GEOTECHNICAL BORROW SOURCE EVALUATION
CRANEY ISLAND DREDGE MATERIAL MANAGEMENT AREA
SOUTH, CENTER, AND NORTH DREDGE CELLS

Portsmouth, Virginia

S&ME Project No. 1081-07-2486

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1. AUTHORIZATION

S&ME, Inc. is pleased to submit this report summarizing our geotechnical evaluation of borrow material within the Craney Island Dredge Material Management Area (CIDMMA) in Portsmouth, Virginia. This is one in a series of reports to be submitted to the United States Corps of Army Engineers – Norfolk District (USACE) as part of the Craney Island Eastward Expansion Project.

We completed our services in general accordance with Task 3 of the scope document entitled *Summary of Geotechnical Tasks to Support the Eastward Expansion of CIDMMA*, dated February 2008, which was jointly developed by S&ME, Craney Island Design Partners (CIDP), and the USACE. The USACE executed Task Order 21 to Contract No. W91236-04-D-0089 on September 27, 2007.

2. SITE AND PROJECT DESCRIPTION

The CIDMMA is located in Portsmouth, Virginia on the south bank of Hampton Roads at the mouth of the Elizabeth River. A site vicinity map is provided as Figure 1 in Appendix I. The existing facility is formed by sand perimeter dikes and berms and measures approximately two- by two-mile square in plan dimension. Interior separation dikes divide the facility into three dredge disposal cells (south, central, and north). Since completion of construction in 1958, the CIDMMA has served as a depository for spoil dredged from shipping channels in the Hampton Roads and Newport News areas.

Currently, perimeter dike crest elevations range from approximately 40 feet on the east dike to 33 feet on the west dike. Surface elevation within the dredge cells ranges from approximately 27 to 48 feet (MLLW) with an average of approximately 35 feet. The ground surfaces within the dredge cells are relatively flat, however, tend to decrease in elevation by up to approximately 10 feet towards the western extent of the cells.

Dredge material is hydraulically placed into the facility from influent points along the eastern dike. In general, coarser, more granular soils are deposited nearest the influent points in the east and sediments become finer (grading to silt and clay) towards the western extent of the facility. Portions of the east ends of the cells are currently and have been previously mined for sand and gravel. Large, open excavations remain in the upper 10 to 15 feet in these areas.

The USACE – Norfolk District, in a joint venture with the Virginia Port Authority (VPA), is proposing a project that will increase the dredge material storage capacity of the CIDMMA by creating an additional containment cell directly to the east of the existing facility. Following rapid filling of the additional cell, the area will provide reclaimed land for a new, 580-acre port terminal facility.

Rapid filling and dike construction for the eastward expansion project will require large quantities (millions of cubic yards) of granular borrow material. Potential borrow sources currently being considered are dredged shipping channels (Newport News, Thimble

Shoals, and Atlantic Ocean Channel) and previously deposited dredge material within the Craney Island facility itself.

3. OBJECTIVE AND SCOPE OF WORK

The objective of this phase of our geotechnical study (overland borrow source evaluation) is to estimate volumes of potential granular borrow material in the CIDMMA and characterize their engineering behavior for construction of the proposed eastward expansion.

Our detailed scope of services for the project is defined in Task 3 of the document titled, *Summary of Geotechnical Tasks to Support the Eastward Expansion of CIDMMA*, dated February 2008. In summary, we executed the following general scope of services for this phase of the project:

- Coordinated with the USACE and CIDP to identify specific project goals and scope the geotechnical subsurface exploration program

- Completed 72 pairs of direct push explorations and CPTu soundings to depths of up to 81 feet (typical exploration depth of 30 feet) within the south, center, and north dredge cells

- Completed 12 additional CPTu soundings after the initial event to depths of up to 30 feet

- Collected 15 surficial grab samples from the south, center, and north dredge cells (five samples collected from each cell)

- Completed laboratory soil testing on samples from direct push and surficial grab samples collected during our exploration

- Identified, contoured, labeled, and characterized bodies of coarse-grained materials within the limits of our exploration program in conjunction with Fugro Atlantic

- Estimated volumes of coarse- and fine-grained soil bodies within the limits of our exploration program in conjunction with Fugro Atlantic

- Prepared this report summarizing the results of our field and laboratory efforts and providing estimated quantities, approximate locations, and engineering characteristics of granular borrow material within the CIDMMA.

