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STRIP DRAINS IN DREDGED MATERIAL PLACEMENT AREAS

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ABSTRACT: Prefabricated strip drains can be used to accelerate consolidation of dredged fill and underlying foundation soils. This consolidation causes an increase in storage capacity, and thus service life of the placement area. In addition, consolidation causes an increase in soil shear strength that will allow perimeter dikes to be constructed to higher elevations and/or future development of the site. This paper presents the results of a strip drain test section installed in an active dredged material placement area. The strip drains accelerated consolidation of the dredged fill and soft foundation soil resulting in measured settlements of approximately 1.8 m (6 ft).

INTRODUCTION

Fine-grained dredged material usually enters a confined management area in a slurry consisting of 10 to 25 percent soil particles. After the slurry flows over the management area, the fine-grained material starts undergoing sedimentation. At some point in the sedimentation process, the soil particles begin touching each other and eventually a continuous soil matrix is created. Further settlement is controlled by the rate at which water can be expelled from the soil matrix. This densification process is governed by a process called primary consolidation. At the start of primary consolidation, the soil matrix is very soft and usually has a void ratio of 10 to 20 and a saturated unit weight of 65 to 75 pounds per cubic foot.

Primary consolidation is caused by excess pore-water pressures forcing water out of the soil matrix. The excess pore-water pressures are induced by the weight of overlying dredged material and are in addition to the natural hydrostatic water pressures. Once the excess pore-water pressures have dissipated and consolidation is completed, a hydrostatic condition is established in which no flow or consolidation occurs.

The time required for 90 percent consolidation to occur can be estimated using Terzaghi's one-dimensional consolidation equation:

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$$t_{90\%} = \left[0.848 \times \frac{H_{dr}^2}{C_v} \right] \tag{1}$$

where H_{dr} is the maximum length of drainage path and C_v is the vertical coefficient of consolidation. This equation shows that the time required for consolidation is controlled by the coefficient of consolidation, that is, permeability, of the soil matrix and maximum length of drainage path that the water must travel to exit the soil matrix. As water exits the soil matrix, the volume of the matrix decreases, causing an increase in storage capacity and soil shear strength within the management facility.

CRANEY ISLAND DREDGED MATERIAL MANAGEMENT AREA

The Craney Island Dredged Material Management Area (CIDMMA) is a 2,200-acre confined management area located near Norfolk, Virginia. Dredged material has been placed in the management area almost continuously since it was completed in 1957. The original design was for an initial capacity of about 100 million cubic yards and a 20-year life for the facility.

Increased dredging in the Norfolk channel has required the capacity of the CIDMMA to be increased through three major dike raising efforts. The dikes were raised from elevation +2.4 m (8 feet) to elevation +5.2 m (17 feet) mean low water (mlw) in 1969, to elevation +7.9 m (26 feet) mlw in 1980, and to elevation +10.4 m (34 feet) mlw in 1988. The final dike raising required the placement of a 305 m (1,000-foot) wide underwater stability berm along the outer toe of the west perimeter dike and large dike setbacks along the north and east perimeter dikes to ensure stability of the perimeter dikes (Figure 1). The dike setbacks are usually 60 to 90 m (200 to 300 feet), which results in approximately 80 to 120 km^2 (20 to 30 acres) of lost storage capacity during each dike raising.

Interior dikes were built within the CIDMMA to create three containment areas to improve sedimentation in the compartment being filled and allow the other two compartments to desiccate and consolidate faster. Desiccation will be accelerated by the removal or evaporation of surface water and will increase the amount of consolidation because the effective unit weight of the soil increases as the pore-water evaporates. Construction of the interior dikes was completed in 1983. On the average, 3 to 4 million cubic meters (4 to 5 million cubic yards) of dredged fill is placed in a compartment each year. Dredging results in a net increase in dredged fill thickness of 0.9 to 1.8 m (3 to 6 feet) per year in each compartment being filled.

The U.S. Army Engineer Waterways Experiment Station conducted an extensive consolidation and desiccation analysis to predict the life expectancy of the CIDMMA (Palermo and Schaefer 1990). The microcomputer program PCDDF89 (Primary Consolidation and Desiccation of Dredged Fill) was used to predict the service life of the CIDMMA. PCDDF89 is described by Stark (1991) and Stark and O'Meara (1994). Palermo and Schaefer (1990) concluded that the current capacity of Craney Island will be exhausted by the year 2000. Since the perimeter dikes are at their maximum height because of foundation stability, and the Virginia State Legislature ruled that Craney Island cannot be expanded or replaced, new techniques for increasing the storage capacity of Craney Island were sought.

