. This paper contains some theoretical design considerations important in the design and construction of a fabric-reinforced embankment. The report also presents the design parameters and analytical procedure used for design and fabric selection in construction at Pinto Pass, Mobile, Ala., and an embankment test section in Holland.

POTENTIAL EMBANKMENT FAILURE MODES

Design and construction of geotechnical fabric-reinforced embankments on soft foundations have been found to be a technically feasible, operationally practical, and cost-effective alternative to conventional soft ground construction in many embankments. To successfully design a fabric-reinforced embankment on a very soft foundation, three possible failure modes must be investigated: (1) horizontal sliding/lateral spreading, (2) rotational slope/foundation failure, and (3) excessive foundation displacement (see Fig. 1) (1). The fabric must resist the unbalanced forces necessary

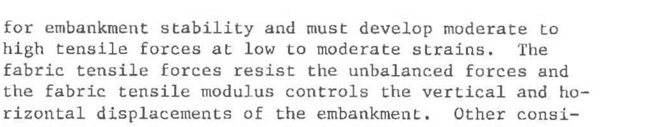

Fig. 1. Potential failure mode that might occur for fabric-reinforced embankments

for embankment stability and must develop moderate to high tensile forces at low to moderate strains. The fabric tensile forces resist the unbalanced forces and the fabric tensile modulus controls the vertical and horizontal displacements of the embankment. Other considerations are development of adequate soil-fabric friction to transfer embankment loads to the fabric as tensile stresses, and the use of proper construction sequence to develop fabric tensile forces at small fabric elongation or strain.

Design Data and Assumptions, Pinto Pass Embankment

A cross section of the Pinto Pass embankment constructed at Mobile, Ala., by the U. S. Army Engineer District, Mobile, is shown in Fig. 2. In addition to

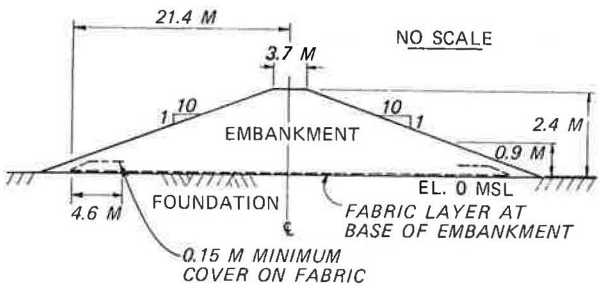

Fig. 2. Simplified fabric-reinforced embankment section at Pinto Pass.

the embankment design cross section, the following detailed data and/or assumptions were used for the analysis:

1. Settlements were computed assuming normally consolidated soils, 12.2 m of sediment thickness, an average initial void ratio of 2.7 and compression index C_c = 0.8. Based on these values and a dike height of 2.4 m, settlement was computed to be about 0.9 m.

2. A crest width of 3.7 m was designed to allow future vehicle traffic.

3. To allow for future dike raising, side slopes were 1 vertical and 10 horizontal.

4. Moist unit weight of the cohesionless backfill was estimated to be 1600 kg/m^3 above the permanent water table and 960 kg/m^3 below the water table.

5. It was determined from laboratory tests that the minimum angle of friction $\emptyset$ sf = 30° for the loosely placed backfill and the soil-fabric friction was essentially the same.

6. Field vane shear tests and laboratory tests indicated that the unconsolidated undrained shear strength of the foundation materials prior to construction were cohesion c = 2395 Pa from the surface to a depth of el -3.7 m and increasing linearly from about 4790 Pa to 7185 Pa at a depth of 12.2 m where a dense sand was encountered (see Fig. 3).

Horizontal Sliding/Lateral Spreading of Embankment, Pinto Pass

Resistance to horizontal sliding criteria assumed that, although the soil-fabric frictional resistance of the embankment may be sufficiently greater than the lateral earth pressure necessary to cause sliding, the tensile strength of the fabric may not be great enough and failure may result in fabric tearing and outward sliding of the embankment along the soft foundation.

