ERDC/CHL TR-22-11

Coastal and Hydraulics Laboratory

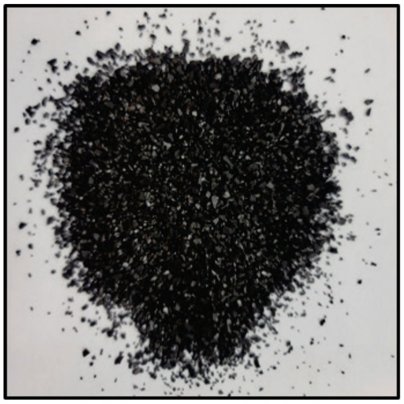
US Army Corps
of Engineers®
Engineer Research and
Development Center

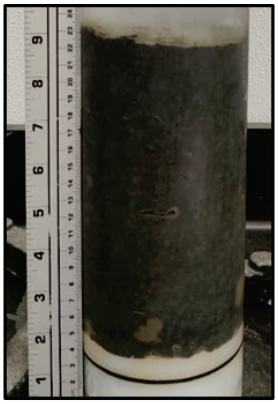
Dredging Operations Environmental Research Program

Impacts of Granular Activated Carbon (GAC) on Erosion Behavior of Muddy Sediment

Danielle R. N. Tarpley and David W. Perkey

July 2022





Dredging Operations Environmental
Research Program

ERDC/CHL TR-22-11
July 2022

Impacts of Granular Activated Carbon (GAC) on Erosion Behavior of Muddy Sediment

Danielle R.N. Tarpley and David W. Perkey

Coastal and Hydraulics Laboratory
US Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Final report

Prepared for Dredging Operations Environmental Research Program
US Army Engineer Research and Development Center
Vicksburg, MS 39180-6199

Under Funding Account Code U4381626; AMSCO Code 089500

Abstract

Recent policy changes regarding the placement of dredged material have encouraged the USACE to increase its beneficial use (BU) of the sediments dredged from the nation's navigation channels. A good portion of this material is fine grained (<63 μm), which traditionally has limited use in BU applications, in part due to its dispersive nature. A need exists to evaluate the potential of stabilizing and using fine-grained sediment (FGS) in BU projects. Previous studies have shown the addition of granular sand to FGS reduces the mobility of the bed. The potential of using Granular Activated Carbon (GAC), an amendment commonly used in environmental capping involving FGS, as a similar bed stabilizing material was explored in this study. A series of laboratory erosion tests using Sedflume were performed on FGS-GAC mixtures that ranged from 5% to 20% GAC by mass. Results suggested that GAC content ≤10% had no influence on the stability of the bed while GAC content ≥15% appeared to reduce both critical shear stress (τ_{cr}) and erosion rate (n). However, when compared to control cores, those without GAC, clear evidence of bed stabilization of FGS from the addition of GAC was not observed.

Contents

Figures and Tables

Figures

Tables

Preface

This study was conducted for the Dredging Operations Environmental Research Program under Funding Account Code U4381626; AMSCO Code 089500. The technical monitor was Dr. Todd S. Bridges.

The work was performed by the Field Data Collection and Analysis Branch of the Navigation Division, US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (ERDC-CHL). At the time of publication of this report, Mr. William C. Butler was chief of the Field Data Collection and Analysis Branch; Ms. Ashley E. Frey was chief of the Navigation Division; and Mr. Charles E. Wiggins was the technical director for Navigation. The deputy director of ERDC-CHL was Mr. Keith W. Flowers, and the director was Dr. Ty V. Wamsley.

The commander of ERDC was COL Teresa A. Schlosser, and the director was Dr. David W. Pittman.