4. ACKNOWLEDGEMENTS

This report has been a cooperative effort by the two members of the geotechnical design team in the interest of achieving a common goal for the Craney Island Eastward Expansion project. Fugro Atlantic, the lead geotechnical engineer for the CIDP, provided the following invaluable support for the preparation of this report:

- Input into the planning of our subsurface exploration within the dredge disposal cells
- Effort in support of the identification, contouring, and labeling of sand bodies within the dredge disposal cells.
- Complete graphical support in the form of exploration location plans, subsurface cross sections, and isopach maps for the interpreted sand bodies
- Estimated volumes of coarse- and fine-grained bodies within the limits of our explorations
- Lab parameter plots to assist in the characterization of grain sizes for the coarse- and fine-grained bodies.

5. REVIEW OF HISTORIC DATA

The following sections provide a brief overview of construction of the CIDMMA, the current dredge disposal process, sand reclamation activities at the site, and the previous USACE test pit exploration within the dredge disposal cells.

5.1 Overview of Construction History

Initial construction of the CIDMMA, completed in 1957, raised the perimeter dikes to an approximate elevation of +8 feet from an original mudline elevation of approximately -10 feet. Settlement of the dikes and the need for additional storage capacity required the dikes be subsequently raised. In 1969, the dikes were raised to an approximate elevation of +18 feet and again in 1980 to +26 feet. The interior dikes separating the facility into three “cells” were built between 1980 and 1984 to a height consistent with the perimeter dikes. From the late 1980’s to present day, the dikes have been gradually raised and maintained to their current elevation, generally a minimum of 5 feet above the dredge surface elevation within the cells.

Table 1 in Appendix I details the major improvements made to the facility, substantial subsurface exploration programs, approximate dike elevations, and their respective dates. This information has been assembled from various sources, but is well summarized in the slope stability document prepared for the 2006 Feasibility Report issued by the USACE. Cross-sections of the perimeter dikes at various locations on Craney Island that show the major improvements made to the facility can be seen in Stark, 1993.

5.2 Dredge Disposal Process

Dredge material is typically deposited in the cells by hydraulic means. Filling started before construction of the facility was completed in 1957 over an approximate mudline elevation of -10 feet. Records of the approximate volume of material placed in the facility and the mean surface elevations of the cells along with their respective dates have been summarized in Table 1 in Appendix I. The historic average elevations shown in the table were compiled from data provided by the USACE and recent survey activities associated with the project.

Water levels within the dredge cells are known to fluctuate with dredge material deposition activities. During hydraulic placement of dredge materials, the cells are flooded with dredge-laden water that is allowed to stand, giving the particulate material time to settle out. The excess water is then slowly drained from weir structures at the western extent of the cells. The weir heights can be adjusted with the changing level of dredge within the cells.

Currently, all dredge material placement in a single year is restricted to one cell. Usage is then rotated on an annual basis. This allows the surface of each cell to dry and become desiccated over a period of two years, which promotes settlement and increases the available capacity of the individual cell. At times, water levels have been intentionally lowered to hasten desiccation as part of an active dredge management plan. In the areas of current and on-going sand reclamation, water levels have been lowered by typical construction methods (trenching and dewatering by drainage) to ease removal of material from excavations.

Commonly used dredge influent points within the three cells are typically evident based on the mounded surface topography. Higher concentrations of coarse grained materials are also generally observed at the influent points, as the heavier, coarser particles tend to settle out quickly. It follows that sand reclamation activities, described in the following section, generally take place near the dredge influent points. Anticipated dredge influent point locations (or, alluvial fans) are shown on Figure 2 in Appendix I.

5.3 Sand Reclamation Areas

Reclamation of deposited granular dredge spoils within the CIDMMA is an ongoing activity. Settlement of the perimeter dikes and erosion of the sandy soils requires that material be continually mined from the dredge cells for placement on roadways, dikes, and embankment surfaces. The majority of reclamation excavations are made in the eastern portions of the cells near dredge influent points.

5.4 USACE Test Pits

A test pit subsurface exploration program was completed in the north and center dredge cells of CIDMMA by the USACE in February 2003. The purpose of the test pit exploration was to identify coarse-grained borrow sources in the near surface soils for use in on-going dike maintenance. A total of 100 test pits were excavated using a CAT 325 track-mounted excavator and were advanced to depths ranging from 4 to 15 feet below the dredge cell surface at the time of the exploration.