It was assumed that the horizontal force that might cause lateral sliding could be approximated by Mohr-Coulomb active pressure. The lateral load calculated for the end of construction is:

$$P_a = 0.5\ \gamma_m H^2 \tan^2\left(45° - \frac{\emptyset}{2}\right)$$

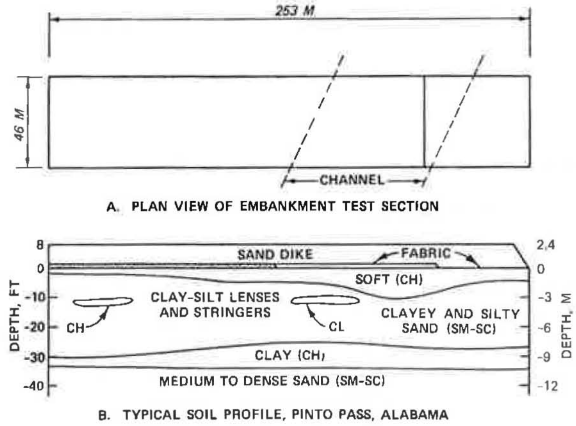

Fig. 3. Plan and soil profile, embankment test section.

where γ_m = density of embankment sand, 1600 kg/m^3; H = maximum embankment height at sta 5+00 at end of construction, 2.5 m; $\emptyset$ = frictional resistance of embankment sand, 30°

or

$$P_a = 0.5\ (1600\ \text{kg/m}^3)(2.5\ \text{m})^2 \tan^2\ (45 - \frac{30°}{2})$$

$$P_a = 1674\ \text{kg/m-width}\ ,\ 16.4\text{KN/m-width}$$

while sliding resistance along the fill material-fabric interface was approximated by

$$P_r = \frac{HL}{2}\ \gamma_m \tan \emptyset\ sf$$

where P_r = resultant of resisting force (N/m-width), and

$\emptyset$ sf = soil-fabric friction angle = 30°

$$P_r = 0.5 \times 2.5\ \text{m} \times 21.3\ \text{m} \times 1600\ \text{kg/m}^3 \times \tan 30°$$

$$P_r = 24{,}600\ \text{kg/m-width}\quad 241\ \text{KN/m-width}$$

and the factor of safety against sliding was defined as the ratio (P_r/P_a), assuming the fabric tensile strength is not exceeded. By inspection, the controlling parameter was fabric tensile resistance due to lateral active earth pressure.

The horizontal sliding resistance necessary to resist the active pressure would be the ultimate stress of the fabric. Observations made during construction and inspection of the vertical and horizontal settlement plate data indicated that horizontal sliding had occurred with a fabric elongation of about 4.0 percent and a fabric tensile stress of about 14.6 KN/m-width for the fabric. If a minimum safety factor of 2.0 is chosen against sliding, the fabric would provide an ultimate tensile strength, $T_f = 2.0 \times P_a$, or 2.0 × 16.4 KN/m-width or 32.8 KN/m-width, which would exceed the measured tensile stress of 14.6 KN/m-width. This very close agreement of measured and calculated tensile stress indicates this potential unsatisfactory mode controlled the sliding behavior of the test section.

To develop fabric tensile forces and to prevent lateral spreading failure, fabric strain must occur during embankment spreading. Fabric tensile modulus controls the amount of lateral spreading and a factor of safety of 2.0 is normally recommended to determine the minimum required fabric tensile modulus. When the fabric tensile strength T_f is used to determine the required fabric tensile modulus, E_f, a factor or safety of 2.0 is included, and the required fabric tensile modulus is expressed as

$$E_f = T_f/E_{max}$$

where E_f = minimum required fabric tensile modulus (N/m-width), and
E_{max} = maximum fabric strain along the fabric centerline (dimensionless)

The maximum fabric strain over the enbankment width is assumed to be twice the average strain. Lateral spreading of 5 percent has been found to be a reasonable limiting value from previous construction and fabric testing (1). Therefore if 5 percent strain is used as an average value, then the maximum expected strain would be 10 percent and the required tensile modulus would be

$$E_f = T_f/0.10 = 10T_f = (10)(32.8 \text{ KN/m-width})$$
$$E_f = 328 \text{ KN/m-width}$$

This value is the minimum required fabric tensile modulus to prevent lateral embankment spreading failure.

