AD-A115 574 HALIBURTON ASSOCIATES STILLWATER OK F/G 13/2
DESIGN OF TEST SECTION FOR PINTO PASS DIKE, MOBILE, ALABAMA.(U)
JUN 78 DACW01-78-C-0092
UNCLASSIFIED NL

1 OF 1

END
DATE
FILMED
7-82
DTIC

DESIGN OF TEST SECTION FOR PINTO PASS DIKE,
MOBILE, ALABAMA

Conducted for

U. S. Army Engineer District, Mobile

under

Contract No. DACW01-78-C-0092

by

HALIBURTON ASSOCIATES
Engineering Consultants
Stillwater, Oklahoma

June, 1978

The opinions, findings, and conclusions contained herein are those of Haliburton Associates and not necessarily those of the U. S. Army Engineer District, Mobile.

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A115574
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) Design of Test Section for Pinto Pass Dike, Mobile, Alabama	5. TYPE OF REPORT & PERIOD COVERED Final Report
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Haliburton Associates	8. CONTRACT OR GRANT NUMBER(s) Contract no. DACW01-78-C-0092
9. PERFORMING ORGANIZATION NAME AND ADDRESS Haliburton Associates Engineering Consultants P O Box 1132, Stillwater, Oklahoma 74074	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Dredging Operations Technical Support Program
11. CONTROLLING OFFICE NAME AND ADDRESS U S Army Engineer District, Mobile Mobile, Alabama 36628 and Office, Chief of Engineers, U S Army Wash DC 20314	12. REPORT DATE June 1978
	13. NUMBER OF PAGES 52
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report) Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Dredged material disposal
Earth fills
Embankment construction
Embankment design
Embankment foundations
Fabrics
Mobile Bay
Soft soils

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Construction of earth embankments on soft foundations is often a difficult geotechnical engineering problem. Construction of a proposed confined dredged material disposal area for Mobile Harbor, Alabama, requires the U S Army Engineer District, Mobile, to construct approximately 5000 linear feet of eight foot high embankments on extremely soft cohesive foundation soils, with undrained shear strength from 50 to 150 p.s.f. The initial

embankment would have to provide a stable base for raising an additional 17 feet. and fusture raising an additional 25 feet. Fine, poorly gradded sand was available nearby for use as borrow material in construction of the initial embankment.

It was determined that the most cost-effective and potentially acceptable solution would be to construct civil engineering fabric-reinforced dikes along the proposed alignment. The civil engineering fabric would be placed between the soft cohesive foundation and the sand embankment material in long, narrow strips perpendicular to the alignment, with the strips overlapped and sewn together. The civil engineering fabric would act as tensil reinforcement, preventing lateral spreading and localized bearing failure of the dike and maintaining its integrity until sufficient foundation consolidation could occur to support the total embankment weight.

As the concept was essentially experimental in nature, it was decided to construct and instrumented embankment test section. Design criteria for the embankment test section are presented herein, along with construction procedures, required equipment and estimated costs.

PREFACE

This report presents the results of U. S. Army Engineer District, Mobile (MDO), Contract No. DACW01-78-C-0092 for the design of a civil engineering fabric-reinforced embankment test section across the west end of Pinto Pass, Mobile Harbor, Alabama, as part of MDO long-term development of Pinto Island as a dredged material disposal site. A previous MDO-supported study indicated that dike construction across Pinto Pass was necessary for proper development of the Pinto Island disposal area, and that a fabric-reinforced embankment might be a cost-effective solution. Other MDO-supported work evaluated currently available civil engineering fabrics for their suitability in fabric-reinforced embankment construction.

General site survey, foundation characterization, and background data for the study were provided by the MDO under the general direction of Mr. Patrick A. Douglas, Civil Engineer, MDO Foundations & Materials Branch (F&MB). General assistance and guidance during the study was provided by Mr. J. Patrick Langan, Assistant Chief, MDO Project Operations Branch, Mr. Harvey Blakeney, Chief, MDO F&MB, and Mr. Robert W. Chamlee, Civil Engineer, MDO F&MB. Contract manager for the study was Mr. Kenneth Jackson, Civil Engineer, MDO Mobile Area Office.

LTC Donald R. Pope, CE, MDO Assistant District Engineer, was Contracting Officer. District Engineer of the MDO is COL Charlie L. Blalock, CE.

TABLE OF CONTENTS

DESIGN OF TEST SECTION FOR PINTO PASS DIKE, MOBILE, ALABAMA

PART I. INTRODUCTION

Relevant Background Information

In the report, "Feasibility of Pinto Island as a Long-Term Dredged Material Disposal Site," conducted for the U. S. Army Engineer District, Mobile (MDO), by the U. S. Army Engineer Dredged Material Research Program as Work Unit 5A16 (Ref 1), Haliburton, Douglas, and Fowler concluded that feasibility of using Pinto Island, Mobile Harbor, Alabama, as a long-term confined dredged material disposal area was contingent upon constructing approximately 5,000 lin ft of containment dike across both ends of Pinto Pass and along the south tidal line of Pinto Pass at Pinto Island. Construction of these dikes posed a difficult engineering problem, as foundation conditions consisted of up to 40 ft of extremely soft cohesive sediments.

In their study, Haliburton, Douglas, and Fowler reviewed various engineering alternatives for construction of the dikes and concluded that the most cost-effective and potentially acceptable solution would be to construct civil engineering fabric-reinforced "floating" dikes along the proposed alignment. The civil engineering fabric (also called geotechnical fabric, geofabric, or filter cloth) would act as tensile reinforcement, preventing lateral spreading and localized bearing failure of the dike and maintaining its integrity until sufficient foundation consolidation could occur to support the total embankment weight.

After review of the feasibility study by the Project Operations Branch, Foundations and Materials Branch, and Mobile Area Office, MDO, the fabric-reinforced dike construction concept was accepted. As the concept was essentially experimental in nature, the MDO decided to construct an initial instrumented embankment test section across the west end of Pinto Pass, to:

a. Evaluate technical feasibility of the concept,

b. If technically feasible, develop data on proper construction procedures and techniques for contract advertisement to complete the remaining portions of the fabric-reinforced dike, and

c. Collect and evaluate data necessary to develop and verify fabric-reinforced embankment design criteria for use in other future construction by the MDO.

The general location of the proposed embankment test section relative to City of Mobile and Mobile Harbor, Alabama, is shown in Figure 1. Figure 2 is an aerial view of Pinto Pass, while Figure 3 is a ground photograph showing the general area of proposed test section construction. As may be noted in the photographs, the proposed test section must be constructed across an intertidal area, with existing ground elevations over most of the alignment ranging between El. 1.5 Mean Sea Level (MSL) and El. -1.0 MSL.

After deciding to proceed with test section construction, it was necessary to obtain a proper design for the test section, including exact location, size, construction procedure, specifications for MDO contract advertisement, necessary plans, and related items. Also, in order to allow proper design of the embankment, it was necessary to select a civil engineering fabric or fabrics to be used as reinforcement. The latter consideration was resolved by MDO Contract No. DACW01-78-C-0055 with the School of Civil Engineering, Oklahoma State University, Stillwater, Oklahoma, to obtain, test, and evaluate currently available civil engineering fabrics for use as embankment reinforcement. Data obtained from this study (Ref 2) were furnished to the Contractor for use in fabric selection and development of an embankment test section design.

Scope of this Report

After a review of necessary design constraints, this report presents a suggested design for an embankment test section across Pinto Pass,

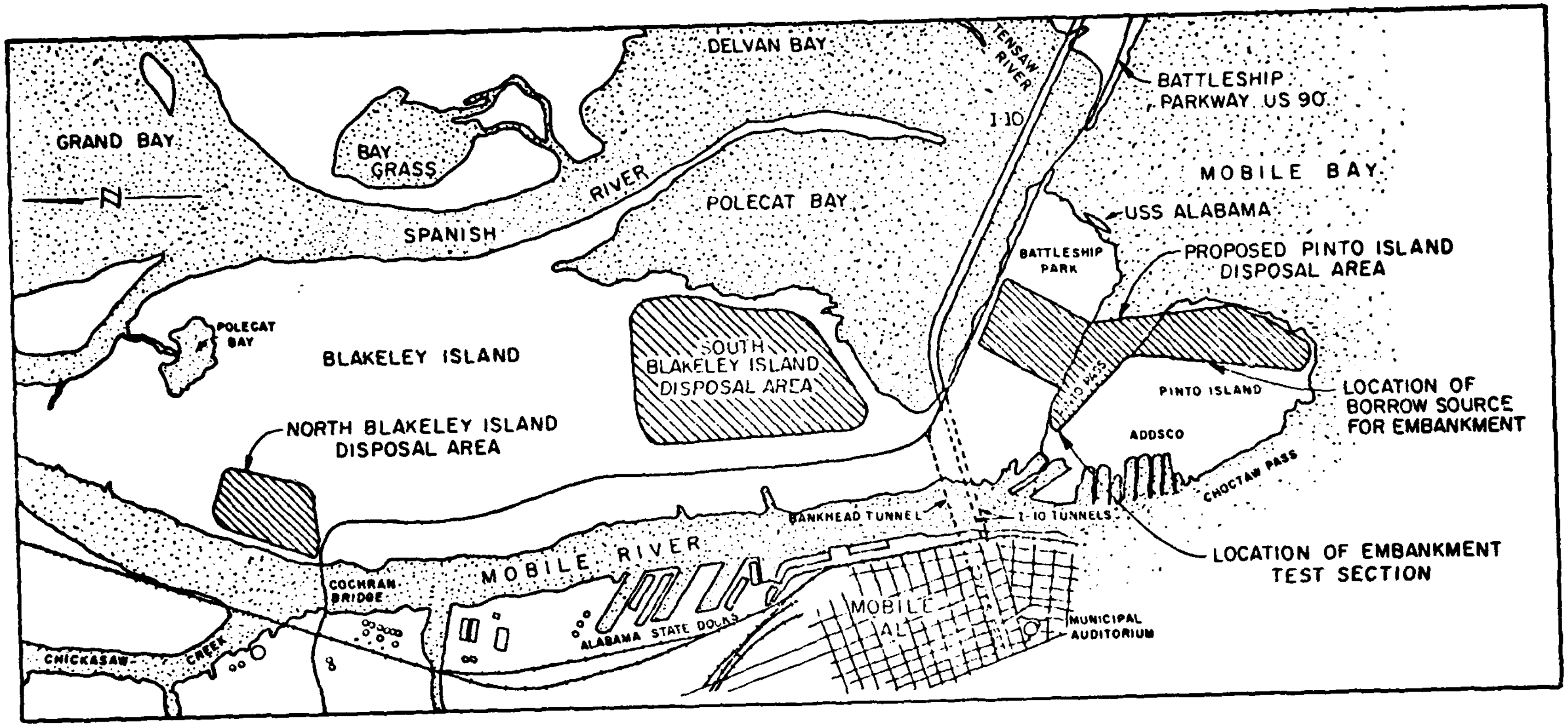

Figure 1. General location of embankment test section in Mobile Harbor, Alabama.

