Case Study of Undrained Strength Stability Analysis for Dredged Material Placement Areas

Timothy D. Stark[1]; Hangseok Choi[2]; and Chulho Lee[3]

Abstract: This paper describes the stability of the west perimeter dike at the Craney Island Dredged Material Management Area (CIDMMA) using an undrained strength stability analysis. An undrained strength stability analysis expresses the undrained shear strength in terms of the effective overburden stress of the dredged material and the marine clay underlying the dike. An undrained strength stability analysis was used to evaluate the current stability of the west perimeter dike, the possibility of raising the perimeter dike, and the effect of undrained strength increase along with full consolidation by installing vertical strip drains on the current stability and the potential for raising the dike. Vertical strip drains would accelerate consolidation of the confined dredged material and underlying marine clay and thus produce an increase in undrained shear strength and dike stability. The analyses show that installation of vertical strip drains and full consolidation of the dredged material and underlying marine clay should allow the perimeter dike and dredged material to be raised and an increase in CIDMMA service life.

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Introduction

The U.S. Army Corps of Engineers is continually addressing the placement problem of fine-grained dredged material from navigable waterways. Increasing environmental concerns along with a decrease in the number of available placement areas have required the need to maximize utilization of existing dredged material containment areas. To evaluate the maximum long-term storage capacity of dredged material placement areas, the stability of perimeter dikes containing dredged materials should be properly assessed.

The Craney Island Dredged Material Management Area (CIDMMA) is a $10\ \text{km}^2$ site with a storage area of approximately $8.9\ \text{km}^2$. The CIDMMA is located near Norfolk, Va., in Portsmouth, Va. Planned in the early 1940s, construction of the CIDMMA began in August 1954 and was completed in January 1957. Craney Island is the long-term placement area for material dredged from the channels and ports in the Newport News/Hampton Roads area.

The original design was for an initial capacity of about $76,400,000\ \text{m}^3$ at an annual dredging rate of 3,100,000–$5,400,000\ \text{m}^3$. Therefore, the CIDMMA was designed for a service life of approximately 20 years (1957–1977) based on an annual dredging rate of $3,800,000\ \text{m}^3$. Continued dredging in the Norfolk channel and harbor has required the capacity of the CIDMMA to be increased through three major dike raising efforts. However, the dike setbacks used to prevent foundation instability have resulted in approximately $0.1–0.2\ \text{km}^2$ of lost storage capacity during each dike raising. After the third dike raising in 1992, the perimeter dikes were at their maximum height without inducing foundation instability (Fowler et al. 1987). However, if the undrained shear strength of the dredged material and underlying marine clay was increased as a result of consolidation, the perimeter dikes could be raised again. The time required for this consolidation would be substantial and thus would not alleviate the short-term storage problem.

Piezometers were installed in the perimeter dikes at Craney Island to investigate the pore-water pressures and degree of consolidation of the dredged material and underlying marine clay (Stark 1995). The piezometers revealed that large excess pore-water pressures existed in the dredged material and underlying marine clay. The excess pore-water pressure levels in February 1991 exceeded the ground surface elevation by 6.0–7.5 m in some locations. The dissipation of these excess pore-water pressures would result in substantial consolidation settlement of the perimeter dikes, which causes a significant increase in the undrained shear strength of these materials and probably allow the perimeter dikes to be substantially raised. This strength gain would also allow the perimeter dikes to be constructed to higher elevations without setbacks or underwater stability berms.

The purpose of this study is to evaluate the stability of the west perimeter dike using an undrained strength stability analysis. In addition, the effect of undrained strength increase along with full consolidation by installing vertical strip drains in the west perimeter dike on the stability and potential raising of the dike was investigated. Installation of vertical strip drains would accelerate consolidation of the marine clay underlying the west perimeter dike. Only the west perimeter dike is evaluated in this study because Fowler et al. (1987) conclude that the west perimeter dike is the least stable with respect to foundation stability.

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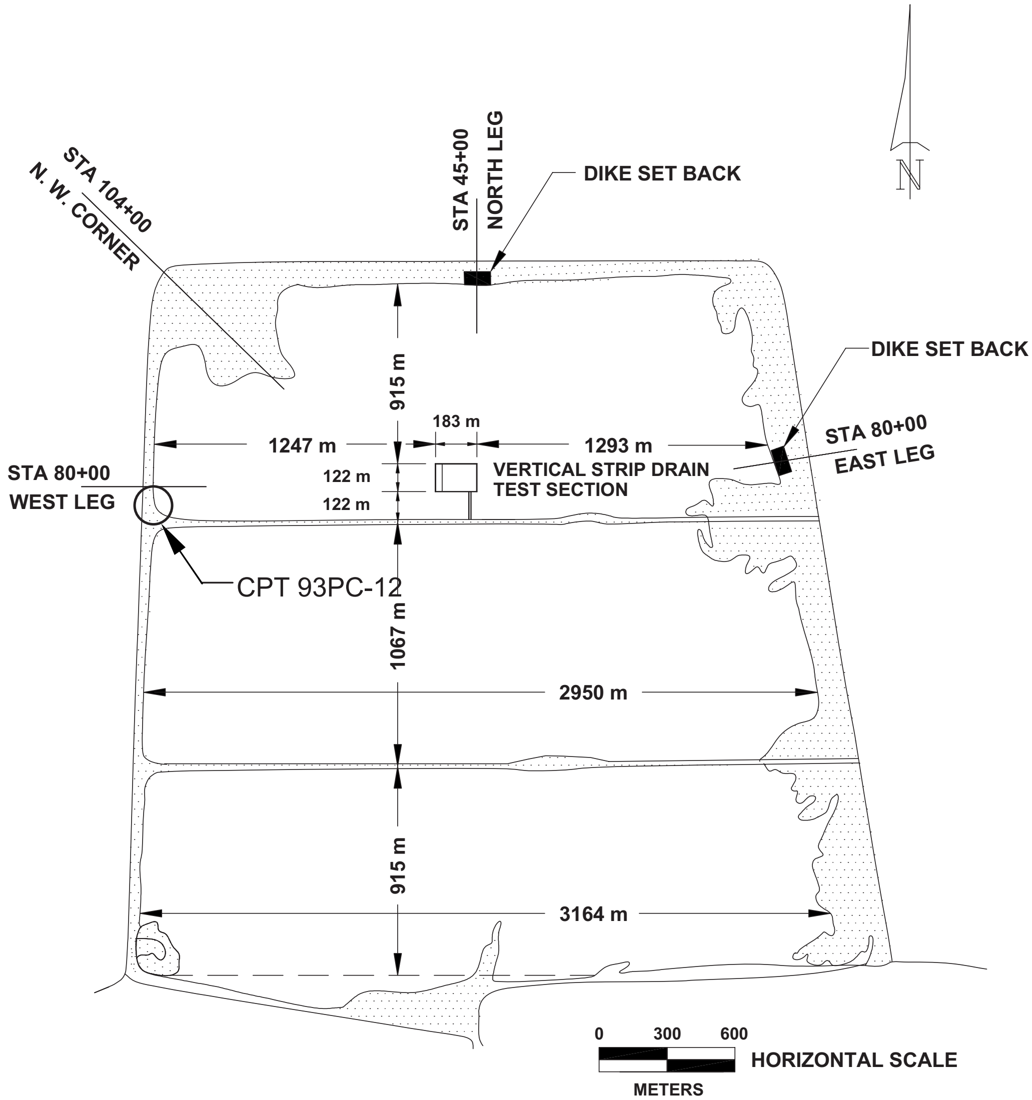