6. FIELD EXPLORATIONS

The subsurface exploration program for the CIDMMA overland borrow study consisted of three elements: direct push soil sampling, CPTu soundings, and surficial grab sampling. In general, our overland borrow exploration was limited to the eastern half of the cells due to the higher concentrations of granular materials located nearest the dredge influent points. CPTu soundings and direct push borings were completed in pairs at 72 exploration locations within the south, center, and north cells. Twelve additional CPTu soundings were completed at selected locations of interest after the initial phase of the exploration to augment subsurface data. Explorations were completed and/or monitored by S&ME personnel in the field.

Tables 2 and 3 in Appendix I provide exploration locations, depths, surface elevations, and quantity of laboratory testing completed at each location. Depths were documented relative to the existing ground surface at the time of our exploration. As-drilled exploration locations and surface elevations were instrument surveyed by NXL, Inc and are shown on Figure 2 in Appendix I. Plan views of the individual dredge cells are shown in Figures NC-1, CC-1, and SC-1 in Appendices II, III, and IV, respectively.

6.1 Electric Piezocone Penetration Testing (CPTu)

S&ME completed 84 electric piezocone penetrometer (CPTu) soundings in the dredge disposal cells between the dates of November 15, 2007 and February 5, 2008. Nine of the soundings were performed to depths of up to 82 feet to penetrate the dredge material and the remaining soundings were advanced to depths of up to 30 feet. The soundings were performed by hydraulically advancing a 15-cm^2 (2.32 in^2) piezocone (pore pressure sensor in the u_2 position) from a pontoon-mounted drill rig in the south cell and from a ram-set mounted in a small skiff platform in the center and north cells. The ram-set consists of a small, lightweight steel frame with a hydraulic cylinder that advances drill rod The CPT data was captured using Vertek software. Logs of the CPTu soundings are provided in Appendix V.

6.2 Direct Push Soil Sampling

Direct push-method core borings were completed at 72 locations (note that CPTu soundings were also completed at the 72 macrocore locations) in the disposal cells to collect physical samples of the dredge materials. Borings were completed between the dates of November 15, 2007 and January 19, 2008. Eight of the direct push sample locations were completed to depths of up to 78 feet to penetrate the dredge material and the remaining borings were advanced to depths of up to 30 feet. Fifteen of the 72 locations were used for environmental evaluation (five in each dredge cell) by Malcolm Pirnie.

A four-foot direct push soil sampler was hydraulically advanced by a pontoon-mounted drill rig in the south cell and by the ram-set in the center and north cells. The samples were collected in four-foot long, 1¾-inch diameter transparent plastic tubes inside of a steel direct-push sampler that was hydraulically advanced into the soil. The plastic tubes were extracted from the sampler, the ends were capped, and the samples were logged and prepared for shipment to our Richmond office by an S&ME staff professional.

Logs of the direct push core samples are provided in Appendix VI. The logs include specific observations, sampling intervals, remarks, and selected laboratory test results.

We developed the logs for the recovered cores samples based on visual classification in the field and lab and augmented by laboratory index testing on selected samples.

6.3 Surficial Grab Sampling

Fifteen surface soil samples were taken in the three dredge cells (five in each cell). The samples were gathered by shovel within two feet of the ground surface for index, corrosivity, and self-weight consolidometer testing. The locations of the surficial grab samples are seen in Figure 2 in Appendix I. The exploration numbers, locations, and coordinates are provided on Table 5 in Appendix I.

6.4 Water Observations

In general, at the time of our exploration, water levels within the dredge cells were observed at, near, or above the ground surface. Specific water observations at the exploration locations are shown on the direct push sample logs provided in Appendix VI. Water levels are variable across the site and fluctuate as a result of a combination of factors, including precipitation, dredge placement and management activities, sand reclamation, and seasonal wetting and drying. Water levels are likely to vary from those observed during our exploration.

Ponded water in areas of surficial fine-grained materials can be observed throughout the site, especially following periods of precipitation or dredge pumping. Perched subsurface water levels are also possible due to fine-grained deposits below the ground surface.

6.5 Site Survey Control

We retained the services of NXL Construction Services, Inc. to perform survey of ground surface elevations and plan coordinates at as-drilled exploration locations. The elevations in this report reference the Mean Lower Low Water (MLLW), 1983-2001 Tidal Epoch Datum. The plan coordinates in this report reference the horizontal Virginia State Plane Coordinate System, South Zone, U.S. Survey Feet, North American Datum 1983 (NAD 83) HARN (1992).