Figure 2. Aerial view of Pinto Pass looking east to west. Embankment test section will cross Pinto Pass at about the top quarter point of the photograph.

Figure 3. Ground photograph of Pinto Pass looking east to west, with Mobile Harbor in the background. Embankment test section to be constructed west of the narrow channel shown in the photograph.

including embankment location, analysis of expected embankment behavior, selection of civil engineering fabric for use as structural reinforcement, description of required instrumentation, description of necessary construction procedure, listing of equipment required to construct the embankment in necessary detail for MDO contract advertisement, and a cost and time estimate for conducting the work. Necessary easements, rights of access, and related details necessary to conduct test section construction are also described. In addition to material contained in this report, reference will also be made to material contained in Appendix 1 - Construction Plans, a separate attachment to this report.

PART II. DESIGN CONSTRAINTS

Design constraints existing for the Pinto Pass fabric-reinforced embankments were described in detail by Haliburton, Douglas, and Fowler (Ref 1). Briefly, the embankments were to act as multi-purpose structures to:

a. Allow initial containment of dredged material up to El. 8 MSL.

b. Act as preload structures to consolidate underlying soft foundation materials and allow rapid dike-raising up to at least El. 25 MSL.

c. Provide a stable base section for future dike raising.

To minimize total costs of dike construction, the embankment test section was to be located along the proposed alignment, such that if construction were successful, it could be incorporated into the disposal area containment dike system. The dikes were to be constructed initially to El. 8 MSL and raised to El. 12 MSL with coarse-grained material available in the south part of the proposed Pinto Island disposal area (see Figure 1). Subsequent raising would be conducted with dewatered fine-grained dredged material from inside the Pinto Island disposal site. These constraints resulted in the selection of an initial embankment section with crest at El. 8.0 MSL, 12-ft crest width, and 1v on 10h side slopes. This initial section would provide a stable base section for raising to El. 25 MSL with 1v on 3h side slopes, and allow future raising up to El. 50 should same be desired by the MDO.

In addition, the embankment test section located north to south across the west end of Pinto Pass was constrained in location by requirements that:

a. The north end abut existing dikes at approximately El. 12-16 MSL, which would be renovated and raised during overall Pinto Island disposal site dike construction.

b. It be located as far east as practicable, without causing undue loss of potential disposal site storage volume, from a bridge across the east end of Pinto Pass, to minimize disturbance to this structure in the event of test section failure.

c. The south end of the test section be located approximately 400 ft north of the centerline of the paved access road to the Alabama Dry Dock and Shipbuilding Company (ADDSCO).

Assuming that the MDO will generally follow Plan C as described by Haliburton, Douglas, and Fowler (Ref 1) for development of the Pinto Island disposal area, the test embankment was located as shown in Sheet 1 of Appendix 1. The probable alignment of remaining fabric-reinforced dikes, assuming successful test section construction, is also shown on Sheet 1. A larger-scale plan of the embankment location is shown on Sheet 2 of Appendix 1.

PART III. EMBANKMENT ANALYSIS

Review of Available Design and Analysis Concepts

Criteria for analysis and design of fabric-reinforced embankments on soft foundation are not well-defined, thus necessitating test section construction at Pinto Pass to verify a potentially cost-effective dike construction method. In conducting their initial feasibility study (Ref 1), Haliburton, Douglas, and Fowler found that numerous dikes of varying size and width had been constructed on numerous soft foundations using numerous fabrics, with varying degrees of success. However, in almost every instance, construction had been of an expedient and/or remedial nature conducted without preliminary design and/or analysis, and, other than an observation relative to the success or failure of the project, no useful data on observed behavior were obtained. Numerous manufacturers' technical brochures are available which promote or suggest use of their fabrics to support roadways and embankments on soft foundation. Such literature contains artistic sketches of the finished structure, but little design criteria other than a recommendation for use of the promoted fabric and a disclaimer of manufacturer liability concerning reliability of any technical information contained in the brochure. Survey of literature from a recent international conference held in Paris, France, on use of civil engineering fabrics (Ref 3) yielded several construction case history papers concerning fabric-reinforced dikes, but these papers contained minimal data on design and analysis. One paper presented at the 1978 American Society of Civil Engineers Geotechnical Engineering Specialty Conference on Use of Solid Waste Materials (Ref 4) described construction of a fabric-reinforced embankment constructed of wood chips in Wisconsin. Again, the paper format was that of reporting a case history and minimal design/analysis detail was presented. Another paper was obtained through technical representatives of the Nicolon Corporation (Ref 5) which apparently summarized the results of a consultant study undertaken for Nicolon in Europe to develop design and analysis criteria for constructing fabric-reinforced dikes. While review of this paper was informative, in the Contractor's opinion, methods of analysis for the most critical case of unsatisfactory fabric-reinforced embankment performance were omitted.

Detailed study was then carried out by the Contractor relative to the potential applicability of current structural mechanics theories of membrane, thin-plate, and thin-shell behavior to the problem of analyzing a fabric-reinforced embankment on soft foundation. These theories were deemed inapplicable because they did not adequately consider foundation support characteristics, assumption of permanent fixed anchorage for the fabric was required, and the effect of internal embankment arching and load redistribution from relative soil displacement, thus changing the applied bearing pressure, could not be considered. Perhaps most importantly, the membrane-oriented theories assumed biaxial stress behavior while the loading encountered by fabric reinforcement strips placed transverse to a dike alignment would probably be in uniaxial tension. Use of a membrane on elastic springs model was also considered. However, no existing computer program to solve this statically indeterminate problem in soil-structure interaction could be located, and formulation and debugging of such a program was beyond the scope of this study, especially as the primary use of such a program would be in attempting to obtain best and worst (upper and lower bound) conditions.

The final conclusion of the Contractor was that a proper analysis of the entire embankment-fabric-foundation continuum could be made by use of the finite element modeling technique. However, at this stage of development, too many unknowns were believed to exist with respect to both soil and fabric properties to allow an accurate before-the-fact prediction of behavior. Instead, use of the finite element technique after test section construction, when a set of proper field data are available for model validation, is a more proper use of the methodology.

After considering and discarding the previously described more elegant methods of analysis, the Contractor then approached the problem in more simplistic terms. In their report on evaluation of civil engineering fabrics for use as embankment reinforcement, Haliburton, Anglin, and Lawmaster (Ref 2) postulated four potentially unsatisfactory modes of behavior for civil engineering fabric-reinforced embankments on soft foundation, as illustrated in Figure 4:

a. Lateral spreading of the embankment, by horizontal embankment sliding along the embankment-fabric interface.

b. Localized foundation bearing failure or rotational slope failure, propagating through the embankment.

c. Excessive vertical settlement of the entire embankment from generalized foundation bearing failure and use of a fabric with low stress-strain modulus.

d. Insufficient fabric anchorage, causing fabric pullout under applied tensile stress.

More detail on these unsatisfactory behavior conditions is available in Ref 2.

As the particular configuration of the embankment was fixed by constraints described previously, the Contractor analyzed, somewhat crudely at times, the embankment test section to determine its potential for unsatisfactory behavior under the four above-mentioned conditions. Civil engineering fabric behavior necessary to obtain satisfactory performance was tabulated for comparison with fabric test data obtained in Ref 2. Selection of fabric for use in the embankment is described in Part IV.

The embankment cross-section used for design purposes is shown in Figure 5. A more detailed typical cross-section of the embankment is shown on Sheet 4 of Appendix 1. The primary difference between the section chosen for analysis purposes and the typical construction section is the assumption (for analysis) that the fabric is located at the base of an 8-ft-high embankment. In actual construction, the fabric might be located 1.0-1.5 ft above this assumed location. Errors in this assumption are believed to be small compared to the relative crudity of the analyses performed, and also appear to be conservative.