Fig. 1. Plan view of the CIDMMA

Perimeter Dike Configuration

The CIDMMA is approximately 3,050 m by 3,200 m in a rectangular shape as shown in Fig. 1. A perimeter dike surrounds the entire management area, and two dividing dikes running parallel with the shoreline and north perimeter dike separate the facility into three nearly equal areas of approximately 3.2 km^2 each.

The initial dike raising was from elevation +2.6 m MLW (mean low water) to elevation +5.4 m MLW and occurred around 1969, and the second increase was to elevation +8.1 m MLW around 1980. The third raising of the west perimeter dike from elevation +8.1 m MLW to elevation +10.6 m MLW occurred in the mid-1990s. However, this raising required the placement of a 300-m-wide underwater stability berm along the outer toe of the west perimeter dike to ensure stability. The perimeter dike in the northwest corner was raised to elevation +10.6 m MLW using a dike setback of approximately 137 m. The north and east perimeter dikes were raised to elevation +12.4 m MLW with setbacks from the dike perimeter road of 131 and 137 m, respectively, in the mid-1990s. Dike setbacks have resulted in approximately 0.1–0.2 km^2 of lost storage capacity during each dike raising.

Most of the coarse-grained dredged material is located along the east dike because sluiced dredged material deposited along the east dike and the coarse material settles out quickly and the finer material migrates across the CIDMMA resulting in the finest particles being deposited along the west dike. Because this coarse-grained dredged material exhibits a large shear strength, progressive raising of the east dike has not caused any stability problems. However, a dike setback of approximately 135 m was required to raise the east dike from elevation +2.6 m to elevation +8.1 m MLW. A dragline has been used to excavate and place coarse-grained dredged material along the dike alignment. Coarse-grained dredged material has also accumulated over an extensive area in both the northeast and northwest corners of the management area and along the inside of the north perimeter dike. As a result, the stability of the east and north dikes was not evaluated during this investigation.

Because of the continuously wet condition of the fine to finest-grained dredged material adjacent to the west perimeter dike, it has been virtually impossible to construct a benched dike section without a bearing capacity failure. Incremental dike raising has historically been achieved by displacing sand fill into the containment area adjacent to the existing perimeter dike. Coarse-grained dredged sand is hauled by trucks from the east side and dumped

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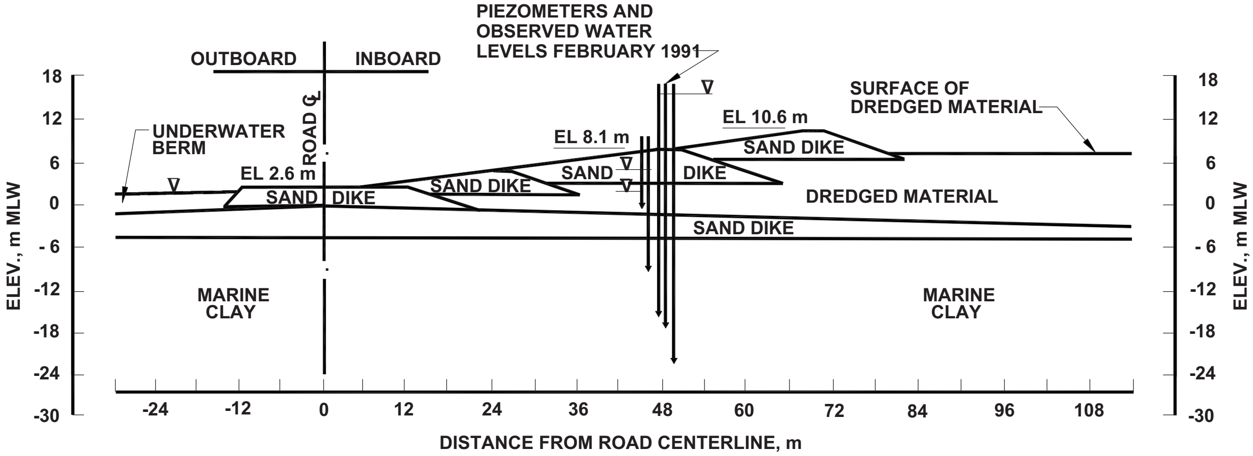

Fig. 2. General cross section and piezometer head in west perimeter dike

on the slope, and a dozer pushes the sand up the slope and into the disposal area creating a large mud wave as the weight of the sand displaces the soft fine-grained dredged material.

