Miscellaneous Paper GL-93-15
August 1993

US Army Corps
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Disposal Alternatives for New Work Dredged Material, Deepening of Norfolk Harbor

by Timothy D. Stark, George R. Briest
San Diego State University

WES

Prepared for U.S. Army Engineer District, Norfolk

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Final report

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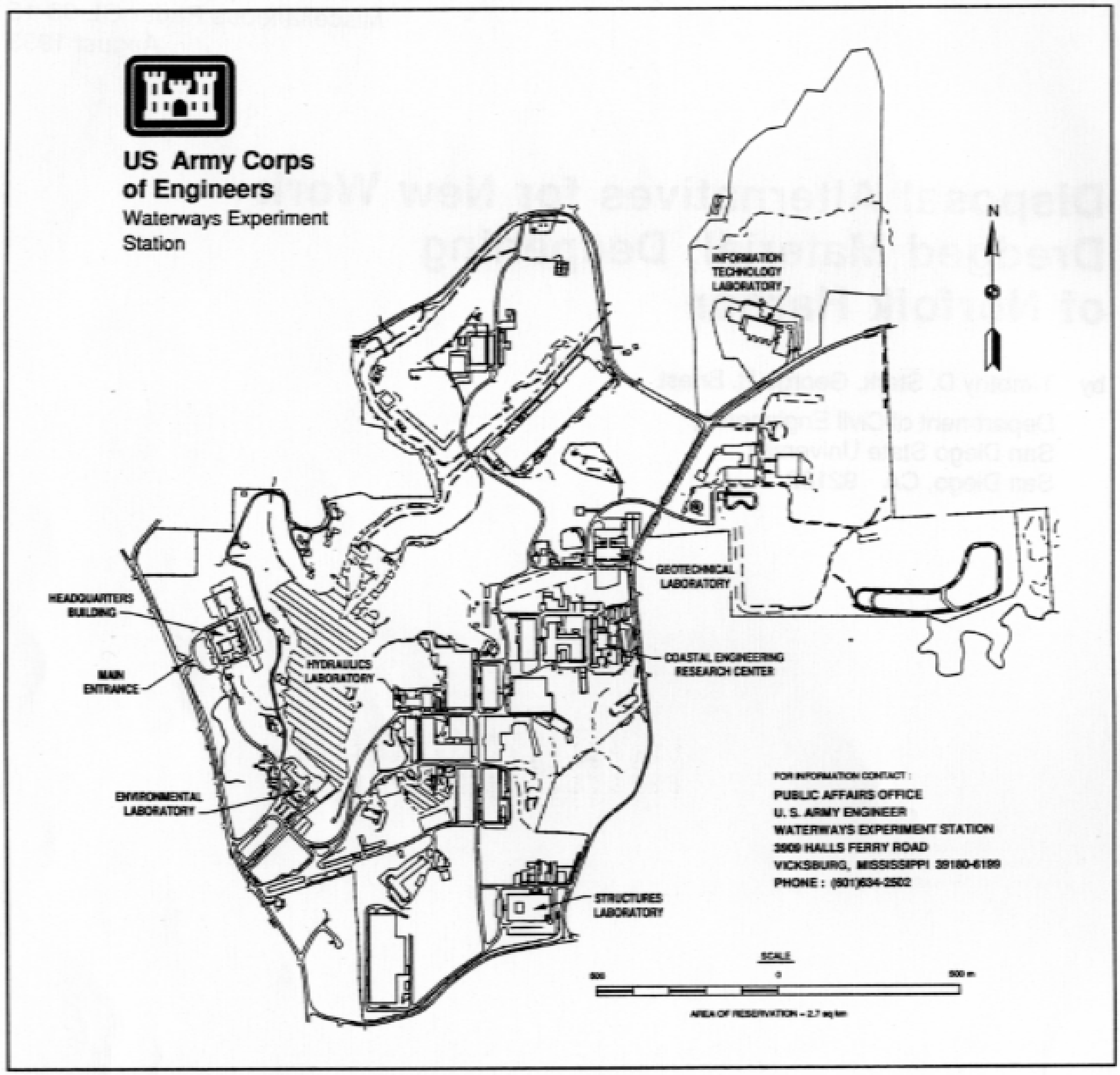
Prepared for U.S. Army Engineer District, Norfolk
Norfolk, VA 23510-1096



Waterways Experiment Station Cataloging-in-Publication Data

Stark, Timothy D.

Disposal alternatives for new work dredged material, deepening of Norfolk Harbor / by Timothy D. Stark, George R. Briest; prepared for U.S. Army Engineer District, Norfolk.

69 p.: ill.; 28 cm. -- (Miscellaneous paper; GL-93-15)

Includes bibliographical references.

1. Dikes (Engineering) -- Virginia -- Norfolk. 2. Spoil banks -- Virginia -- Norfolk -- Design and construction. 3. Dredging -- Virginia -- Norfolk -- Environmental aspects. 4. Dredging spoil -- Virginia -- Norfolk. I. Briest, George R. II. United States. Army. Corps of Engineers. Norfolk District. III. U.S. Army Engineer Waterways Experiment Station. IV. Title. V. Series: Miscellaneous paper (U.S. Army Engineer Waterways Experiment Station); GL-93-15.

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Preface

This publication describes the evaluation of various disposal alternatives for the estimated 12 million cu yd of new work dredged material resulting from the proposed deepening of Norfolk Harbor from elevation -50 to -55 ft Mean Low Water (MLW).

This project was conducted for the U.S. Army Engineer District, Norfolk (NAO), Norfolk, Virginia, and the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, during the period January 1989 to July 1989.

Concept formulation and general supervision of the study were carried out by Mr. Sam McGee, NAO, and Dr. Jack Fowler, Geotechnical Laboratory (GL) WES, under the guidance of Mr. Ron G. Vann, Chief, Civil Programs Branch, and Mr. James Thomasson, Chief, Engineering Division, NAO.

Dr. Timothy D. Stark and Mr. George R. Briest, Department of Civil Engineering, San Diego State University, performed the analyses and wrote this report under the supervision of Dr. Jack Fowler, WES. This was performed under an Intergovernmental Personnel Agreement No. CQGTF383BAGB10T between WES and Dr. Stark from December 1988 through June 1989. Dr. William F. Marcuson III was Director, GL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard.

1 Introduction

Background

The Craney Island disposal area is a 2,500-acre confined dredged material containment area located near Norfolk, Virginia, in Portsmouth, Virginia (Figure 1). Construction of Craney Island began in August 1954 and was completed in January 1957. Craney Island is the major disposal area for material dredged from the channels and ports in the Hampton Roads area.

Dredged material has been placed in the disposal area almost continuously since it was completed in 1957. The original design was for an initial capacity of about 100 million cu yd and a 20-year life of the facility. Increased dredging in the Norfolk channel has required the capacity of Craney Island to be increased through three major dike raising efforts. The initial change from el +8 to el +17 ft MLW occurred around 1969 with the second increase to el +26 ft around 1980. The U.S. Army Engineer District, Norfolk (NAO) is currently in the process of raising the perimeter dike system based on recommendations presented by Fowler et al., (1987). The west dike has been raised to el +34 ft MLW but required the placement of an underwater stability berm along the outer toe of the dike. The eastern and northern dikes are currently being raised to evaluations of +40 ft MLW with dike crest setbacks of 420 and 450 ft, respectively, from the dike perimeter road (Fowler et al., 1987).

Plans developed by Palermo (1981) using interior dikes were built within Craney Island to create three containment areas that would improve sedimentation in the containment area being filled and allow the other two area to desiccate and consolidate at a faster rate. Construction of the interior dikes was completed in 1983, and the dredged material management plan (Palermo, 1981) was implemented in 1984 starting with the center compartment. The interior dikes are usually maintained approximately 4 ft below the crest of the perimeter dikes.

NAO estimated the proposed deepening of the Norfolk Harbor and the accompanying shipping channels from el -50 to el -55 ft MLW will result in approximately 12 million cu yd of maintenance and new work dredged material. NAO estimated that approximately 3 million cu yd will consist of sandy material which is suitable for dike construction. Alternatives for disposing of the 12 million cu yd of new work material, such as the expansion of Craney

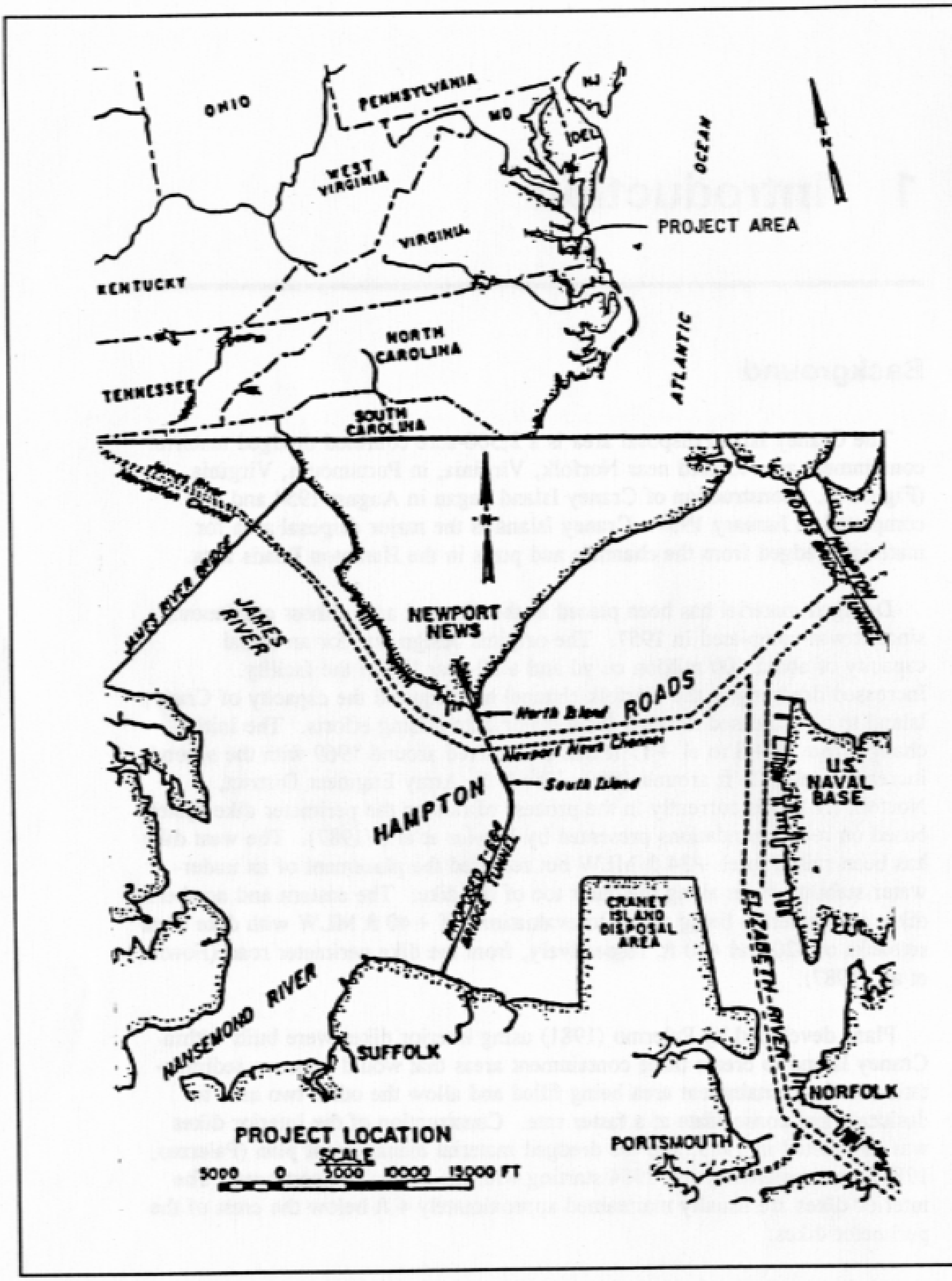


Figure 1. Project location

Island using the six configurations shown in Figure 2 (Goforth, 1986). Ocean dumping, stabilization and/or raising of existing dikes at Craney Island, or combinations of these alternatives, have been proposed.

Purpose

The purpose of this study was to evaluate the proposed disposal alternatives for the 12 million cu yd of new work dredged material generated from the proposed deepening of Norfolk Harbor from el -50 to el -55 ft MLW.

Scope of Work

The scope of this work included the following items. First was the assembling available geotechnical and related information from conferences with the U.S. Army Engineer Waterways Experiment Station (WES) and NAO personnel and from existing published and unpublished literature. Secondly, estimating the volume of suitable dike material required to construct the six underwater expansion configurations proposed by Goforth (1986) and the resulting storage capacity of each configuration using navigation charts. Dike subsidence was calculated and incorporated into these analyses. Thirdly was investigating the possibility of increasing the stability of the existing dikes with the 3 million cu yd of sandy material. The limit equilibrium slope stability analyses were performed using the microcomputer program UTEXAS2 (CAGE, 1986). Lastly, investigating the feasibility of raising the perimeter dikes from el +34 to +40 ft MLW on the west side and from el +40 to +45 ft MLW on the east and north sides using the 3 million cu yd of suitable dike material. The raising would allow the level of the confined dredged material to be increased to el +36 ft MLW on the west side and el +41 ft MLW on the east side, resulting in approximately 18 million cu yd of additional storage capacity.

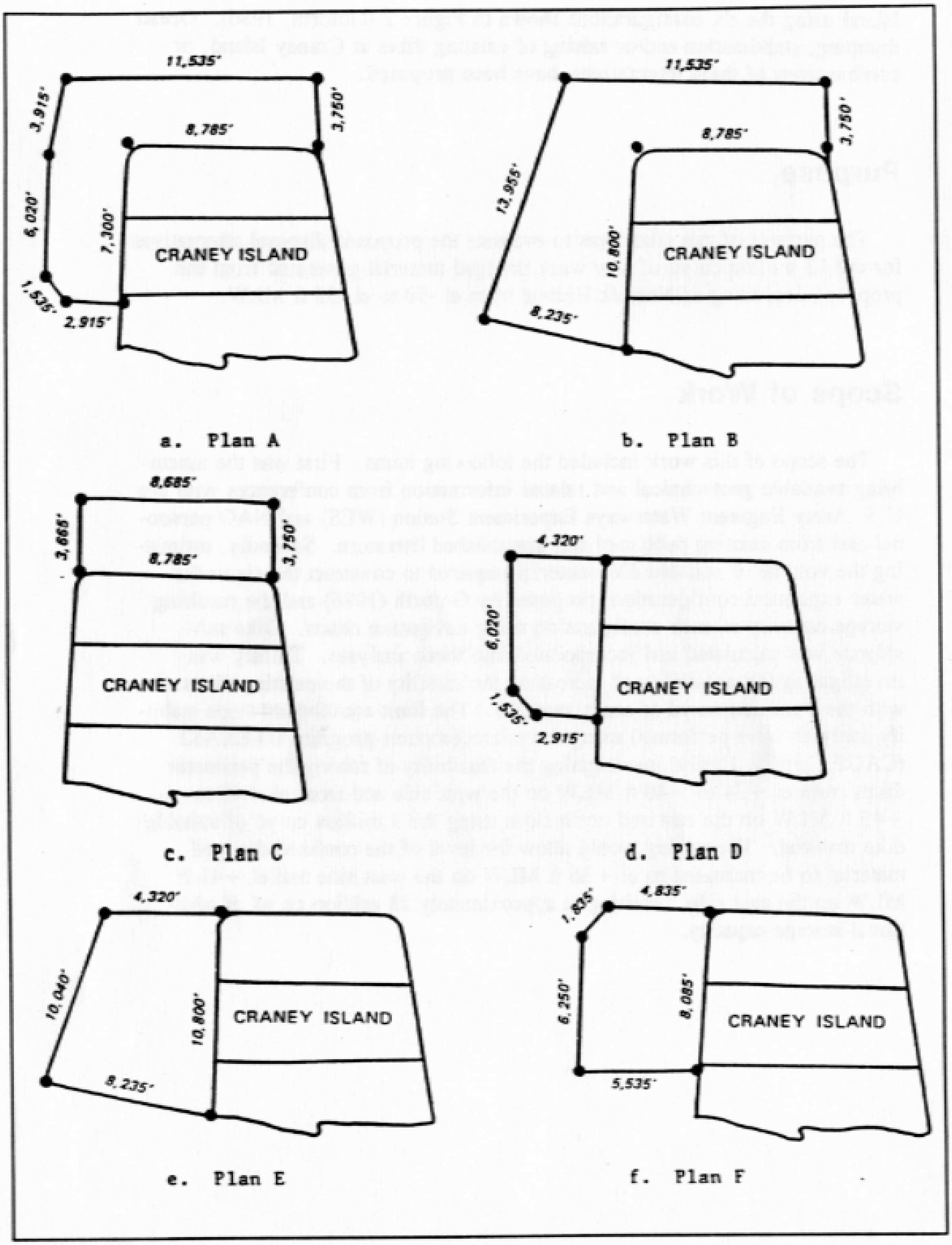


Figure 2. Dimensions of Craney Island enlargement alternatives (from Goforth, 1986)

2 Expansion of Craney Island

Expansion Alternatives

NAO estimated that approximately 12 million cu yd of dredged material would be generated by maintenance dredging and the proposed deepening of Norfolk Harbor from el -50 to el -55 ft MLW. Due to the inadequate capacity of Craney Island, expansion alternatives were sought which would have a minimal impact on Craney Island and the surrounding area. Spigolon and Fowler (1987) investigated the feasibility of expanding Craney Island using dikes constructed to el +8 ft MLW in the six configurations proposed by Goforth, (1986). During this study, expansion of Craney Island using underwater dikes in the same six configurations was investigated.