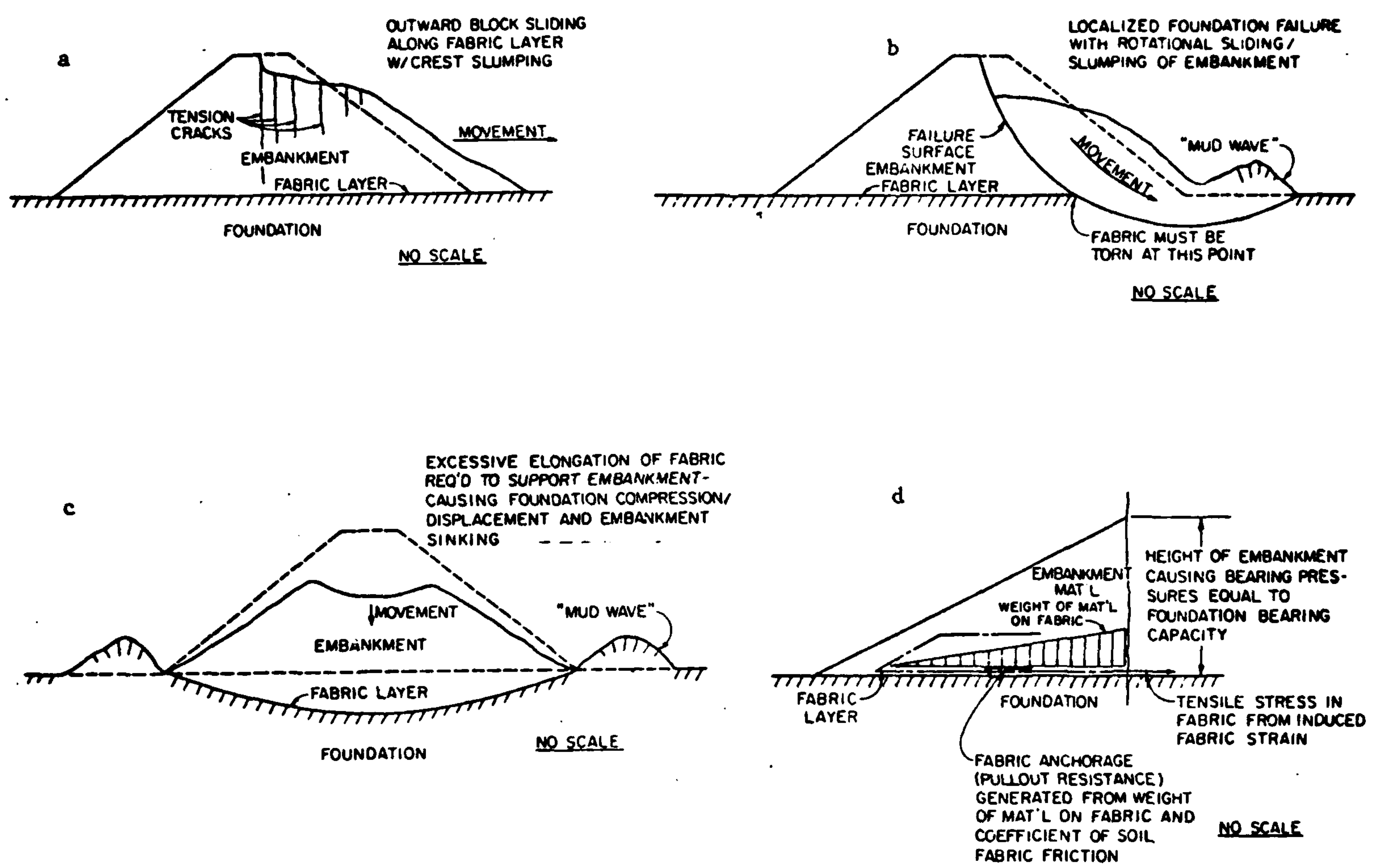

Figure 4. Potential failure modes for a fabric-reinforced embankment on soft foundation (after Ref 2).

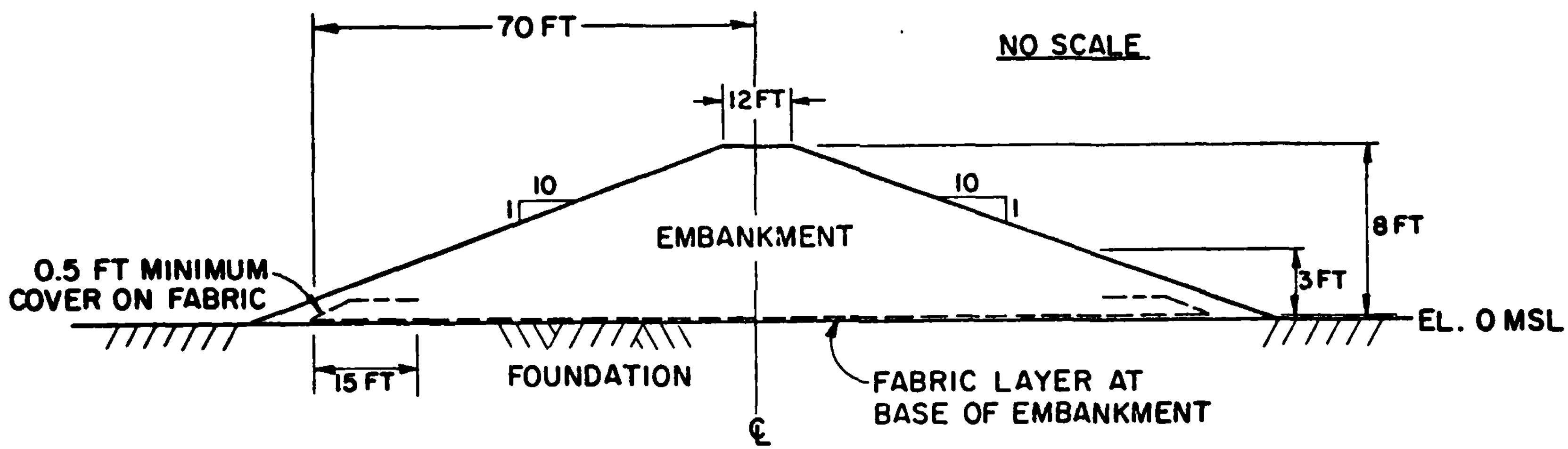

Figure 5. Simplified fabric-reinforced embankment section used for analysis purposes.

In addition to the assumed design section of Figure 5, the following data and/or as.umptions were made in all analyses:

a. Computed maximum centerline settlements from foundation consolidation under initial construction and successive dike raising load increments were assumed to be those computed by Haliburton, Douglas, and Fowler in their Pinto Island disposal area feasibility study (Ref 1).

b. The embankment was assumed to be constructed of Mobile Sand, a fine, poorly graded, semi-angular, fairly clean material with 100% passing the U. S. No. 10 sieve, 83% passing the U. S. No. 40 sieve, and 2% passing the U. S. No. 100 sieve, with a uniformity coefficient of 1.3 (Ref 2). This material may be classified SP by the Unified Soil Classification System. These data were obtained from samples taken at the borrow area location shown in Figure 1 and on Sheets 1 and 6 of Appendix 1.

c. The sand was assumed to be placed in the embankment in a loose relative density state. For such a placement condition, the friction angle ϕ_{sf} between sand and civil engineering fabric was essentially the same as the friction angle ϕ for the sand alone, thus an angle $\phi_{sf} = 30$ deg is appropriate for use in analysis (Ref 2).

d. The unit weight of the embankment material was taken as 100 pcf above the permanent water table and 60 pcf below the permanent water table, with the latter value used in computing effective bearing pressures for future dike raising after foundation consolidation and settlement. The permanent water table was assumed to exist at El. 0 MSL.

e. Based on the results of field vane shear tests and strength tests conducted by the Soils and Pavements Laboratory, U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, on undisturbed samples of foundation material at the west end of Pinto Pass, assumed minimum unconsolidated undrained (Q) soil strength conditions at the time of test section construction will consist of material with $\phi = 0$ deg, C = 50 psf from the surface to El. -10 MSL, $\phi = 0$ deg, C = 100 psf from El. -10 MSL to El. -20 MSL, and $\phi = 0$ deg, C = 150 psf from El. -20 MSL to El. -40 MSL, where medium-dense to dense clean sand is found. In predicting available foundation strength for future dike raising, results of consolidated undrained (R) shear strength tests conducted by the WES on the material indicated a cohesion C of 0.15 tsf and a friction angle ϕ of 11 deg.

With these assumptions and/or data, the embankment can now be analyzed relative to the four potential unsatisfactory modes of behavior described previously.

Horizontal Sliding/Lateral Spreading of Embankment

The potentially unsatisfactory behavior possible in this instance appears to be separation and horizontal outward sliding of a portion of the embankment along the embankment-fabric interface. This mode of behavior is likely to be inhibited by the potential foundation consolidation and compression settlement pattern of the embankment, i.e., greater settlements will occur along the embankment centerline, such that embankment deformations are more likely to be toward the center than edges of the cross-section. However, two possible unsatisfactory conditions might occur; in both instances, the forces generated are similar:

a. A portion of the embankment may slide horizontally outward if the frictional resistance between embankment and fabric is less than the lateral earth pressure which might induce sliding.

b. If the soil-fabric frictional resistance is greater than lateral earth pressures which might cause sliding but the tensile strength of the fabric is insufficient to carry such stress, failure of the fabric might occur, with resultant outward sliding of both embankment and fabric along the soft foundation.

The horizontal force which might induce lateral sliding may be approximated by the Mohr-Coulomb active pressure

$$P_a = 0.5\gamma H^2 \tan (45^o - \frac{\phi}{2})$$

or

$$P_a = 0.5 \times 100 \text{ pcf} \times (8 \text{ ft})^2 \times \tan^2 (45^o - \frac{30^0}{2}) =$$

$$1,080 \text{ lb/ft-width}$$

while the minimum anchoring force for sliding resistance (depending upon which mode of failure is chosen) may be approximated by

$$P_r = (\frac{8 \text{ ft} + 0.5 \text{ ft}}{2}) \times 70 \text{ ft} \times 100 \text{ pcf} \times \tan 30^o =$$

$$17,000 \text{ lb/ft-width}$$

and the factor of safety against sliding could be defined as the ratio (P_r/P_a).

The above calculation indicates that considerably more sliding resistance can be developed than active pressure generated to cause horizontal sliding. However, no fabric evaluated had an ultimate tensile strength of 17,000 lb/ft-width (Ref 2), thus the ultimate tensile strength of the fabric will control the sliding factor of safety.

Assuming a desired minimum factor of safety against sliding of 2.0, necessary fabric ultimate tensile strength required is 1,080 lb/ft-width x 2.0 or 2,160 lb/ft-width. Fabric used as reinforcement should meet or exceed this tensile strength. Because of this relatively high factor of safety chosen against sliding and the likelihood that embankment deformations will be opposite from those assumed in wedge sliding, a more precise analysis does not appear justified, and it may be reasonably concluded that, if the proper fabric is used, the proposed test section will be stable with respect to potential unsatisfactory behavior from lateral spreading.