The first technique for increasing the storage capacity of the CIDMMA was the implementation of a Restricted Use Program (RUP). Under the RUP suitable material would be placed in the ocean and unsuitable material would be placed in the CIDMMA to extend service life. An analysis of the service life of the CIDMMA under the RUP was conducted using PCDDF89 to evaluate the benefits of the RUP (Stark et al. 1994). The analysis showed that the service life would be substantially increased under the

RUP. However, ocean placement is approximately $10 per cubic meter ($8 per cubic yard) more expensive than placement in the CIDMMA. Since the Norfolk District dredges 3 to 4 million cubic meters (4 to 5 million cubic yards) of material annually, ocean dumping would increase annual placement costs by 30 to 40 million dollars. Clearly, more cost effective techniques for increasing storage capacity needed to be developed.

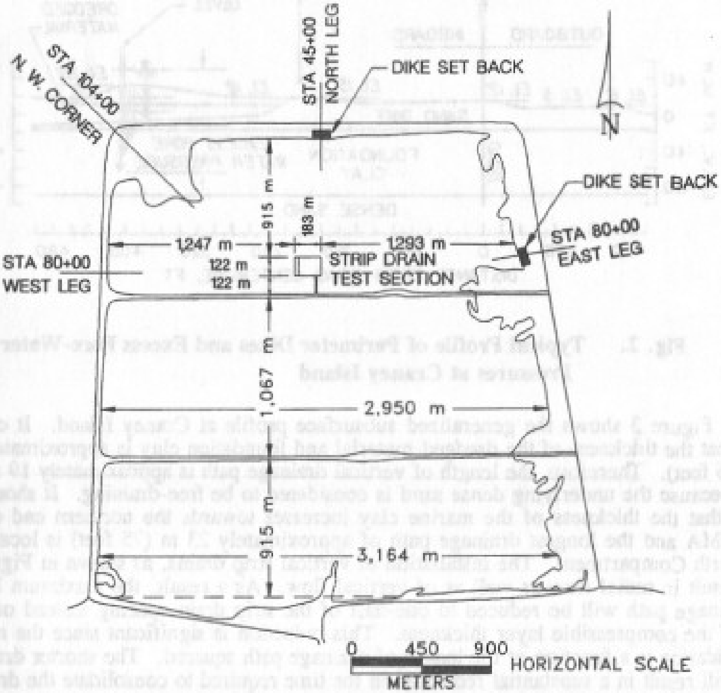

Fig. 1. Plan View of Craney Island and Location of Vertical Strip Drain Test Section

Piezometers installed in the perimeter dikes at Craney Island revealed that large excess pore-water pressures exist in the dredged fill and soft foundation clay. Figure 2 shows that the excess pore-water pressures in the foundation clay typically exceed the ground surface by 6 to 8 m (20 to 25 feet). The cross section shown in Figure 2 is representative of Station 104+00 at the northwest corner of Craney Island (Figure 1).

The dissipation of these excess pore-water pressures will result in substantial consolidation settlement and thus increased storage capacity. The rate of consolidation is controlled by the permeability of the soil and the maximum length of drainage path, as given by Terzaghi's equation presented earlier. Since altering the permeability of a soil in situ is not practical, techniques were sought to decrease the drainage path to accelerate consolidation.

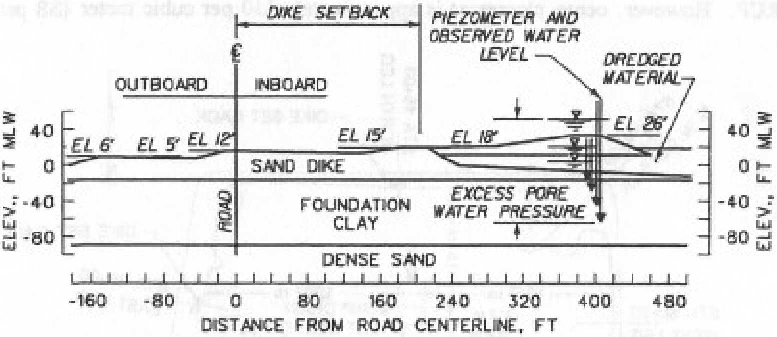

Fig. 2. Typical Profile of Perimeter Dikes and Excess Pore-Water Pressures at Craney Island