Note that locally referenced vertical and horizontal datums have changed several times since construction of the facility. Previous explorations and surveys are likely to reference alternate datums, depending on the year. Figure 9 in Appendix I provides pertinent survey datum notes and depicts various vertical datums and their relationship to one another.

7. LABORATORY TESTING

Testing was completed in our Richmond USACE-certified laboratory on selected disturbed samples collected from the direct push soil borings and surficial grab samples. The objective of the testing program was to aid in the classification of soils observed in the borings and in the estimation of geotechnical engineering parameters for use in characterization. Testing was completed in general accordance with ASTM methodologies, where applicable. The results of the laboratory tests are provided in Appendix VII. Table 1 summarizes the type and quantity of tests completed, divided by type of sampling and cell location.

Table 1 – Summary of Laboratory Testing for Overland Borrow Study

Laboratory Test	Procedure	No. of Tests Direct Push			No. of Tests Grab Samples			Total # Tests
		South Cell	Center Cell	North Cell	South Cell	Center Cell	North Cell	
Natural Moisture	ASTM D2216	21	20	23	5	5	5	79
Atterberg Limits	ASTM D4318	21	20	23	5	5	5	79
Grain Size Analysis	ASTM D422	21	20	23	5	5	5	79
Hydrometer	ASTM D422	3	3	3	5	5	5	24
Specific Gravity	ASTM D854	--	--	--	5	5	5	15
Organic Content	ASTM D2974	--	--	--	3	5	5	13
Angularity	Folk (1955)	3	3	3	--	--	--	9
Corrosivity Series	ASTM D4972, G162	--	--	--	5	5	5	15
Self-weight Consolidation	N/A	--	--	--	--	2	1	3

8. BORROW SOURCE VOLUME DETERMINATION

The primary objective of this study was to identify the locations and volumes of potential granular borrow sources within the existing CIDMMA for use in the eastward expansion project. The following sections provide details regarding the procedures used to identify the granular borrow sources, estimate their volumes, and summarize and depict the results.

8.1 Identification of Coarse-Grained Soil Bodies

CPT explorations completed as part of this study served as the primary source of information regarding the identification of contiguous sand bodies within the dredge disposal cells. The following general procedure was utilized:

- Initial subsurface cross sections were made based on CPT subsurface explorations. Longitudinal cross sections were generated from east to west, and perpendicular cross sections were generated from north to south.
- Granular soils, as indicated by tip and sleeve resistance measurements from the CPT, were visually evaluated for contiguity from east to west, and north to south, using the cross sections.
- Contiguous sand bodies were labeled with unique identifiers indicating the dredge cell, the influent point from which the sand body was thought to originate within the cell, and a number indicating relative depth. For example, sand body "CS1" is within the center cell (for C), originated from an influent point in the south of the cell (for S), and is the upper most sand body in the area (for 1 – generally, increasing number indicates increasing depth).

- Using top and bottom elevations for the identified sand bodies at individual CPT locations, the top and bottom structural contours of the individual sand bodies were drawn by hand. Structural contours were then digitized for input into the project GIS database.
- Interim cross sections were generated using initial structural contours to check for reasonable results. Structural contours were adjusted, as necessary, based on interpretation of the interim cross sections.
- Volumes of granular materials were calculated using the adjusted structural contours and multiple excavation templates. Excavation templates were determined based on the presence of sand bodies that might be excavated within "reasonable" depths without the excessive mining of fine-grained materials. Volumes of fine-grained materials that might also be excavated during the course of sand excavation were also calculated.

The following sections provide brief descriptions of the figures used to depict the results of the borrow source evaluation. All figures and tables are provided in Appendices II through IV.

8.2 Subsurface Cross Sections

Interpreted subsurface cross sections within the north, center, and south dredge disposal cells are provided in Appendices II through IV. Nine to eleven cross sections are provided for each cell. Cross sections A through C for each cell are longitudinal from west to east, starting in the north. The remaining cross sections for each cell are perpendicular from north to south, starting in the west.