1 Introduction

1.1 Background

Annually, the US Army Corps of Engineers (USACE) dredges approximately 350–400M yd^3[1] of material from the nations' navigable waterways (USACE RSM 2021). Recent changes in policy (e.g., The Water Resources Development Act of 2020) are encouraging the USACE to find more ways to beneficially utilize the sediments it dredges and reduce its placement within inland and offshore disposal locations. Traditionally, the beneficial use of dredged fine-grained sediment (FGS), <63 μm in size, is limited in many USACE projects, in part due to the dispersive nature of these sediments after placement but before consolidation. Stabilizing FGS immediately after placement can increase application for source control, environmental capping, thin layer placement in intertidal zones, and wetland construction. A need exists to evaluate potential for using dredged FGS in beneficial use projects and to identify potential stabilizers to minimize the erosion and transport of placed sediments immediately following placement. The goal of this experiment is to evaluate if the addition of limited amounts of Granular Activated Carbon (GAC) to fine sediment has measurable impacts on erosion behavior.

GAC is an amendment that is frequently used in dredged material capping involving contaminated sediments. The sorbent properties of GAC allow it to significantly reduce the bioavailability of PAHs, PCBs, dioxins, and pesticides (USEPA 2005, 2013). These contaminants are often associated with fine-grained sediments, and thus amendments involving GAC and mud are not uncommon in environmental dredging projects. However, the addition of GAC to muddy material may serve an added benefit beyond contaminant treatment. Previous studies evaluating the erosion rate and critical shear stress of sediment beds have demonstrated that the addition of sand to muddy beds can effectively reduce erosion rates and increase the critical shear stress (Mitchener and Torfs 1996). However, this increase in erosion resistance has been associated with both the alteration

---

[1] For a full list of the spelled-out forms of the units of measure used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office 2016), 248-52, https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

of the bed structure and density. While the addition of GAC may similarly increase the coarse granular bed structure as sand, the lower specific gravity of GAC (~1.3 g/cm^3) would not impact the bulk density of the sediment bed in the same manner as quartz sand (~2.65 g/cm^3). Testing is required to evaluate if adding GAC to muddy beds has similar impacts to erosion behavior of muddy beds as the addition of sand.

1.2 Objective

The objective of this study is to conduct erosion experiments on GAC-mud mixtures to evaluate if the addition of GAC to FGS has a stabilizing impact on the sediment mixture by making it more resistant to erosion.

1.3 Approach

A series of laboratory experiments were conducted to quantify changes in critical shear stress and erosion rate of GAC-FGS mixtures as a function of GAC content (percent by mass) and consolidation time. The experimental set consisted of 15 artificially created cores prepared from muddy sediments obtained from a confined disposal facility (CDF) near Pascagoula, MS. The GAC content for each core varied between 0% to 20%. Erosion rates were measured as a function of flow rate (and thus applied shear stress) in the USACE-developed Sedflume[1] erosion device.

1.4 Report content

This report presents the methodologies utilized and results from laboratory erosion experiments conducted. Impacts of GAC content on both critical shear stress and erosion rate will be discussed.

---

[1] Sediment Erosion with Depth

2 Methods

This section describes the experimental and data analysis methods used in determining cohesive sediment erosion of sediment cores comprised of GAC and FGS obtained from a CDF adjacent to the Pascagoula Shipping Channel near Pascagoula, MS. Background and technical information about the experimental devices are presented first, followed by a description of how these devices were utilized during laboratory experiments to meet the study objectives.

2.1 Sediment properties of test material

The physical properties of the bed material from a CDF near Pascagoula, MS (Figure 2-1), were analyzed, including the grain size distribution and bulk density. The water content measurement was used to determine the mass of GAC to add to each mixture to obtain mixtures of 5%, 10%, 15%, and 20% GAC. The GAC mixed with the CDF material in this study was 3M Aqua-pure activated carbon filter media A-050P, a coconut shell material. The granule size range was 0.420–1.68 mm, and the specific gravity of the GAC material was 1.33 g/cm^3.

Figure 2-1. Map of the Gulf Coast of Mississippi and Alabama, United States, with a red star marking Pascagoula, MS.