Two dike cross-sections were considered for each expansion configuration. The first dike cross-section has a crest elevation of -5 ft MLW and a crest width of 50 ft. It was assumed that a stable side slope would be 1V:30H for all cases. Figure 3 illustrates this cross-section in 30 ft of water. The second dike cross-section is similar to the first with a crest elevation of -2 ft MLW. Freeboards, i.e. distances from the dike crest to the top of the confined dredged material, of 2 and 3 ft were analyzed for each different dike cross-section. Stability analyses, conducted using UTEXAS2 Version 1.209 described by CAGE, (1986), showed that both underwater dike cross-sections would have a factor of safety greater than 1.3 for the water depths and dike configurations proposed.

Storage Capacity

The volume of sandy material required to construct the underwater dikes for the six configurations and two cross-sections are shown in Table 1. The storage capacities for each dike configuration are also tabulated in Table 1. The subsidence of the dikes was estimated to be 2.4 ft and 2.1 ft for the crest elevations of -2 ft MLW and -5 ft MLW, respectively. The anticipated subsidence was incorporated into the volume of suitable dike material required for each configuration. Subsidence calculations are discussed in Part V of this report.

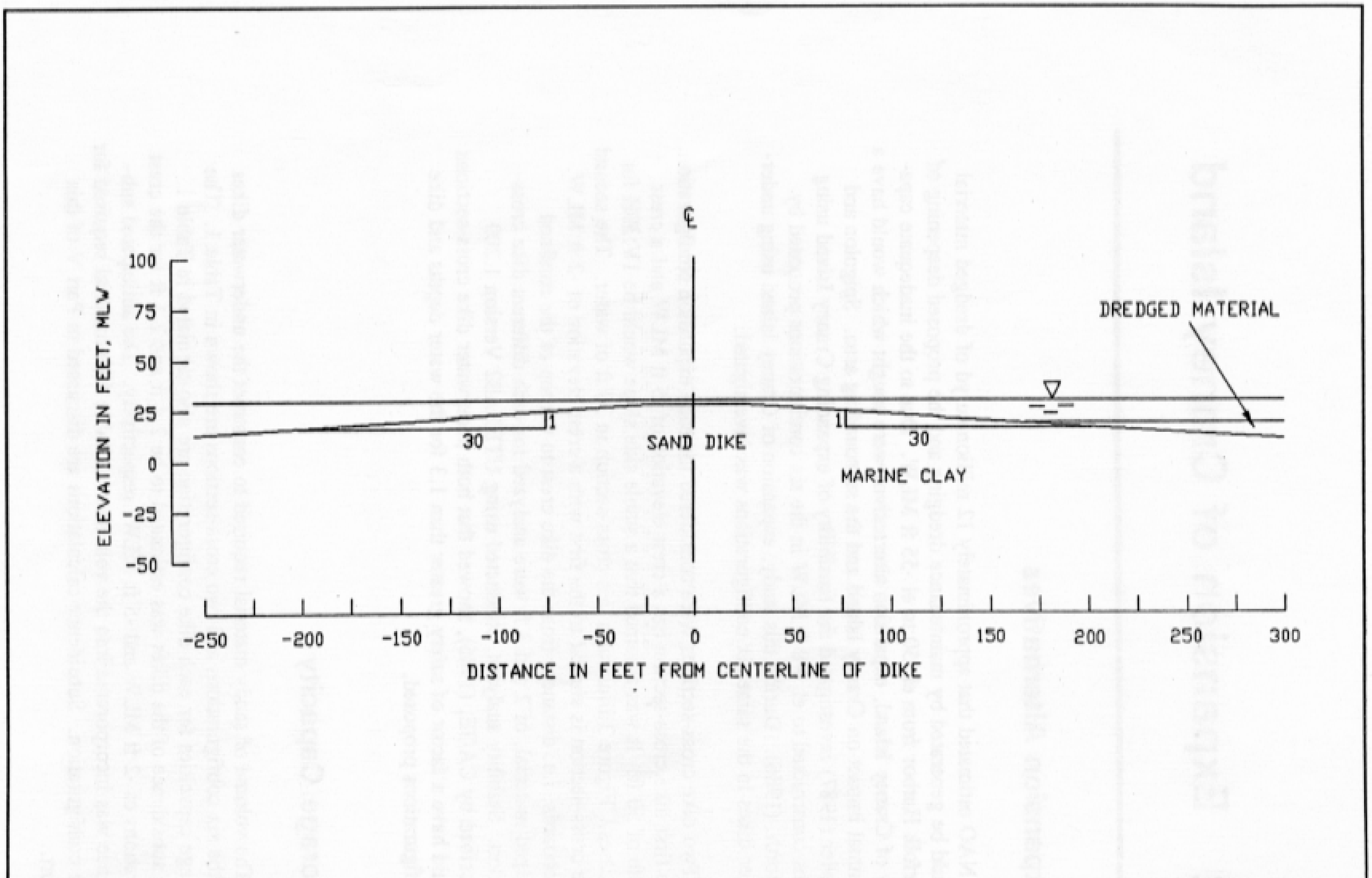


Figure 3. Typical dike cross-section for underwater expansion of Craney Island

Table 1
Volume Estimates for Craney Island Expansion Alternative

Volume (cu yd)	Configuration					
	A	B	C	D	E	F
I. Top of Dike at -2 ft MLW and 2 ft of freeboard						
Dike (x 10^6)	10.890	10.566	8.354	1.710	1.590	1.291
Dredged material. (x 10^6)	31.021	35.593	16.108	5.890	10.364	7.527
II. Top of Dike at -2 ft MLW and 3 ft of freeboard						
Dike (x 10^6)	10.890	10.566	8.354	1.710	1.590	1.291
Dredged material. (x 10^6)	28.048	31.820	14.593	4.990	8.6774	6.380
III. Top of Dike at -5 ft MLW and 2 ft of freeboard						
Dike (x 10^6)	7.565	7.437	5.839	0.887	0.853	0.666
Dredged material (x 10^6)	23.346	25.488	12.480	3.444	5.5444	4.282
IV Top of Dike at -5 ft MLW and 3 ft of freeboard						
Dike (x 10^6)	7.529	7.424	5.741	0.887	0.853	0.666
Dredged material (x 10^6)	20.376	21.718	10.970	2.544	3.8594	3.133

Recommendations

The largest water depths and storage volumes were found along the north side of Craney Island. The 1988 bathometric data used in this study was provided by NAO. It can be seen from Table 1 that configuration B provides the largest storage capacity. However, NAO estimated that only 3 million cu yd of the approximately 12 million cu yd of new work material would be suitable for dike construction. Therefore, only configurations D, E, and F appear to be constructible. Configuration E provides the largest storage capacity and is recommended. It additional dike construction material becomes available, one of the configurations utilizing the north side of Craney Island should be considered.

3 Stabilization of Existing Craney Island Perimeter Dikes

NAO is considering ocean dumping of the nine million cu yd of clayey dredged material generated from the proposed deepening. Alternatives for disposing of the remaining three million cu yd of suitable dike material on the existing perimeter dikes at Craney Island are considered in this section. Numerous dike geometries were investigated of the existing dikes.

Various dike geometries were analyzed using UTEXAS2 and a factor of safety greater than or equal to 1.3 had to be maintained. Circular shear surfaces were assumed in all cases and Bishop's modified procedure was used to calculate the factor of safety. Factors of safety were also calculated using Spencer's method for a number of different cross-section at Station 80+00 of the West leg dike. A comparison of the factors of safety revealed both methods gave approximately the same values. As a result, Bishop's method was used throughout the study because it is more suited to circular slip surfaces (Duncan and Wright, 1980).

Foundation Soil Conditions

The stability of the perimeter dikes is directly dependent on the shear strength of the harbor bottom, soft marine clays and the rate at which the shear strength increases under the load of the gradually placed fill. A generalized north-south profile through the existing Craney Island Disposal Area (Fowler et al., 1987) is shown in Figure 4. The soil profile indicates incompressible materials al et -90 ft MLW consisting of dense sands and silty sands. Above the sands are a layer of marine clay. Since the harbor bottom in the study area ranges from 0 ft MLW to -32 ft MLW, the marine clay is approximately 58 to 90 ft thick.

The marine clay layer is a continuous stratum of recent marine sediments which are presumed to be normally consolidated. Fowler (et al., 1987. Presented an extensive summary of the results of geotechnical subsurface investigations made in the area of Craney Island during the period from 1943

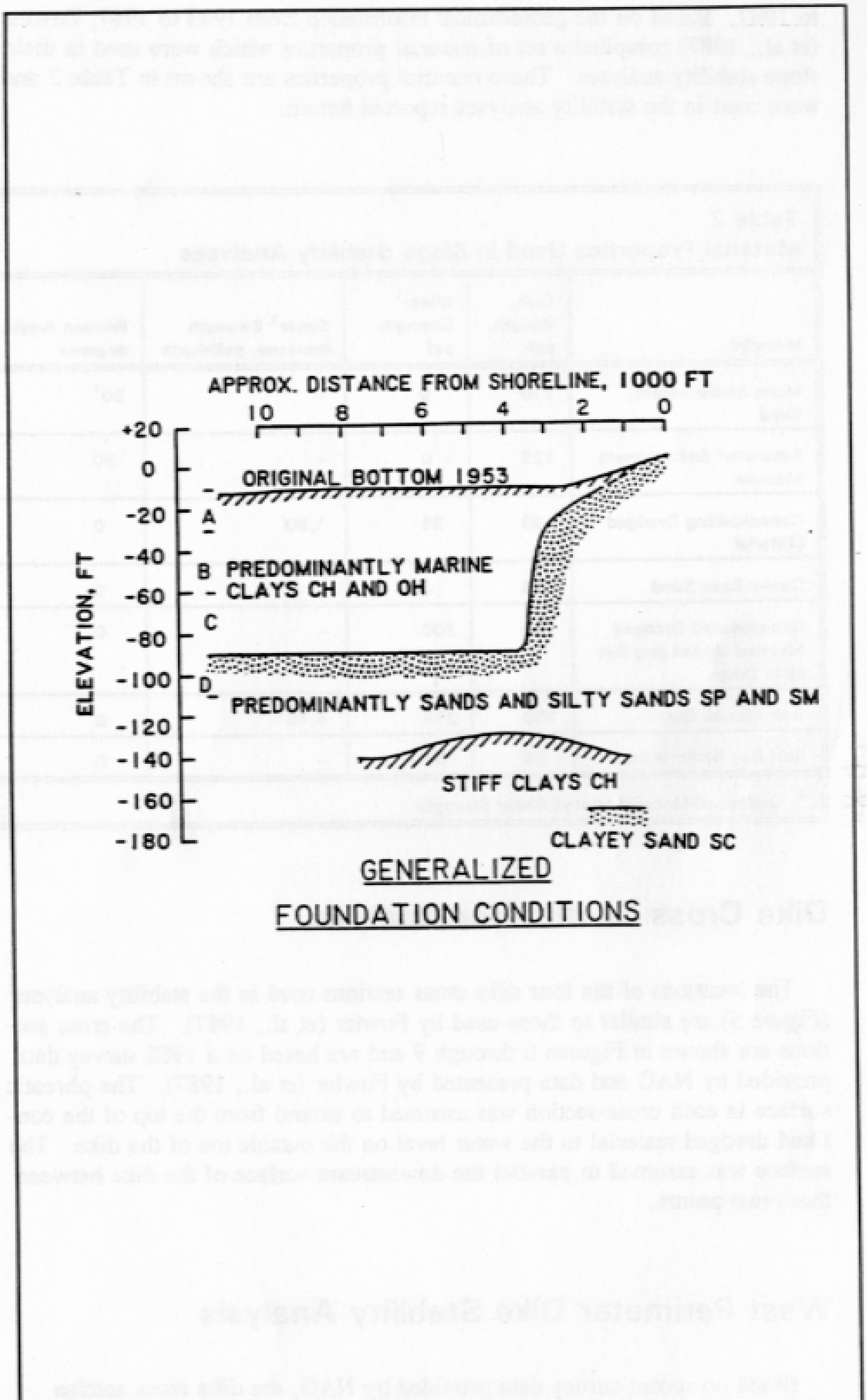


Figure 4. Generalized foundation conditions (from Fowler et al., 1987)

to 1987. Based on the geotechnical information from 1943 to 1987, Fowler (et al., 1987) compiled a set of material properties which were used in their slope stability analyses. These material properties are shown in Table 2 and were used in the stability analyses reported herein.

Table 2
Material Properties Used in Slope Stability Analyses

Material	Unit Weight, pcf	Shear[1] Strength psf	Shear[1] Strength Increase, psf/depth	Friction Angle, degrees
Moist Embankment Sand	110	0	--	30[1]
Saturated Embankment Material	125	0	--	30
Consolidating Dredged Material	90	35	1.80	0
Dense Base Sand	125	0	--	0
Consolidated Dredged Material Underlying Set-back Dikes	90	100	--	0
Soft Marine Clay	100	275	4.75	0
Soft Bay Sediments	95	50	--	0

[1] Undrained-Unconsolidated Shear Strength

Dike Cross Section for Analysis

The locations of the four dike cross sections used in the stability analyses (Figure 5) are similar to those used by Fowler (et al., 1987). The cross sections are shown in Figures 6 through 9 and are based on a 1988 survey data provided by NAO and data presented by Fowler (et al., 1987). The phreatic surface in each cross-section was assumed to extend from the top of the confined dredged material to the water level on the outside toe of the dike. The surface was assumed to parallel the downstream surface of the dike between these two points.

West Perimeter Dike Stability Analysis

Based on recent survey data provided by NAO, the dike cross section shown in Figure 6 was developed and included the water berm recently placed on the toe of the west perimeter dike. The as-built sand berm located

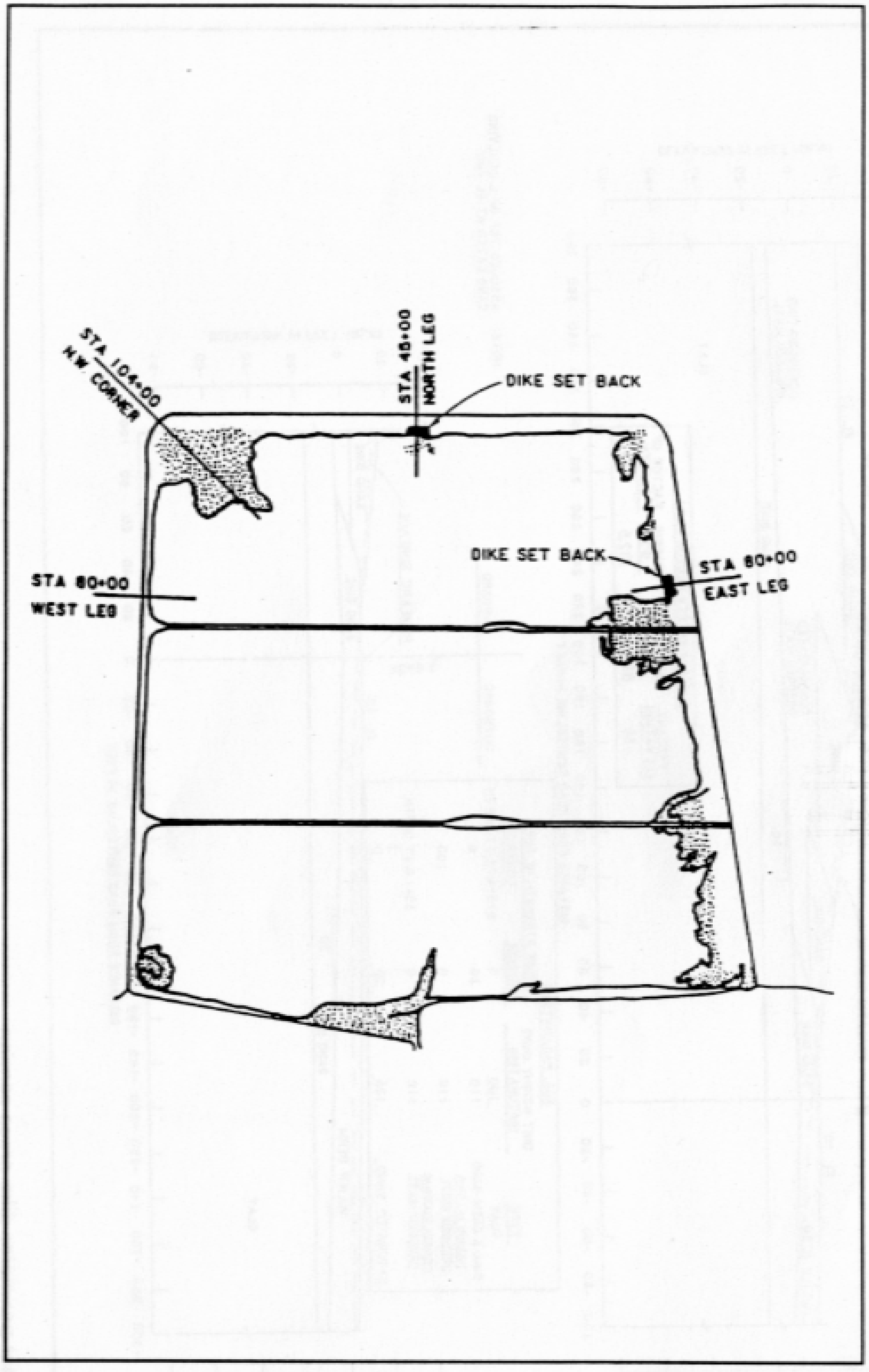


Figure 5. Locations of cross-sections investigated during dike stability analysis (from Fowler et al., 1987)