Localized Foundation Bearing Failure and Rotational Subsidence of the Pinto Pass Embankment

This potential unsatisfactory behavior was analyzed by the simplified Bishop slope stability analysis for estimating the ultimate fabric tensile strength necessary to provide a factor of safety against rotational slope failure of a sand embankment on a soft cohesive foundation (Fig. 2b) and the following assumptions were considered in the analysis:

1. Full fabric tensile strength is developed before slope failure.

2. Consideration of shear strength in the embankment was neglected as tensile cracks may occur.

3. The critical slip circle passes through the embankment behind the crest and is tangent to the assumed foundation strength change layer at el -3.7 m where c = 2,395 Pa. Critical failure arcs for the embankment with and without fabric reinforcement are considered to be identical.

4. The embankment and fabric are placed on the foundation simultaneously, and foundation cohesion and ultimate fabric tensile strength are mobilized simultaneously.

5. The likelihood of internal embankment slope failure is minimal because the factor of safety against failure was F = tan 30°/tan 5.7° = 5.8 (where 30° = Ø and 5.7° is embankment slope).

6. The fabric strength is equivalent to the strength of a cohesive clay layer uniformly distributed along the failure arc or plane, and the angle of internal friction is zero.

7. Only the end-of-construction case is considered with the groundwater assumed to be at the same elevation as the fabric reinforcement layer.

Treatment of Fabric Strength, Pinto Pass Embankment

The fabric was laid flat on the soft underlying foundation materials beneath the base of the embankment and the potential failure plane extended through the toe of the embankment. Resistance was provided by the tensile strength of the fabric embedded beneath the embankment and was assumed to act uniformly along the length of the embedded arc length beneath the fabric. Therefore, the total resistance may be mathematically expressed as the sum of the resistance contributed by the fabric and cohesive resistance of the soil or:

$$c = c_f + c_u$$

where c = total cohesive strength, Pa
c_f = equivalent fabric cohesive strength, Pa
c_u = soil cohesive strengths, Pa

The relationship between the fabric tensile strength, T_f , and the equivalent fabric cohesion, c_f , is determined by the following expression:

$$T_f = c_f L_f$$

where L_f = length of the failure arc embedded in the foundation materials beneath the fabric reinforcement.

Therefore, it can be seen that the total resistance, R, for each linear foot of the fabric and foundation soil is as follows:

$$R = L_f c$$

$$R = L_f\ (c_f + c_u)$$

$$R = L_f \left(\frac{T_f}{L_f} + c_u\right)$$

$$R = T_f + L_f c_u$$

Parameter Investigation

To study the influence of the various parameters such as height of the embankment H, the thickness of the soft foundation layer h, and the variables c_f and c_u defined earlier, it was necessary to develop design charts to illustrate their behavior and relationship to one another. Therefore, it was necessary to introduce dimensionless numbers by combining the above parameters as follows:

1. The depth ratio (D) is the sum of the embankment height (H) and foundation layer (h) divided by H, or D = (H + h)/H. A reference line is drawn horizontal and tangent to H at the top of the embankment crest, and dimensions are taken from this line.

2. In conventional slope stability problems, the stability number (N) is defined as $Nc/\gamma_m H$ where γ_m is the moist density of soft foundation soil and c and H are as defined previously.

For a given set of parameters, a critical arc is established first; then the factors of safety and total cohesion are determined for a given arc. All computations for each set of conditions were conducted with the use of the U. S. Army Engineer Waterways Experiment Station (WES) computer.

Design Curves

Since the geometry of the test section was constrained by various design considerations, it was decided to include two sets of design charts that included the design parameters in a dimensionless form. Dimensionless design curves 1 and 2, prepared from several computer runs are shown in Figs. 4 and 5 and