2.1.1 Grain size

Grain size distribution for the Pascagoula material was obtained through Laser Diffraction Particle Size Analysis with a Malvern Mastersizer 3000E, which measures particle sizes in the range of 0.01 to 1000 µm. Sediments were homogenized and disaggregated overnight in a solution of sodium metaphosphate (40 g/L). To remove any macro-organic material, samples were passed through a 1000 µm sieve into the instrument's reservoir and sonicated for 60 sec prior to analysis. The Wentworth (1929) scale was used for the classification of sand (>63 µm)-, silt (63-4 µm)-, and clay (<4 µm)-sized particles. Additionally, the equivalent spherical diameter for which 10% (D_{10}), 50% (D_{50}), and 90% (D_{90}) of the sample by volume was smaller than was calculated.

2.1.2 Bulk density

Water content (w) of each sample was measured through wet-dry weight analysis following ASTM International (2019) D2216-19 in which w is given by

$$w = \left(\frac{m_w - m_d}{m_d} \right) \tag{1}$$

where m_w and m_d are the wet and dry weights, respectively. The total volume of sample was assumed to consist of both solid particles and water, with assumed densities of 2.65 g/cm^3 and 1.0 g/cm^3, respectively. As the density of the GAC was 1.33 g/cm^3, the assumed density of the solid particles was adjusted for the test core samples using the GAC content (*GAC%*), as shown in Equation 2. The bulk density as a function of w and the densities of the solid particles (ρ_s) and water (ρ_w) was calculated with Equation 3, derived from Jepsen et al. (2010).

$$\rho_s = 2.65 \times (1 - GAC\%) + 1.33 \times GAC\% \tag{2}$$

$$\rho = \rho_s + \frac{w\rho_s\left(\rho_w - \rho_s\right)}{\rho_w + w\rho_s} \tag{3}$$

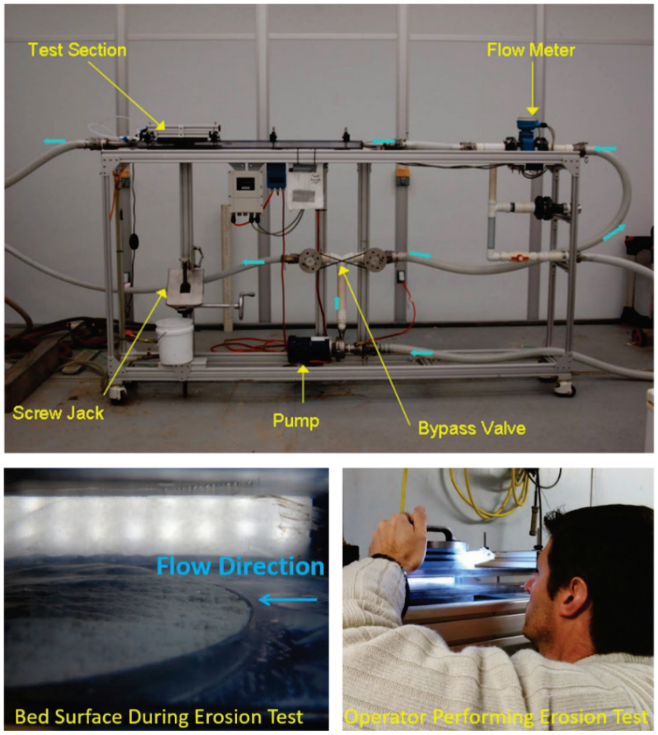
2.2 Erosion testing

2.2.1 Sedflume

All erosion testing was performed with the USACE-developed Sedflume, which is a derivative of the flume developed by researchers at the University of California at Santa Barbara (McNeil et al. 1996). The flume includes an 80 cm long inlet section (Figure 2-2) with cross-sectional area of 2 × 10 cm for uniform, fully developed, smooth-turbulent flow, as described in McNeil et al. (1996). The inlet section is followed by a test section with a 10 cm diameter open bottom. Coring tubes and flume test section, inlet section, and exit sections are constructed of clear polycarbonate materials to permit observation of sediment-water interactions during the erosion experiments. The flume includes a port over the test section to provide access to the core surface for physical sampling. The maximum length for a testing core is 80 cm.