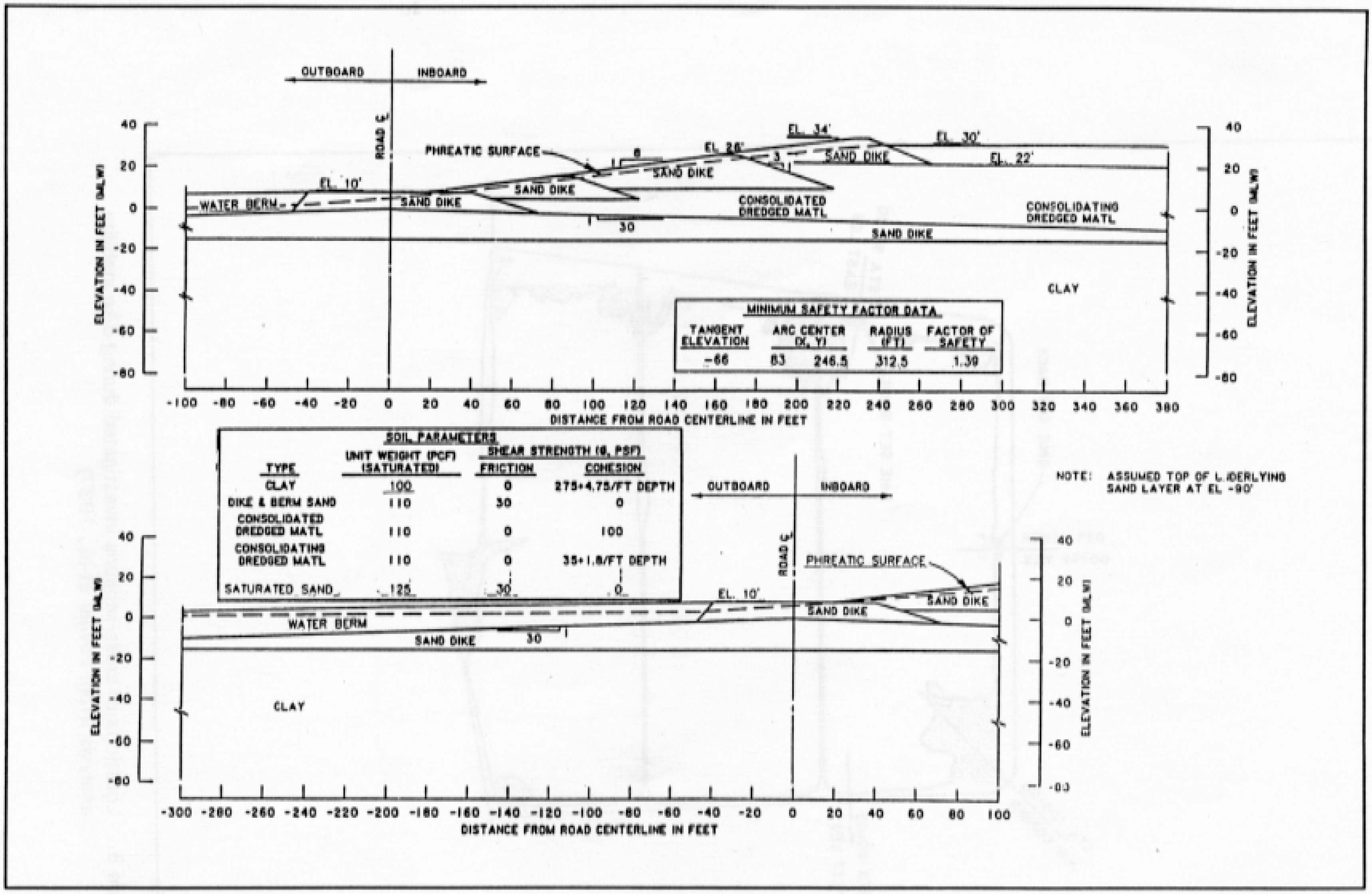


Figure 6. West perimeter dike cross-section

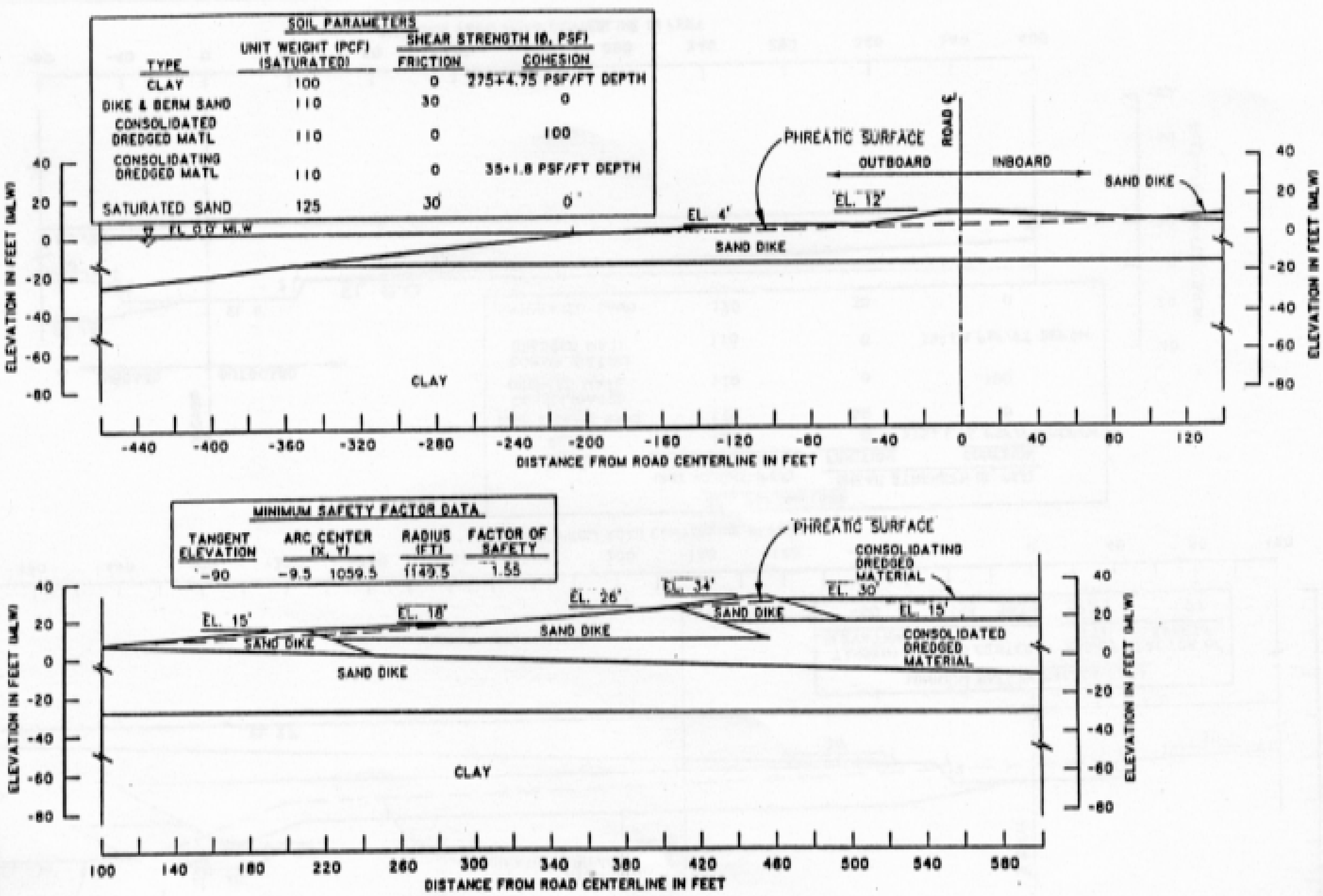


Figure 7. Northwest perimeter dike cross-section

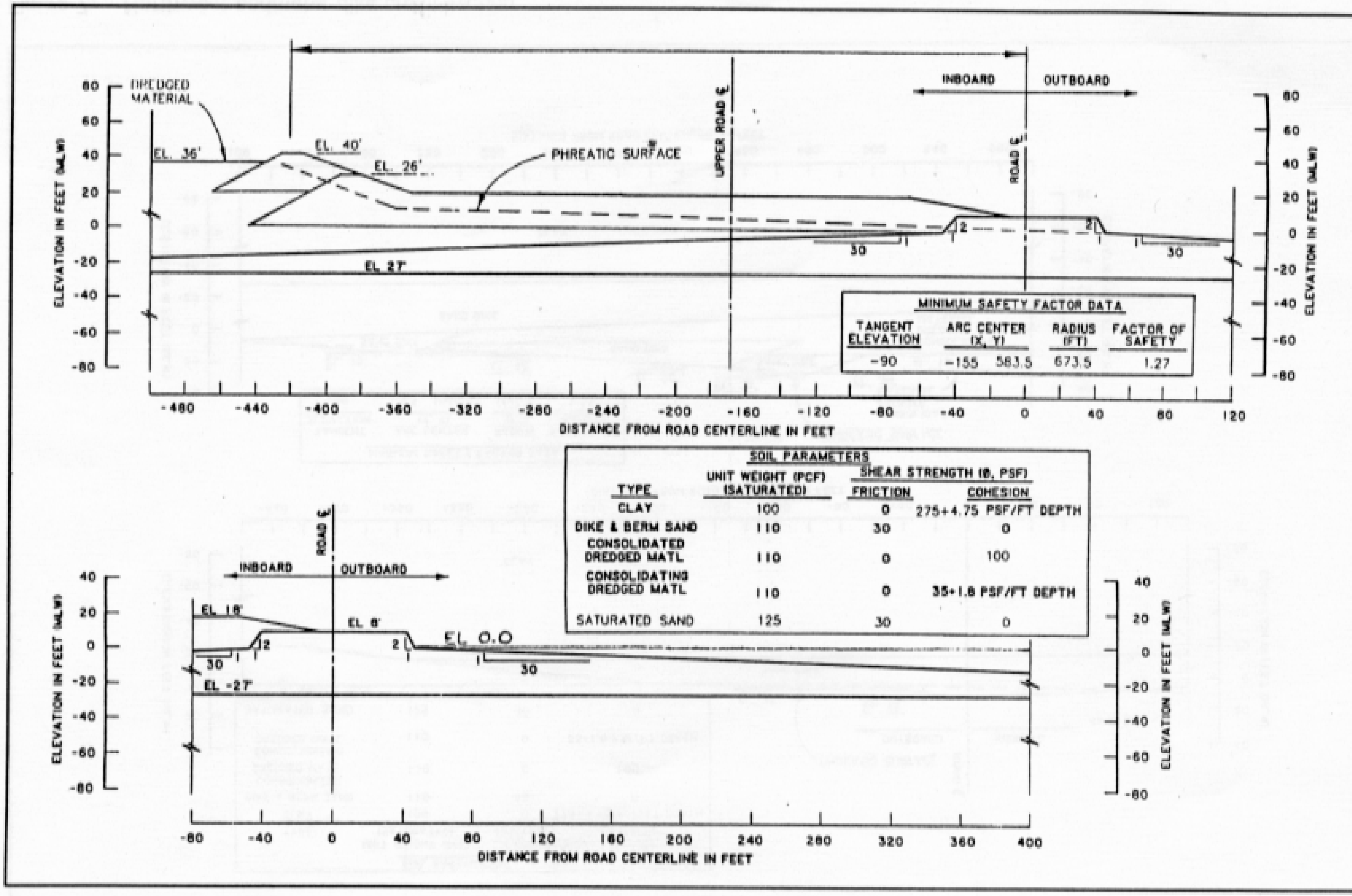
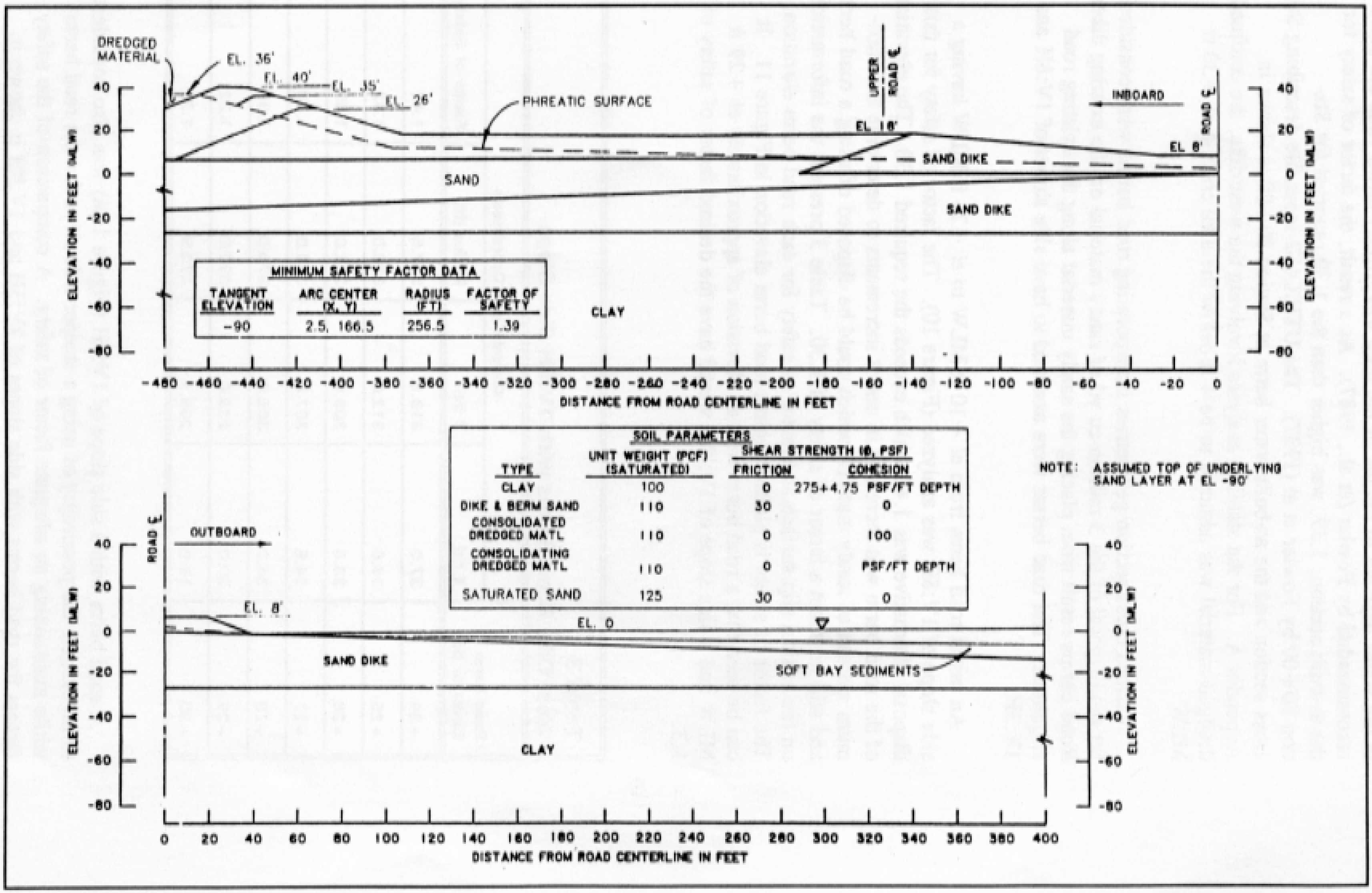


Figure 8. North perimeter dike cross-section



MINIMUM SAFETY FACTOR DATA			
TANGENT ELEVATION	ARC CENTER (X, Y)	RADIUS (FT)	FACTOR OF SAFETY
-90	2.5, 166.5	256.5	1.39

SOIL PARAMETERS		SHEAR STRENGTH (Φ, PSF)	
TYPE	UNIT WEIGHT (PCF) (SATURATED)	FRICTION	COHESION
CLAY	100	0	275+4.75 PSF/FT DEPTH
DIKE & BERM SAND	110	30	0
CONSOLIDATED DREDGED MATL	110	0	100
CONSOLIDATING DREDGED MATL	110	0	PSF/FT DEPTH
SATURATED SAND	125	30	0

Figure 9. East perimeter dike cross-section

in the water adjacent to the toe of the dike was slightly larger than the berm recommended by Fowler (et al., 1987). As a result, the factor of safety for the as-built section, 1.39, was higher than the 1.30 reported for Station 80+00 by Fowler et al (1987). The UTEXAS2 input file describing this cross section and the as-built water berm at Station 80+00 is shown in Appendix A. For the stability analyses involving the west dike, the confined dredged material was assumed to be 4 ft below the dike crest at el +30 ft MLW.

Various cross section geometries incorporating road berms were considered for the disposal of the 3 million cu yd of sandy material on the existing dikes. Road berms result from placing the sandy material along the existing road alignment. The road berms were assumed to have side slopes of 1V:8H and 1V:3H.

An initial road berm from el +10 ft MLW to el +24 ft MLW having a side slope of 1V:8H was analyzed (Figure 10). The factor of safety for this disposal alternative was 1.42 which exceeds the required 1.30. The elevation of the road berm was increased in one ft increments to determine the maximum amount of sandy material which could be disposed of using a road berm and still maintain a factor of safety of 1.30. Table 3 presents the information on the critical slip surface and factor of safety for each road berm elevation. The factor of safety is plotted against road berm elevation in Figure 11. It can be seen that a road berm with an elevation of approximately el +29 ft MLW and a side slope of 1V:8H, would have the desired factor of safety of 1.3.