Localized Foundation Bearing Failure and Rotational Subsidence of Embankment

This potential unsatisfactory behavior may be analyzed by conventional slope stability analysis, adding the strength of the fabric layer to the resisting forces which oppose rotational sliding, as the embankment may not fail in the manner indicated (Figure 4c) unless the fabric is physically torn. Initial consideration of the problem would indicate that fabric shear strength might control behavior, but as the fabric has essentially no flexural resistance, it cannot sustain shear forces and its ultimate strength in tension must likely be exceeded before rotational failure can occur. As the embankment configuration and foundation conditions are fixed, appropriate slope stability analyses may be carried out to locate the critical failure circle or circles, and the necessary ultimate tensile strength of fabric required to provide proper stability may be determined.

In conducting a stability analysis where a strong embankment overlies a soft foundation, considerable judgment and interpretation must be applied to stability calculations, especially with the realization that slope failure per se may occur as a result of foundation bearing failure. If proper consideration is not given this factor, critical circles could be determined which might satisfy assumed conditions of force equilibrium but would be too shallow or too deep to simulate realistic behavior.

The factor of safety of the embankment itself against internal slope failure may be given by the relationship

$$F_s = \frac{\tan 30^\circ}{\tan 5.7^\circ} = 5.8$$

assuming that, for all practical purposes, the embankment slope may be considered infinite, and the angle of repose for Mobile Sand in a loose condition approximates 30 deg. From the resulting computation, it is noted that the likelihood of internal embankment slope failure is minimal.

Reference 5 contains a procedure, based on Modified Bishop slope stability analysis, for estimating the fabric ultimate tensile strength required to give a desired factor of safety against rotational slope failure of a sand embankment on soft cohesive foundation, the case illustrated in Figure 4b. This procedure was used by the Contractor, with assumptions (in addition to those given at the beginning of this Part):

a. Full tensile strength of the fabric is developed before slope failure.

b. Because of possible tensile crack formation, any shear strength developed in the embankment along the slippage plane is neglected.

c. The critical slip circle is assumed to pass through the embankment behind the crest, be tangent to the assumed foundation strength change layer at El. -10 MSL (from C = 50 psf to C = 100 psf), and surface beyond the embankment toe.

d. The embankment and fabric are assumed to be instanteously placed on the foundation.

e. Foundation cohesion and ultimate fabric tensile strength are mobilized simultaneously.

Using the assumed conditions, the minimum factor of safety for no fabric was less than unity. Approximate fabric strengths required to give various minimum factors of safety were then computed as:

Worst Case Minimum Factor of Safety	Required Fabric Ultimate Tensile Strength (lb/in.-width)
1.0	170
1.1	225
1.2	285
1.3	341

Selection of an appropriate design factor of safety is difficult as the effect of assumptions a., d., and e. is not well-known. Conventional recommendations for dredged material dike slope stability factor of safety would be on the order of 1.2-1.3. However, the construction procedure described in Part V will delay completion of the embankment center section until several weeks after construction is begun. During this interval, it is likely that significant foundation consolidation will occur, with resulting shear strength increase. Also, the minimum shear strength conditions (C = 50 psf) occur only near the center of Pinto Pass. Finally, one purpose of test section construction is to properly evaluate actual vs. calculated behavior.

It is therefore recommended that a minimum factor of safety between 1.1-1.2 be used, and that a fabric with this factor of safety be placed over the weaker foundation materials in the Pass adjacent to a fabric with considerably greater ultimate tensile strength also placed over the weak foundation. By observation of settlement plate data and piezometer levels in the adjacent fabric sections, any potential slope failure through the weaker fabric can be predicted. Construction in this zone can then be halted until piezometers drop to acceptable levels. Resulting field data can then be used to develop a more accurate method of stability analysis. If both strong and weak fabric sections behave more or less identically, the Contractor's calculation method is perhaps conservative, and a factor of safety of 1.1-1.2 could be assumed satisfactory for design purposes.

Estimation of Fabric Tensile Stresses Developed from Embankment Deformation

Methods for estimating the tensile stresses developed in the fabric as a result of embankment deformation are the least understood of all factors concerning analysis, design, and construction of fabric-reinforced embankments. More than any other factor, lack of knowledge in this area led to the decision for test section construction. As described previously, the Contractor's review of existing structural mechanics plate, shell, and membrane theory essentially determined that these analysis techniques appear inapplicable. An alternate technique, that of considering the reinforced embankment similar to a reinforced concrete beam and making an analysis for tension and compression loadings in flexure, also appears inapplicable at this time. While the behavior of the fabric reinforcement is, in some ways, similar to the behavior of tension steel in a reinforced concrete beam, the embankment material is subject to large internal deformations, significant readjustments in lateral pressure, effects of arching, and other parameters which, if they occur, are of negligible magnitude in reinforced concrete beams. Finally, a continuum-type finite element analysis of structure, fabric, and foundation is beyond the scope of time and funds allowed the Contractor, even if proper input parameters for such a study could be defined.

It should be noted that several fabric-reinforced embankments have been actually constructed, though little data relative to design procedures and construction history have been maintained. Also, relatively low strength lightweight nonwoven fabrics, considerably weaker than the best materials identified by Haliburton, Anglin, and Lawmaster (Ref 2), have been used. Thus, some mechanism must exist for embankment load redistribution and embankment support sufficient to allow construction, even with weaker fabric reinforcement. As an exact analysis of stress conditions appears uncertain at this time, it is more logical to consider the potential deformation state of the foundation, embankment, and reinforcement, and to estimate, based on assumed deformation conditions, any stresses which might develop in the fabric.

For design purposes, it will therefore be hypothesized that, once foundation bearing capacity is exceeded by embankment bearing pressure, foundation bearing failure and resulting foundation deformation will occur, allowing embankment settlement. Construction procedures will be used to insure that the fabric is placed, anchored, and covered by embankment material over its entire length before this condition is artificially produced at the approximate outer third points of the embankment. For additional details, see Part V and the construction sequence drawing on Sheet 4 of Appendix 1.

Worst case foundation bearing failure may be expected when the embankment height exceeds El. 3.0 MSL. When this operation (Step 7 in the construction procedure) occurs, the lateral extent of embankment on either side of the approximate third points will act as a stabilizing berm to minimize rapid lateral foundation deformations. When foundation deformations do occur, the embankment and fabric will subside. When such subsidence occurs, it is assumed that the tendency of the embankment sand will be to slip laterally relative to the fabric in the direction of maximum settlement. If the fabric can carry these developed incipient slippage forces with small strains, relative movements in the embankment should cause internal arching. The net effect of this internal arching will be to reduce the effective vertical forces in the region of maximum deformation and thus embankment settlement, and to redistribute these forces outward toward the less heavily loaded portions of the fabric and foundation. It is further hypothesized that, assuming relatively small fabric strains, the embankment will remain in an integral, stable mass until sufficient foundation consolidation has occurred to support the entire embankment weight without general foundation bearing failure. While such a hypothesis is technically unverified at this stage, it is consistent with the embankment-fabric-foundation deformation conditions expected and is at least semi-verified by the previous successful construction by others of fabric-reinforced embankments.

Following the suggested construction plan described in detail in Part V and shown on Sheet 4 of Appendix 1, completion of Steps 8 and 9 in the construction sequence will raise embankment bearing pressures to a maximum at the center of the embankment. At this time, the relatively flat outer slopes of the embankment will tend to act as stabilizing berms and minimize lateral foundation movement, while the suggested construction procedure may already have produced some consolidation beneath the outer portions of the embankment, also resisting lateral foundation movement. It is thus expected that embankment centerline settlements, followed by development of sliding forces at the embankment-fabric interface, will produce internal arching, temporarily reducing the net bearing pressure in the center of the embankment until adequate foundation consolidation can occur.

While initial minimum soil shear strengths in the foundation are extremely low, consolidated undrained shear strength data described in the beginning of this Part indicate that a rapid improvement in strength may be expected with consolidation. Further, the soil profile, while generally composed of soft cohesive material, contains the numerous sand and silt lenses and stringers typically found in an alluvial deposit. These channels of high permeability should cause extremely rapid foundation consolidation and strength improvement once initial loadings are applied. Also, it should be noted that use of porous fabric reinforcement and free-draining embankment material will allow dissipation of foundation excess pore pressures by upward drainage in the most critical foundation zone, that nearest the fabric.

Table 1 is a summary of bearing pressures and related data for the fabric-reinforced embankment, for design crest elevations ranging from initial construction at El. 8 MSL through four raise conditions to El. 25 MSL. Estimated maximum bearing pressures are those at the fabric reinforcement level, assuming the embankment to exist from the design crest elevation to a distance below the original soil surface resulting from foundation consolidation. Minimum foundation bearing capacity data were obtained by extrapolating results of unconsolidated undrained (R) strengths, assuming complete consolidation under the previous embankment loading. As may be noted from the Table, only the initial construction condition to El. 8 MSL indicates a deficit in bearing capacity, i.e., embankment bearing pressures exceed foundation bearing capacity. The initial factor of safety without fabric against bearing failure is 0.4, while unreinforced embankment bearing factors of safety vary from 1.5 to 1.8 for subsequent raisings. It should be noted that these values are for worst case conditions at the embankment centerline and conservatively assume no foundation consolidation will occur during construction. When the numerical values of factor of safety are reviewed in the light of the

Table 1. Bearing Pressures and Related Data for Embankment

Design Crest Elevation (ft MSL)	Expected Maximum Consolidation from Previous Load (ft)	Estimated Maximum Bearing Pressure BP (psf)[1]	Minimum Foundation R Shear Strength (psf)	Minimum Foundation Bearing Capacity BC (psf)	BC - BP (psf)	Bearing Factor of Safety w/o Fabric BC/BP	Maximum Horizontal Force at Soil-Fabric Interface[2] (lb/ft-width)	Maximum Horizontal Force at Soil-Fabric Interface[2] (lb/in.-width)
8	0.0	800	50	290	-510	0.4	460	38
12	2.9	1,380	400	2,280	900	1.7	800	67
16	4.1	1,850	570	3,240	1,390	1.8	1,070	89
20	5.0	2,300	660	3,760	1,460	1.6	1,330	111
25	5.7	2,860	750	4,260	1,400	1.5	1,650	138

[1] γ_m assumed 100 pcf above W.T., γ' assumed 60 pcf below W.T., W.T. at El. 0 MSL.