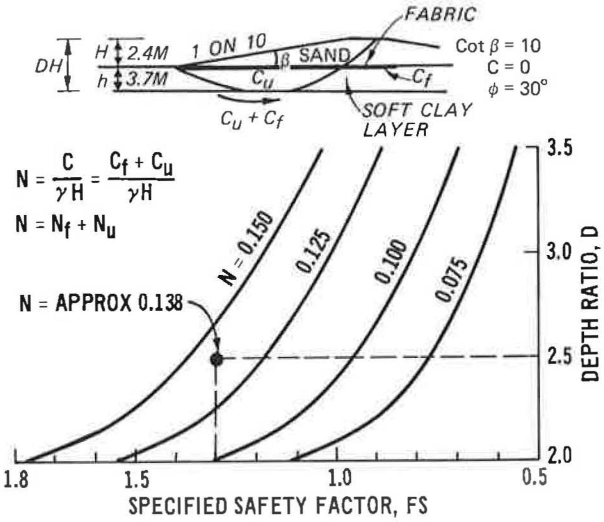

Fig. 4. Design chart 1 for determining stability number N

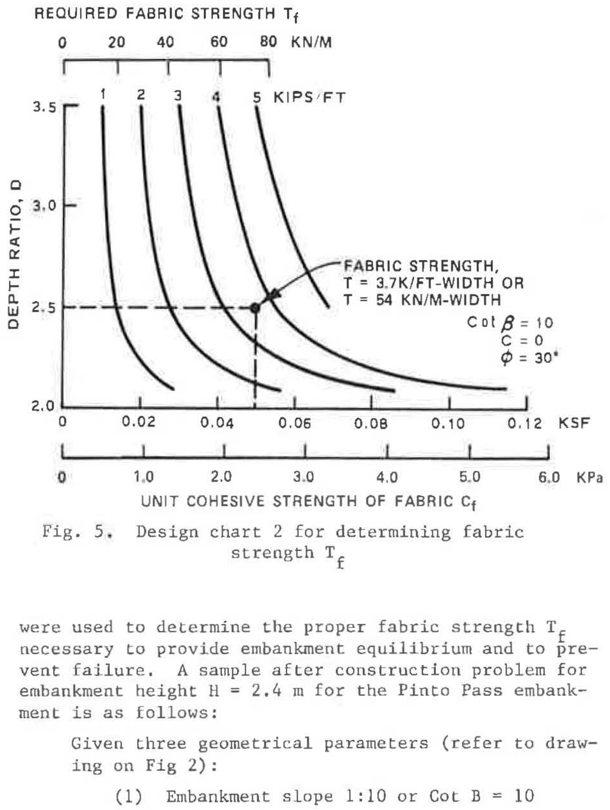

Fig. 5. Design chart 2 for determining fabric strength T_f

were used to determine the proper fabric strength T_f necessary to provide embankment equilibrium and to prevent failure. A sample after construction problem for embankment height H = 2.4 m for the Pinto Pass embankment is as follows:

Given three geometrical parameters (refer to drawing on Fig 2):

(1) Embankment slope 1:10 or Cot B = 10

(2) Embankment height H = 2.4 m

(3) Soft foundation layer h = 3.7 m

and three soil parameters:

(1) Density of embankment materials γ_H = 1600 kg/m^3

(2) Density of soft foundation materials γ_h = 1440 kg/m^3

(3) Cohesive strength of soft foundation soil c_u = 2.4 kPa or KN/m^2

Specified safety factor FS = 1.3

Required: fabric tensile strength T_f

Solution: Find depth ratio D

$$D = \frac{H + h}{H} = \frac{2.4 + 3.7}{2.4} = 2.5$$

From Chart 1, Fig. 4, for a given safety factor FS = 1.3, the total stability number N equals 0.138. The component number N_u for the soil cohesion is:

$$N_u = \frac{c_u}{\gamma_h H} = \frac{2.4 \text{ KN/m}^2}{1440 \text{ kg/m}^3 \text{ (2.4 m)(9.81 N/kg)}}$$

$$N_u = 0.069$$

Therefore, the component number N_f for the fabric is:

$$N = N_u + N_f$$
$$0.138 = 0.069 + N_f$$
$$N_f = 0.069$$

Then, the unit cohesion c_f of the fabric is:

$$c_f = N_f \gamma_h H$$

$$c_f = 0.069 \text{ (1440 kg/m}^3\text{)(2.4 m)}$$

$$c_f = 238 \text{ kg/m}^2 \text{ or } 2.3\text{kPa}$$

From Chart 2, Fig. 5, the required fabric tensile strength was determined to be T = 54 KN/m-width.

Results of this investigation indicated that the fabric ultimate tensile strength required to prevent circular arc failure was 32 KN/m-width at an FS of 1.0. This fabric strength requirement is twice as large as the fabric strength required to resist the horizontal sliding mode and also about twice the actual fabric stresses measured after construction. To prevent rotational subsidence an FS of 1.1 to 1.2 was recommended (2), but because this behavior is one of the most difficult to measure, an FS of 1.3 would be more conservative and the chances of success more probable.