Table 3
West Dike Road Berms with 1V:8H Side Slope

Road Berm Elevation (ft)	Critical Circle Coordinates			
	X (ft)	Y (ft)	Radius (ft)	Factor of Safety
+24	37.0	313.5	387.5	1.42
+25	36.0	312.0	386.0	1.42
+26	36.0	309.0	382.0	1.39
+27	34.5	307.0	380.0	1.38
+28	34.0	305.0	376.0	1.36
+29	20.0	223.0	290.0	1.32
+30	19.0	206.5	272.5	1.28

A road berm with a side slope of 1V:3H (Figure 11A) was also considered to investigate the possibility of using a steeper side slope for the road berm while maintaining an adequate factor of safety. A comparison of the safety factors for road berms with side slopes of 1V:3H and 1V:8H is shown in

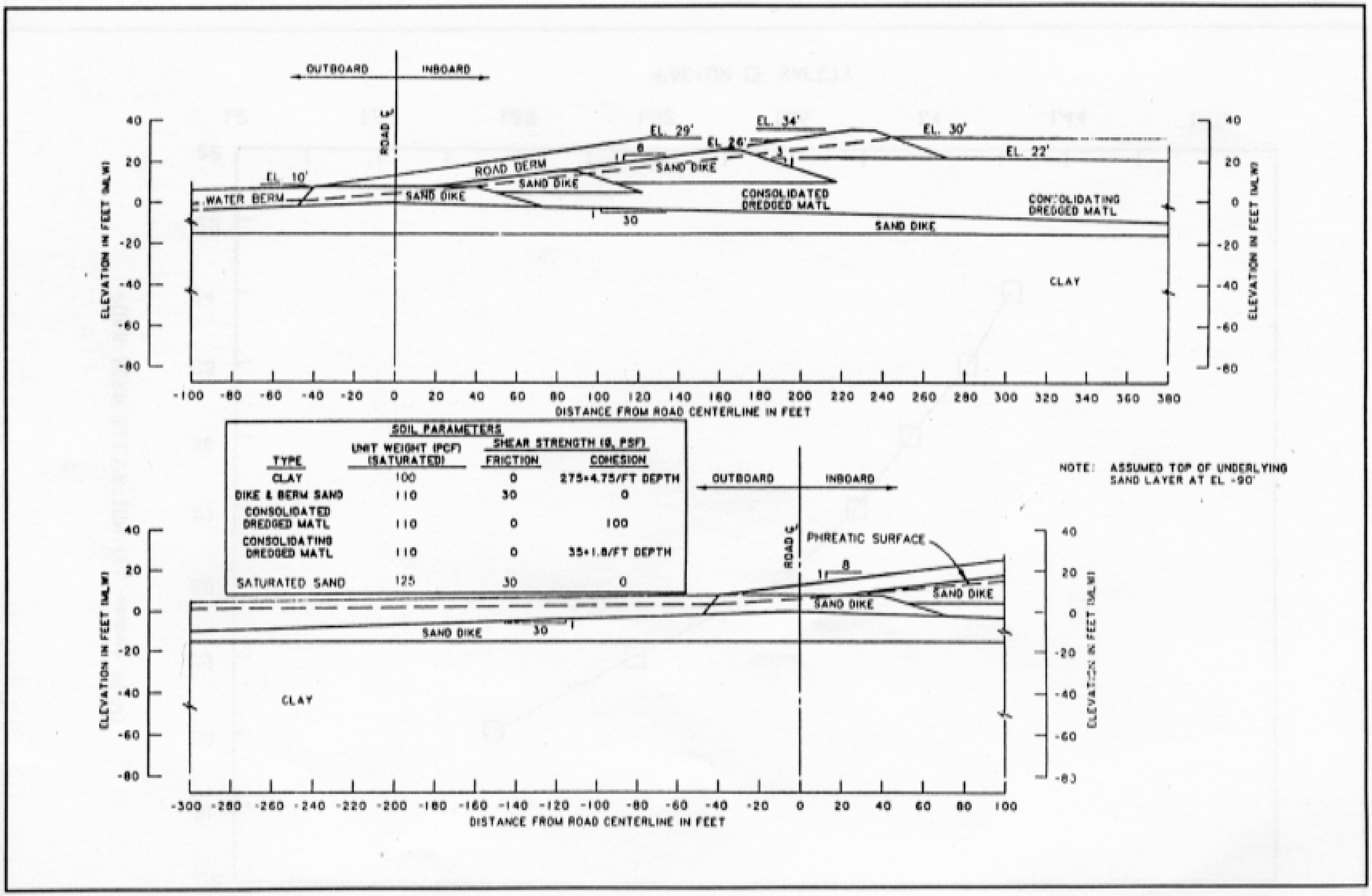


Figure 10. West perimeter dike cross-section with road berm addition (1V:8H slope)

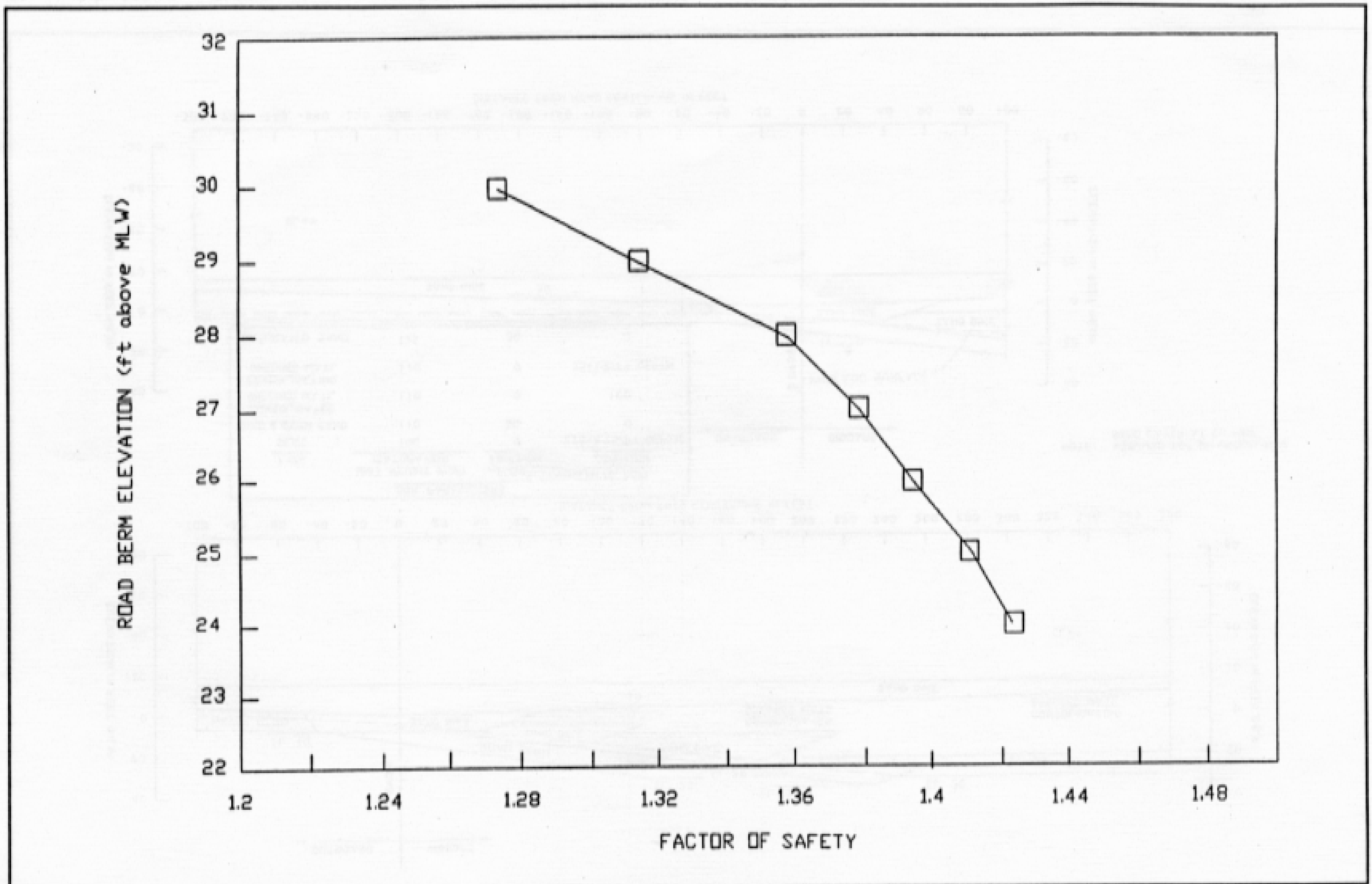
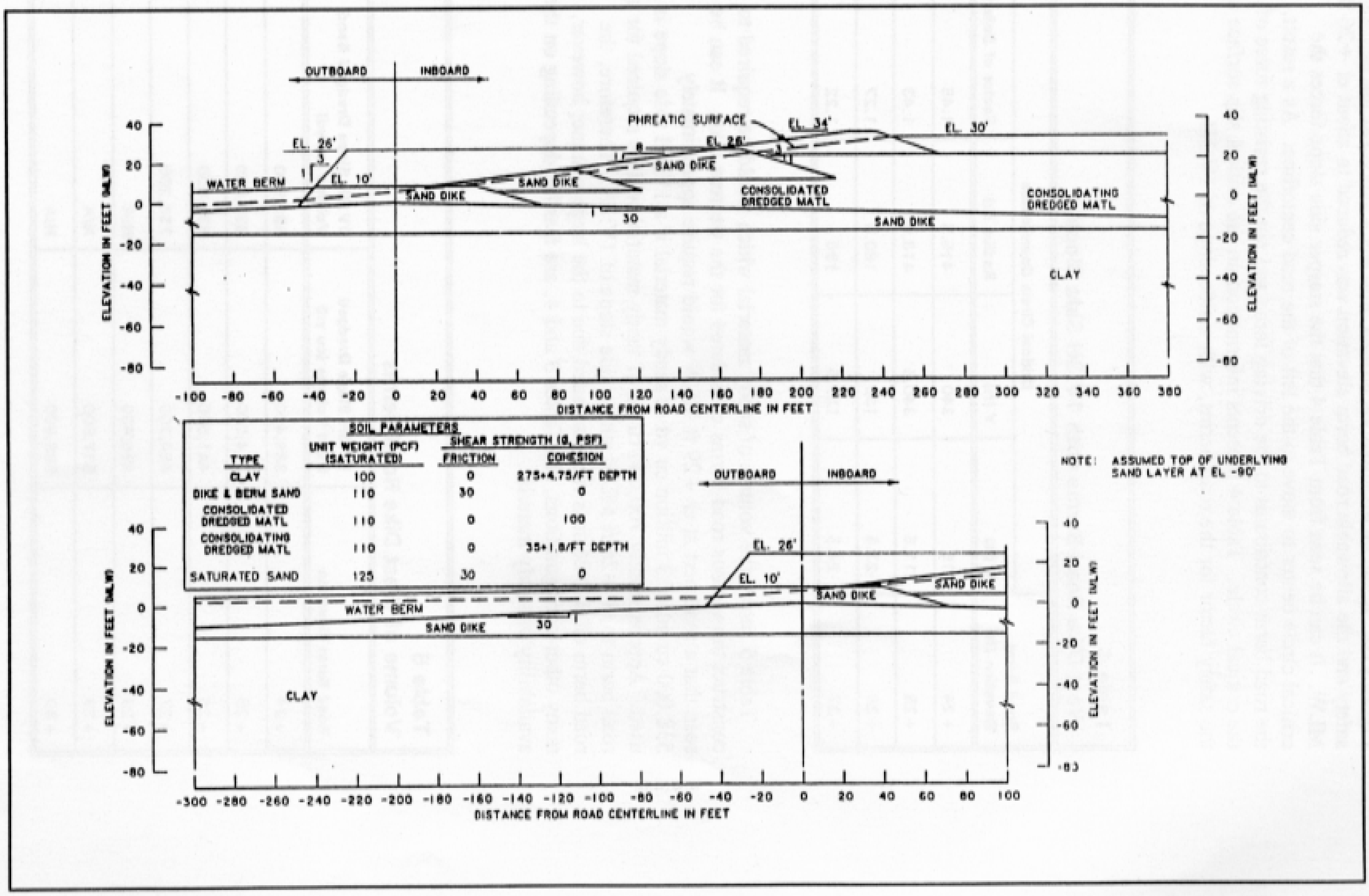


Figure 11. Safety factor as a function of west dike road berm height



SOIL PARAMETERS

TYPE	UNIT WEIGHT (PCF) (SATURATED)	SHEAR STRENGTH (0, PSF) FRICTION	COHESION
CLAY	100	0	275+4.75/FT DEPTH
DIKE & BERM SAND	110	30	0
CONSOLIDATED DREDGED MATL	110	0	100
CONSOLIDATING DREDGED MATL	110	0	35+1.8/FT DEPTH
SATURATED SAND	125	30	0

Figure 11A. West perimeter dike cross-section with road berm addition (1V:3H slope)

Figure 11B. It can be seen that the steeper side slope decreased the factor of safety and the allowable road berm elevation was reduced to about el +26 ft MLW. It can be seen from Table 4 that the steeper side slope forces the critical circle center to move to the left of the road centerline. As a result, the road berm contributes to the driving force and not the resisting force of the critical circle. Table 4 presents information on the critical slip surface and the safety factor for the road berms, with a side slope of 1V:3H.

Table 4
West Dike Road Berms with 1V:3H Side Slope

Road Berm Elevation (ft)	Critical Circle Coordinates			
	X (ft)	Y (ft)	Radius (ft)	Factor of Safety
+24	15	340	415.5	1.45
+25	11.5	340.5	418.5	1.43
+26	-27.5	130	180.5	1.27
+27	-24.5	137.5	196	1.22

Table 5 shows the volume of sandy material which would be required to construct the various road berms considered for the western dike. It can be seen that a road bert at el +29 ft MLW would require approximately 538,000 cu yd of 3 million cu yd of sandy material if a 1V:8H side slope is used. Approximately 700,000 cu yd of sandy material will be required for a road berm to el +26 ft MLW with a side slope of 1V:3H. Therefore, the road berm of el +26 ft is recommended due to the large volume; however, many other configurations, see Tables 3 and 4, are feasible depending on the availability of sandy material.

Table 5
Volume of West Dike Road Berms

Road Berm Elevation	1V:8H Slope Dredged Sand Volume (cu yd)	1V:3H Slope Dredged Sand Volume (cu yd)
+24	386,400	482,500
+25	414,000	639,000
+26	441,600	697,600
+27	464,300	758,200
+28	496,400	N/A
+29	537,900	N/A
+30	588,800	N/A

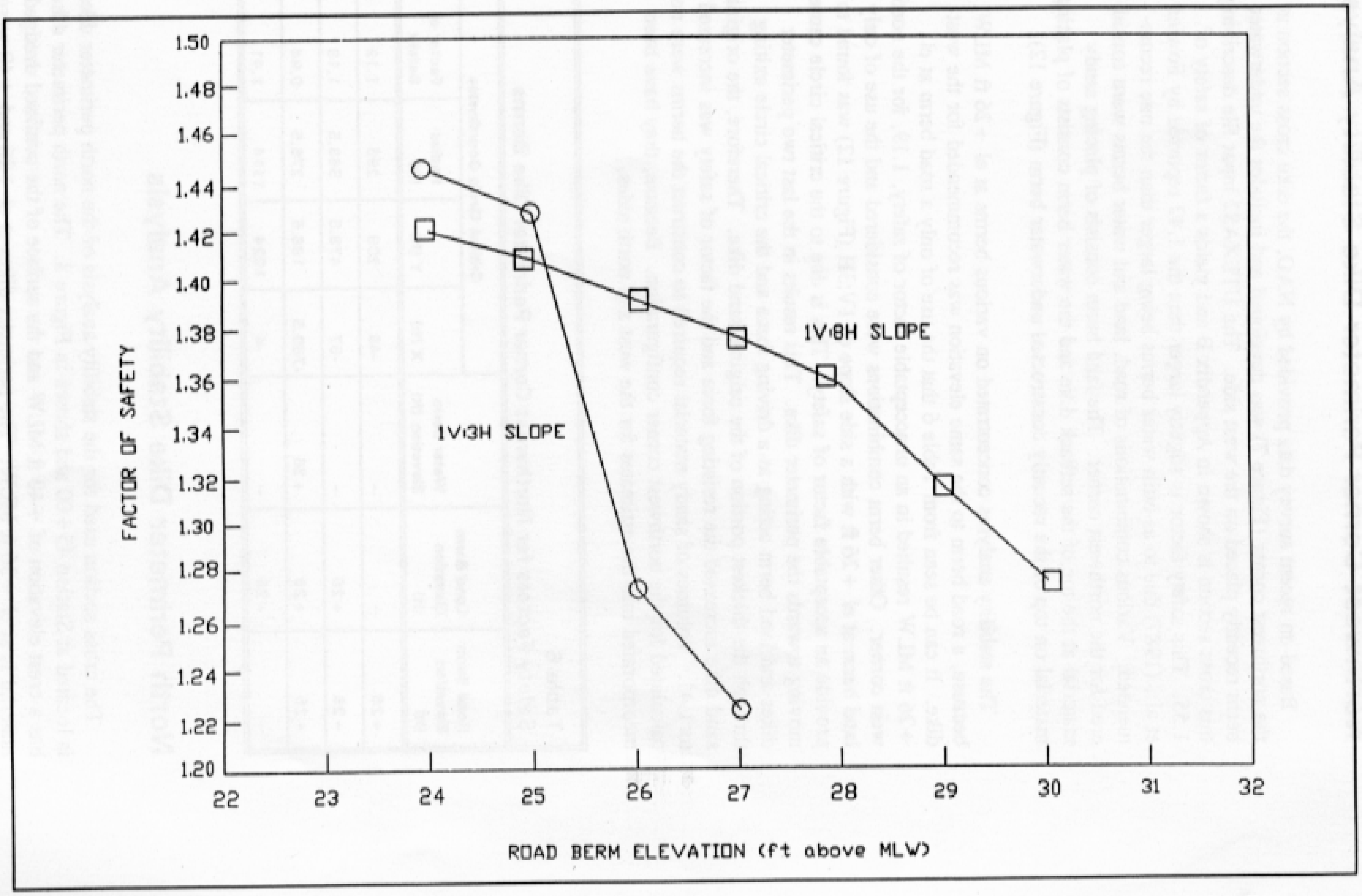


Figure 11B. West dike road berm height as a function of inclination

Northwest Corner Perimeter Dike Stability Analysis

Based on recent survey data provided by NAO, the dike cross section at the northwest corner (Figure 7) was developed and includes the underwater berm recently placed on the west side. The UTEXAS2 input file describing this cross section is shown in Appendix B and yields a factor of safety of 1.55. This safety factor is slightly larger than the 1.42 reported by Fowler et al., (1987) due to as-built water berms being larger than the one recommended. Various combinations of road, land and water berms were considered for the northwest corner. The land berm consists of placing sandy material at the toe of the setback dike and the water berm consists of placing material on top of the recently constructed underwater berm (Figure 12).