[2] Computed as $(BP \tan \phi_{sf}) \times (1 \text{ ft-length})$, $\phi_{sf} = 30^{\circ}$.

conservative assumptions used in their calculation, it may be essentially concluded that, if the embankment could be constructed initially with fabric reinforcement, it may be raised sequentially as indicated in Table 1 without further bearing failure problems, after excess pore pressures have dissipated.

Assuming that foundation deformations will certainly occur for the initial raising to El. 8 MSL, and would occur under the center portions of the embankment from foundation consolidation as subsequent raisings are carried out, the frictional force which must be carried by the fabric from internal embankment incipient sliding may be computed by the product of embankment weight and the tangent of the angle of internal friction ϕ_{sf} between soil and fabric. Maximum friction force development will occur at the crest elevation, and using a value of 30 deg for ϕ_{sf} , a maximum tensile force of 460 lb/ft-width or 38 lb/in.-width is developed for initial raising to El. 8 MSL.

Alternatively, calculations could be made assuming the frictional force against the fabric would be caused by the difference in pressure between that generated by embankment weight and the foundation bearing capacity. However, this assumption does not seem rational in view of the preceding assumptions relative to foundation-fabric-embankment deformation behavior. Also, applying this logic would result in a net horizontal force of zero for subsequent raisings to El. 25 MSL, whereas it is likely that, even if foundation bearing capacity is not exceeded, consolidation settlements from the increased load would tend to cause repetition of the embankment settlement/incipient sliding/arching behavior during and immediately after completion of the raise increments. In such cases, at least some consideration should be given to necessary fabric strength.

Assuming the most critical case will be initial construction to El. 8 MSL and applying a factor of safety of 2.5 with respect to reserve strength needed in the fabric, a fabric strength of at least 95 lb/in.-width would be necessary to provide satisfactory reinforcement behavior. While the exact deformation of the embankment cannot be predicted except in general terms, selection of a fabric which would carry working loads at relatively low fabric strains would minimize the chances of the embankment failing from excessive deformation as indicated in Figure 4d. Thus, the required 95 lb/in.-width, or, for convenience purposes, 100 lb/in.-width, should be developed at not more than 10% fabric elongation. This requirement would insure that, assuming linear stress-strain behavior for the fabric, only about 4% elongation of the fabric would be required to carry these stresses in the zone of maximum embankment bearing pressure, and working strains would be less than 4% over the remainder of the fabric. Also, the fabric should have an ultimate strength in tension of at least 138 lb/in.-width, or for convenience, 140 lb/in.-width, in the somewhat improbable likelihood that the horizontal forces as computed in Table 1 will actually be developed in the fabric during final raising to El. 25 MSL.

Thus, minimum strength criteria necessary for fabric reinforcement would be the ability to carry a minimum tensile stress of 100 lb/in.-width at not more than 10% elongation as determined in uniaxial tension, and an ultimate fabric strength in uniaxial tension of at least 140 lb/in.-width.

Estimation of Fabric Pullout Resistance

It was previously hypothesized that, while the internal portions of the embankment subsided with resulting development of tensile stress in the fabric reinforcement, the outside portions of the embankment with bearing pressure less than foundation bearing capacity would remain in a quasi-stable condition, with the weight of these embankment portions on the fabric constituting a method of anchoring the ends of the fabric to prevent its pullout in response to developed tensile stresses.

The maximum horizontal stress in fabric was estimated previously for the initial raising to El. 8 MSL as 460 lb/ft-width. Using the section shown in Figure 5 but assuming the fabric to be placed at El. 1.0 MSL, the minimum expected anchorage force for this condition might be expected to be 15 ft x $\left(\frac{2\text{ ft} + 0.5\text{ ft}}{2}\right)$ x 100 pcf x tan 30° x 2 sides = 2,170 lb/ft-width. Thus the factor of safety against fabric pullout under expected tensile stress may be estimated as 2,170/460 = 4.7. This computation does not consider the effect of fabric end lapping, which might cause development of passive pressures if actual pullout were occurring. Thus, based on the above calculations, it may be concluded that little chance of fabric pullout is likely under the estimated tensile working stresses in the fabric.

PART IV. SELECTION AND LOCATION OF CIVIL ENGINEERING FABRIC REINFORCEMENT

Fabric Strength Required

In Part III, strength requirements of fabric reinforcement were established as follows:

a. To prevent horizontal sliding of embankment: 180 lb/in.-width ultimate tensile strength.

b. To prevent rotational subsidence of embankment: between 225 and 285 lb/in.-width ultimate tensile strength.

c. To support anticipated embankment deformation under working loads: 100 lb/in.-width at 10% elongation and 140 lb/in.-width ultimate tensile strength.

Fabric selected for reinforcement in the embankment should meet or exceed these tensile strength criteria.

Selection of Fabric Reinforcement

In their evaluation of civil engineering fabrics for use as embankment reinforcement, Haliburton, Anglin, and Lawmaster (Ref 2) identified four civil engineering fabrics which met or exceeded these strength criteria: Nicolon 66475, Nicolon 66186, Advance Type I, and Polyfilter-X, plus one fiberglass fabric, Bay Mills 196-380-000. Nicolon 66475 is a heavyweight woven fabric made of fibrallated polypropylene strands and Nicolon 66186 is an intermediate-weight woven polyamide monofilament fabric. Both fabrics are manufactured by the Nicolon Corporation. Advance Type I is an intermediate-weight woven monofilament polypropylene fabric manufactured by Laurel Plastics, Inc., and distributed by Advance Construction Specialties Company. Polyfilter-X is a woven polypropylene monofilament of intermediate weight manufactured by Carthage Mills. Bay Mills 196-380-000 is a woven fiberglass monofilament normally used as a reinforcing material in construction of fiberglass boat hulls.

Haliburton, Anglin, and Lawmaster recommended that all five fabrics be considered for evaluation under field conditions by test section construction. In addition to tensile stress-strain modulus and ultimate tensile strength, they considered potential creep behavior, i.e., tendency for continued deformation under long-term static load, soil-fabric frictional resistance, and strength loss upon wetting/soaking to be important parameters in final fabric selection.

Test data for these five fabrics developed from Ref 2 are summarized in Table 2. Of the various fabrics, it is seen that both Nicolon materials have essentially nil creep tendency and wet strength loss, Advance Type I has a high creep tendency with moderate strength loss upon wetting, and Polyfilter-X has a moderate creep tendency with high strength loss upon wetting. The Bay Mills fabric failed at 8% elongation in tension testing, had zero creep tendency and was not tested for wet strength loss. More data are available in Ref 2.

Haliburton, Anglin, and Lawmaster recommended that, if more than one fabric was selected for use in the embankment test section, the two Nicolon materials should be considered for use in portions of the embankment where highest stress levels might be anticipated because of their negligible creep tendency and wet strength loss. Despite their undesirable creep potential and wet strength loss predicted from laboratory tests, they thought that Advance Type I and Polyfilter-X, being somewhat lighter weight and lower cost materials, should also be evaluated, and could be placed in portions of the embankment where stress levels might be lower. Should these latter two fabrics provide acceptable behavior under field conditions, their use might be more cost-effective than the more technically suitable but also probably more expensive Nicolon materials. They also considered Bay Mills 196-380-000 an acceptable fabric if further testing confirmed their expected essentially zero strength loss when wetted for the fiberglass material.

After consideration of the various factors involved, the Contractor eliminated the Bay Mills fabric from consideration for use in the embankment test section, as its stress-strain modulus is only slightly

Table 2. Summary of Fabric Warp Direction Laboratory Test Results

Fabric	Tensile Stress at 10% ε (lb/in.-width)	Ultimate Tensile Stress (lb/in.-width)	Design Soil-Fabric Friction Angle ϕ_{sf} (deg)	Creep Tendency	Wet Strength Loss
Nicolon 66475	362	902	30	Nil	Nil
Nicolon 66186	109	226	30	Nil	Nil
Polyfilter-X	103	311	30	Moderate	High
Advance Type I	108	252	30	High	Moderate
Bay Mills 196-380-000	318 (8% ε)	318	30	Zero	Not Tested

higher than that of Nicolon 66475 and its ultimate strength is considerably less. Also, this fabric is currently considerably more expensive than petrochemical-based artificial textile products. Following the advice of Haliburton, Anglin, and Lawmaster, the Contractor selected all four of the remaining materials for experimental evaluation in the test section, on grounds that the experimental nature of the project justified evaluation of the greatest number of potentially applicable materials currently available on the market. Data thus obtained would allow the MDO better criteria for fabric selection, both for the remaining portions of reinforced embankment necessary at Pinto Island and at other future locations where such fabric-reinforced embankment construction may prove feasible.

Location of Fabric in Embankment

All four fabrics should be obtained and used in the test section. In order to facilitate embankment construction when, as will be described in Parts V and VI, a rental-type contract appears most desirable for embankment construction, the fabric to be used as reinforcement should be obtained by the MDO and provided the embankment contractor.

Following the general placement guidelines of Haliburton, Anglin, and Lawmaster, Advance Type I fabric should be used for reinforcement from embankment Sta 0+60 to Sta 2+40, Polyfilter-X fabric from Sta 2+40 to Sta 4+20, Nicolon 66475 fabric from Sta 4+20 to Sta 6+45, and Nicolon 66186 fabric from Sta 6+45 to Sta 8+00. Nicolon 66186 fabric should also be used in construction of the south haul access strip from Sta 8+00 to Sta 8+20 and Nicolon 66475 used in construction of the south haul road from the edge of the south haul access strip to the north edge of the ADDSCO parking lot.