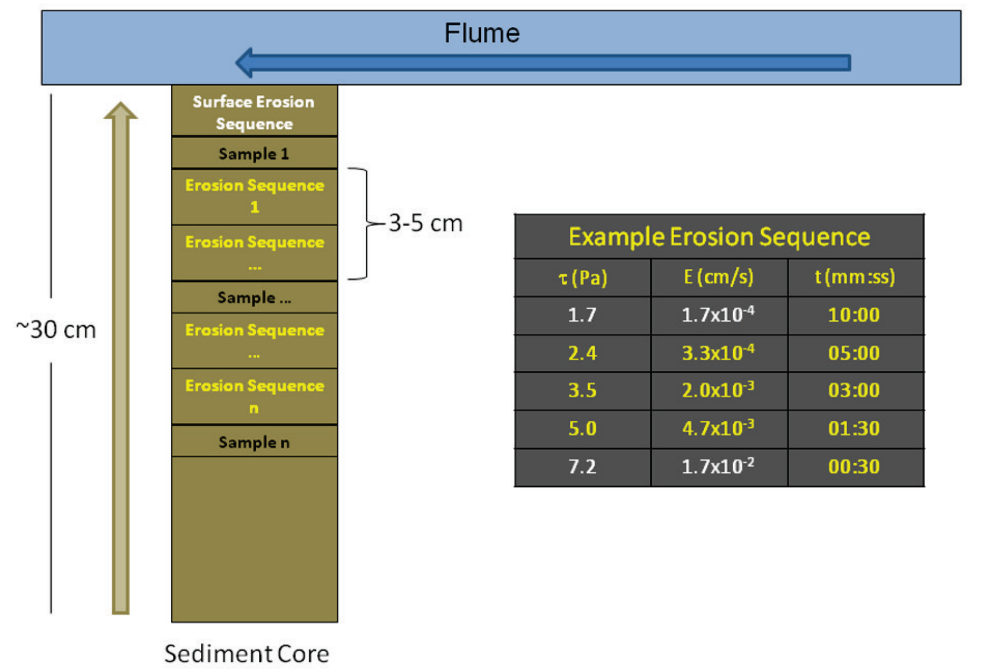
Cores are inserted into the testing section of Sedflume, and a screw jack is used to advance the plunger such that the core surface becomes flush with the bottom wall of the flume. Flow is directed over the sample by diverting water from a 5.5 hp trash pump, through a 5 cm inner diameter hose, into the flume. The flow through the flume produces shear stress on the surface of the core. Numerical, analytical, and experimental analyses have been performed to relate flow rate to bottom shear stress (Figure 2-2). As sediment is eroded from the core surface, the operator advances the screw jack to maintain the sediment surface flush with the bottom wall of the erosion flume. Erosion experiments are performed by repeating a sequence of increasing shear stresses. Physical samples of the core surface used for bulk density measurements were taken after the first, third, and last erosion sequence. Approximately 1–5 mm of sediment is eroded at each specified shear stress; thus, the duration of each test is dependent on the rate of erosion. A diagram depicting this erosion test process along with an example erosion sequence is shown in Figure 2-3.

Figure 2-2. Images of the Sedflume (upper left), erosion surface (lower left), and operator (lower center), along with operational test range of the flume (right).



Shear Stress (Pa)	Flow Rate (GPM)
0.1	5.2
0.2	7.9
0.4	11.5
0.8	17.8
1.5	25.8
1.0	20.3
1.5	25.8
2.0	30.6
2.5	34.9
3.0	38.8
4.0	46.0
5.0	52.4
6.0	58.3
8.0	69.1
10.0	78.8
12.0	87.7

Figure 2-3. Diagram of sediment core erosion process. The brown arrow indicates advancement of sediment into the flume with erosion. The blue arrow indicates flow direction of water. An example erosion sequence is provided in the table to the right of the sediment core.