The stability analyses concentrated on various berms at el +26 ft MLW because, a road berm to the same elevation was recommended for the west dike. It can be seen from Table 6 that the use of only a road berm at el +26 ft MLW resulted in an unacceptable factor of safety, 1.19, for the northwest corner. Other berm combinations were considered and the use of only a land berm at el +26 ft with a side slope of 1V:3H (Figure 12) was found to provide an acceptable factor of safety. This is due to the critical circle center moving towards the perimeter dike. This results in the last two perimeter dikes and land berm acting as a driving force and the critical circle exiting through the thickest portion of the original sand dike. Therefore, the original sand dike increased the resisting force and the factor of safety was increased to 1.41. Volumes of sandy material required to construct the berms were not calculated for the northwest corner configuration. Because, they have been incorporated into the estimates for the west and north sides.

Table 6
Safety Factors for Northwest Corner Perimeter Dike Berms

Road Berm Elevation (ft)	Land Berm Elevation (ft)	Water Berm Elevation (ft)	Critical Circle Coordinates X (ft)	Y (ft)	Radius (ft)	Factor of Safety
+26	--	--	-48	209	299	1.19
+26	+26	--	-57	478.5	568.5	1.18
+26	+26	+26	-780.5	186.5	276.5	0.94
--	+26	--	-4	1024	1114	1.41

North Perimeter Dike Stability Analysis

The cross section used for the stability analysis of the north perimeter dike is located at Station 45+00 and shown in Figure 8. The north perimeter dike has a crest elevation of +40 ft MLW and the surface of the confined dredged material is at el +36 ft MLW. The perimeter dikes at el +26 and +40 were

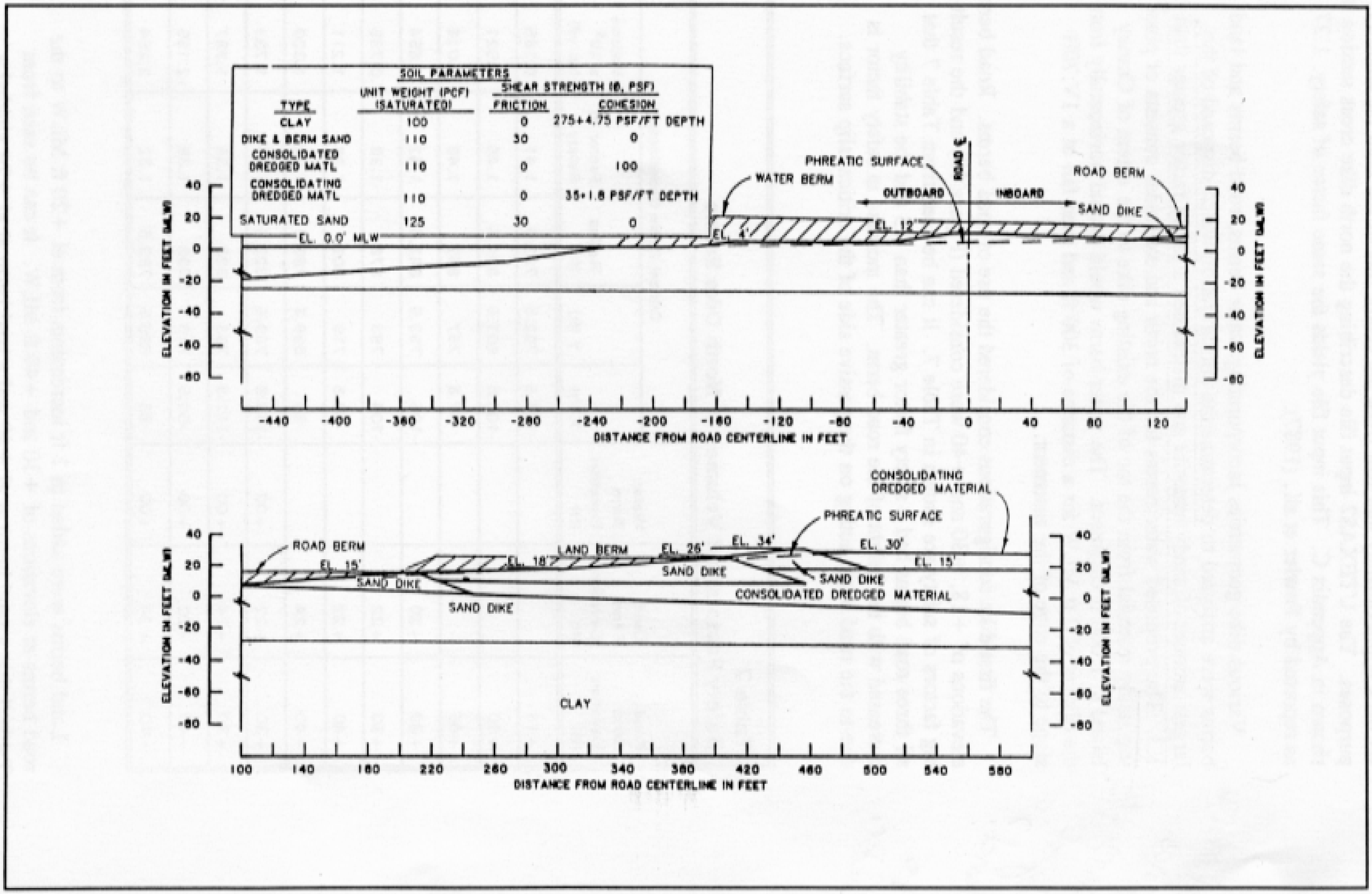


Figure 12. Northwest perimeter dike cross-section showing relation between road, land and water berms

set back approximately 420 feet from the center line of the road for stability purposes. The UTEXAS2 input file describing the north dike cross section is shown in Appendix C. This input file yields the same factor of safety, 1.27, as reported by Fowler et al., (1987).

Various dike geometries incorporating water berms, road berms and land berms were analyzed to determine the configuration which disposed of the largest amount of sandy material and maintained a safety factor greater than 1.3. The proposed water berms for the north and east sides consists of placing sandy material from the toe of the existing dike to the extent of Craney Island's 1,000 ft easement. The water berm would extend horizontally from the dike et el 0 ft MLW for a distance of 300 ft and then fall at a 1V:70H slope to the edge of the easement.

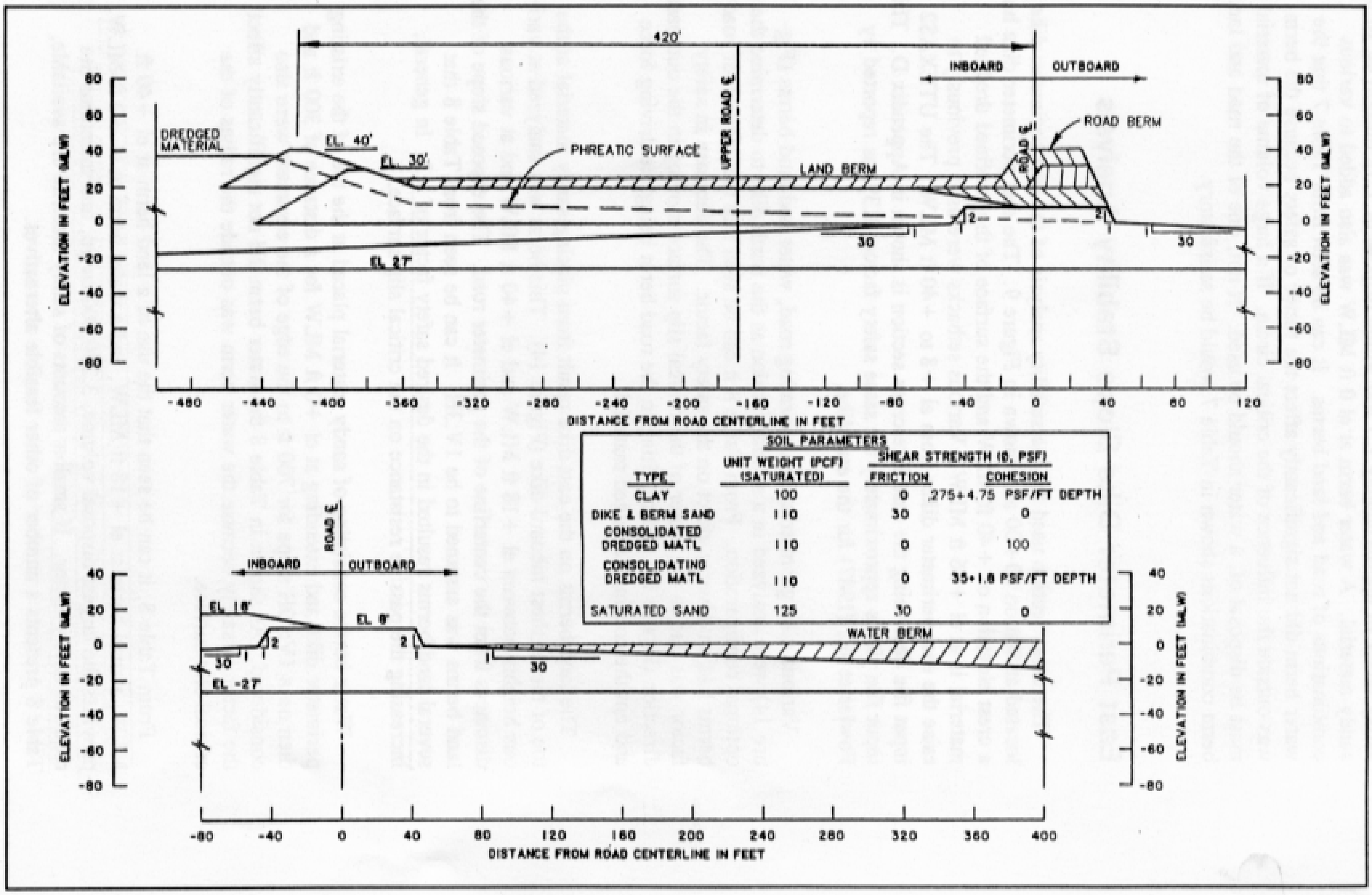
Do we need more work to... place sand to maximize total capacity of Craney Island?" ie maximize Safety Factor.

The first dike configurations considered the use of road berms. Road berm elevations of +18, +30 and +40 were considered (Figure 13) and the resulting factors of safety are shown in Table 7. It can be seen from Table 7 that all three road berms had a safety factor greater than 1.3 and the stability increased with the height of the road berm. The increase in safety factor is due to the road berm acting on the passive side of the critical slip surface.

Table 7
Safety Factors and Volumes of North Dike Berms

Road Berm Elevation (ft)	Land Berm Elevation (ft)	Water Berm Elevation (ft)	Critical Circle Coordinates				
			X (ft)	Y (ft)	Radius (ft)	Factor of Safety	Volume x 10^6 (cu yd)
+18			-127.5	702.5	792.5	1.41	0.185
+30			-105.5	801.5	891.5	1.46	0.521
+40			-47.5	757	847	1.48	1.016
+30	+20		-105	793.5	883.5	1.42	0.654
+30	+22		-104	788	878	1.38	0.795
+40	+22		-50.5	719	809	1.38	1.211
+40	+24		-55	699.5	789.5	1.32	1.320
+30	+22	+00	-113.5	739.5	829.5	1.42	1.739
+30	+24	+00	-112.5	733	823	1.38	1.887
+40	+22	+00	-50.5	719	809	1.38	2.155
+40	+24	+00	-55	699.5	789.5	1.32	2.264

Land berms were added in 2 ft increments from el +20 ft MLW to the road berms at elevations of +30 and +40 ft MLW. It can be seen from Table 7 that a road berm at el +40 and a land berm at el +24 yielded a



SOIL PARAMETERS

TYPE	UNIT WEIGHT (PCF) (SATURATED)	SHEAR STRENGTH (Ø, PSF) FRICTION	SHEAR STRENGTH (Ø, PSF) COHESION
CLAY	100	0	.275+4.75 PSF/FT DEPTH
DIKE & BERM SAND	110	30	0
CONSOLIDATED DREDGED MATL	110	0	100
CONSOLIDATING DREDGED MATL	110	0	35+1.8 PSF/FT DEPTH
SATURATED SAND	125	30	0

Figure 13. North perimeter dike cross-section showing relation between road and land berms

safety factor of approximately 1.3 and would dispose of 1.32 million cu yd of sandy material. A water berm at el 0 ft MLW was also added to various combinations of road and land berms. It can be seen from Table 7 that the water berm did not significantly affect the factor of safety because the berm was outside the influence of the critical circle. If a large volume of material must be disposal of, a water should be used. If not, one of the road and land berm combinations shown in Table 7 would be satisfactory.

East Perimeter Dike Slope Stability Analysis

The cross section used for the stability analysis of the east perimeter dike is located at Station 80+00 and shown in Figure 9. The east perimeter dike has a crest elevation of +40 ft MLW and the surface of the confined dredged material is at el +36 ft MLW. Various setbacks were used previously to raise the east perimeter dikes from el +8 to +40 ft MLW. The UTEXAS2 input file describing the east dike cross section is shown in Appendix D. This input file yields approximately the same safety factor, 1.39, as reported by Fowler et al., (1987) for the east dike.

Various dike geometries incorporating road, water and land berms (Figure 14) were analyzed in a similar fashion as the north dike to determine the optional configuration. From Table 8 it can be seen that the addition of road berms had an adverse effect on the safety factor. The decrease in safety factor was due to the center of the critical slip surface moving in the outboard direction (Figure 14) and resulting in the road berm being the driving force and not the confined dredged material.

The land berms on the east dike result from placing sandy material at the toe of the furthest inboard dike (Figure 14). This berm was analyzed at various heights between el +18 ft MLW and el +40 ft MLW and at various distances from the centerline of the perimeter road. The exposed slope of the land berms was assumed to be 1V:3H. It can be seen from Table 8 that several land berms resulted in the desired safety factor of 1.3. In general, increasing the passive resistance on the critical slip surface.

Water berms consisting of sandy material placed at the toe of the existing perimeter dike and extending at el +0 ft MLW for a distance of 300 ft and then on a 1V:70H slope for 700 ft to the edge of the easement were also considered. As shown in Table 8 the water berm did not significantly affect the factor of safety because the water berm was outside the radius of the critical slip surface.

From Table 8, it can be seen that the use of a land berm at el +40 ft MLW, a road berm at el +18 ft MLW, and a water berm at el +0 ft MLW, provides the largest disposal volume, 3,250,000 cu yd, and maintains the required safety factor. If smaller amounts of sandy material are available, Table 8 presents a number of other feasible alternatives.

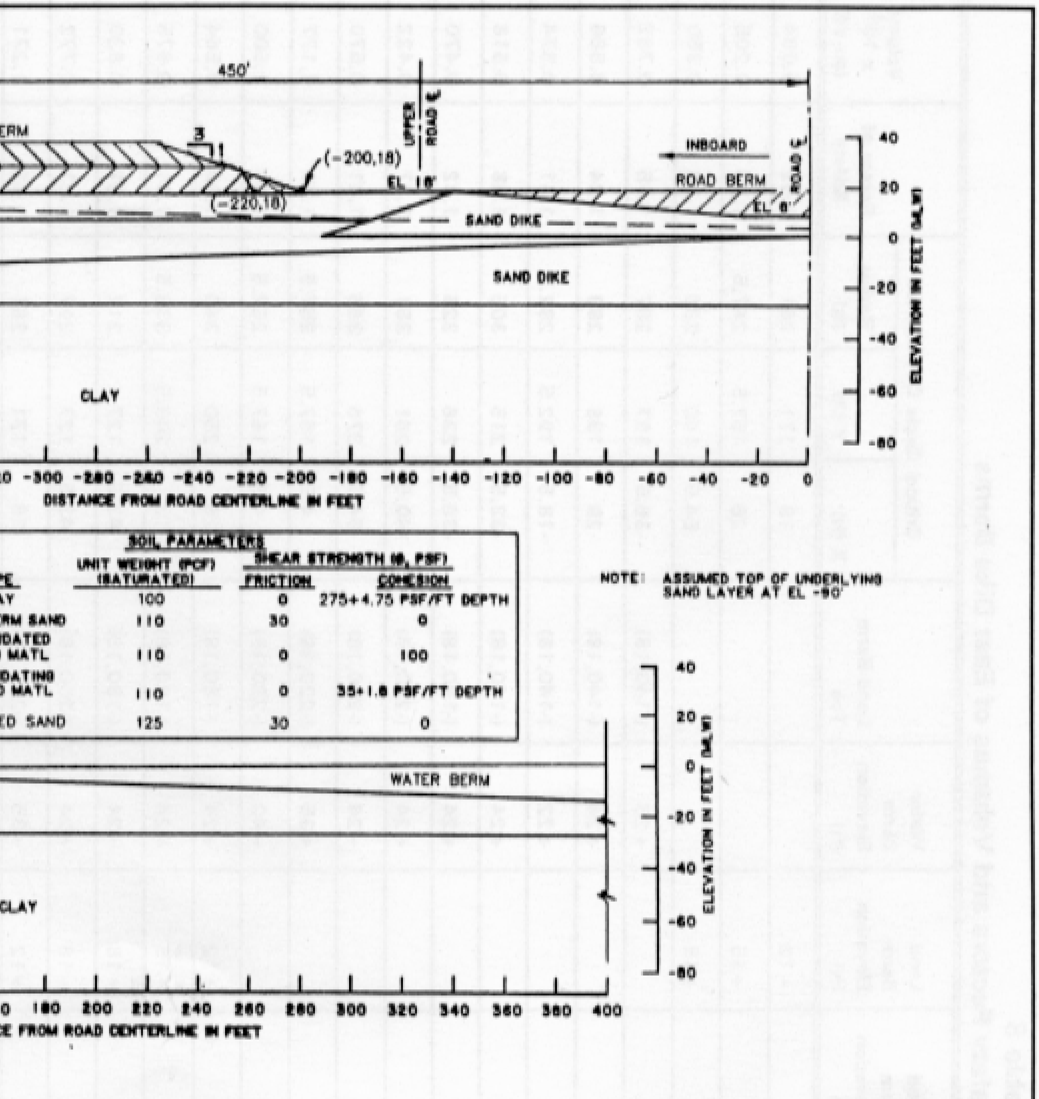


Figure 14. East perimeter dike cross-section showing relation between road, land, and water berms