There was no evidence of sliding or slumping that might have resulted in a localized bearing failure or stress concentration in the fabric in the embankment test section. A circular arc rotational type failure that resulted in deformation of the embankment and resulting failure in the fabric at the point of sliding was observed in a test section constructed in Holland and reported by Risseeuw (3). This type of failure was documented and data supporting this type of failure are provided and will be discussed later.

Until additional data from controlled tests (such as those in Holland) or prototype structures of this type of behavioral mode become available, it would be expedient to use the fabric strengths determined by the modified Bishop method of analysis. Identifying and measuring the stress in the fabric where these rotational failures may occur, especially at localized points of possible high fabric stress concentration, are very important to these analyses, and every effort should be made to document this type of potential unsatisfactory behavior in future projects. However, based on observed behavior for the test embankment, classic slope stability analysis overpredicts the needed fabric strength by a factor of about 32 KN/m/14.6 KN/m-width or 2.2. Thus, this assumed mode of failure was not critical for the Pinto Pass test section.

Fabric Tensile Stress Developed by Embankment Deformation-Pinto Pass

It has been postulated (2) that once the foundation bearing capacity was exceeded by the embankment bearing pressure, bearing failure and resulting deformation of the foundation would occur. To avoid this type of failure, insofar as possible, the fabric was placed, covered, and anchored by the embankment material before excessive deformations could occur. Bearing capacity of the foundation was exceeded when the embankment height exceeded 0.9 m or ($q = 3.8 \times 2395$ Pa for soft foundations) about 9,100 Pa, and it was assumed that the fabric would carry the remaining weight of the dike (39.8 kPa - 9.1 kPa, or 30.7 kPa) and the embankment would tend to slide or spread laterally, causing tension stresses in the fabric.

Effective soil stresses determined from piezometers along the centerline of the embankment at the end of construction near sta 6+00 was 0 Pa. This confirms the rationale of using unconsolidated undrained shear strength for ultimate bearing capacity calculations. The use of the bearing capacity method for determining the required fabric strength to resist the static loads of the embankment was unsatisfactory.

It was estimated that about 0.9 m of consolidation would occur near the centerline of the embankment, but actually only about 0.5 m occurred. If no lateral displacement is allowed, then the percent fabric elongation and consequent fabric stress can be determined geometrically. The percent fabric elongation was calculated to be less than 0.02 percent; therefore, it was concluded that this magnitude of elongation would not produce appreciably large stresses in the fabric and minimal end anchorage would be necessary.

Controlled Fabric-Reinforced Embankment Failure, Holland

A 120-m-long highway embankment controlled fabric-reinforced test section was constructed in Holland to evaluate several woven geotechnical fabrics for incorporation in a highway to be built across very soft foundation material consisting of clay and peat to a depth of 4.4 m.

Underlying foundation materials consisted of a very soft clay layer having an unconfined compressive strength of about 2395 Pa to a depth of about 0.4 m and approximately 4.0 m of peat with about the same strength. The minimum angle of internal friction for the semicompacted sand fill was considered to be about 30° and equal to the soil-fabric friction. The average saturated unit weight of the foundation material was assumed to be about 1280 kg/m^3 to depth of 4.4 m and the fill material was assumed to be about 1600 kg/m^3. Below this depth was a very dense sand deposit.

The embankment was instrumented with piezometers, settlement plates, and strain wires attached to the fabric to determine the behavior of the reinforced embankment. The embankment had been constructed to a height of 2.5 m and a width of 80 m when a shallow rotational failure about 50 m long and 7.5 m wide occurred and created a subsidence of about 1 m. Excavation test pits were dug both at sections A that did not fail and at section D where the embankment failure was located.