The cross sections show interpreted subsurface stratigraphy based on the data obtained in our CPTu explorations. The following information is provided on the cross sections:

- Data at individual CPT soundings including corrected tip resistance (qt), friction ratio, and correlated fines content.
- Laboratory-measured fines contents (on samples obtained from direct push explorations).
- Labeled sand bodies with interpreted boundaries.
- Ground surface elevation at the time of our exploration and approximate pre-construction elevation. Ground surface from topographic surveys completed in 2001 and 2003 are also shown on the sections.

8.3 Isopach Maps

Isopach thickness maps for selected sand units within the north, center, and south dredge disposal cells are provided in Appendices II through IV. Five to seven isopach maps are provided for each cell. The purpose of the isopach maps is to provide a "quick" reference showing the top elevation and thickness of individual sand units. The isopach maps each have four windows, summarized here:

- Upper Left: Topographic map showing exploration locations and existing surface elevations

- Upper Right: Contour plot showing the top elevation of the sand unit
- Lower Left: Isopach thickness plot showing the thickness of the sand unit
- Lower Right: Index map showing referenced sand unit in spatial relation to other sand units within the cell

Note that isopach maps were not provided for all sand units. Selected sand units were chosen for individual mapping based on the quantity of granular material available and the depth required for excavation. Sand units of lower volume and/or greater required excavation depth are not shown on individual maps.

8.4 Borrow Source Volume Estimation

Volumes of potential granular borrow sources were estimated based on the contoured sand units and corresponding excavation templates. Excavation templates were determined based on the presence of sand bodies that might be excavated within "reasonable" depths without the excessive mining of fine-grained materials. Templates are defined by both lateral extent and bottom elevation.

Drawings showing possible excavation templates in each cell are provided in Appendices II through IV. Four drawings are provided for each cell, summarized here:

- Plan showing lateral extents of excavation templates (excavation templates, or "elements," are lettered sequentially). The plan view also provides the bottom elevation of each excavation, the bulk volume of the excavation, and the subdivided coarse-grained and fine-grained portions of the bulk volume.
- Longitudinal cross sections (A through C) showing the bottom elevation and east-west extents of the individual excavation templates. Labeled sand bodies are shown on the cross sections.

Tables summarizing the volume calculation results within each cell are also provided in Appendices II through IV. Three tables are provided for each cell, summarized here:

- Table 1: Tabular results of bulk, coarse-grained, and fine-grained volumes based on excavation templates shown on the previously described drawings.
- Table 2: Volumes of individual sand units that were considered within the excavation templates. Note that portions of the sand units shown in this table might have volume outside the excavation templates. Refer to Table 3 for total volumes of each individual sand unit.
- Table 3: Total volumes of each individual sand unit mapped as part of this study.

"Overburden" excavation areas, or templates, are shown in the center and north cells. These, and several other areas in the south and north cell are noted on the drawings as having two to five feet of fine-grained overburden soils overlying granular soils.

Table 2 briefly summarizes portions of the volume calculations made for this study.

Table 2 – Summary of Volume Calculations

Dredge Cell	Bulk Volume [1] (cy)	Sand Unit Volume [1] (cy)	Fine Grained Volume [1] (cy)	Total Volume of All Mapped Sand Units [2] (cy)
North	4,127,000	3,486,000	641,000 [3]	5,341,000
Center	2,535,000	1,630,000	905,000 [3]	4,370,000
South	3,875,000	2,450,000	1,425,000	4,653,000
Totals	10,537,000	7,566,000	2,971,000	14,364,000

[1] Bulk, sand unit, and fine-grained volumes are totals from within all excavation templates. The bulk volume = sand unit volume + fine-grained volume.
[2] Total volume of all mapped sand units includes volumes of sand outside the excavation templates assumed for this study.
[3] Fine-grained volume does not include Overburden Area "O" within center and north cells. Refer to drawings in associated appendix for more information.

8.5 Limitations to Volume Estimation

It is important to note that the results of volume calculations presented in this report are estimates. The estimates are based on interpretations of subsurface conditions between explorations and the associated contouring of continuous sand bodies. The project team's interpretation of subsurface conditions and sand unit contouring are shown on the cross sections and the isopach maps provided in Appendices II through IV. Our interpretations are based on subsurface conditions indicated at the test exploration locations and at the time they were conducted. Actual subsurface conditions between explorations might differ from those shown, and therefore, actual volumes of coarse- and fine-grained material might differ from those provided in this report and the appendices.