Table 8
Safety Factors and Volumes of East Dike Berms

Road Berm Elevation (ft)	Land Berm Elevation (ft)	Water Berm Elevation (ft)	Land Berm Toe	Critical Circle Coordinates X (ft)	Y (ft)	Radius (ft)	Factor of Safety	Volume x 10^6 (cu yd)
	+12			16	171	261	1.42	0.094
	+15			26	157.5	247.5	1.35	0.205
	+18			54.5	140	230	1.12	0.350
		+26	(-140,18)	-36.5	197	287	1.15	0.762
		+24	(-140,18)	-29	198	288	1.24	0.566
		+22	(-140,18)	-18.5	192.5	282.5	1.31	0.374
		+24	(-160,18)	-33.5	215	305	1.28	0.518
		+24	(-180,18)	-36.5	236	326	1.32	0.470
		+24	(-200,18)	-40.5	261	351	1.37	0.422
		+26	(-200,18)	-54.5	276	366	1.31	0.570
		+35	(-220,18)	4.5	167.5	257.5	1.44	1.177
		+40	(-220,18)	4.5	167.5	257.5	1.44	1.500
	+12	+24	(-180,18)	-25	250	340	1.33	0.564
	+15	+24	(-180,18)	-13	249.5	339.5	1.31	0.675
	+18	+24	(-180,18)	43.5	127	217	1.21	0.820
	+18	+24	(-200,18)	43.5	127	217	1.21	0.772
	+12	+35	(-220,18)	16	171	261	1.42	1.271
	+15	+35	(-220,18)	27	159	249	1.35	1.382
	+18	+35	(-220,18)	44	127.5	217.5	1.21	1.527
	+15	+40	(-220,18)	27	159	249	1.35	1.705
	+18	+40	(-220,18)	44	126	216	1.21	1.850
+00				-18.5	128.5	218.5	1.63	1.400
+00	+15	+35	(-220,18)	4.5	127	217	1.55	2.782
+00	+18	+35	(-220,18)	20.5	96	170	1.38	2.927
+00	+15	+40	(-220,18)	4.5	127	217	1.55	3.105
+00	+18	+40	(-220,18)	-20.5	95	169	1.38	3.250

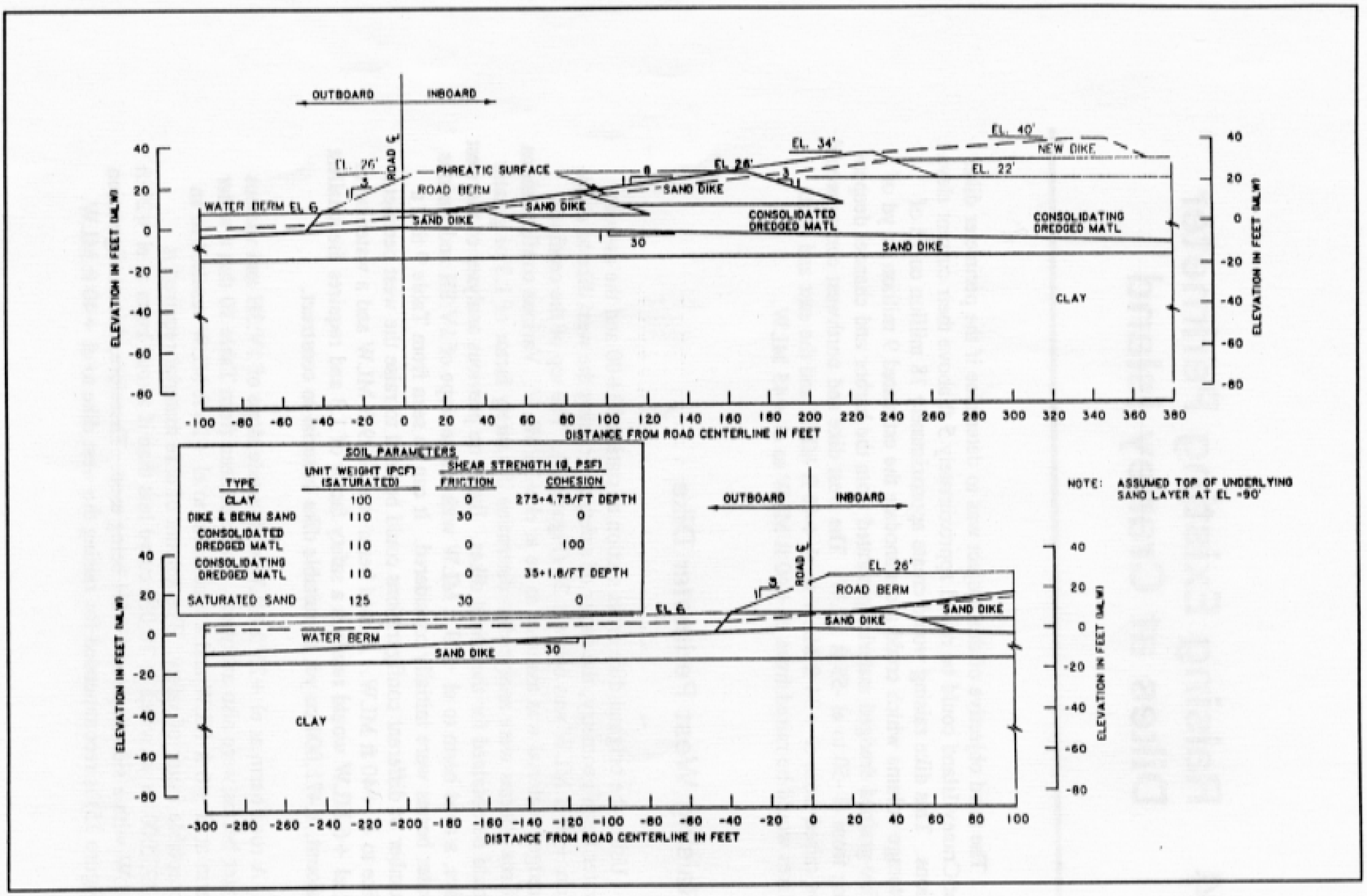
4 Raising Existing Perimeter Dikes at Craney Island

The third objective of this project was to determine if the perimeter dikes at Craney Island could be raised approximately 5 ft above their current elevations. This dike raising would create approximately 18 million cu yd of storage volume which could accommodate the estimated 9 million cu yd of fine-grained dredged material generated from the harbor and channel deepening from el -50 to el -55 ft MLW. The west dike and northwest corner would be raised from el +34 ft MLW to el +40 ft MLW and the east and north dikes would be raised from el +40 ft MLW to el +45 MLW.

Raising West Perimeter Dike

Using the original dike cross section at station 80+00 and the as-built water berm geometry, the factor of safety for raising the west dike to elevation +40 ft MLW was below 1.20 (Figure 15). The top of the confined dredged material was assumed to be at el +36 MLW. Various configurations of road berms were analyzed to determine if a safety factor of 1.3 or greater could be obtained for the raised dikes. Based on previous analyses of the west dike, a road berm to el +29 ft MLW with a side slope of 1V:8H and various water berms were initially considered. It can be seen from Table 9 that a number of different configurations could be used to raise the west perimeter dike to el +40 ft MLW. A road berm at el +29 ft MLW and a water berm at el +6 MLW would result in a safety factor of 1.3 and requires the smallest amount, 1,471,000 cu yd, of suitable dike material to construct.

A road berm at el +26 ft MLW with a side slope of 1V:3H and various water berms were also analyzed. It can be seen from Table 10 that a water berm at el +6 ft MLW and a road berm to el +26 ft MLW resulted in an acceptable factor of safety. The amount of dike material required is 1,393,000 cu yd which is 78,000 cu yd less than if a road berm at el +29 ft MLW with a side slope of 1V:8H being used. Therefore, this configuration (Figure 15) is recommended for raising the west dike to el +40 ft MLW.



SOIL PARAMETERS

TYPE	UNIT WEIGHT (PCF) (SATURATED)	SHEAR STRENGTH (S, PSF) FRICTION	COHESION
CLAY	100	0	275+4.75/FT DEPTH
DIKE & BERM SAND	110	30	0
CONSOLIDATED DREDGED MATL	110	0	100
CONSOLIDATING DREDGED MATL	110	0	35+1.8/FT DEPTH
SATURATED SAND	125	30	0

Figure 15. West perimeter dike cross-section raised to elevation +40 ft MLW

Table 9
Raising West Perimeter Dike to El +40 ft MLW using 1V:8H Side Slope

Road Berm Elevation (ft)	Water Berm Elevation (ft)	Water Berm Toe	Critical Circle Coordinates X (ft)	Critical Circle Coordinates Y (ft)	Critical Circle Coordinates Radius (ft)	Factor of Safety	Berm Volume x 10^6 (cu yd)
+29	+4	(-730,0)	63	371	444	1.26	1.011
+29	+6	(-730,0)	78	342.5	412	1.28	1.471
+29	+8	(-730,0)	-87	324.5	392.5	1.38	1.742
+29	+10	(-730,0)	69.5	344.5	419	1.64	2.001
	+14	(-730,0)	189.5	171	209.5	1.30	2.563
	+16	(-730,0)	190	168.5	207	1.38	3.119
	+18	(-730,0)	199	157.5	193	1.51	3.674
	+20	(-730,0)	220	129.5	159	1.56	4.229
	+26	(-1100,-3.5)	-903	106.5	155.5	1.78	11.947
	+27	(-1100,-3.5)	-901	105.5	156	1.70	12.359
	+28	(-1100,-3.5)	-894.5	112	165.5	1.63	12.773
	+30	(-1100,-3.5)	-891	109.5	165.5	1.51	13.611
	+34	(-1100,-3.5)	-894	130.5	192.5	1.35	15.323

Table 10
Raising West Perimeter Dike to El +40 ft MLW Using 1V:3H Slope

Road Berm Elevation (ft)	Water Berm Elevation (ft)	Critical Circle Coordinates X (ft)	Critical Circle Coordinates Y (ft)	Critical Circle Coordinates Radius (ft)	Factor of Safety	Dike Material Required (cu yd) x10^6
+26	+4	55	373	450	1.29	0.941
+26	+6	66	359	433	1.32	1.393
+26	+8	71	347	420	1.43	1.709
+26	+10	75	353	422	1.59	1.965
	+14	189	177	214	1.25	2.517
	+16	190	170	209	1.33	3.123
	+18	198	158	194	1.49	3.742
	+20	220	131	160	1.51	4.360

Raising Northwest Corner Perimeter Dike

Using survey data provided by NAO, a northwest corner dike cross section was analyzed which included the as-built geometry of the water placed at the toe of the perimeter dike. Figure 16 shows the configuration of the northwest dike with the elevation increased to el +40 ft MLW and the confined dredged material at el +36 ft MLW. The factor of safety for this configuration was 1.46 and thus no berms are required. However, it can be seen from Table 11 that the use of stabilizing berms on the west and north sides will not adversely affect the stability of the northwest corner when raised to el +40 ft MLW. It is interesting to note that the use of road, land and water berms to elevation +26 ft MLW resulted in a factor of safety of 0.94, in the previous section on stabilizing the perimeter dikes. (see paragraph 22). Comparing the critical circle centers in Tables 6 and 11, it can be seen that raising the perimeter dike to el +40 ft MLW and using road, land and water berms to elevation +26 ft MLW moved the critical circle center from 780.5 ft to the left of the road centerline to 391 ft to the right of the centerline. This forced the critical circle center into the consolidating dredged material resulting in the road, land and water berms supplementing the resisting force. If berm configurations selected for the west and north sides are different than those analyzed, additional analyses should be conducted to verify an adequate safety factor.

Table 11
Raising Northwest Perimeter Dike to El +40 ft MLW

Road Berm Elevation (ft)	Land Berm Elevation (ft)	Water Berm Elevation (ft)	Critical Circle Coordinates			Factor of Safety
			X (ft)	Y (ft)	Radius (ft)	
--	--	--	2.5	1098.5	1188.5	1.46
+15	--	+15	364.5	92	148	1.67
+26	+26	+26	391	60.5	110.5	1.84
+34	+34	+34	122	625	715	1.56

Raising North Perimeter Dike

Raising the north perimeter dike to el +45 ft MLW proved to be the most difficult. Although several configurations yielded a factor of safety of 1.30 or greater, most of these configurations could not be constructed easily due to the irregularly shaped berms required for stability. The only configuration which presented a suitable geometry consisted of constructing a water berm in the easement area at an elevation of +8 ft MLW (Figure 17). The water berm would extend horizontally from the toe of the dike at el +0 ft MLW for 300 ft, then fall at a slope of 1V:70H for 700 ft to the edge of the easement.

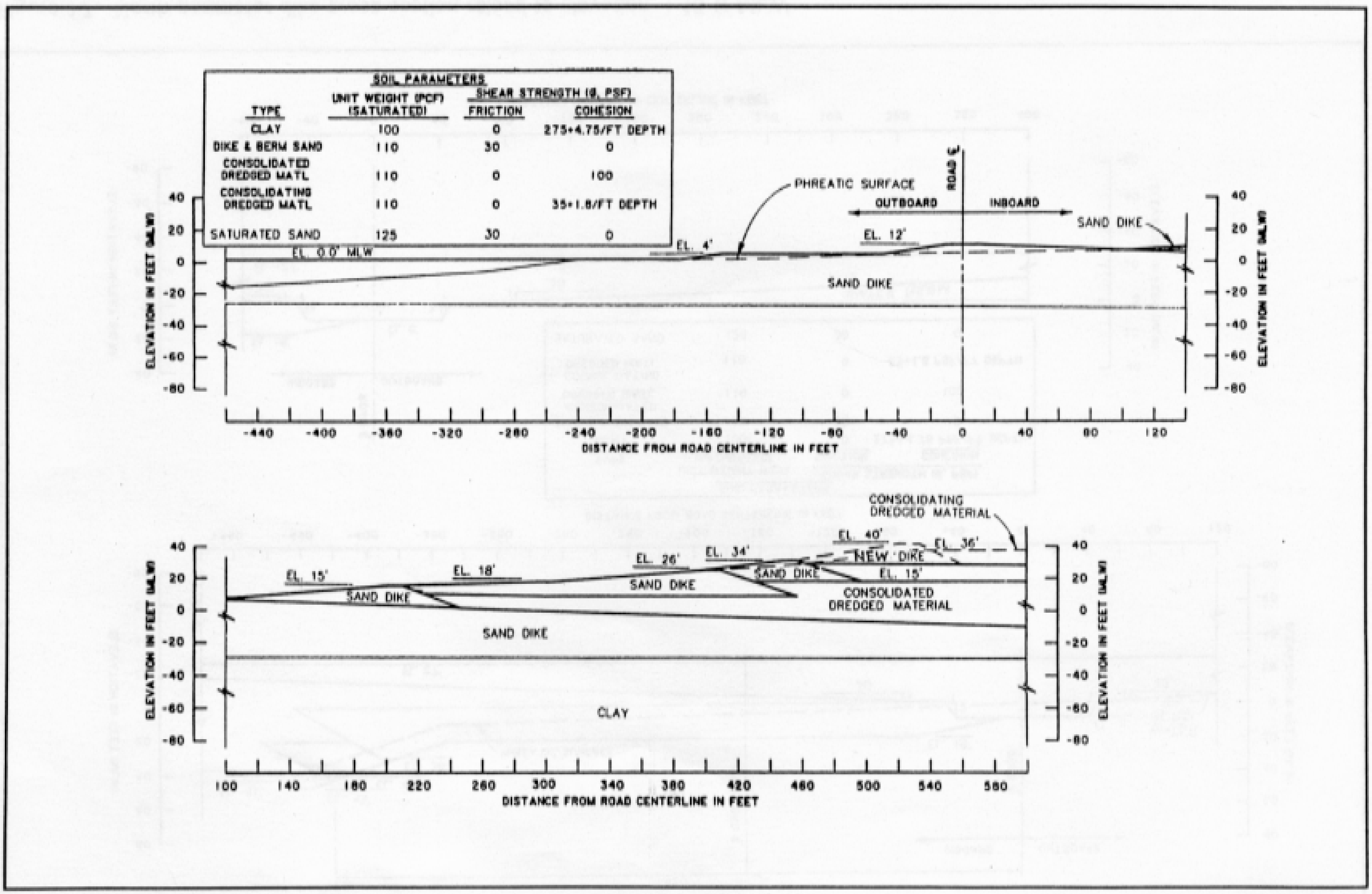


Figure 16. Northwest corner perimeter dike cross-section raised to elevation +40 ft MLW