A profile view of the embankment test section in Fig. 6 includes both sections A and D for comparison purposes. This figure shows the fabric prior to failure (section A) and after failure (section D). Embankment slope decreased from 1:1 to 1.5:1 after the embankment surface has subsided about 1 m. About 1 m of fabric was

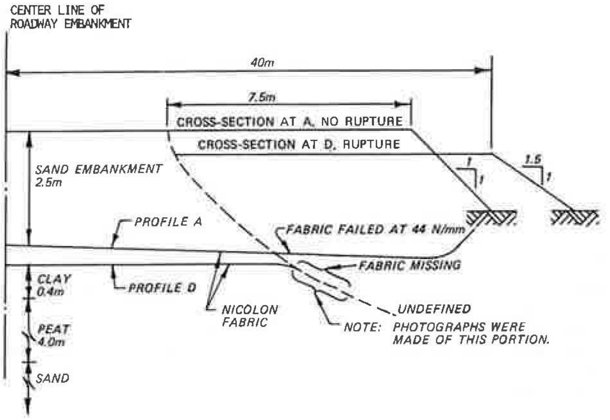

Fig. 6. Profile view of embankment, Holland

missing in the rotational shear zone shown in Fig. 6. A photograph of the fabric after failure and excavation is shown in Fig. 7. The failure is typical of the type

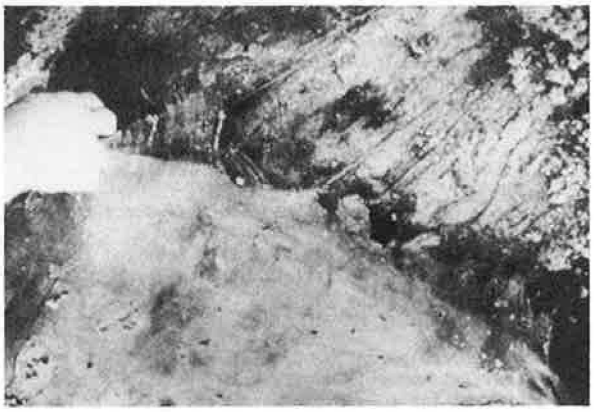

Fig. 7. Fabric failure in Holland highway embankment

of failure observed after a uniaxial fabric test. Strain wires attached to the fabric were set for 5 percent strain (fabric elongation) increments up to 25 percent total strain, and the fabric failed at about 20 percent strain or a fabric strength, based on uniaxial testing results of about 43.8 KN/mm. No attempt was made to fold back the fabric at the embankment toe to act as an anchor, but there was no evidence that this procedure was necessary or would have provided any additional embankment stability in this case. However, if the fabric had been doubled in the area of the rotational failure, the additional layer of fabric might have served to prevent this potential failure mode.

Analysis of the rotational failure for the highway embankment test section indicated that the failure strength of the fabric was considered to be about the equivalent soil strength necessary to prevent embankment subsidence and subsequent foundation bearing failure. An additional documented failure, such as the one described, has been reported by the Dutch, but to date an account of it has not been published.

Horizontal Sliding/Lateral Spreading of Embankment, Holland

Since the embankments in Holland and at Pinto Pass were almost the same height and exhibited about the same embankment and foundation conditions, it was decided from inspection that this potential failure was not critical. However, further inspection of the slope angle indicated that the probability of internal embankment slope failure is maximized because the factor of safety against failure was $F = \tan 30^\circ/\tan 45^\circ = 0.58$ (where $30^\circ = \phi$ and 45° is the embankment slope). Since the embankment was constructed at the apparent angle of repose of the sand fill, the angle of internal friction ϕ could have been much greater than 30°, and the cohesion of the moist sand could be responsible for supporting these initially steep slopes. The lateral load calculated to be resisted by the fabric at the end of construction was $P_a = 16.4$ KN/m-width, while sliding resistance was $P_r = 454$ KN/m-width, and as at Pinto Pass the controlling parameter was fabric tensile resistance due to lateral earth pressure.

It was further shown as in the previous example analysis at the Pinto Pass test section that the most likely failure mode was the rotational or slip circle type failure. A sample after-construction problem for embankment height, H = 2.5 m for the Holland Roadway embankment is as follows for the rotational failure mode.