9. BORROW SOURCE MATERIAL CHARACTERISTICS

The secondary objective of this study was to characterize the material behavior of the identified granular borrow sources within the existing CIDMMA. The following sections detail our approach to characterization and summarize ranges of material characteristics based on the laboratory test results.

9.1 Material Type Definitions

Pursuant to discussions with the USACE and CIDP, potential borrow soils were divided into four groups based on their % of fine-grained material (% passing the No. 200 sieve) to aid in their characterization. Type A material contains from 0 to 20% fines; Type B material contains from 20 to 35% fines; Type C material contains from 35 to 50% fines; and Type D material contains greater than 50% fines.

9.2 Laboratory Testing

S&ME completed a laboratory testing program on selected samples obtained from the dredge disposal cells to aid in our borrow source characterization. Our testing program is discussed in Section 7 of this report and laboratory test results are provided in Appendix

VII. Table 3 provides a breakdown of the laboratory tests completed for each borrow source material type.

Table 3 – Laboratory Tests Performed on Material Types A, B, C, and D

Test	Procedure	Type A	Type B	Type C	Type D	Total
Natural Moisture	ASTM D2216	12	16	11	40	79
Atterberg Limits	ASTM D4318	12	16	11	40	79
Grain Size Analysis	ASTM D422	12	16	11	40	79
Specific Gravity	ASTM D422	1	1	--	13	15
Organic Content	ASTM D854	--	--	--	13	13
Hydrometer	ASTM D2974	1	1	2	20	24
Angularity	Folk (1955)	3	4	2	--	9
Corrosion Analysis	ASTM D4972, G162	1	1	--	13	15
Self-weight Consolidation	N/A					3

Notes:
1. Tests summarized in this table were performed on direct push and surficial grab samples.

9.3 Laboratory Index Parameter Plots

Laboratory index parameter plots are provided in the Appendices to aid in the characterization process. The parameter plots depict grain size distribution properties for the samples tested. The properties are typically plotted versus depth, elevation, or radial distance from a dredge influent point. The purpose of the plots is to serve as a quick reference guide for grain size information for a specific dredge cell or sand unit.

Inclusive plots showing results from the three dredge cells together are provided in Appendix I. Plots showing results from the individual dredge cells broken into tests completed per sand unit are provided in Appendices II through IV. In general, the following plots are provided (not an all inclusive list):

- Fines content vs. depth and elevation
- Median grain size vs. depth and elevation
- Median grain size vs. fines content
- Radial distance from influent point vs. fines content
- Radial distance from influent point vs. median grain size
- Grain size envelopes for sand units

9.4 Subsurface Direct Push Samples

Table 4 provides ranges of index test results for a number of sand units within the dredge disposal cells, based on the samples tested for this study. Material type ranges were assigned to the sand units based on the percent of fine-grained material. It is important to note that laboratory testing was not completed for all sand units mapped within the dredge disposal cells. As testing was assigned prior to finalized mapping of sand units, no specific sand unit was targeted for detailed laboratory testing. The following tables might provide limited data, in our opinion, for a full characterization of the granular borrow source materials.

Table 4 – Index Testing Ranges for Material Types A, B, and C

Dredge Cell	Sand Unit	No. Index Tests	% Passing No. 200 Sieve	Plasticity Index	Liquid Limit	D_{50} (mm)	Material Type
North	NC1	2	23 to 43	3 to 5	25 to 30	0.088 to 0.118	B to C
	NN1	1	8	NP	NP	0.383	A
	NNS2	10	9 to 50	NP to 19	NP to 47	0.076 to 0.245	A to C
	NN3	1	40	21	43	0.092	C
Center	CE1	3	21 to 48	23 to 34	39 to 53	0.097 to 0.205	B to C
	CS1	4	14 to 31	NP to 31	NP to 50	0.186 to 0.279	A to B
South	SN1	1	18	7	20	0.587	A
	SN2	5	18 to 23	NP	NP	0.155 to 0.184	A to B
	SN3	2	34 to 35	NP	NP	0.103 to 0.113	B to C
	SN4	1	22	NP	NP	0.165	B
	SS3	1	14	14	26	0.239	A

Notes:
1. Tests summarizes in this table were performed on direct push samples only.

Some excavation of fine-grained materials will be required in most cases to obtain the granular materials within the mapped sand units. As such, fine-grained materials were targeted for laboratory testing, as well. Table 5 provides ranges of index test results for samples that tested as Material Type D (greater than 50% fine-grained material).