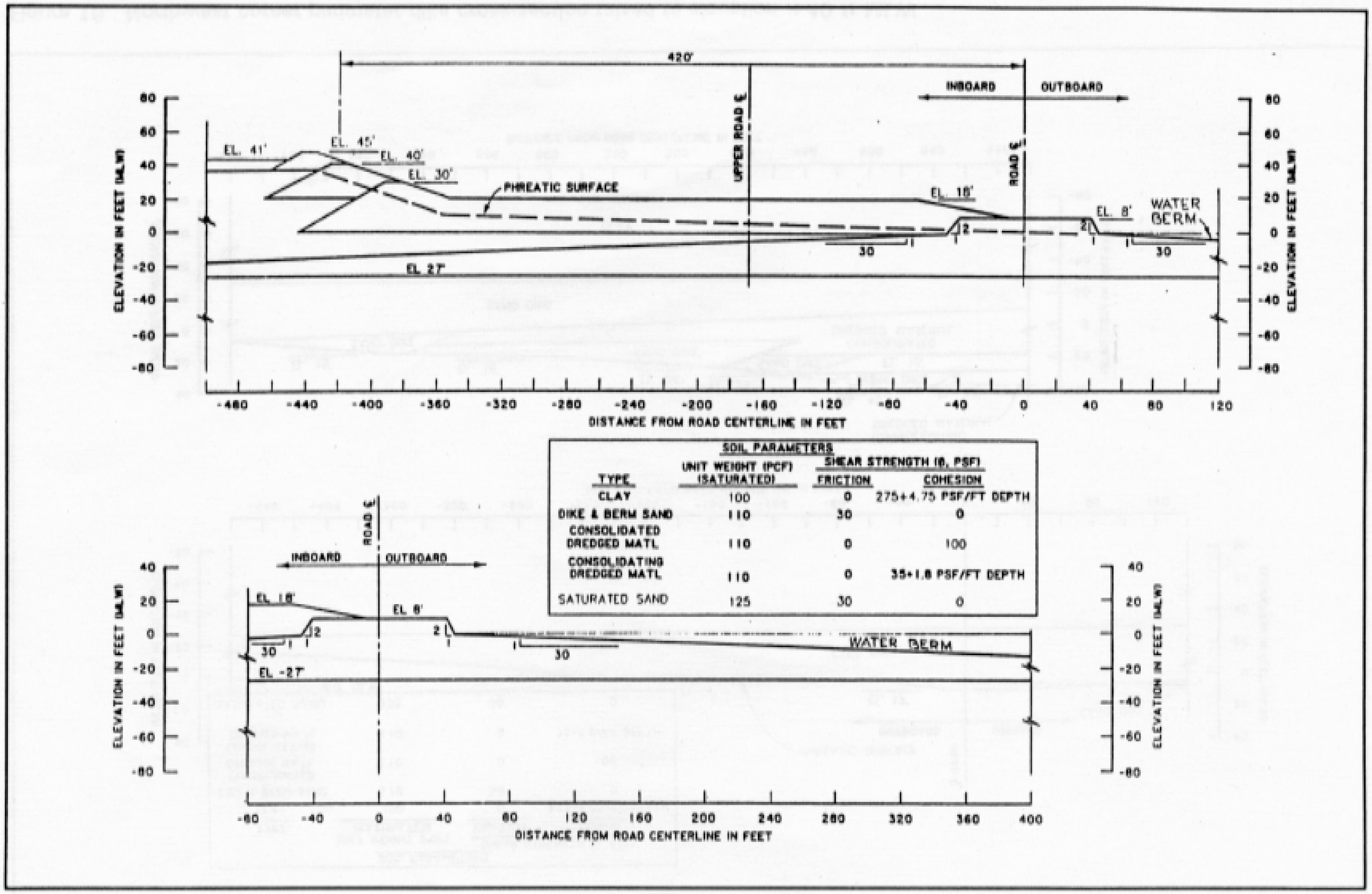


Figure 17. North perimeter dike cross-section raised to elevation +45 ft MLW

The safety factors and required dike material for the other geometries considered for the north dike are shown in Table 12. The road berm extension shown in Table 12 consists of placing sandy material on top of the water berm for a particular distance from the road centerline. As shown, a number of configurations provide an adequate factor of safety. However, a water berm of el +8 ft MLW is recommended because it provides one of the largest factors of safety and requires the least amount of dike material.

How much? Can't find this alt in table 12.

Raising East Perimeter Dike

Stability analyses revealed that the east dike could be raised to el +45 ft MLW (Figure 18) without using stability berms. The factor of safety for this configuration is 1.43 which is slightly higher than the pre-existing factor of safety of 1.39. This is due to the critical circle center moving approximately 2 ft outboard of the road centerline and thus the new dike material does not influence the critical circle center.

A road berm at el +15 ft MLW, a land berm at el +35 ft MLW, and a water berm at el +0 ft MLW were recommended in the previous section to stabilize the dike and dispose of 2,782,000 cu yd of sandy material. Raising the east dike to el +45 ft MLW using these berms results in a suitable safety factor of 1.38 (Table 13) and a disposal of 3,370,000 cu yd of sandy material. Therefore, this configuration is acceptable for both stabilizing and raising the east dike.

Raising Cross Dikes

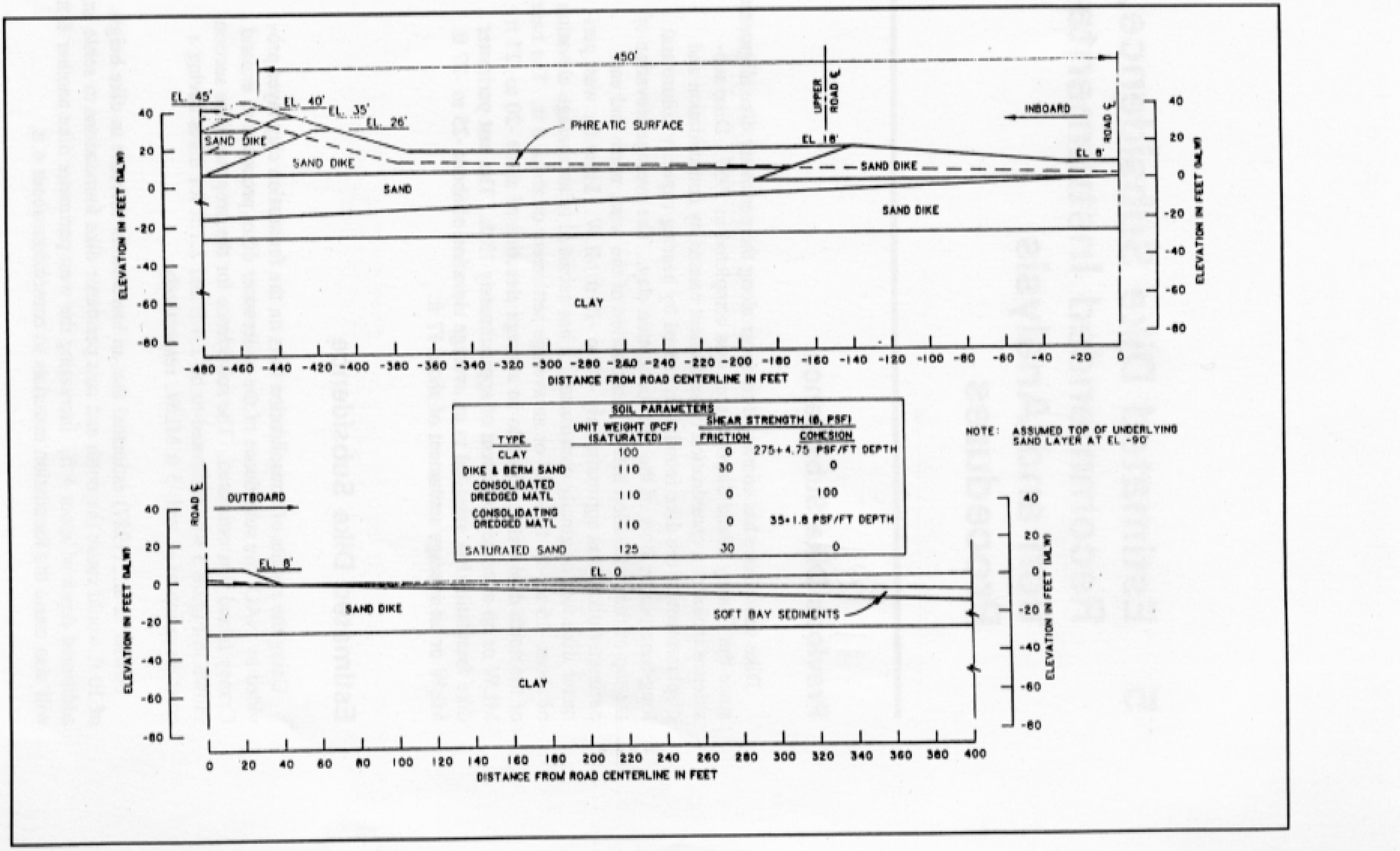
If the existing perimeter dikes and confined dredged material are raised, the two cross dikes will also require raising in order to maintain the Craney Island dredged fill management plan currently being used. The cross dikes were constructed using a geotextile and are currently "floating" on the confined dredged material. Therefore, an extensive stability analysis of the cross dikes should be performed to determine the feasibility of raising these dikes. The stability analysis should use the previous slides in the cross dikes to back calculate the shear strength of the dredged material and the mobilized strength of the geotextile. Raising the cross dikes from el +30 ft MLW to el +36 ft MLW will require approximately 1.05 million cu yd of sandy dike material. This estimate is based on the existing triangular cross section and side slopes of 1V:8H. The incremental raising of the cross dikes to el +36 ft MLW will require careful monitoring to insure that the material placement does not exceed el +36 ft MLW.

Table 12
Raising North Perimeter Dike to El +45 ft MLW

Road Berm Elevation	Road Berm Extension	Water Berm Elevation	Land Berm Elevation	Critical Circle Coordinates X (ft)	Y (ft)	Radius (ft)	Factor of Safety	Dike Material (cu yd x10^6)
+18				-146	689.5	779.5	1.27	0.271
+30				-124.5	790	880	1.32	0.606
+40				-100.5	902.5	992.5	1.33	1.101
+30		+00		-134.5	740	830	1.36	1.023
+40		+00		-110.5	849.5	939.5	1.38	1.508
				-235.5	378	468	1.56	1.283
+8	100			-153.5	661	751	1.26	0.247
+8	200			-177	852.5	942.5	1.39	0.542
+40			+22	-102	877	967	1.27	1.348
+22	200		+22	-2.5	1060.5	1150.5	1.57	1.705
+20	200		+20	-54	1187	1277	1.47	1.470
+18	200		+18	-60.5	1166	1256	1.54	1.236

Table 13
Raising East Perimeter Dike to El +45 ft MLW

Road Berm Elevation (ft)	Land Berm Extension (ft)	Land Berm Toe	Water Berm Elevation (ft)	Critical Circle Coordinates X (ft)	Y (ft)	Radius (ft)	Factor of Safety	Dike Material Required (cu yd x10^6)
				4.5	169	259	1.43	.123
+15	+35	(-220,18)		26.5	161	251	1.34	1.505
+15	+40	(-220,18)		48	166	256	1.23	1.828
+15	+35	(-220,18)	+00	11.5	139	229	1.47	2.905
+18	+14	(-220,18)	+00	20.5	95	169	1.38	3.370



SOIL PARAMETERS

TYPE	UNIT WEIGHT (PCF) (SATURATED)	SHEAR STRENGTH (θ, PSF) FRICTION	COHESION
CLAY	100	0	275+4.75 PSF/FT DEPTH
DIKE & BERM SAND	110	30	0
CONSOLIDATED DREDGED MATL	110	0	100
CONSOLIDATING DREDGED MATL	110	0	35+1.8 PSF/FT DEPTH
SATURATED SAND	125	30	0

Figure 18. East perimeter dike cross-section raised to elevation +45 ft MLW

5 Estimated Dike Subsidence, Recommended Instrumentation and Analysis Procedures

Previous Dike Subsidence

Dike subsidence has continued to occur along the perimeter dike alignment since the Craney Island disposal area was completed in 1957. Dike subsidence includes a combination of settlement caused by consolidation and displacement of the dike foundation caused by bearing capacity failure and long-term plastic flow of the soft foundation clay. The average elevation of the top of the foundation before construction of the west, north and east perimeter dikes was approximately -10 to -12 ft MLW. Since the west perimeter dike was originally constructed, it has subsided to an average elevation of about -15 to -17 ft MLW or an average settlement of about 6 ft. The base of the north dike has subsided to an average elevation of about -20 to -27 ft MLW or an average settlement of approximately 13 ft. The east perimeter dike foundation has subsided to an average elevation of about -25 to -27 ft MLW or an average settlement of about 17 ft.

Estimated Dike Subsidence

Using the results of consolidation tests on the foundation clay layer provided by NAO, the subsidence of the underwater dikes proposed to expand Craney Island was estimated. The subsidence for the proposed dike section shown in Figure 3 was estimated to be 2.4 ft and 2.1 ft for dikes having a crest elevation of -2 and -5 ft MLW, respectively.

Fowler et al., (1987) estimated that an incremental increase in dike height of 10 ft would cause the north and east perimeter dike foundations to settle an additional depth of about 4 ft. Increasing the west perimeter dike another 8 ft will also cause the foundation materials to consolidate about 4 ft.

Using the subsidence estimates presented by Fowler et al., (1987), and consolidation data provided by NAO, the subsidence due to raising the west dike 6 ft to el +40 ft MLW will probably be about 3 ft. Raising the north and east dikes 5 ft to el +45 will probably result in approximately 2 ft of subsidence. The subsidence due to the placement of land and road berms was not estimated because the final configuration were not known. However, using the information provided above, the subsidence can be easily estimated.

Use of Prefabricated Strip Drains

The use of prefabricated strip drains to increase the rate of consolidation has been considered. Because the soft materials in the dike foundation extend to a depth of about 90 ft, it was decided that the use of vertical strip drains installed through the dike may not be cost effective. However, the installation of strip drains through the perimeter dike and into the confined dredged material and/or the foundation clay may be economically feasible. It is anticipated that the strip drains would be installed in a vertical and horizontal fan-shaped pattern at certain points along the perimeter dike. The drains would reduce the pore water pressures in the dike, the dredged material and the foundation clay. The dredged material adjacent to the dike could then be slowly surcharged to increase the shear strength of this material. The increase in strength should force the critical slip surface farther out into the disposal area and facilitate the raising of the perimeter dikes.

Recommended Instrumentation

It is recommended that piezometers be installed at the four stations studied by Fowler et al., (1987), and shown in Table 14. The piezometers will greatly increase the understanding of the behavior of the dredged material, the perimeter dike and the foundation clay layer. The piezometers will measure the changes in pore water pressure in these materials and will indicate the rate at which consolidation is occurring in the cohesive materials. The piezometers will also allow NAO to monitor the pore water pressures and thus the stability of the dikes during construction processes.

Table 14
Recommended Locations of Piezometers at Craney Island

Dike	Station	Piezometer Location MLW Elevation (ft)				
East	80+00	-5[1],	-40,	-55,	-70	
North	45+00	+5,	-30,	-50,	-70	
Northwest Corner	104+00	-5[1],	-30,	-45,	-60	
West	80+00	+5[1],	-25,	-40,	-55,	-70

[1] Piezometer should be located in "consolidated dredged material" underlying setback dikes.

One slope indicator should be installed at each of the four locations shown in Table 14. The slope indicator should be installed at approximately el -100 ft MLW or about 5 to 10 ft into the dense sand foundation. The slope indicators will help determine if the foundation material is consolidating or if it is spreading laterally and the location of the spreading.

If the elevations of the piezometers can be surveyed accurately, it is recommended that settlement rods not be installed. However, if the piezometers can not be accurately surveyed, settlement rods should be installed at the stations shown in Table 14. These settlement rods may be cast-in-place in concrete at a depth corresponding to the top of the foundation clay. The rods should be placed in a safe location and in an orientation that facilitates surveying.

During the drilling and installation of the piezometers and slope indicators, in situ vane shear tests should be performed every 5 to 10 ft of depth in the foundation clay. A vane similar to the one used in the previous testing at Craney Island should be used. However, at a number of depths it is recommended that two tests, one using the same vane as used previously and the other with a larger vane, be conducted to investigate the anisotropy of the marine clay.

It is also recommended that cone penetration tests (CPT) be performed near the borings where the vane shear tests are conducted. The continuous sounding provided by the CPT will help clarify the scatter that has been observed in the shear strength profiles obtained from vane shear and triaxial tests. Using the CPT and neighboring vane shear test results, cone factors relating cone resistance to undrained shear strength can be developed. Once the cone factor has been developed for the materials at Craney Island, the CPT can be used to estimate the undrained shear strength in future investigations.

Recommended Stability Analysis

The confined dredged material and the foundation clay at Craney Island are continually undergoing consolidation and thus undergoing an increase in effective stress and shear strength. Currently, total stress analyses are being used to assess the stability of the perimeter dikes at Craney Island. The total stress analysis uses a constant value of undrained shear strength, Su, which corresponds to a particular value of effective stress. Since the effective stress is increasing as consolidation progresses, it appears the use of a previously determined value of Su is underestimating the strength of the confined dredged material and foundation clay. The use of Su and a total stress analysis would be satisfactory if, no consolidation was occurring or if new values of Su were constantly being obtained as consolidation progressed.

An effective stress slope stability analysis is recommended to quantify the effects of excess pore water pressures and their subsequent dissipation on the stability of the perimeter dikes. The effective stress analysis can model the increase in shear strength as consolidation occurs and also the increase in pore pressure due to dike construction. The major difficulty in performing effective stress slope stability analyses is accurately determining the pore water pressures. If the recommended piezometers are installed, it is anticipated that the pore pressures at the four cross sections studied by Fowler et al., (1987), can be estimated satisfactorily. The effective stress stability analysis can be performed using the microcomputer program UTEXAS2.

It is also recommended that a three dimensional representation of the subsurface conditions at Craney Island be created using a microcomputer CAD package such as AUTOCAD. This would facilitate the presentation of the numerous boring logs obtained from the area and the interpretation of the numerous field and laboratory test results. The three-dimensional display will help locate additional cross-sections which should be considered in slope stability analyses. The use of a microcomputer CAD package will also allow the boring and test results to be easily updated.