The west perimeter dike was raised in late 1985 to about elevation +8.1 m MLW without the displacement type failure toward the inside of the containment area as experienced in the past because of improved foundation conditions caused by trenching and desiccation of the fine-grained material. This increased desiccation resulted from the construction of two interior dikes, which subdivided the management area into three separate containment areas. Continued site drainage caused about 150–300 mm of desiccated crust to develop along the west perimeter dike. The interior dikes were built within Craney Island to create three containment areas that would improve sedimentation in the compartment being filled and allow the other two compartments to desiccate and consolidate at a faster rate using planes developed by Palermo et al. (1981). Construction of the interior dikes was completed in 1983, and the dredged material management plan (Palermo et al. 1981) was implemented in 1984 starting with the center compartment.

Geotechnical Investigations

This section describes the geotechnical investigations of the foundation soil conditions below the west perimeter dike and dredged material deposited within the north compartment of the CIDMMA. The engineering properties used in the stability analyses of the west perimeter dike are also described.

Initial Excess Pore-Water Pressure

In February 1991, piezometers revealed that the excess pore-water pressure level beneath the west perimeter dike exceeded the dike surface elevation by approximately 6.0–7.5 m (see Fig. 2). Large excess pore-water pressures in the marine clay were also found in the strip drain test section (Stark and Williamson 1994; Stark et al. 1999), which is denoted in Fig. 1. These initial excess pore-water pressures were estimated from installed piezometers and the results of piezocone dissipation tests. These measurements were made prior to the strip drain installation. The maximum excess pore-water pressure was estimated to be about 150 kPa at a depth between 15 and 35 m, which corresponds to the marine clay underlying the dredged material (see Fig. 2). The existence of large excess pore-water pressures clearly indicates that the marine clay is underconsolidated due to the stress applied by the overlying sand dike material.

If the excess pore-water pressures in the dredged material and marine clay underlying the containment area are dissipated, a substantial amount of consolidation settlement will occur, which would result in an increase in storage capacity. This was the main motivation for installing the strip drain test section to assess how much settlement would occur and the corresponding increase in storage capacity. In addition, an increase in undrained shear strength would occur.

The prefabricated vertical drain test section of 183 m by 122 m was constructed in 1993 in the CIDMMA (Stark et al. 1999). The test section was proposed to evaluate the effectiveness of prefabricated vertical drains in accelerating the consolidation of the dredged fill and underlying marine clay. Settlement plates installed in the main test section reveal a rate of settlement is about 0.9–1.1 m/year after the installation of the prefabricated vertical drains. This rate can be compared with a rate of 0.11–0.12 m/year from 1991 to 1994 prior to the vertical drain placement. The measured settlements were also used to estimate mobilized or field values of compression index (C_c) of 0.71 and horizontal coefficient of consolidation (C_h) of 1.3×10^{-3} m^2/day. These mobilized values have been used to design future vertical drain installations at Craney Island (Stark and Williamson 1994; Stark et al. 1999).

However, the large area of the CIDMMA (8.9 km^2) would require a large number of vertical strip drains to be installed and thus a large cost. As a result, the U.S. Army Corps of Engineers was interested in investigating the use of vertical strip drains in only the perimeter dikes to reduce costs and accelerate the increase in service life because there would be a smaller area that would have to be consolidated.

Initial Undrained Shear Strength

In 1993, the existing undrained shear strength, S_u, was estimated from cone penetration tests (CPT 93PC-12) conducted through the west perimeter dike near the cross section being evaluated in the stability analysis (see Fig. 1) and field vane shear tests. The undrained shear strength profile for the west perimeter dike is presented in Fig. 3 and the values of S_u were estimated using the following expression:

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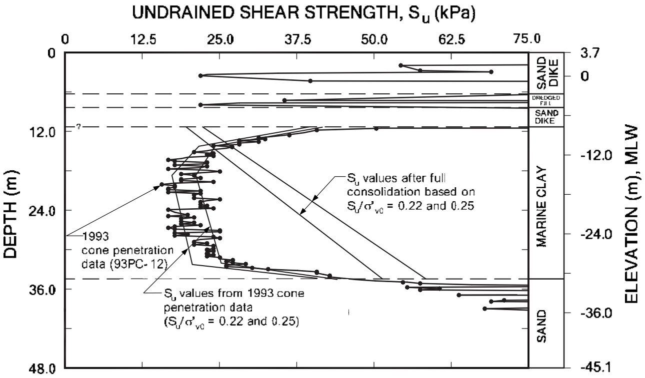

Fig. 3. Undrained shear strength profile below Craney Island west perimeter dike in 1993

$$S_u = \frac{q_c - \sigma_{v0}}{N_k} \tag{1}$$

where q_c=cone tip resistance; σ_{v0}=total overburden stress; and N_k=empirical cone factor. Empirical correlations of N_k have been developed using the results of field vane shear tests (Lunne and Kleven 1981; Meigh 1987) and unconsolidated-undrained triaxial compression tests (Stark and Delashaw 1990; Eid and Stark 1998). To differentiate the unconsolidated-undrained triaxial mode of shear from the field vane shear, Stark and Delashaw (1990) denote their cone factor N_{kUU}. It should be noted that the field vane shear strengths were corrected using Bjerrum's (1972) correction factor. The empirical correlations of N_k and N_{kUU} utilize plasticity index (PI) to estimate values of cone factor.