Table 5 – Index Testing Ranges for Material Type D

Dredge Cell	No. Index Tests	No. Hydrometer Tests	Plasticity Index	Liquid Limit	% Passing No. 200 Sieve	% Clay < 2 μm
North	8	2	17 to 65	39 to 92	57 to 91	19 to 23
Center	10	3	10 to 80	34 to 109	52 to 98	21 to 25
South	8	2	27 to 75	48 to 109	57 to 98	25 to 27

Notes:
1. Tests summarized in this table were performed on direct push samples only.

Based on our discussions with CIDP, we completed an angularity and mineralogy analysis of nine samples within the dredge disposal cells. A detailed description of the procedure used to complete the analysis is provided in Appendix VII. The results of the analysis is provided in Table 6.

Table 6 – Angularity and Mineralogy Test Results

Cell	Sand Unit	No. Tests	Average Roundness	Average Shape	Mineralogy		
					% Quartz	% Mica	% Shell
North	N/A	1	Sub-Angular	Subequant	80	12	8
	NNS2	1	Sub-Angular	Subequant	80	12	8
	NN1	1	Sub-Angular	Intermediate	84	2	14
Center	CS1	1	Sub-Rounded	Subequant	80	10	10
	N/A	1	Sub-Angular	Intermediate	84	10	6
	CE1	1	Sub-Angular	Subequant	98	1	1
South	SN2	1	Well-Rounded	Intermediate to Subequant	82	12	6
	SN1	1	Sub-Angular to Sub-Rounded	Subequant	97	1	2
	SN3	1	Sub-Angular	Intermediate to Subequant	86	6	8

Notes:
1. Tests summarizes in this table were performed on direct push samples only.

9.5 Surface Grab Samples

Fifteen surface soil samples were taken in the three dredge cells (five in each cell). The samples were gathered by shovel within two feet of the ground surface for index, corrosivity, and self-weight consolidometer testing. The locations of the surficial grab samples are shown on Figure 2 in Appendix I. Table 7 provides ranges and averages of the test results.

Table 7 –Surficial Grab Sample Test Results

Dredge Cell		Organic Content %	Specific Gravity	Sulfate (mg/kg)	Chloride (mg/kg)	pH	Resistivity (ohm-cm)	% Passing No. 200 Sieve	Percent Clay < 2 μm
North	# Tests	5	5	5	5	5	5	5	5
	Min.	1.8	2.72	1640	5000	7.3	41	79	13
	Max.	4.7	2.77	6840	17200	7.8	70	99	55
	Avg.	3.9	2.75	3358	8672	7.5	53	94	32
Center	# Tests	5	5	5	5	5	5	5	5
	Min.	3.4	2.68	2620	3200	7.5	48	83	25

Dredge Cell		Organic Content %	Specific Gravity	Sulfate (mg/kg)	Chloride (mg/kg)	pH	Resistivity (ohm-cm)	% Passing No. 200 Sieve	Percent Clay < 2 μm
	Max.	5.2	2.77	4070	7070	7.6	110	100	44
	Avg.	4.3	2.73	3182	5868	7.5	66	96	35
South	# Tests	3	5	5	5	5	5	5	5
	Min.	3.2	2.69	1280	4140	7.9	58	13	5
	Max.	4.1	2.74	2440	5190	8.3	75	96	50
	Avg.	3.6	2.71	1618	4680	8.1	65	64	30

Notes:
1. Tests summarized in this table were performed on surficial grab samples only.

Figures 11 and 12 in Appendix I show the test results for each cell plotted versus their location from west to east across the individual dredge disposal cells.

9.6 Strength, Compressibility, and Permeability

The following sections present our general approach and test results for the strength, compressibility, and permeability portions of the overland borrow source characterization.

9.6.1 General Approach

Limitations in the quantity of discrete samples collected at depth within the dredge disposal cells prevented the direct application of relative density, strength, compressibility, and permeability testing. Larger sample quantities collected within the offshore borrow areas allowed for this level of testing. Based on discussions with the project team, our approach to this portion of behavior characterization was to complete strength, compressibility, and permeability testing on offshore samples and "calibrate" the results to the onshore granular soils by directly comparing angularity and mineralogy of the two areas (offshore and onshore).