Placement of fabric as described will also satisfy the slope stability criteria of Part III. Nicolon 66186 will provide an estimated slope stability factor of safety of about 1.1 while Nicolon 66475 will provide a slope stability factor of safety of about 2.3. Observing the behavior differences between these two parts of the embankment will help to verify reliability of the slope stability calculation method. While Polyfilter-X and Advance Type I also satisfy the Part III slope stability criteria for minimum factor of safety between 1.1-1.2, they are located on stronger foundation material and thus should provide even higher actual factors of safety against embankment-foundation rotational sliding.

To facilitate fabric location along the alignment, it was decided to place the fabric in 15-ft-wide strips. Advance Type I and Polyfilter-X are supplied in multiples of 6-ft widths. Use of a 15-ft placement width will allow 1.5-ft overlap at each end of the fabric for sewing. Nicolon materials are available in 5-m (16.4-ft) widths, and use of a 15-ft placement width will allow 0.7-ft overlap for sewing. Location of each fabric strip along the embankment alignment is tabulated in Table 3, while fabric placement locations and methods of fabric overlap and seaming are shown on Sheet 5 of Appendix 1. Fabric edges should be overlapped and sewn with a portable field sewing machine capable of lockstitch sewing and using polyester thread. Construction procedures necessary for sequential fabric placement are described in Part V.

Data Needed for Fabric Purchase

Data required for MDO purchase of the fabrics are as follows:

a. Advance Type I, 4,800 sq yd of fabric required, furnished as 2,400 lin ft of fabric 18 ft wide, made by factory-sewing three 6-ft widths together. Fabric rolls must be furnished in length multiples of 200 ft. Fabric should be obtained from Advance Construction Specialties Company, P. O. Box 17212, Memphis, TN 38117, ATTN: Mr. H. M. Vann, Telephone: (901) 362-0980.

b. Polyfilter-X, 4,800 sq yd of fabric required, furnished as 2,400 lin ft of fabric 18 ft wide, made by factory-sewing three 6-ft widths together. Fabric rolls must be furnished in length multiples of 200 ft. Fabric should be ordered from Carthage Mills, Erosion Control

Table 3. Type and Location of Fabric Reinforcement in Embankment

Place North Edge of Fabric Strip at Station	Fabric To Be Used	Place North Edge of Fabric Strip at Station	Fabric To Be Used
0+60	Advance Type I	4+20	Nicolon 66475
0+75	Advance Type I	4+35	Nicolon 66475
0+90	Advance Type I	4+50	Nicolon 66475
1+05	Advance Type I	4+65	Nicolon 66475
1+20	Advance Type I	4+80	Nicolon 66475
1+35	Advance Type I	4+95	Nicolon 66475
1+50	Advance Type I	5+10	Nicolon 66475
1+65	Advance Type I	5+25	Nicolon 66475
1+80	Advance Type I	5+40	Nicolon 66475
1+95	Advance Type I	5+55	Nicolon 66475
2+10	Advance Type I	5+70	Nicolon 66475
2+25	Advance Type I	5+85	Nicolon 66475
		6+00	Nicolon 66475
2+40	Polyfilter-X	6+15	Nicolon 66475
2+55	Polyfilter-X	6+30	Nicolon 66475
2+70	Polyfilter-X	6+45	Nicolon 66475
2+85	Polyfilter-X		
3+00	Polyfilter-X	6+60	Nicolon 66186
3+15	Polyfilter-X	6+75	Nicolon 66186
3+30	Polyfilter-X	6+90	Nicolon 66186
3+45	Polyfilter-X	7+05	Nicolon 66186
3+60	Polyfilter-X	7+20	Nicolon 66186
3+75	Polyfilter-X	7+35	Nicolon 66186
3+90	Polyfilter-X	7+50	Nicolon 66186
4+05	Polyfilter-X	7+65	Nicolon 66186
		7+80	Nicolon 66186
		7+95	Nicolon 66186
		8+10	Nicolon 66186

NOTE: All fabric strips 200 ft long.
Polyfilter-X and Advance Type I 18 ft wide, 1.5-ft overlap at each end.
Nicolon 66186 and 66475 16.4 ft (5 m) wide, 0.7-ft overlap at each end.

Division, 124 W. 66th Street, Cincinnati, OH 45216, ATTN: Mr. Robert J. Barrett, Telephone: (513) 242-2740.

c. Nicolon 66186, 4,374 sq yd of fabric required, furnished as 2,400 lin ft of fabric 5 m (16.4 ft) wide. Fabric rolls must be furnished in length multiples of 200 ft. Fabric should be obtained from Nicolon Corporation, 4229 Jeffrey Drive, Baton Rouge, LA 70816, ATTN: Mr. Dana H. Toups, Telephone: (504) 292-3010.

d. Nicolon 66475, 6,197 sq yd of fabric required, furnished as 3,400 lin ft of fabric 5 m (16.4 ft) wide. Fabric rolls must be furnished in length multiples of 200 ft. Fabric should be obtained from Nicolon Corporation, 4229 Jeffrey Drive, Baton Rouge, LA 70816, ATTN: Mr. Dana H. Toups, Telephone: (504) 292-3010.

Advance Type I and Polyfilter-X fabrics are manufactured in the United States. Nicolon 66186 and Nicolon 66475 are distributed in the United States, but the Contractor is unsure whether or not these fabrics are manufactured in the United States or abroad. In the latter instance, an exception to the "Buy America" policies of the Government should be obtained for purchase of these two fabrics, on the grounds that their use is for experimental research evaluation, and that no comparable fabrics of U. S. manufacture are available. This justification is borne out by testing described in Ref 2, where the two Nicolon materials were described as being the only ones which met the required selection criteria, with the two U. S. fabrics recommended for evaluation under less than worst case conditions. In the opinion of the Contractor, failure to obtain and evaluate the two Nicolon materials will minimize the chances of successful embankment test section construction.

PART V. EMBANKMENT CONSTRUCTION DETAILS

As certain modes of embankment deformation and embankment-fabric-foundation interaction have been assumed in estimating and predicting embankment behavior, a construction sequence must be followed which will help to insure desired embankment performance. The general concepts required to obtain satisfactory embankment performance were discussed in Ref 1 and may be summarized as follows:

a. To maximize behavior of fabric reinforcement, a thin working table of sand should be placed between existing soil and the fabric. The purpose of this working table is essentially to level the existing ground surface, fill in holes, etc., and provide a smooth, fairly level surface upon which to unroll the fabric. By placing the fabric in such a manner, the possibility of localized tearing or excessive fabric strains under working loads will be minimized.

b. Fabric should be placed on this working table with longitudinal or warp direction perpendicular to the embankment alignment, and the fabric seams should be overlapped and sewn.

c. Material used to construct the embankment should be placed in a sequential manner to anchor the fabric and produce foundation deformation necessary to tension the fabric while minimizing chances of rapid embankment sinking from excess fabric elongation.

The overall construction process may be subdivided into two parts: operations related to site preparation and borrow removal and operations related to actual embankment construction.

Preliminary Operations and Borrow Removal

Construction of north haul road and access strip

In order to bring material to the site of embankment test section construction, a haul road and access strip must be constructed to the north of the proposed embankment test section. Location detail for the north haul road is shown on Sheets 1 and 2 of Appendix 1, while north haul access strip detail is shown on Sheets 2 and 4 of Appendix 1.

Soil conditions to the north of the proposed embankment test section consist of medium, fine, and very fine sand with some thin innerlayered silt and clay stringers. A small dozer may construct the haul road and haul access strip, rough-grading the road at approximately El. 8-10 MSL, followed by back-dragging and track compaction as necessary to provide a fairly stable subgrade. Crushed shell should then be brought to the access road site by dump truck, dumped, and dozer-spread and track-compacted to form a 12-ft-wide by 6-in.-thick surface over the track-compacted sand subgrade. Use of a water truck at intervals during the road preparation and compaction process should facilitate operations.

The north haul road and haul access strip should be completed prior to beginning construction of the embankment test section.

Construction of south haul access strip and haul road

In order to facilitate construction operations, a haul access strip and exit haul road are to be constructed at the south end of the embankment test section, at locations shown on Sheets 1 and 2 of Appendix 1. South haul access strip detail is shown on Sheet 4 of Appendix 1. The purpose of the south access strip and haul road is to allow exit of unloaded truck traffic from the embankment test section. The south access strip will be fabric-reinforced and constructed after normal embankment construction operations, to be described subsequently, have resulted in fabric placement to embankment Sta 8+00. At this time, the sand working table and fabric reinforcement will be placed the full width of the embankment cross section out to Sta 8+20 and covered with a 6-in. thickness of dozer track-compacted crushed shell, which will be transported to the site via the north haul road and access strips along the outer edges of the proposed embankment test section. Upon completion of the haul access strip, a 12-ft-wide exit haul road will be constructed at the location shown on Sheets 1 and 2 of Appendix 1, from the south access strip to the ADDSCO parking lot. The road will be constructed by placing a minimum 12-ft-wide fabric strip with warp direction longitudinal from the south haul access strip to the parking lot, and covering the strip with a minimum 6-in. thickness of dozer track-compacted crushed shell. Fabric placement details are shown on Sheet 5 of Appendix 1. Use of a water truck may facilitate compaction operations.

Construction and maintenance of haul road access to embankment borrow area

As described previously, the embankment test section is to be composed of Mobile Sand obtained from the general borrow source area indicated on Sheets 1 and 6 of Appendix 1. In order to facilitate removal of borrow material, a haul road must be constructed from the paved roadway at the east edge of the ADDSCO facility east to the borrow location.