Figure 3 shows the generalized subsurface profile at Craney Island. It can be seen that the thickness of the dredged material and foundation clay is approximately 38 m (125 feet). Therefore, the length of vertical drainage path is approximately 19 m (63 feet) because the underlying dense sand is considered to be free-draining. It should be noted that the thickness of the marine clay increases towards the northern end of the CIDMMA and the longest drainage path of approximately 23 m (75 feet) is located in the North Compartment. The installation of vertical strip drains, as shown in Figure 4, will result in radial flow as well as of vertical flow. As a result, the maximum length of drainage path will be reduced to one-half of the strip drain spacing instead of one-half of the compressible layer thickness. This reduction is significant since the rate of consolidation is a function of the length of drainage path squared. The shorter drainage path will result in a substantial reduction in the time required to consolidate the dredged fill and underlying foundation clay. It should be noted that if Craney Island were not underlain by a permeable dense sand, the compressible layer would be singly drained and the maximum drainage path would be 38 m (125 feet) (Figure 3).

STRIP DRAIN TECHNOLOGY

In the last 5 to 10 years, prefabricated strip drains have replaced conventional sand drains as the preferred method to accelerate the consolidation of soft cohesive soils. Most strip drains are modeled after the cardboard strip drain developed by Kjellman (1948 a and b). Strip drains are band-shaped and have a rectangular cross section approximately 10 cm (4 inches) wide and 0.4 to 0.5 cm (0.15 to 0.20 inch) thick. A plastic core with grooves, studs, or channels is surrounded by a filter fabric. The filter fabric is most commonly a nonwoven geotextile. The core carries the excess pore-water to the ground surface or underlying drainage layer, and the filter fabric keeps soil particles from entering the core.

Vertical strip drains have been used in many projects throughout the United States to accelerate consolidation of soft cohesive soils, including the recent expansion of the Port of Los Angeles, the Seagirt project in Baltimore Harbor, the construction of dredged material containment areas in the Delaware River near Wilmington, Delaware, and the New Bedford Superfund site in New Bedford, Massachusetts.

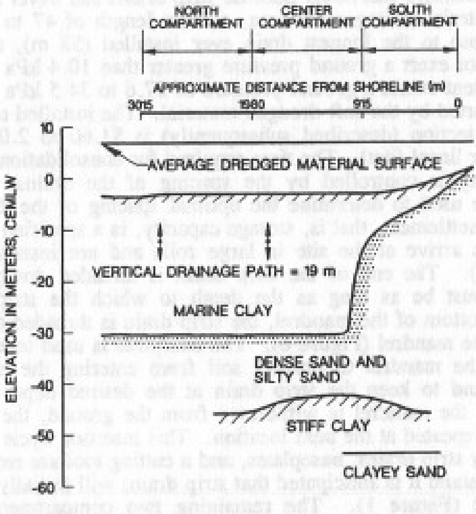

Fig. 3 Generalized Subsurface Profile at Craney Island

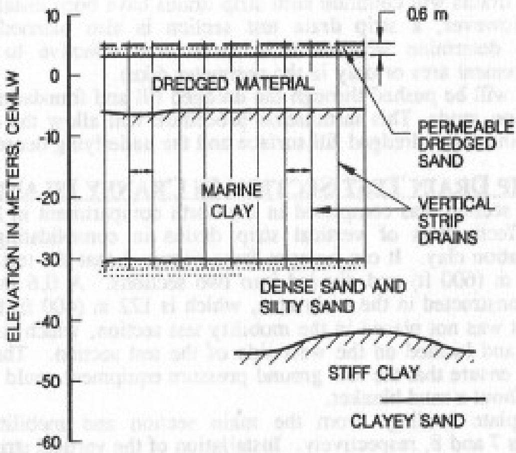

Fig. 4 Radial Drainage Pattern Using Vertical Strip Drains

The recommendation of prefabricated strip drains to increase the storage capacity of the CIDMMA was novel because strip drains had never been installed in an active dredged material management area, a drain length of 47 to 50 m (155 to 160 feet) would be close to the longest drain ever installed (58 m), and the installation equipment could not exert a ground pressure greater than 10.4 kPa (1.5 psi). Typical installation equipment exerts a ground pressure of 27.6 to 34.5 kPa (4 to 5 psi), which could not be supported by the soft dredged material. The installed cost of vertical strip drains in the test section (described subsequently) is $1.60 to 2.00 per lineal meter ($0.50 to $0.60 per lineal foot). The time required for consolidation of the dredged fill and foundation clay is controlled by the spacing of the drains. Therefore, value engineering can be used to determine the optimal spacing of the drains to produce a certain increase in settlement, that is, storage capacity, in a specified time.