In order to calibrate the coarse-grained material encountered offshore to the coarse-grained material collected within the existing CIDMMA dredge cells, S&ME completed angularity analyses on 23 samples obtained from the borrow source areas. Specifically, 14 angularity tests were completed on offshore composite samples and nine tests were completed on samples collected from the dredge cells. Angularity analyses consisted of degree of roundness, particle shape, and mineralogy. Results of the angularity analysis for the onshore samples are summarized in Table 6.

Results of our angularity analyses indicate the average roundness, shape, and mineralogy of offshore coarse-grained material is similar to that of the coarse-grained material encountered within the dredge cells. Based on results of our angularity analyses, we judge the engineering behavior of coarse-grained material encountered within the dredge cells will be comparable to the behavior of offshore granular material, when subject to similar environmental conditions such as relative density (void ratio) and confining pressure. As such, strength, permeability and compression test results for offshore coarse-grained material are assumed to be representative of the granular soils encountered within the cells.

9.6.2 Results of Offshore Testing

S&ME completed 15 direct shear tests on select composite coarse-grained samples obtained from the three offshore locations. Type A soils were remolded to dry densities corresponding to 25%, 50% and 75% relative density. Type B and C soils were remolded to dry densities corresponding to 70%, 80% and 90% maximum dry density per the Standard Proctor compaction test. A summary table displaying the ranges of effective stress strength parameters as interpreted from the direct shear tests is provided in Table 8.

S&ME completed ten permeability tests and ten one-dimensional consolidation tests on select composite offshore samples. Type A soils were remolded to dry densities corresponding to 25% and 75% relative density. Type B and C soils were remolded to dry densities corresponding to 70% and 90% maximum dry density per the Standard Proctor compaction test. A summary showing the range of permeability values and consolidation parameters for the offshore coarse-grained composite samples is provided in Table 8.

Test reports for compressibility, strength, and permeability tests are provided under separate cover in our Borrow Source Characterization Reports for AOC, NNCA and TSC.

Table 8 – Range of Offshore Test Results

Material Type	Relative Compaction[1]	Permeability (cm/sec)	Consolidation			Direct Shear	
			CR	RR	c_v (ft^2/yr)	c' (psi)	φ' (degrees)
Type A	25% Dr	4.5×10^{-4} to 4.9×10^{-4}	0.04	0.006	47 to 917	--- [2]	--- [2]
	50% Dr					--- [2]	--- [2]
	75% Dr	3.4×10^{-4} to 5.5×10^{-4}	0.03	0.006 to 0.007	142 to 993	--- [2]	--- [2]
Type B	70% MDD	3.9×10^{-4}	0.08	0.003	24 to 644	0.5	39
	80% MDD					4.3	32
	90% MDD	5.4×10^{-6}	0.09	0.012	110 to 755	1.9	37
Type C	70% MDD	1.1×10^{-4} to 5.6×10^{-5}	0.08 to 0.1	0.005 to 0.009	38 to 682	1.3 to 2.5	28 to 36
	80% MDD					0.3 to 1.2	37 to 39
	90% MDD	1.6×10^{-4} to 2.7×10^{-5}	0.09	0.009 to 0.011	149 to 1290	1.1 0 3.2	36 to 41

[1] Dr = Relative Density, MDD = Maximum Dry Density.
[2] Direct shear tests for Type A material not completed at the time of this report.

10. LIMITATIONS

This Geotechnical Report has been prepared for the exclusive use of the US Army Corps of Engineers for specific application to the Craney Island Eastern Expansion project in Portsmouth, Virginia. S&ME understands that the Corps will provide copies of this report to the Virginia Port Authority, their consultants and others for use in design of the eastern expansion and increased capacity of the CIDMMA. This report has been prepared in accordance with generally accepted geotechnical engineering practices. No other warranty, express or implied, is made.

This report provides estimated volumes of soil material that might be used as borrow for the eastward expansion project. The estimates are based on interpretations of subsurface conditions between explorations and the associated contouring of continuous sand bodies. Our interpretations are based on subsurface conditions indicated at the test exploration locations and at the time they were conducted. Variations in both the nature and extent of the subsurface conditions, as well as the resulting volumes, should be anticipated.

Standard test methods are referenced in this report. Other standards or documents referenced in any given standard cited in this report, or otherwise relied upon by the authors of this report, are only mentioned in the given standard; they are not incorporated into it or "included by reference," as that latter term is used relative to contracts or other matters of law.

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