6 Conclusions and Recommendations

Expansion of Craney Island

Alternatives for disposing of the 12 million cu yd of new work dredged material from the proposed deepening of the Norfolk Harbor and the associated shipping channels were investigated. NAO estimated 3 million cu yd of the new work dredged material would consist of sandy material which is suitable for dike construction. As a result, alternatives for expanding Craney Island using underwater dikes, and stabilization and raising of the existing perimeter dikes using the sandy material were investigated and reported herein.

It was concluded that Craney Island could be expanded using underwater dikes located along the six alignments (Figure 2) proposed by Goforth (1986). However, only configurations D, E and F would require less than 3 million cu yd of sandy material (Table 1) for dike construction. Configuration E provides the largest storage capacity of these configurations and is recommended. If additional dike construction material becomes available, one of the configurations utilizing the north side of Craney Island, e.g. A, B or C, is recommended due to the larger water depths and increased storage capacity.

Stabilization of Existing Craney Island Perimeter Dikes

If the 9 million cu yd of cohesive new work dredged materials is ocean dumped, the possibility of stabilizing the existing perimeter dikes with the remaining 3 million cu yd of sandy dredged material appears feasible. Various combinations of road berms, land berms and water berms were considered for each side of Craney Island. Tables 3 through 8 contain the geometry of the berms, the critical slip circle, the factor of safety and the volume of sandy dredged material required for the West, Northwest, North and East dikes. It can be seen from these Tables that a number of different dike configurations are suitable for the disposal of the 3 million cu yd while maintaining a safety factor of 1.3. The east dike has the highest factor of safety initially and as a result, it is recommended that most of the new sandy material be deposited there using one of the geometries presented in Table 8 that has a safety factor greater than 1.3. Table 15 summarizes the recommended geometries for stabilizing each perimeter dike. If each of the recommended geometries are used, approximately 5.3 X 10^6 cu yd of dredged material can be disposal of.

Table 15
Recommended Geometries for Stabilization of Each Perimeter Dike

Dike	Road Berm Elevation	Land Berm Elevation	Water Berm Elevation	Factor of Safety	Dike Material Required (cu yd) X 10^6
West	+26	--	--	1.27	0.698
Northwest	+26	--	--	1.41	--
North	+40	+24	--	1.32	1.320
East	+18	+40	+00	1.38	3.250

Raising Existing Craney Island Perimeter Dikes

It was concluded that it is technically feasible to raise the west perimeter dike to el +40 ft MLW and the confined dredged material to el +36 ft MLW if a road berm at el +26 ft MLW and a water berm at el +6 MLW are also constructed (Table 10). It was also concluded that the north and east dikes could be raised to el +45 ft MLW and the confined dredged material to el +41 ft MLW with satisfactory factors of safety. The north dike proved to be the most difficult to raise; however, the use of a water berm at el +8 ft MLW (Table 12) would result in an adequate factor of safety. The east dike could be raised without using a stability berm. It can be seen from Table 13 that various road, land and water berms could be used on east dike. The north-west corner can also be raised to elevation +40 ft MLW using the berm configurations recommended for the west and north dikes while maintaining a satisfactory factor of safety (Table 11). The proposed dike raising would result in 18 million cu yd of storage capacity. The recommended geometries for raising the perimeter dikes are summarized in Table 16.

Table 16
Recommended Geometries for Raising Craney Island Perimeter Dikes

Dike	Road Berm Elevation	Land Berm Elevation	Water Berm Elevation	Factor of Safety	Dike Material Required (cu yd) X 10^6
West	+26	--	+6	1.27	0.698
Northwest	--	--	--	1.46	--
North	--	--	+8	1.56	1.283
East	--	--	--	1.43	0.123

Σ 2.1 MCY
CREATES 18 MCY
STORAGE CAPACITY

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Appendix A
Typical Input for Analysis of the West Perimeter Dike at Station 80+00 Using the UTEXAS2 Slope Stability Program

```
HEADING
WEST LEG AT STA 80 + 00 WITH WATER BERM
CRANEY ISLAND NORFOLK DISTRICT
BISHOP'S METHOD
PROFILE LINES

1  1  SOFT TO MED STIFF CLAY
-1000 -15
-450 -15
450  -15
1000 -15

2  5  ORIGINAL DIKE SAND
-450 -15
-44  .00
.00  .00
72.0 -2.5
450 -15

3  5  WATER BERM SAND
-1100 -3.5
-900 -3.2
-800 -1
-730 0
-44 0
```

4 2 MOIST EMBANKMENT SAND
-730 0
-700 0.5
-300 4.5
-200 5.0
-100 6.2
-60 8.0
-50 8.5
0 9.5

5 6 WATER
-1000 .00
-730 .00

6 2 MOIST EMBANKMENT SAND
-60 8.0
17 8
40 8
42.5 7.25

7 5 SATURATED EMBANKMENT SAND
-44 0
42.5 7.25
49 5
72 -2.5

8 3 CONSOLIDATED DREDGED MATERIAL
49 5
122 5.0

9 2 MOIST EMBANKMENT SAND
0 9.5
33 10
81 16
89 16
105 12.5

10 5 SATURATED EMBANKMENT SAND
42.5 7.25
105 12.5
107 10
122 5

11 3 CONSOLIDATED DREDGED MATERIAL
107 10
217 10

12 2 MOIST EMBANKMENT SAND
81 16
161 26
169 26
190 20

13 5 SATURATED EMBANKMENT SAND
105 12.5
190 20
200 17
217 10

14 3 CONSOLIDATED DREDGED MATERIAL
200 17
331 17
1000 17

15 2 MOIST EMBANKMENT SAND
161 26
285 34
295 34
307 30

16 5 SATURATED EMBANKMENT SAND
307 30
331 17

17 4 CONSOLIDATING DREDGED MATERIAL
307 30
1000 30

MATERIAL PROPERTIES
1 CLAY
100
LINEAR INCREASE WITH DEPTH
275 4.75
PIEZOMETRIC LINE
1
2 MOIST EMBANKMENT SAND
110
CONVENTIONAL SHEAR STRENGTH
.00 30
P L
1
3 CONSOLIDATED DREDGED MATERIAL
90
C
100 .00
P L
1

4 CONSOLIDATING DREDGED MATERIAL
90
L
35 1.8
P L
1
5 SATURATED EMBANKMENT SAND
125
C
0 30
P L
1
6 WATER
62.4
C
.00 .00
P L
1

PIEZOMETRIC LINE
1 62.4 PIEZOMETRIC LINE
-1000 .00
-44 .00
307 30
1000 30

ANALYSIS/COMPUTATION
CIRCULAR SEARCH
83.5 253.0 0.5 -90
TANGENT
-90
PROCEDURE
BISHOP'S METHOD

COMPUTE

Appendix B Typical Input for Analysis of the Northwest Corner at Station 104+00 Using the UTEXAS Slope Stability Program

HEADING
CRANEY ISLAND, NORFOLK DISTRICT
STATION 104+00 NORTHWEST LEG
BISHOP'S METHOD
PROFILE LINES

1 1 MEDIUM STIFF CLAY
-1000 -21
-550 -27
550 -27
1000 -10

2 6 INITIAL DIKE SAND
-1000 -21
-700 -19.5
-600 -19.5
-500 -18.4
-300 -6
-220 0
140 8
214 13
225 8
250 0
1000 -10

3 2 MOIST EMBANKMENT SAND
-220 0
-100 4
-50 4.5
0 11.2
200 15
210 15
214 13

4 3 CONSOLIDATED DREDGED MATERIAL
225 8
455 8
1000 8

5 2 MOIST EMBANKMENT SAND
210 15
272 17

6 6 SATURATED EMBANKMENT SAND
214 13
272 17
400 26
410 26
430 15
455 8

7 3 CONSOLIDATED DREDGED MATERIAL
430 15
495 15
1000 15

8 2 MOIST EMBANKMENT SAND
410 26
445 34
455 34
460 30

9 6 SATURATED EMBANKMENT SAND

410 30
1000 30

11 5 WATER
-1000 0
-220 0

MATERIAL PROPERTIES
1 MEDIUM STIFF CLAY
100
LINEAR INCREASE WITH DEPTH

```
220   5
PIEZOMETRIC LINE
1
2   MOIST EMBANKMENT SAND
110
CONVENTIONAL SHEAR STRENGTH
0   30
PIEZOMETRIC LINE
1
3   CONSOLIDATED DREDGED MATERIAL
90
LINEAR INCREASE WITH DEPTH
100  3.0
PIEZOMETRIC LINE
1
4   CONSOLIDATING DREDGED MATERIAL
90
LINEAR INCREASE WITH DEPTH
35   1.8
PIEZOMETRIC LINE
1
5   WATER
62.4
CONVENTION SHEAR STRENGTH
0   0
PIEZOMETRIC LINE
1
6   SATURATED EMBANKMENT SAND
125
CONVENTIONAL SHEAR STRENGTH
0   30
PIEZOMETRIC LINE
1
PIEZOMETRIC LINE DATA
1   62.4   PHREATIC LINE
-1000  0
-220   0
140    8
460   30
1000  30

ANALYSIS/COMP
C  S
-155   590   0.5   -90
TANGENT
-90
PROCEDURE
BISHOP'S METHOD

COMPUTE
```

Appendix C
Typical Input for Analysis of the North Perimeter Dike at Station 45+00 Using the UTEXAS2 Slope Stability Program

HEADING
CRANEY ISLAND, NORFOLK DISTRICT
STATION 45+00 NORTH LEG
BISHOP'S METHOD - FULL SETBACK
PROFILE LINES
1 1 MEDIUM STIFF CLAY
-1000 -10
-550 -27
550 -27
1000 -10

2 6 INITIAL DIKE SAND
-1000 -10
-580 -7
-44 0
-43 2
44 0
580 -7
1000 -10

3 2 MOIST EMBANKMENT SAND
-43 2
-40 8
40 8
44 0

4 3 CONSOLIDATED DREDGED MATERIAL
-453 0
-250 0

5 6 SATURATED EMBANKMENT SAND
-453 0
-415 20
-403 26
-350 10
-43 2

6 2 MOIST EMBANKMENT SAND
-403 26
-397 30
-387 30
-350 18
-70 18
-17 8

7 3 CONSOLIDATED DREDGED MATERIAL
-1000 20
-465 20
-415 20

8 6 SATURATED EMBANKMENT SAND
-465 20
-435 36
-403 26

9 2 MOIST EMBANKMENT SAND
-435 36
-425 40
-415 40
387 30

10 4 CONSOLIDATING DREDGED MATERIAL
-1000 36
-435 36

11 5 WATER
44 0
1000 0

MATERIAL PROPERTIES
1 MEDIUM STIFF CLAY
100
LINEAR INCREASE WITH DEPTH
220 5
PIEZOMETRIC LINE
1
2 MOIST EMBANKMENT SAND
110
CONVENTIONAL SHEAR STRENGTH
0 30

PIEZOMETRIC LINE
1
3 CONSOLIDATED DREDGED MATERIAL
90
LINEAR INCREASE WITH DEPTH
100 3.0
PIEZOMETRIC LINE
1
4 CONSOLIDATING DREDGED MATERIAL
90
LINEAR INCREASE WITH DEPTH
35 1.8
PIEZOMETRIC LINE
1
5 WATER
62.4
CONVENTIONAL SHEAR STRENGTH
0 0
PIEZOMETRIC LINE
1
6 SATURATED EMBANKMENT SAND
125
CONVENTIONAL SHEAR STRENGTH
0 30
PIEZOMETRIC LINE
1

Appendix D
Typical Input for Analysis of the East Perimeter Dike at Station 80 + 00 Using the UTEXAS2 Slope Stability Program

```
HEADING
CRANEY ISLAND, NORFOLK DISTRICT
STATION 80+00 EAST LEG
BISHOP'S METHOD - FULL 400 FT SETBACK
PROFILE LINES
1   1   SOFT TO MEDIUM STIFF CLAY
-1000 -10
-550  -25
550   -25
1000  -10

2   7   ORIGINAL UNDERLYING SAND DIKE
-550  -25
0     0
40    0
550   -25

3   5   VERY SOFT BAY BOTTOM SEDIMENTS
40    0
552   -8
1000  -10

4   6   WATER
40    0
1000  0

5   3   CONSOLIDATED DREDGED MATERIAL
-194  0
0     0
```

6 2 MOIST EMBANKMENT SAND
-171 8
-140 18
-20 8
20 8
40 0

7 7 SATURATED EMBANKMENT SAND
-171 8
40 0

8 3 CONSOLIDATED DREDGED MATERIAL
-480 5
-176 5

9 2 MOIST EMBANKMENT SAND
-421 25
-420 26
-410 26
-370 18
-140 18

PIEZOMETRIC LINE DATA
1 62.4 PHREATIC LINE
-1000 36
-435 36
-350 10
44 0
1000 0

ANALYSIS/COMP
CIRCULAR SEARCH
-150 597.5 0.5 -90
TANGENT
-90
PROCEDURE
BISHOP'S METHOD

COMPUTE

10 3 CONSOLIDATED DREDGED MATERIAL
-465 22
-430 22

11 7 SATURATED EMBANKMENT SAND
-480 5
-430 22
-421 25
370 15
-171 8

12 2 MOIST EMBANKMENT SAND
-450 31
-440 35
-430 35
-410 26

13 7 SATURATED EMBANKMENT SAND
-465 22
-452 30
-450 31
-421 25

14 3 CONSOLIDATED DREDGED MATERIAL
-1000 30
-488 30
-452 30

15 2 MOIST EMBANKMENT SAND
-474 36
-460 40
-450 40
-430 35

16 7 SATURATED EMBANKMENT SAND
-488 30
-474 36
-450 31

17 4 CONSOLIDATING DREDGED MATERIAL
-1000 36
-474 36

MATERIAL PROPERTIES
1 SOFT TO MEDIUM CLAY
100
LINEAR INCREASE WITH DEPTH
280 2.5
PIEZOMETER LINE
1
2 MOIST EMBANKMENT SAND
110
CONVENTIONAL SHEAR STRENGTH
0 30
PIEZOMETRIC LINE
1
3 CONSOLIDATED DREDGED MATERIAL
90
CONVENTIONAL SHEAR STRENGTH
200 20
PIEZOMETRIC LINE

1
4 CONSOLIDATING DREDGED MATERIAL
90
LINEAR INCREASE WITH DEPTH
200 1.8
PIEZOMETRIC LINE
1
5 VERY SOFT BAY BOTTOM SEDIMENTS
95
CONVENTIONAL SHEAR STRENGTH
50 0
PIEZOMETRIC LINE
1
6 WATER
62.4
CONVENTIONAL SHEAR STRENGTH
0 0
PIEZOMETRIC LINE
1
7 SATURATED EMBANKMENT SAND
125
CONVENTIONAL SHEAR STRENGTH
0 30
PIEZOMETRIC LINE
1

PIEZOMETRIC LINE DATA
1 62.4 PHREATIC SURFACE
-1000 36
-474 36
-370 15
40 0
1000 0

ANALYSIS/COMP
CIRCULAR SEARCH
4.5 167.5 0.5 -90
TANGENT
-90
PROCEDURE
BISHOP'S METHOD

COMPUTE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	August 1993	Final report

4. TITLE AND SUBTITLE
Disposal Alternatives for New Work Dredged Material, Deepening of Norfolk Harbor

5. FUNDING NUMBERS

6. AUTHOR(S)
Timothy D. Stark, George R. Briest

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Department of Civil Engineering
San Diego State University
San Diego, CA 92182

8. PERFORMING ORGANIZATION REPORT NUMBER
Miscellaneous Paper GL-93-15

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Engineer District, Norfolk
Norfolk, VA 23510-1096

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Available from National Technical Information Service 5285 Port Royal Road, Springfield, VA 22161

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approval for public release distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This publication describes the evaluation of various disposal alternatives for the estimated 12 million cu yd of maintenance and new work dredged material resulting from the proposed deepening of Norfolk Harbor from elevation -50 to -55 ft MLW. The U.S. Army Engineer District, Norfolk, Virginia estimated that 3 million cu yd of the dredged material will consist of sandy material which is suitable for dike construction. The remaining 9 million cu yd will probably consist of cohesive material and will require a disposal alternative. The disposal alternatives included 1.) expanding Craney Island using underwater dikes, 2.) stabilizing the existing perimeter dikes using berms constructed of suitable dike material, and 3.) raising the west perimeter dike from el +34 to el +40 ft MLW and raising the north and east perimeter dikes from el +40 to +45 ft MLW.

It was concluded that Craney Island could be expanded using underwater dikes located along the six alignments proposed by Goforth (1986). The underwater dikes could be constructed using the sandy dredged material and the 9 million cu yd of cohesive material would be contained by the underwater dikes.

(Continued)

14. SUBJECT TERMS

Consolidation	Dredging	Slope stability
Desiccation	Dredged material	Strip drains
Dike	Geotechnical	

15. NUMBER OF PAGES 69

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified		

13. ABSTRACT (Continued)

Extensive slope stability analyses of the perimeter dikes showed that a number of different combinations of water berms, road berms, and land berms are suitable for stabilizing the existing perimeter dikes. The berms would be constructed using the 3 million cu yd of sandy material while maintaining a safety factor of 1.3. In this alternative the 9 million cu yd of cohesive dredged material would be ocean dumped.

Extensive stability analyses also showed that the west perimeter dike could be raised from el +34 to el +40 using a road berm to el +26 ft and a water berm to el +6 ft MLW. As a result, the confined dredged material on the west side of Craney Island could be raised to el +36 ft MLW. It was also concluded that the north and east perimeter dikes could be raised from el +40 to el +45 ft MLW and the confined dredged material increased to el +41 ft MLW with satisfactory factors of safety. The dikes would be raised using the 3 million cu yd of sandy dredged material and the 9 million cu yd of cohesive dredged material would be deposited in Craney Island.