Maps provided the Contractor of the Pinto Island site by the MDO did not delineate the topography or define existing improvements in the region west of the proposed borrow location, as may be observed by inspection of Sheet 1 of Appendix 1. However, field reconnaissance by the Contractor indicated that an existing unsurfaced roadway extends from the paved road east of the ADDSCO buildings to the only existing access to the proposed borrow area, where a drain pipe has been placed and covered as shown in Sheet 6 of Appendix 1. This unpaved roadway appears capable of supporting loaded dump trucks if periodic maintenance, consisting of dozer back-dragging followed by water truck operation, is carried out on a regular basis.

The exact location of the access haul road inside the borrow area will depend upon locations selected for actual borrow of material. However, the material in the borrow area is primarily sand and a small dozer supplemented by a water truck should be able to construct and adequately maintain any haul roads, turnarounds, and related items

Embankment Construction Procedure

Based on general concepts described in Ref 1, the specific construction sequence recommended for construction of the Pinto Pass embankment test section comprises nine separate operations. These operations will be discussed below and effect of each operation on the completed embankment cross section is shown on Sheet 4 of Appendix 1. Because of the experimental nature of the project, it is assumed and recommended that construction will be by equipment rental contract, with direction of the work by the MDO.

Place sand working table on existing ground surface

Initial recommendations of Haliburton, Douglas, and Fowler were to place the working table up to about El. 1.0–1.5 MSL by hydraulic means. However, development of a proper contractual specification for such a procedure would be troublesome, especially on a rental basis. Thus, the Contractor reviewed soft ground equipment support capacity data developed by the DMRP (Ref 6) and based on these data, the working table may be placed mechanically on the soft foundation if a minimum 0.5- to 1.0-ft working table thickness is maintained and spreading is accomplished by a low-ground-pressure small wide-tracked dozer with maximum 2.5 psi track pressure.

Inspection of the elevation profile along the embankment centerline, shown on Sheet 3 of Appendix 1, indicates that fabric placement will be initiated at approximately Sta 0+60 of the embankment test section. Looking south along the proposed alignment past this Station, the existing ground surface drops rapidly to below El. 1.5 MSL. Using the north haul road and access strip, dump trucks will deliver sand to approximately Sta 0+60, where an initial working table, extending the full width of the embankment and of a length slightly longer than needed for laying an initial fabric strip, will be constructed by dozer spreading from north to south. After this initial working table segment is completed, the first fabric strip will be placed and the ends anchored, using procedures described in subsequent sections.

Dump trucks will then proceed out onto the covered fabric at the east and west edges of the embankment and will deposit their loads at the end of these edge access strips. This material will be dozer-spread east to west and west to east in front of the initial fabric segment, with the dozer(s) working behind the material and always maintaining a minimum 0.5-ft thickness of sand between tracks and existing foundation. It is anticipated that two dozers will be used for this operation, each advancing the working table from the outer portion of the dike toward the center. When this working table segment is complete, a second fabric layer will be placed adjacent to the first, edges overlapped and sewn, and the embankment edge access strips extended to the south edge of this second strip, where the process will be repeated until fabric is placed to the south end of the embankment at Sta 8+00, and the fabric-reinforced south haul access strip and exit haul road have been completed, with detail as shown on Sheets 2 and 4 of Appendix 1.

Placement of Fabric Reinforcement

As each segment of working table is completed, the fabric will be placed on the working table in a single continuous strip 200 ft long with warp direction at right angles to the alignment. The fabric will be unrolled in such manner as to leave 100 ft of the fabric on either side of the embankment centerline. After initial fabric strip placement, subsequent strips will be overlapped with the existing strip and the north edge of the newly placed strip sewn to the south edge of the existing strip by a portable field sewing machine capable of providing chain stitching with polyester thread. Fabric placement will be conducted in such manner along the alignment until the entire embankment and south haul access strip have been covered. For placing the four different types of fabric recommended for use in the test embankment, a plan view of fabric strip sequences is shown on Sheet 5 of Appendix 1. This fabric placement operation will be conducted sequentially in conjunction with working table establishment and construction of outer fabric access strips.

Construction of outer fabric access strips

After working table and fabric placement, material should be placed over the outer edges of each fabric strip, as illustrated in Step 3 of the construction sequence illustrated on Sheet 4 of Appendix 1. Horizontal distance from embankment centerline to the outer edges of the sand cover will vary, depending upon existing natural ground and working table elevations, and should be chosen such that, after lapping and covering (construction sequence Steps 4 and 5 shown on Sheet 4 of Appendix 1), a minimum 0.5-ft cover will exist over the fabric. Lapping detail, as well as location of outer and inner settlement plates (which should be placed at this time) are shown on the typical embankment cross-section detail given on Sheet 4 of Appendix 1.

The two outer access strips may be constructed by small wide-tracked dozer(s), pushing material ahead such that a 0.5-ft thickness of cover is always maintained between dozer tracks and fabric. After these two outer strips have been advanced along the embankment alignment, dump trucks may back down these access strips and dump their loads closer to the dozers used for spreading. It is anticipated that two dozers will be employed, allowing simultaneous construction of both outer strips. To obtain satisfactory truck mobility, sand cover on these strips should be semi-compacted by dozer track during the spreading operation. The two access strips will be advanced simultaneously down the test section alignment until the south end of the embankment is reached. At such time, dump trucks will carry crushed shell down the alignment and dump at the south end, allowing the two dozers to construct the south access strip, and, upon completion of this strip, spread additional crushed shell over the fabric strip leading from the south access strip to the edge of the ADDSCO parking lot.

Completion of outer haul access strips

After the outer haul access strips have been completed, the remaining uncovered ends of fabric should be lapped back over the just-completed sand access strip, as shown in Step 4 of the construction operation summary on Sheet 4 of Appendix 1, and covered with additional sand brought by dump truck haulage, starting at the north end of the proposed test section (Step 5). A minimum 0.5-ft cover should be maintained between spreading dozer tracks and the lapped fabric layer, and this cover material should be semi-compacted by dozer track to facilitate future truck traffic. Again, two dozers should be used, allowing simultaneous coverage of the lapped fabric at each outer edge. As the operation moves further away from the north end of the embankment test section, loaded trucks may back onto the newly covered lapped fabric strip to deliver their loads closer to the spreading dozers. This operation should be conducted simultaneously along each edge of the embankment until the south end of the embankment test section is reached. Also, installation of outer embankment piezometer clusters, located as shown on Sheets 3 and 4 of Appendix 1, may be initiated once the fabric lapping and covering operation has passed their desired location along the alignment.

Placement of interior cover material on fabric

After the outer access strips have been placed, fabric lapped, and additional cover material placed, the remaining inner portion of the fabric layer should be covered, as shown in construction summary operation Step 6 on Sheet 4 of Appendix 1. Loaded trucks should bring their material to the embankment using the north haul road, dump along the outer fabric strips, and exit empty down the access strips across the south access strip and haul road and through the ADDSCO parking lot, returning to the borrow area. Two dozers will again be used to spread the material from its dumped locations toward the centerline of the embankment, keeping a minimum 0.5-ft cover between dozer tracks and fabric. This entire interior layer should be semi-compacted by dozer track. After construction is completed, truck traffic should be able to drive anywhere on the surface of the embankment cross-section to deliver material at the optimum locations as necessary for remaining construction. When allowing truck traffic on the interior of the embankment, care should be taken to minimize rutting by directing each incoming truck to follow a different path from the north access strip to its dump point. After dumping, unloaded trucks may move south down the embankment test section and exit via the south haul road.

Completion of embankment cross section

After the entire fabric area is covered, the remainder of the embankment may be constructed. As shown on Sheet 4 of Appendix 1, the two outer portions of the embankment should be raised to El. 5 MSL, with truck haulage bringing material to both the center and outer edges of the embankment and dozer shaping to obtain the desired cross section. Upon completion of the outer segments to El. 5 MSL, the center portion of the embankment should be completed to El. 5 MSL, as shown on Sheet 4 of Appendix 1, and then the final embankment section, to El. 8 MSL, should be constructed, with material provided by truck haulage and the two wide-tracked dozers used to shape the material to required cross-section. Trucks should enter loaded using the north haul road and exit unloaded via the south haul road. Installation of center piezometer clusters may be initiated any time after the center portion of the fabric has been covered with sand.

Additional considerations

During all the above-mentioned construction operations when work has proceeded to the point where truck traffic would have mobility on the embankment surface, a water truck should be used to maintain the sand in a damp condition. Apparent cohesion provided by this wetting will allow truck traffic to maintain better mobility on the embankment material, minimizing chances of rutting or of vehicles becoming immobilized in loose dry sand, and will also assist in dozer track compaction of the material. Water truck usage during construction and maintenance of the north haul road and the haul road into the embankment borrow area will also facilitate truck mobility.

Finally, it should be noted that some initial construction activities may have to be conducted during periods of high tidal level. While saturation (or lack of same) should have little effect on strength of the embankment, during these periods it will be necessary for equipment to move at relatively slow rates such that localized quick conditions, with resulting loss of embankment material support capacity, are not obtained.

Additional Considerations Relative to Embankment Construction

In order to facilitate embankment construction, prior arrangements should be made by the MDO to:

a. Obtain right of access to the property north of the proposed embankment test section and permission to construct the north haul road and access strip on this property.

b. Obtain permission to extend the south haul road to the edge of the ADDSCO parking lot and obtain permission for use of part of the parking lot for vehicle egress from the south haul road to the paved road.

c. Obtain permission for dump truck and other equipment travel between the paved road to the east of the ADDSCO site and the proposed embankment borrow area.

d. Obtain right of access and permission to remove sand borrow from the proposed borrow area.

e. Provide surveying services to locate the centerline and Stations of the embankment test section and delineate the north and south access strips and haul roads.

f. Provide rapid response services necessary to install instrumentation in the embankment test section as soon as construction operations have progressed to the point where such installation is feasible.

