Beneficial use of Savannah River dredged material in large-scale geotechnical applications

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ABSTRACT

The Port of Savannah is located 18 miles inland from the Atlantic Ocean in the southeastern United States. Historically, 6 million cubic meters of river sediment is dredged from the Savannah River each year; however, the Savannah Harbor Expansion Project (SHEP) (Georgia, USA), which is proposed to accommodate post Panamax ships in the channel, will result in further increased dredge volume for disposal. Because dredge materials are currently disposed on land, this study was focused on identifying possible beneficial uses of dredge material in order to reduce the requirements for land disposal. A laboratory-based study was performed to assess the feasibility of large volume geotechnical use options for dredged sediments. Four samples were collected from the disposal facilities and characterized using physical, chemical and morphological analysis techniques, including grain size distribution, Atterberg limits test, specific gravity, scanning electron microscopy (SEM), laser diffraction particle size analysis (PSA), total organic carbon content (TOC), loss on ignition (LOI), and thermogravimetric analysis (TGA) analysis. The compactibility of the dredge was quantified using the standard Proctor test. Overall, characterization and compaction results demonstrated that the dredge material is viable for use as a nonstructural fill material, indicating that additional research and feasibility studies focused on specific beneficial use options is warranted. These results have important implications on the potential for beneficial use of the dredged sediment.

Keywords: beneficial use, characterization, geotechnical applications

1 INTRODUCTION

The U.S Army Corps of Engineers has been dredging the Savannah River since the 19th century. Currently, large containment areas are required for land disposal of the dredged sediments due to ongoing dredging operations. Up to 6 million cubic meters of river sediment is dredged from the Savannah river each year in order to maintain the navigability of the inner harbor (USACE, 2012b). In addition, the SHEP project will deepen Savannah Harbor and the associated shipping channels from 12.8 m to 14.3 m to accommodate larger ships, which will result in an increasing rate in the accumulation of dredge sediment (USACE, 2012a), which is currently disposed in the nearby confined disposal facilities that cover 22.2 km^2 along the South Carolina side of the lower Savannah River. The disposal facility is maintained by the Georgia Department of Transportation (GDOT); however, the long-term operation of this facility is uncertain due to the possibility of commercial and indusrial development of the land area. Given the mineralogical composition and relatively low contamination (Yeboah et al., 2011), exploration of the engineering feasibility of beneficial use options for the dredge material from the Savannah River is attractive for reducing the land use required for disposal both new dredge soils and currently stored materials.

Dredge materials are often used beneficially in engineering and environmental restoration projects. Previous studies have investigated applications in nearshore placement, beach nourishment, creation of shorebird nesting habitat, restoration of the river shoreline, creation of tidal marsh and wetlands, production of bricks, capping of cadmium-laden sediments, and reuse of material for future dike raisings (Yeboah et al., 2011; Mezencevova et al., 2012;USACE , 2012a). The material dredged from the Savannah River consists primarily of sands, clay and silts, so alternative beneficial use of dredged sediments as suitable raw materials may be evaluated and considered for large scale geotechnical applications. A thorough physical, chemical and morphological characterization of dredged material is critical for determining the suitability, feasibility and sustainability analysis for beneficial use of dredged material.

2 EXPERIMENTAL MATERIALS AND METHODS

Dredged soils were sampled in the disposal site at eight different locations (designated: 12A, 13A, 13B-1, 13B-2, 14A-1, 14B-1, 14B-2, 14B-3). Two nineteen-liter buckets of soil were collected in each location, and soil samples were obtained at relatively shallow depths (up to 0.7 m of depth). The pH values of all samples ranged from 6 ~ 7, as measured by a pH indicator in the field. After oven-drying, the samples had color that ranged from homogeneously light brown to black. Larger aggregates found in the sample were broken down into individual particles with a mortar and pestle. In the field, the soil classified as predominantly sand and silt with a very small amount of aggregated particles. The results of four out of the eight samples are presented in this paper, chosen to represent separate USCS soil classification types, which includes CH (high plasticity clay), SC (clayey sand), SP (poorly graded sand) and SP-SM (poorly graded sand with silt).

Grain size distributions were determined according to ASTM D422 and with a Malvern 3000 Hydro Eve laser particle size analyzer, and the results were combined to yield the overall particle size distribution (Fig. 1). Fine-grained soils from samples CH and SC were also tested by hydrometer in accordance with ASTM D7928-17 to determine the grain size distribution of the fines content (passing No. 200 sieve). Comparing the results from the hydrometer (sedimentation analysis) with the results obtained from the laser diffraction tests (PSA), demonstrated that the grain size curves diverged due to the different assumptions for calculating particle size in each method (Fig. 1). The hydrometer analysis relies on Stokes's law, with the assumption that all particles are spherical, while the PSA is primarily useful when particle size distributions are uniform, resulting in deviations in the resulting grain size analysis curves.