Table 1 presents the index properties of the marine clay underlying the CIDMMA. The statistical values of the index properties were determined from the results of 135 tests from 1949 to 1992 (Ishibashi et al. 1993). Because the dredged material is similar to the foundation clay the same index properties except the natural water content are used to characterize both deposits.

The value of N_k based on 1981–1983 field vane shear tests was estimated to range from 10 to 15 for an average PI of 41.4 from Table 1. The value of N_{kUU}, which is based on unconsolidated-undrained triaxial tests, ranges from 8 to 14 for an average PI of 41.4 (Stark and Delashaw 1990; Eid and Stark 1998). Therefore, a representative value of N_k equal to 12 was utilized in the analysis. This is also an average value of N_{kUU} for the 20 sites studied by Stark and Delashaw (1990). Fig. 3 presents the variation of undrained shear strength with depth using N_k equal to 12. Each data point corresponds to a calculation of S_u using Eq. (1), the appropriate total stress, and a value of N_k equal to 12.

Table 1. Summary of Index Properties of Marine Clay (after Ishibashi et al. 1993)

Variable	Natural water content (%)	Liquid limit	Plastic limit	Plasticity index	Clay size fraction (%)	Specific gravity of solids
Average	70.2	70.7	29.3	41.4	94.4	2.71
Standard deviation	12.4	14.7	4.88	12.3	7.25	0.04
Coefficient of variation	0.17	0.21	0.17	0.3	0.04	0.02

It can be seen that the undrained shear strength in the upper 2–3 m of the marine clay is substantially larger than at the mid-depth of the marine clay. This is probably caused by the sand dike acting as a drain, which allows the upper 2–3 m of marine clay to consolidate rapidly. However, from a depth of about 20–35 m the marine clay under the west dike exhibits lower values of S_u. Below a depth of 35 m, the undrained shear strength again increases due to the drainage provided by the underlying sand layer. Stability analyses show that the marine clay from a depth of 20–35 m controls the stability of the west perimeter dike because the critical slip surfaces for various cross sections are located between these depths.

Undrained Shear Strength Ratio

Ladd and Foott (1974) and Mesri (1975) show that the undrained shear strength can be normalized with respect to the effective overburden stress. The resulting ratio, S_u/σ'_{v0}, where σ'_{v0} is the effective overburden stress, is termed the undrained shear strength ratio. These researchers show that the undrained shear strength ratio is approximately constant for a particular deposit. Therefore, one of the main objectives of the subsurface investigation was to estimate the value of the S_u/σ'_{v0} ratio of the marine clay. The increase in effective overburden stress, caused by consolidation of the normally consolidated dredged material and marine clay, then could be used to estimate the resulting increase in S_u. The after-consolidation value of S_u is estimated by multiplying the undrained shear strength ratio by the new value of effective overburden stress. The after-consolidation (full consolidation) value of S_u can then be used in a stability analysis. This stability analysis is termed an undrained strength stability analysis by Mesri (1983) and subsequently an undrained strength analysis by Ladd (1991). Therefore, the objective of subsequent subsurface investigations was to measure the effective overburden stress profile with depth and then estimate the new S_u profile.

The initial range of S_u values in the marine clay corresponds to an undrained shear strength ratio of 0.22 to 0.25, which are selected from a range of 1993 cone penetration test data (CPT 93PC-12) through the west perimeter dike near the cross section where the stability analyses are performed (see Fig. 3). This range of S_u is based on effective overburden stresses estimated from piezocone test results and piezometer data. Stark and Williamson (1994) describe the piezocone test results. It should be noted that an undrained shear strength ratio of 0.22 is recommended by Mesri (1989) and Terzaghi et al. (1996) in stability analyses for inorganic soft clays and silts. For organic soils, excluding peats, an undrained strength ratio of 0.26 is recommended (Terzaghi et al. 1996).

Profiles of S_u are denoted in Fig. 3, which are estimated using an undrained shear strength ratio of 0.22 and 0.25 and the effective overburden stress under the west perimeter dike after 100% consolidation. It can be seen that the marine clay is significantly underconsolidated in the midpoint of the marine clay under the west perimeter dike. Consolidating the marine clay would result in a substantial increase in S_u and thus increased stability of the west perimeter dike.

Slope Stability Analysis

Slope stability analyses conducted during this investigation were performed using the two-dimensional slope stability microcomputer program UTEXAS2, version 2 (Edris and Wright 1987).

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Table 2. Results of Slope Stability Analysis

Stability analysis	Dike crest elevation (m, MLW)	Dredged material elevation (m, MLW)	Analysis condition	Shear strength	Critical circle center X (m)	Critical circle center Y (m)	Critical circle radius (m)	Circle tangent elevation (m, MLW)	Side force inclination (deg)	Factor of safety
a	7.3	6.0	1994 geometry (Fig. 4)	1993 shear strength (Fig. 3)	18.4	36.7	63.2	−26.4	1.17	1.91
b	10.3	9.0	Raise dike until FS=1.3	1993 shear strength (Fig. 3)	31.3	50.4	77.3	−26.6	1.73	1.30[a]
c	7.3	6.0	1994 geometry	100% consolidation with strip drains ($S_u/\sigma_p'=0.22$)	21.3	42.3	60.5	−18.0	2.29	2.43
d	7.3	6.0	1994 geometry	100% consolidation with strip drains ($S_u/\sigma_p'=0.25$)	21.6	43.2	60.5	−18.0	2.64	2.48
e	17.9	16.7	Raise dike until FS=1.3	100% consolidation with strip drains ($S_u/\sigma_p'=0.22$)	58.4	135.5	156.9	−21.5	4.16	1.30[a]
f	20.3	19.1	Raise dike until FS=1.3	100% consolidation with strip drains ($S_u/\sigma_p'=0.25$)	67.8	176.8	198.5	−21.5	4.42	1.30[a]

Note: FS=factor of safety.