Given three geometrical parameters (refer to Fig. 7):

(1) Embankment slope 1:1
(2) Embankment height H = 2.5 m
(3) Soft foundation layer h = 4.4 m

and three soil parameters:

(1) Density of embankment material $\gamma_H = 1600$ kg/m^3
(2) Density of foundation materials $\gamma_h = 1280$ kg/m^3
(3) Cohesive strength of soft foundation soil $c_u = 2.4$ kPa or 2.4 KN/m^3

Specified safety factor FS = 1.3; Required fabric tensile strength T , solution; Find depth ratio D:

$$D = \frac{H + h}{H} = \frac{2.5 + 4.4}{2.5} = 2.76$$

From Fig. 4 for a given safety factor FS = 1.3 the total stability number N equals 0.160 and the component number N_u for the soil cohesion is

$$N_u = \frac{c_u}{\gamma_h H} = \frac{2.4 \text{ KN/m}^2}{(1280 \text{ kg/m}^3)(2.5 \text{ m})(9.81 \text{ N/kg})}$$

$$N_u = 0.076$$

Therefore, the component number N_f for the fabric is:

$$N = N_u + N_f$$
$$0.160 = 0.076 + N_f$$
$$N_f = 0.084$$

Then the unit cohesion C_f of the fabric is

$$C_f = N_f \gamma_h H$$
$$C_f = (0.084)(1280 \text{ kg/m}^3)(2.5 \text{ m})$$
$$C_f = 269 \text{ kg/m}^2 \text{ or } 2.6 \text{ kPa}$$

From Fig. 5, the required fabric tensile strength T_f was estimated to be about 65.6 KN/m-width. If the proper fabric strength had been used, the embankment would not have failed at the 43.8 KN/m-width strength estimated from the strain wires attached to the fabric during fabric rupture. The FS would have been about 1.5. An FS of 1.0 was used to estimate the fabric strength of 33.6 KN/m^2, which was about 77 percent of the failure strength estimated in the field test.

SUMMARY AND CONCLUSIONS

Analysis based on field observations and design strengths determined by various design procedures confirmed the need for fabric for reinforcement to prevent embankment failure. Maximum fabric elongation (strain) of 4 percent at 14.8 KN/m-width was recorded in the fabric at the Pinto Pass test section and fabric failure of 43.8 KN/m-width at 20 to 25 percent elongation in the fabric at the Holland embankment.

Data from the Pinto Pass embankment indicated that fabric elongation was within the maximum elongation allowed for the fabric selected during fabric tests in the laboratory. As stated earlier, an average fabric elongation of 5 percent was desired, but fabric elongation of 10 percent would be acceptable in the test section design. The controlled fabric failure in the Holland embankment was predictable when the proper design procedures were used. Comparison of the design procedures used in these analyses indicated that the sliding wedge analysis was more appropriate in that the fabric stress determined for the Pinto Pass embankment by this method was almost identical to the fabric stress measured in the field. The modified Bishop method of analysis using a factor of safety of 1.0 was more conservative, predicting a fabric stress of approximately double that measured in the field at Pinto Pass embankment and about one and one-third times the stress at failure for the Holland embankment. When a factor of safety of 1.0 was used to determine the fabric strength at failure for the Holland embankment, the value determined from the modified Bishop method was only 76 percent of the value measured during failure in the field. The bearing failure method predicted a value of about one-half the field measurements at both the Pinto Pass and Holland embankments. Fabric elongation due to vertical foundation displacement or consolidation was minimal in each embankment.

It is concluded that the modified Bishop method of analysis would provide the most conservative design approach for predicting fabric strength for most embankments constructed utilizing geotexile fabrics on soft foundation materials.

REFERENCES

(1) Fowler, J., Design, Construction, and Analysis of Fabric-Reinforced Embankment Test Section at Pinto Pass, Mobile, Alabama, Technical Report EL-81-7, U. S. Army Engineer Waterways Experiment Station, (Vicksburg, Miss., 1981).

(2) Haliburton, T. A., Anglin, C. C., and Lawmaster, J. D., Selection of Geotechnical Fabrics for Embankment Reinforcement, prepared by Oklahoma State University for the U. S. Army Engineer District, Mobile, (Mobile, Ala., 1978).

(3) Risseeuw, P., Stabilenka Woven Reinforcement Fabric in Raising Mounds of Soft Soil, Akzo Research Laboratories, (Arnhem, 1977, unpublished).

Gleitsicherung: E_{Textil} so wählen, daß 2x Erddruck in Dammmitte 10% Dehnung des Geotextils entspricht

Gleitkreisuntersuchungen mit y = 0