Strip drains arrive at the site in large rolls and are installed using a hollow mandrel (Figure 5). The end of the strip drain is threaded down the inside of the mandrel, which must be as long as the depth to which the strip drains are to be installed. At the bottom of the mandrel, the strip drain is threaded through a baseplate and inserted into the mandrel (Figure 6). The baseplate is used to keep the strip drain at the bottom of the mandrel to prevent soil from entering the mandrel during the insertion process and to keep the strip drain at the desired depth as the mandrel is withdrawn. When the mandrel is withdrawn from the ground, the strip drain is cut, and the process is repeated at the next location. This insertion cycle is very rapid (1 to 3 minutes) and only strip drains, baseplates, and a cutting tool are required.

At Craney Island it is anticipated that strip drains will initially be installed in the north compartment (Figure 1). The remaining two compartments have sufficient capacity to receive dredged material for several years. After strip drains accelerate consolidation in the first compartment, this compartment will be used for placement while strip drains are installed in another compartment and the third compartment undergoes desiccation to support the strip drain equipment. It is anticipated that installation of strip drains will continue until strip drains have been installed in all three compartments. However, a strip drain test section is also planned for the west perimeter dike to determine whether it is more cost effective to install drains throughout the placement area or only in the perimeter dikes.

Strip drains will be pushed through the dredged fill and foundation clay into the permeable foundation sands. This installation procedure will allow the expelled water to exit the strip drains at the dredged fill surface and the underlying dense sand.

VERTICAL STRIP DRAIN TEST SECTION IN CRANEY ISLAND

A field test section was completed in the north compartment in February 1993 to evaluate the effectiveness of vertical strip drains in consolidating the dredged material and foundation clay. It can be seen from Figure 1 that the test section is 122 m (400 ft) by 183 m (600 ft) and divided into two sections. A 0.6 m (2 feet) thick sand blanket was constructed in the main area, which is 122 m (400 ft) by 153 m (500 ft). A sand blanket was not placed in the mobility test section, which is 30 m (100 ft) by 122 m (400 ft) and located on the west side of the test section. The mobility test section was used to ensure that the low ground pressure equipment could operate on the desiccated crust without a sand blanket.

Settlement plate readings from the main section and mobility section are presented in Figures 7 and 8, respectively. Installation of the vertical strip drains in the test section was completed on 19 February 1993. As of May 1994 the maximum consolidation settlement in the main test section is approximately 1.8 m (5.9 feet). It should be noted that strip drains were installed in the northern portion of the test area first. As a result, the settlement plates in the northern part of the main test section (SP-1, SP-5, And SP-7) show a faster response than the other settlement plates. For example, settlement plates SP-1 and SP-7 show a significant decrease in elevation after only 20 to 25 days. Conversely, settlement plates SP-3 and SP-9 did not show a significant decrease in elevation until 40 to 50 days after strip drains installation commenced.

The settlement plate data from the main and mobility sections are plotted using a semi-logarithmic scale. The end of primary consolidation is identified by a decrease in the slope of the settlement-time relationship. Therefore, it can be seen in Figures 7 and 8 that none of the settlement plates have reached the end of primary consolidation and more settlement will occur in the coming months.