[a]Minimum factor of safety required to prevent failure during raising dike.

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Spencer's (1967) stability method as coded in UTEXAS2 was used for all analyses because it satisfies all force and moment equilibrium. The phreatic surface is taken as the harbor level outside the west perimeter dike toe and the top of the dredge material inside of the dike. A linear variation in the phreatic surface is assumed between these two horizontal segments. Circular sliding surfaces were used in all analyses because of the uniform nature of the soft marine clay and dredged fill near the west perimeter dike. In addition, the cone penetration tests did not reveal any weak layers within the marine clay (see Fig. 3) that would lead to a translational failure mode. Searches were performed to determine the critical failure surface for each stability task.

Several stability analyses were conducted to evaluate the stability of the west perimeter dike in 1994, to address the importance of undrained shear strength values measured in 1993 along the west perimeter dike stability, and to investigate the effect of undrained strength increase along with full consolidation by installing vertical strip drains through the west perimeter dike on the factor of safety, and thus ability to raise the dike.

In the last 15–20 years, prefabricated vertical strip drains have replaced conventional sand drains as the preferred method to accelerate consolidation of soft cohesive soils. This is primarily due to the ease of installation, higher flexibility and reliability, less environmental impact, and reduced cost of the prefabricated

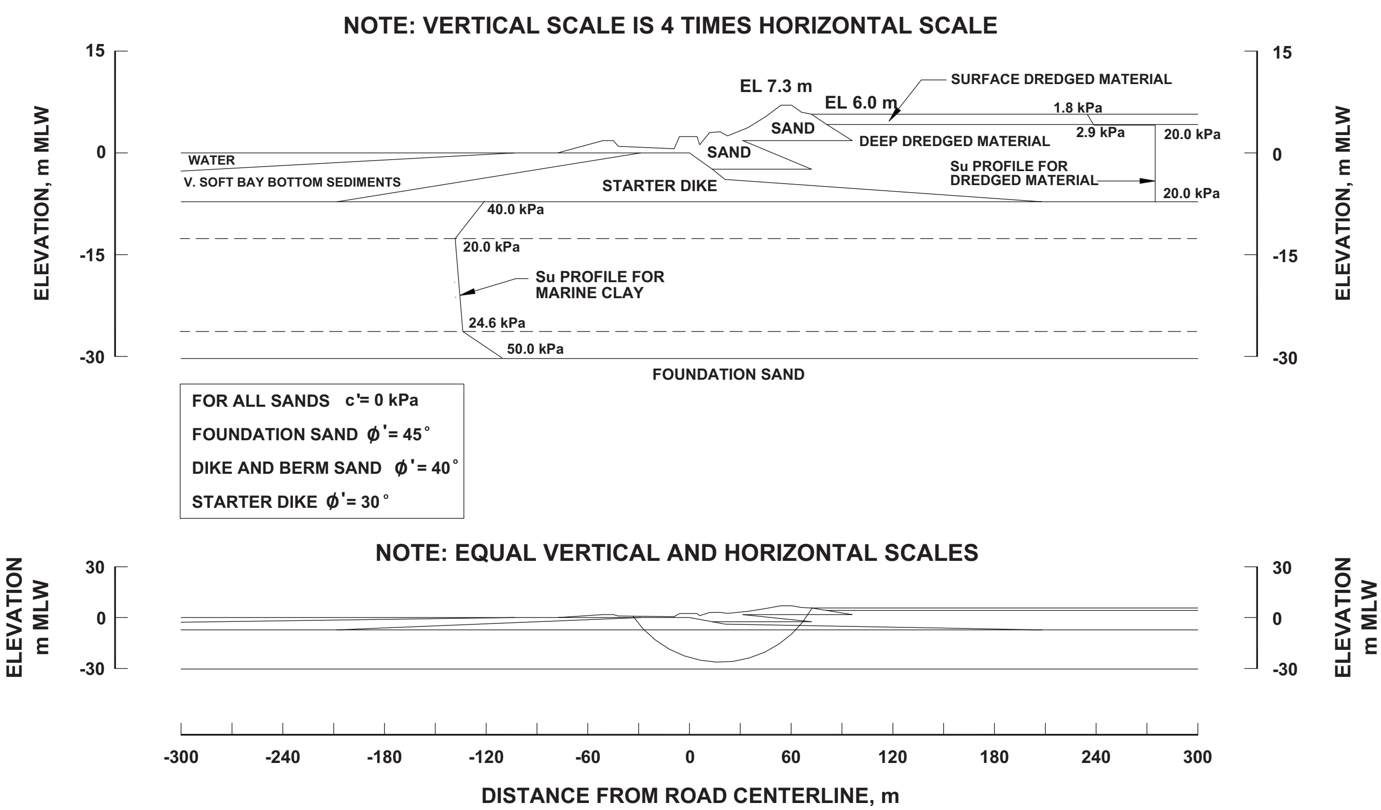

Fig. 4. Stability analysis of 1994 west perimeter dike geometry

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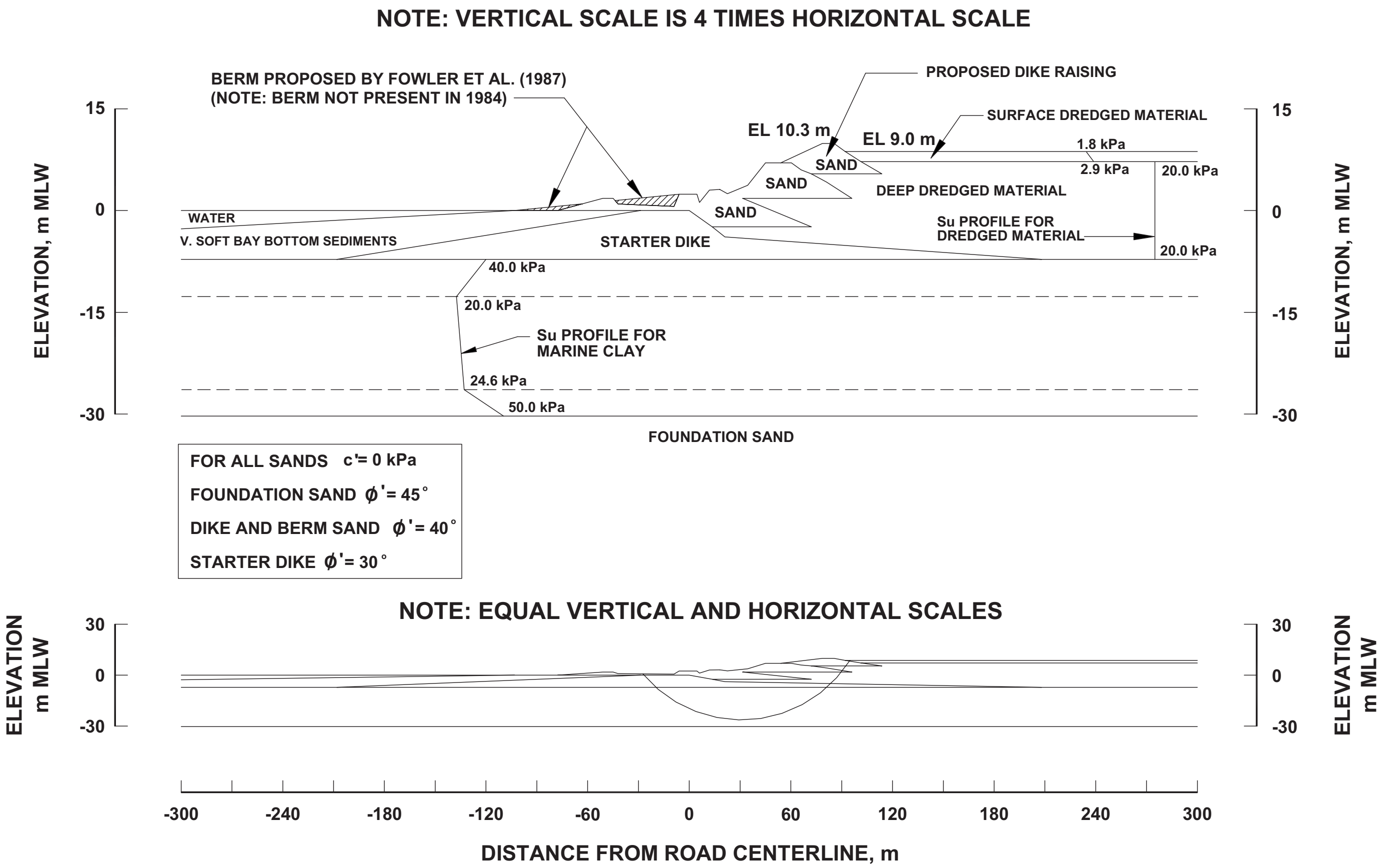

Fig. 5. Geometry of raised west perimeter dike, simultaneously maintaining a factor of safety of 1.3 without vertical strip drains

strip drains. Vertical strip drains have been used to accelerate consolidation of soft cohesive soils in many projects throughout the United States, including the expansion of the Port of Los Angeles (Jacob et al. 1994), the Seagirt project in Baltimore Harbor (Koerner et al. 1986), the construction of a dredge material containment area in the Delaware River near Wilmington, Del. (Koerner and Fritzinger 1988; Fritzinger 1990), and the New Bedford Superfund Site near New Bedford, Mass. (Schimelfenyg et al. 1990).