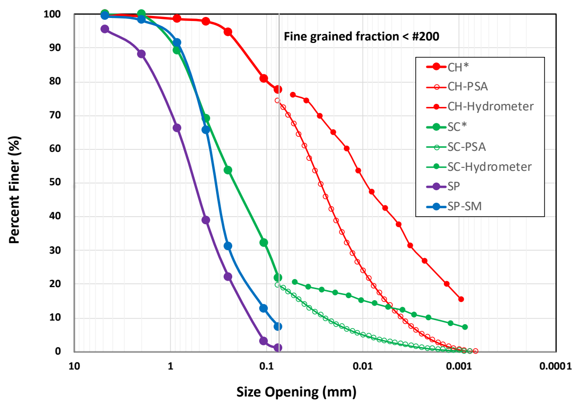

Fig. 1. Grain size distribution of CH, SC, SP and SP-SM. The results of CH and SC are shown in a combination of sieve analysis test, laser diffraction analysis and hydrometer analysis.

Samples, along with their relevant physical properties, are denoted based on their USCS soil classification (Table 1). Atterberg limits tests were performed according to ASTM Standard D4318. Dredged material samples CH and SC were tested to determine maximum dry unit weight according to ASTM D698, using standard effort. Total and inorganic carbon contents were determined using a Shimadzu TOC-V Analyzer fitted with a solid sample module (SSM-5000A). Inorganic and total carbon contents were measured by acidification with 85% nitric acid at 200 °C, and combustion at 900 °C, respectively. Total organic carbon content (TOC) was determined by subtraction. LOI was determined by heating the dredge material to 750°C in a muffle furnace, in accordance with ASTM D7348, Method A. The specific gravity was tested for each sample following ASTM D-854. Each procedure was repeated two times and the average reading was reported. Flexible wall hydraulic conductivity tests were performed according to ASTM D5084 at confining pressures equal to 34.5 kPa, 68.9 kPa and 103.4 kPa. A scanning electron microscope (SEM) (Hitachi SU8010) was used to identify soil morphology.

Table 1. Physical properties of four samples of dredge material.

Sample ID (USCS soil Classification)	Sample Zone	LL (%)	PL (%)	TOC (%)	LOI (%)	TGA (%)	Specific Gravity
CH	12A	69	47	4.0	19.37	18.01	2.51
SC	13A	70	38	4.5	14.73	14.60	2.68
SP	13B-1	(-)	(-)	0.2	2.70	3.61	2.70
SP-SM	14A-1	(-)	(-)	0.2	3.08	3.05	2.74

3 RESULTS AND DISCUSSION

Results from the characterization tests demonstrated that the soils segregated as function of disposal practices. In general, the coarse grained dredge sediments have commercial value and are disposed in isolated containment dikes where they can be harvested for beneficial use. Finer grained dredged sediments are sluiced to containment dikes where they are allowed to gravity settle and consolidate under self-weight. Significant differences were measured as a function of disposal location, as quantified in all physical characteristics (Table 1). The total organic contents of the fine grained soils (CH and SC) were approximately 4% higher than the TOC of the coarse grained soils (SP and SP-SM), which will impact the mechanical properties of dredged soils, including strength and deformability. Additionally, the organic matter in the soils will increase chemical activity, as well as physiochemical and microbiological processes (Malkawi et al., 1999).

While the TOC method measured the amount CO_2 produced during the combustion process, the loss of mass of other mineral phases was not quantified using this technique. Consequently, the loss on ignition (LOI) method, and dual atmosphere thermogravimetry analysis (TGA) method were also applied to the samples to help identify other sources of mass loss as a function of mineralogy. During combustion, iron present in the mineral structures was oxidized to iron oxide phases, such as hematite. The presence of the reddish color in the samples was an indicator of structural iron that was transformed into iron oxides at high combustion temperatures. XRD tests are in process to confirm the mineral phases that were involved in the transformation to iron oxide. The mass loss quantified by the LOI and TGA methods were in close agreement and yielded approximately 15 – 20% in fine grained soils, compared to approximately 3% in coarse grained soils.

The confining stress 34.5 kPa, 68.9 kPa and 103.4 kPa (5 psi, 10 psi and 15 psi) were used for hydraulic conductivity testing to represent similar stress levels in the field. The hydraulic conductivity ranged from 10^{-7} cm/sec for the fine grained soils to 10^{-3} cm/sec for the coarse grained soils (Table 2). The very low hydraulic conductivity values measured for the fines will be a concern in applications that require drainage and dewatering, as 10^{-7} cm/sec is on the order of conductivity values used in barrier applications; however, the conductivity values measured in the coarser soil samples indicate relatively free draining materials, suitable for fills. It was noted that diatoms were present in the samples, which may have some impact on results of hydraulic conductivity. Diagenetic bonding of diatomaceous fabric may reduce the well-connected pore spaces significantly, which would also alter the tortuosity and increase the length of drainage path (Masters and Christian, 1990).

Table 2. Hydraulic conductivity of dredge material.