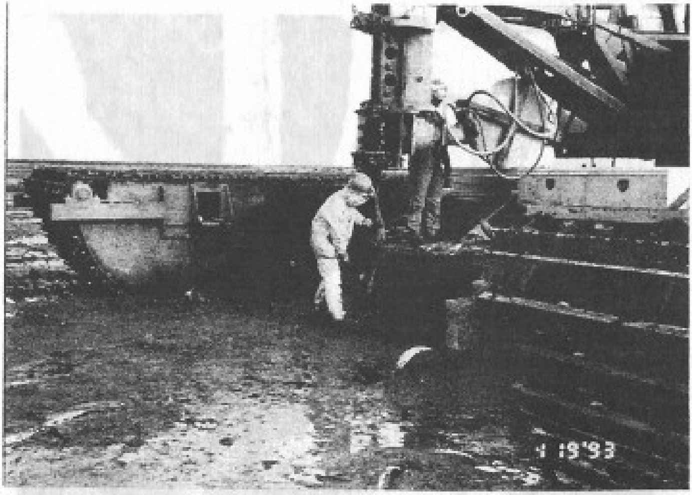

Fig. 5 Vertical Strip Drain Equipment at Craney Island

The mobility section was developed to demonstrate that a 0.6 m (2 feet) thick sand blanket was not required to support the strip drain installation equipment. A comparison of Figures 7 and 8 provides an insight into the effect of the sand blanket on consolidation of the dredged fill and marine clay. It can be seen that settlement plate SP-10 is located at the northern end of the adjacent mobility section and can be compared with settlement plates SP-1 and SP-7 at the northern end of the main section. Settlement plates SP-1 and SP-7 have settled 1.6 to 1.8 m (5.2 ft to 5.9 ft) while settlement plate SP-10 has settled approximately 1.1 m (3.6 ft). Therefore, it may be concluded that the additional surcharge provided by the sand blanket results in a significant increase in consolidation settlement. It is anticipated that the additional consolidation occurred in the dredged fill because of the limited extent of the sand blanket. In summary, the storage capacity lost by the installation of a sand blanket can be recouped by the subsequent consolidation of the underlying dredged fill. However, the cost of the blanket will probably preclude the use of a sand blanket throughout the remainder of the CIDMMA.

CONCLUSIONS

Using prefabricated strip drains to consolidate dredged fill and soft foundation soils will significantly reduce the time required for consolidation, resulting in a rapid increase in storage capacity and soil shear strength. The shear strength gain will allow perimeter dikes to be constructed to higher elevations without setbacks or stability berms. Therefore, prefabricated strip drains appear to be a viable technique for increasing the storage capacity, and service life, of dredged material management areas.

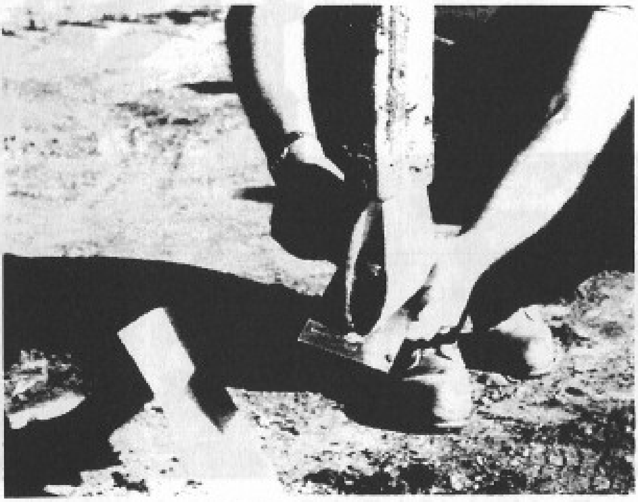

Fig. 6 Vertical Strip Drain Installation Procedure

The installation of vertical strip drains will reduce the height of existing management areas, allowing development of the area or a new management area to be constructed on top of the existing area. The installed strip drains also will accelerate consolidation of the existing dredged fill and foundation clay as new dredged material and perimeter dikes are placed. Strip drains have also been proposed to consolidate inactive management areas for future development.

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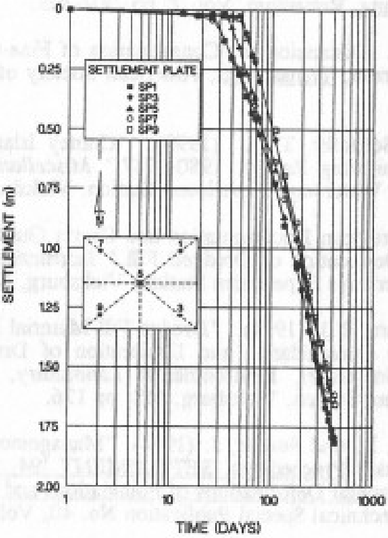

Fig. 7 Semi-Logarithmic Presentation of Settlement Plate Measurements in Main Section

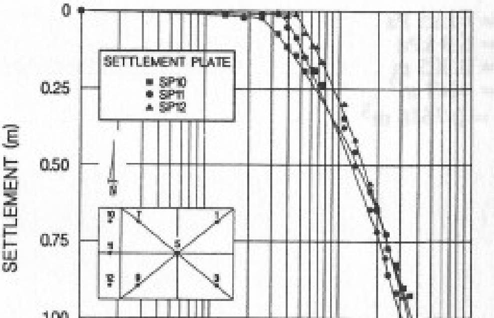

Fig. 8 Semi-Logarithmic Presentation of Settlement Plate Measurements in Mobility Section

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APPENDIX II. SI Unit Conversions

1 psf = 47.85 Pa
1 psi = 6.9 kPa
1 foot = 0.305 m
1 acre = 4047 m^2
1 cubic yard = 0.7646 m^3