Stability of 1994 West Perimeter Dike Geometry

Stability Analysis a in Table 2 was conducted using the January 1994 west perimeter dike geometry at Station 75+67 to evaluate the 1994 stability of the west perimeter dike. Fig. 4 presents the January 1994 dike geometry and it can be seen that the January 1994 elevation of the west perimeter dike is 7.3 m.

The 1993 undrained shear strength profile presented in Fig. 4 is used in Analysis a. These values of S_u represent the best estimate of the in situ strengths at this location in 1993. With these updated shear strengths and geometry, Stability Analysis a represents the best estimate of the January 1994 stability of the west perimeter dike at Station 75+67. The strength parameters for the dike materials are also shown in Fig. 4.

Analyses of the January 1994 stability of the west perimeter dike revealed that the critical slip surfaces are tangent to an elevation of approximately −30.0 m MLW at Station 75+67 on the west perimeter dike. Below this elevation the marine clay shear strength increases due to the dissipation of excess pore-water pressures by the underlying dense sand (see Fig. 4). As a result, the critical slip circles do not extend below this depth. Therefore, at Station 75+67, the vertical strip drains need to extend to a depth approximately 3.0 m above the dense sand to ensure consolidation and strength gain in the critical marine clay. This corresponds to elevation −30.0 m MLW or a depth of 35.0 m from the top of CPT location 93PC-12. The elevation of the dike at CPT 93PC-12 is about +4.0 m MLW.

The computed factor of safety is 1.91 (Table 2), which suggests that the west perimeter had a higher degree of stability in January 1994 than initially thought and also satisfy the minimum factor of safety of 1.3 for the end-of-construction condition (U.S. Army Corps of Engineers 1970). Field observations (no signs of distress) also suggest that the dike was stable in 1994. In summary, improved estimates of soil shear strength and dike geometry resulted in a substantial increase in the estimated factor of safety. Therefore, stability analyses should carefully assess the stability of perimeter dikes when trying to estimate the storage capacity of a placement area.