Confining Pressure (kPa)	CH (cm/s)	SC (cm/s)	SP (cm/s)	SP-SM (cm/s)
34.5	7.5E-07	3.1E-05	7.8E-03	1.2E-03
68.9	6.7E-07	2.5E-05	5.3E-03	8.2E-04
103.4	4.3E-07	1.8E-05	2.5E-03	4.3E-04

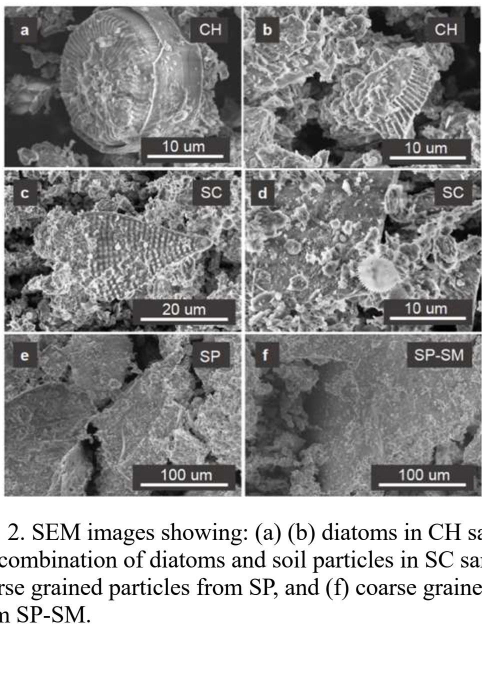

Fig. 2. SEM images showing: (a) (b) diatoms in CH sample, (c) (d) combination of diatoms and soil particles in SC sample, (e) coarse grained particles from SP, and (f) coarse grained particle from SP-SM.

CH and SC were chosen to investigate the compactibity due to their higher fine contents compared with SP and SP-SM. The optimum water content of sample CH was 35.8%, and the maximum dry unit weight was 12.4 kN/m^3, while the optimum water content of the sample SC was 38.0%, and the maximum dry unit weight was 11.8 kN/m^3 (Fig. 3). The results of the optimum water content of the two dredged samples were higher than what has been reported in the literature for dredged sediments, which typically ranges between 19.5% and 30% (Yu et. Al, 2016; Baxter et al, 2005), and was likely caused by the high organic content and the presence of diatoms in the soil (Fig. 2).

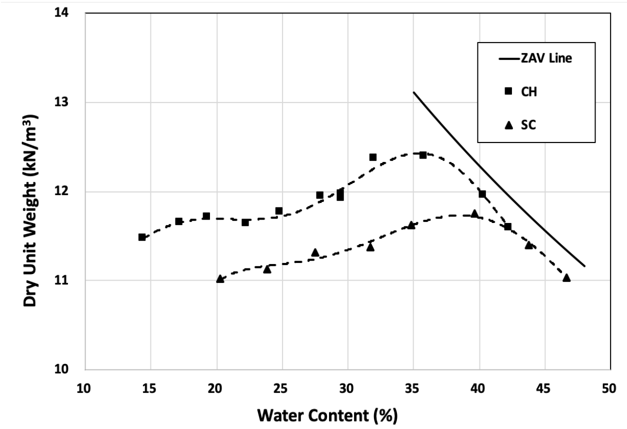

Fig. 3. Water cntent versus dry unit weight for sample CH and SC. Tests were performed using standard Proctor with best polynomial curve. Zero air voids curve (ZAV) is shown in solid line for reference.

For the dredged sediments tested in this study, increasing organic matter content resulted in increased optimum water content and decreased maximum dry unit weight (Hamouche and Zentar, 2020). Organic matter absorbs water, resulting in a sponge-like and soft consistency, thus reducing the soil's compactability by increasing the stability of the soil and also by retaining more water that absorbs energy during compaction (Malkiwi et al., 1999). For use as a fill material, the soil will have highest unit weight when the water content is at optimum, where the fill soil will exhibit the lowest deformability.

From an engineering perspective, the high organic content, low maximum dry densities and high optimum moisture contents of CH and SC would restrict the usage to non-structural fill applications. In general, the presence of high organic content in the soils may lead to long term decomposition settlements attributable to biodegradation. However, this would not affect the usage of CH and SC in non-structural fill applications, for example, on a road embankment where the material does not have to sustain high loads. SP and SP-SM soils can be used as materials for structural fill.

4 CONCLUSIONS

The chemical, physical and morphological properties of dredged sediments from Savannah River were investigated in order to evaluate their potential beneficial use in large-scale geotechnical engineering applications. The engineering tests included particle size distribution, Atterberg limits, specific gravity, standard compaction tests, TOC, LOI, TGA and SEM.

The test results indicated that CH and SC dredge are promising materials in non-structural fill geotechnical applications while SP and SP-SM can be used as structural fill. Further studies are underway elucidating the shear strength and modulus (static and cyclic loading), deformability (consolidation), cost, social and sustainability feasibility of the dredged material in large scale geotechnical applications.

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