PART VI. REQUIRED EQUIPMENT AND ESTIMATED COSTS

Because of the experimental nature of the project and the potential need to alter or otherwise modify construction sequences during test section construction, it is recommended that the work be accomplished by rental contract, with direction of the rental equipment provided by the MDO or their representative. Assuming a rental contract will be used with the work generally conducted as described in the preceding Part, rental construction operations are subdivided into three phases: Phase I - Site Preparation; Phase II - Place Working Table, Fabric, and Exterior Haul/Access Strips; and Phase III - Construction of Main Embankment Section. Site preparation includes construction of the north haul road and haul access strip and the haul road into the borrow area. Placement of working table, fabric, and exterior haul/access strips for the embankment test section also includes construction of the south haul access strip and haul road, and construction of the main embankment section includes placement of the remaining material necessary to construct the embankment.

Approximately 20,000 cu yd of borrow will be required to construct the embankment. Assuming a relatively low effective production rate of 1,000 cu yd per working day, items of equipment required and estimated construction time required for the three phases, as well as estimated hourly rental costs for the equipment, were tabulated in Table 4. As may be noted by inspecting the Table, a cost of $118,902 is estimated for construction of the embankment test section and haul access strips, with a total of 26 working days estimated for project completion.

Tables 5 and 6 summarize the items needed for rental contract construction in a format which may be used to develop bid advertisement specifications.

In preparing specifications for MDO rental contract advertisement, phraseology should be developed indicating that the construction is experimental in nature and that the Government will have the right to exercise considerable latitude in varying the number of operating hours

Table 4. Summary of Construction Costs by Project Construction Phase

I. Site Preparation (5 Working Days)

Contractor Furnished

2 Dozers x $40/hr x 10 hr/day x 5 days	$ 4,000
2 Dump Trucks x $30/hr x 10 hr/day x 5 days	3,000
1 Water Truck x $35/hr x 10 hr/day x 5 days	1,750
3 Laborers x $8/hr x 10 hr/day x 2 days	480
Subtotal	$ 9,230

Government Furnished

400 cu yd shell @ $6.00	$ 2,400
Subtotal	$ 2,400
Total	$ 11,630

II. Install Working Table, Fabric, Haul Strips (6 Working Days)

Contractor Furnished

2 Dozers x $40/hr x 10 hr/day x 6 days	$ 4,800
4 Dump Trucks x $30/hr x 10 hr/day x 6 days	7,200
1 Water Truck x $35/hr x 10 hr/day x 6 days	2,100
1 Dragline x $50/hr x 10 hr/day x 6 days	3,000
4 Laborers x $8/hr x 10 hr/day x 6 days	1,920
2 Field Sewing Machines x $23/hr x 10 hr/day x 6 days	2,760
Subtotal	$ 21,780

Government Furnished

20,171 sq yd fabric @ $2.00	$ 40,342
Subtotal	$ 40,342
Total	$ 62,122

III. Construct Main Dike Section (15 Working Days)

Contractor Furnished

2 Dozers x \$40/hr x 10 hr/day x 15 days	\$ 12,000
4 Dump Trucks x \$30/hr x 10 hr/day x 15 days	18,000
1 Water Truck x \$35/hr x 10 hr/day x 15 days	5,250
1 Dragline x \$50/hr x 10 hr/day x 15 days	7,500
2 Laborers x \$8/hr x 10 hr/day x 15 days	2,400
Total	\$ 45,150

Total estimated cost for all three phases: \$11,630 + \$62,122 + \$45,150 = \$118,902.

NOTE: Estimated times for rental equipment are based on a total material handling capacity of 1,000 cu yd/day (100 cu yd/hr) for the dragline and four dump trucks. In the author's opinion, the equipment is capable of 1,200 cu yd/day without great effort and could probably produce 1,500 cu yd/day on a performance contract. The 1/3 reduction in expected production is typical of rental vs. performance specification work effort if a typical contractor is employed.

Table 5. Items Needed for Rental Contract Construction

Bid Item No.	Quantity	Description	Total Hours for Quantity
1	2	Small wide-track dozer w/blade and operator, IH HD500 or equivalent, maximum ground pressure 2.5 psi.	520
2	2-6*	Dump truck and operator, 10 cu yd struck capacity, short wheelbase, tandem axle (larger trucks not acceptable).	940
3	1	Water truck and operator, 1,500-2,000 gal minimum capacity, self-filling, minimum 8-ft-wide rear spray bar.	260
4	1	Dragline and operator, 1-3/4-cu yd struck bucket capacity (welded sideboards acceptable), 50-ft minimum boom length, furnished with mats sufficient to lower average ground pressure to 2 psi.	210
5	2	Portable (field) sewing machine and operator, Fischbien Model D or equivalent single-needle type capable of field-sewing lapped seams of civil engineering fabric (filter cloth) with No. 43-No. 53 cord multifilament polyster thread. Thread to be supplied with machine.	120
6	2-4*	Laborer, Common	600

*** Quantity of this item will vary depending upon particular phase of the work. The Government will give 24 hr notice when a change (addition or deletion) of the number of items in use is contemplated.**

Table 6. Items To Be Obtained by the Government and Furnished the Rental Contractor

Item No.	Quantity	Description
1	400 cu yd	Crushed Reef Shell
2	4,800 sq yd	Advance Type I Fabric*
3	4,800 sq yd	Polyfilter-X Fabric*
4	4,374 sq yd	Nicolon 66186 Fabric*
5	6,197 sq yd	Nicolon 66475 Fabric*

* See Part IV for procurement details.

required for each equipment item from those contained in the original advertisement, should circumstances dictate and as the estimated total cost of the project is not exceeded. The normal 10% overrun variation allowed in normal MDO equipment rental contracts should not be specified, as this phraseology may prove too restrictive for efficient on-site management of the work.

Finally, it should be recognized that the test section construction is essentially experimental in nature and that instrumentation placed in the test section is to give warning of possible incipient failure, as well as providing data for after-the-fact verification of design and construction criteria. Observation of settlement plate and piezometer data should allow MDO engineers to determine if embankment settlements and foundation pore pressures are increasing at a rate that could be potentially detrimental to embankment stability. In such case, the proper remedial action would be to halt embankment construction until embankment settlements and/or foundation pore pressures stabilize. To protect the MDO in case such conditions are encountered during construction, the contract should contain the provision that, upon 24 hr notice by the Government, construction operations may be suspended for up to 10 working days without penalty, and if such stoppage occurs, operations should be resumed by the contractor within 24 hr after notice to reactivate his equipment.

PART VII. CONSTRUCTION OF UNREINFORCED EMBANKMENT FOR COMPARATIVE PURPOSES

The MDO requested that the Contractor study the concept of constructing an unreinforced embankment across Pinto Pass, to obtain a behavioral comparison with the fabric-reinforced embankment. After consideration, it is the Contractor's opinion that:

a. Construction of an unreinforced embankment using the construction procedures and techniques described in this report is not warranted, as such procedures were designed specifically for constructing the fabric-reinforced embankment.

b. The proper test section to construct for comparative purposes would be one built by end-dumping displacement of soft foundation materials, the conventional MDO method of dredged material retaining dike construction on soft foundation.

c. If fabric-reinforced embankment test section construction is unsuccessful, end-dumping displacement methods will have to be used to construct dikes across Pinto Pass. In the event of reinforced test section failure, the logical remedial action would be to continue adding sand borrow to the failed embankment, until a displacement section is produced.

d. In the event of fabric-reinforced embankment failure, the need for an unreinforced comparison section would be academic.

It is therefore suggested that the decision relative to construction of an unreinforced embankment test section be delayed until validity of the fabric reinforcement concept can be established or disproved. If the fabric-reinforced embankment does not perform properly, additional borrow can be hauled and added along the alignment to convert the test section to an end-dumping displacement dike. Data obtained during this activity should provide the MDO with information needed to estimate the cost of constructing the remaining dikes at Pinto Pass by end-dumping displacement.

If the fabric-reinforced dike construction concept is successful, the existing rental contract could be modified to use a majority of the equipment in construction of a displacement test section to the centerline of Pinto Pass. This displacement test section would provide data relative to the additional material necessary to obtain stable displacement conditions and also the type of section that may be obtained by displacement. These data, when considered in the light of the long-term dike requirements at Pinto Pass, may allow the MDO to make decisions relative to construction of remaining dikes by either fabric-reinforcement or displacement section methods. Location of such a test section should be at least 500 ft east of the fabric-reinforced section and not on the alignment for any future proposed dike construction. Also, the effect of such dike construction on long-term future operation of the Pinto Island disposal area should be considered.

REFERENCES

1. Haliburton, T. A., P. A. Douglas, and J. Fowler, "Feasibility of Pinto Island as a Long-Term Dredged Material Disposal Site," MP D-77-3, Dredged Material Research Program, U. S. Army Engineer Waterways Experiment Station, Vicksburg, MS, December, 1977.

2. Haliburton, T. A., C. C. Anglin, and J. D. Lawmaster, "Selection of Geotechnical Fabrics for Embankment Reinforcement," Contract Report to U. S. Army Engineer District, Mobile, Contract No. DACW01-78-C-0055, School of Civil Engineering, Oklahoma State University, Stillwater, OK, May, 1978.

3. Proceedings, First International Conference on Use of Civil Engineering Fabrics, Paris, France, April, 1977.

4. Schneider, J. R., and L. H. Roth, "Dike Rehabilitation Using Wood Chips," Proceedings, American Society of Civil Engineers Conference on Geotechnical Practice for Disposal of Solid Waste Materials, Ann Arbor, MI, June 13-15, 1977, pp. 661-679.

5. Risseeuw, P., "Stabilenka Woven Reinforcement Fabric in Raising Mounds of Soft Soil," Engineering Report by AKZO Research Laboratories to the Nicolon Corporation, Arnhem, Holland, April, 1977.

6. Willoughby, W. E., "Assessment of Low-Ground-Pressure Equipment for Use in Containment Area Operations and Maintenance," TR D-77-8, Dredged Material Research Program, U. S. Army Engineer Waterways Experiment Station, Vicksburg, MS, November, 1977.