Raising of West Perimeter before Full Consolidation

Stability Analysis b in Table 2 was conducted to determine the maximum elevation that the west perimeter dike could be raised and maintain a factor of safety greater than or equal to 1.3 before full consolidation, which is the end-of-construction condition (U.S. Army Corps of Engineers 1970). The shear strength parameters used in Analysis b are presented in Fig. 5. The geometry corresponding to a factor of safety of 1.3 is also presented in Fig. 5. It can be seen from Fig. 5 that the proposed dike raising follows a slope similar to the existing west perimeter dike. To

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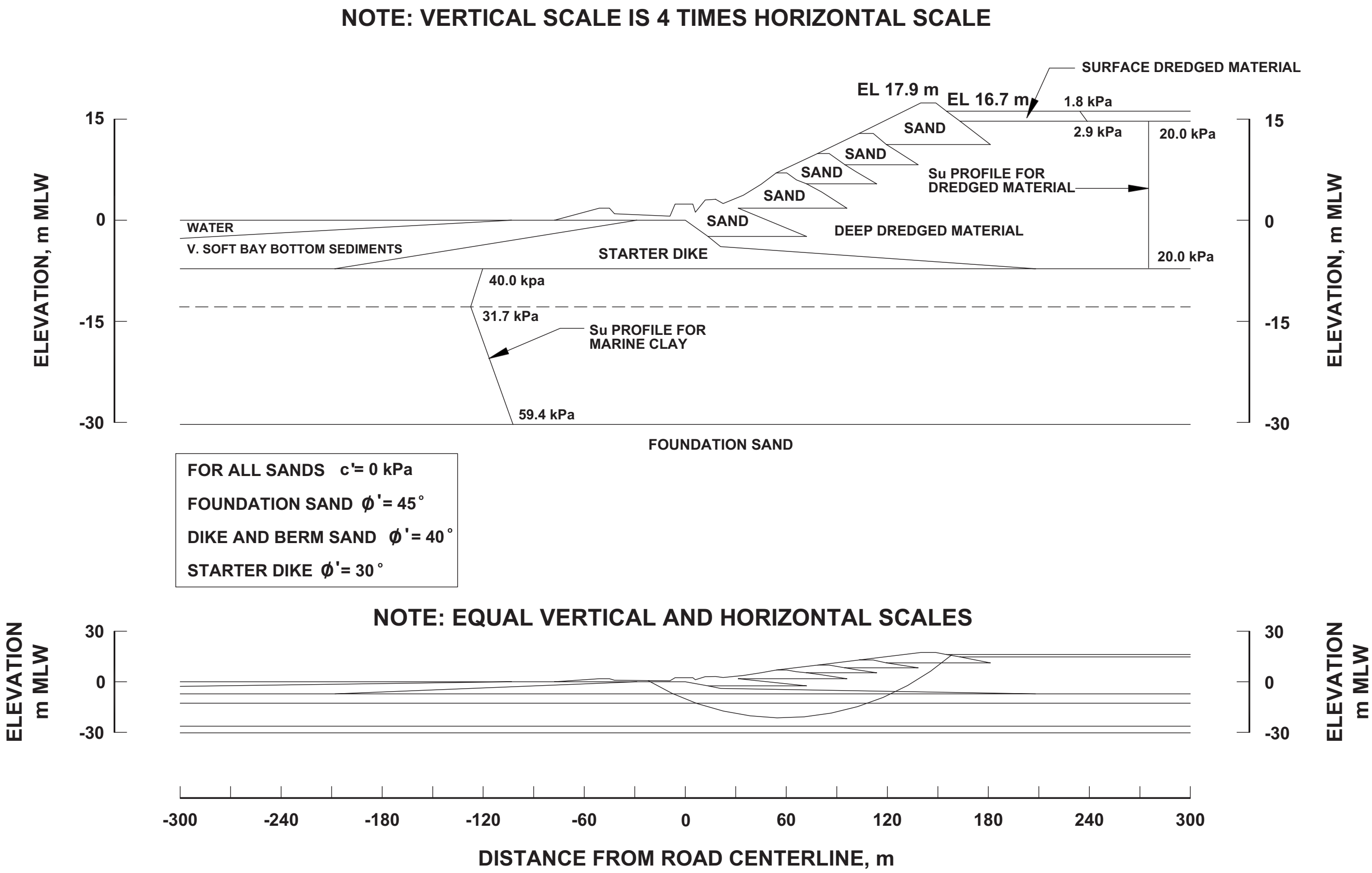

Fig. 6. Geometry of raised west perimeter dike after 100% consolidation by installation of vertical strip drains, simultaneously maintaining a factor of safety of 1.3 ($S_u/\sigma'_p=0.22$)

maintain a factor of safety greater than or equal to 1.3, it is concluded that the maximum dike elevation is +10.3 m MLW and the maximum dredged material elevation is +9.0 m MLW. This represents a similar increase in dike and dredged material height of +10.6 and +9.3 m MLW, respectively, from the estimates by Fowler et al. (1987). However, the main difference is that Fowler et al. (1987) required a large underwater berm along the west perimeter dike to ensure stability, whereas the new and higher values of S_u yield a similar height without the use of an underwater berm. The results for Stability Analysis b are summarized in Table 2.

Effect of Strength Increase by Full Consolidation for 1994 Dike Geometry

The 1994 west perimeter dike geometry (Analysis a in Table 2 and Fig. 4) was reanalyzed to determine the effect of full consolidation of the dredged material and marine clay by the installation of strip drains through the west perimeter dike. The undrained shear strength values corresponding to 100% consolidation of the dredged material and marine clay were estimated using a S_u/σ'_{v0} ratio of 0.22 and 0.25 and the effective overburden stress corresponding to the dike geometry after 100% consolidation. The resulting profiles of S_u versus depth are shown in Fig. 3. Stability Analyses c and d were conducted with S_u values corresponding to S_u/σ'_{v0} ratios of 0.22 and 0.25, respectively. The results of the analyses are presented in Table 2.

The installation of strip drains, and the subsequent consolidation of the dredged material and marine clay, results in factors of safety of 2.43 and 2.48 for S_u/σ'_{v0} values of 0.22 and 0.25, respectively. The factor of safety was not greatly sensitive to the range of S_u/σ'_{v0} used, i.e., 0.22 versus 0.25. The factors of safety satisfy the minimum requirement of 1.5 for long-term steady conditions after fully consolidated (U.S. Army Corps of Engineers 1970) and are significantly greater than 1.91, which corresponds to the January 1994 condition (Analysis a). Therefore, strip drain installation would cause to expedite consolidation and to increase significantly undrained shear strength and dike stability. This increase would allow the dike to be raised to increase service life as discussed in the next section.

Raising of West Perimeter Dike after Full Consolidation

Stability Analysis e in Table 2 was conducted to determine the maximum elevation that the west perimeter dike could be raised and still maintain a factor of safety greater than or equal to 1.3 after full consolidation by strip drain installation because additionally raising the elevation of west dike causes a new transient stress condition not steady-state any more and results in the end-of-construction condition. This analysis was conducted using the undrained shear strengths that correspond to 100% consolidation for the 1994 dike geometry. Stability Analysis e was conducted using a S_u/σ'_{v0} ratio of 0.22.

The geometry corresponding to a factor of safety of 1.3 for an undrained shear strength ratio of 0.22 is presented in Fig. 6. It can be seen from Fig. 6 that the proposed dike raising follows a slope

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similar to the existing west perimeter dike. To maintain a factor of safety greater than or equal to 1.3, it is concluded that the maximum dike elevation is +17.9 m MLW and the maximum dredged fill elevation is +16.7 m MLW. These elevations are significantly higher than the +10.3 and +9.0 m MLW, respectively, for the maximum elevations before full consolidation previously mentioned (Stability Analysis b in Table 2 and Fig. 5). The large increase in maximum dike elevation is attributed to a large increase in the radius of the critical circular failure surface. A larger critical circle radius forces the critical slip surface farther into the containment area, which reduces the driving moment and increases the amount of shear resistance mobilized along the length of the failure circle. This is evident from a comparison of the critical circular failure surfaces in Figs. 5 and 6.

Stability Analysis f in Table 2 was conducted to determine the maximum elevation that the west perimeter dike can be raised and maintain a factor of safety greater than or equal to 1.3 after full consolidation by strip drain installation using an S_u/σ'_{v0} ratio of 0.25. The geometry corresponding to a factor of safety of 1.3 for an undrained shear strength ratio of 0.25 is similar to Stability Analysis e presented in Fig. 6 except that the maximum dike elevation is +20.3 m MLW and the maximum dredged fill elevation is +19.1 m MLW to maintain a factor of safety greater than or equal to 1.3. In this analysis, the range in value of S_u/σ'_{v0} had a significant influence on the maximum height of the west perimeter dike.

In summary, the installation of vertical strip drains will cause to expedite consolidation, and thus result in a substantial increase in undrained shear strength of the marine clay underlying the west perimeter dike. This should allow the west dike to be raised to an elevation of +17.9– +20.3 m MLW and substantially increase the service life of the CIDMMA. The time required for the strip drains to achieve 100% consolidation depends on the spacing of the drains. Value engineering can be performed to determine the optimal cost and drain spacing for 100% consolidation. The Norfolk District of the U.S. Army Corps of Engineers did install strip drains through the west perimeter dike and is preparing to raise the dike. This technique appears to be a viable means for increasing the service life of other dredged material placement areas.

Conclusions

This study investigated the stability of the existing west perimeter dike at the CIDMMA using an undrained strength stability analysis. The undrained strength stability analysis expresses the undrained shear strength in terms of the effective overburden stress. This allows the undrained shear strength to reflect a strength increase caused by consolidation. The undrained strength stability analysis was used to evaluate the 1994 stability of the west perimeter dike and the possibility of raising the dike. In addition, stability analyses were conducted to determine the effect of strength increase along with full consolidation by installing vertical strip drains on the stability and potential raising of the dike. Vertical strip drains will accelerate consolidation of the dredged material and underlying marine clay and result in an increase in shear strength and stability.

The 1994 factor of safety of the west perimeter dike at Station 75+67 is 1.91. This factor of safety reflects the January 1994 geometry and 1993 values of undrained shear strength. Therefore, it was concluded that it is technically feasible to raise the west perimeter dike without installing strip drains to ensure full consolidation. Stability analyses showed that the west dike and dredged material can be raised to elevation +10.3 and +9.0 m MLW, respectively, using the geometry shown in Fig. 5 and still exhibit a factor of safety of 1.3 without installation of an underwater stability berm.

If full consolidation is obtained in a practical time schedule by installing vertical strip drains, the undrained shear strength of the dredged material and, in particular, the marine clay should increase, and thus increase the factor of safety at Station 75+67 to approximately 2.5. A factor of safety of 2.5 is based on the January 1994 dike geometry and undrained shear strength values corresponding to 100% consolidation of the dredged material and marine clay. This increase in shear strength will allow the west perimeter dike to be raised to an elevation of at least +17.9 m MLW after 100% consolidation is achieved in the dredged material and marine clay. This raising should substantially increase the service life of the CIDMMA. The Norfolk District of the U.S. Army Corps of Engineers did install strip drains through the west perimeter dike and is preparing to raise the dike. This technique appears applicable to other dredged material placement areas to increase their service life.

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