Example Erosion Sequence

τ (Pa)	E (cm/s)	t (mm:ss)
1.7	1.7×10^{-4}	10:00
2.4	3.3×10^{-4}	05:00
3.5	2.0×10^{-3}	03:00
5.0	4.7×10^{-3}	01:30
7.2	1.7×10^{-2}	00:30

2.2.2 Slurry and core preparation

The fine-grained, cohesive sediment used for this study was collected from the shipping channel near Pascagoula, MS, from a CDF site. The sediment was shipped to the USACE Engineer Research and Development Center (ERDC) in Vicksburg, MS, and a 15 gal subsample of the material was homogenized with a cement mixer in the ERDC Coastal and Hydraulic Laboratory sediment laboratory. Samples were pulled from the mixture to obtain grain size distribution and bulk density measurements. Following this initial testing, the slurry was stored in a 4°C cooler until the preparation of the sediment cores.

The water content measurement of the CDF material was used to calculate the percentage of dry sediment for the FGS (m_d/m_w). In preparing GAC-FGS mixtures, a portion of the CDF material was weighed and the mass of the solid material was determined using dry sediment percentage. This dry mass of the CDF material was used to calculate the mass of GAC required for the desired mixture content. Following weighing, the two materials were combined and thoroughly mixed. These mixtures with varying GAC content were used in the preparation of the cores, described below.

All cores for erosion analysis were prepared in 10 cm diameter polycarbonate tubes. Prior to placing sediment in the tube, a plunger with bentonite paste (for sealing and lubrication) was inserted into the bottom of the core. The designated homogenized slurry was then poured through a funnel and polyvinyl chloride (PVC) pipe that was inserted into the core tube, allowing the sediment column to be filled from the bottom up to reduce the entrapment of gas that weakens the erosion surface. After filling, the PVC pipe was removed from the slurry, and water was placed on top of the sediment column. The cores were then capped and allowed to consolidate in a 4°C cooler for periods of 2, 7, and 30 days prior to erosion. These consolidation periods were chosen to capture changes during the initial stages of consolidation (2 and 7 days) and long-term consolidation (30 days) as determined in prior research (Mehta 2013). Table 2-1 provides composite sample and core logging information for each of the cores prepared.

2.2.3 Erosion analysis

The goal of the erosion data analysis is to determine if the addition of GAC to FGS impacts sediment bed erodibility. Logarithmic regressions of erosion rate versus applied shear stress are performed to determine coefficients for a common cohesive sediment erosion expression. In this study, the data were fit to the Sedflume erosion expression, $E=A\tau^n$ where E is erosion rate in cm/s, τ is the applied shear stress in Pascals, and A and n are parameters determined from the logarithmic regression fit to the data. Critical shear stress, τ_{cr}, is determined from the regression parameters such that τ_{cr} is the shear stress that corresponds to an erosion rate, E_c of 10^{-4} cm/s (or 3.6 mm/hr).

Table 2-1. Core summary.

GAC Content [%]	Consolidation Time [days]	Preparation Date	Erosion Date	Initial Core Length [cm]	Final Core Length [cm]
0	2	3-8-2021	3-10-2021	24.0	17.2
0	7	3-9-2021	3-16-2021	27.5	17.9
0	30	3-8-2021	4-7-2021	24.6	11.4
5	2	3-9-2021	3-11-2021	24.5	16.8
5	7	3-8-2021	3-16-2021	22.0	11.7
5	30	3-9-2021	4-7-2021	23.3	14.6
10	2	3-16-2021	3-18-2021	19.8	12.7
10	7	3-10-2021	3-17-2021	23.0	15.3
10	30	4-26-2021	5-24-2021	26.0	19.0
15	2	3-16-2021	3-18-2021	21.8	16.8
15	7	3-10-2021	3-17-2021	22.8	15.7
15	30	4-26-2021	5-25-2021	28.5	19.8
20	2	3-17-2021	3-19-2021	28.8	22.2
20	7	3-12-2021	3-19-2021	23.0	15.9
20	30	4-26-2021	5-25-2021	28.5	20.0

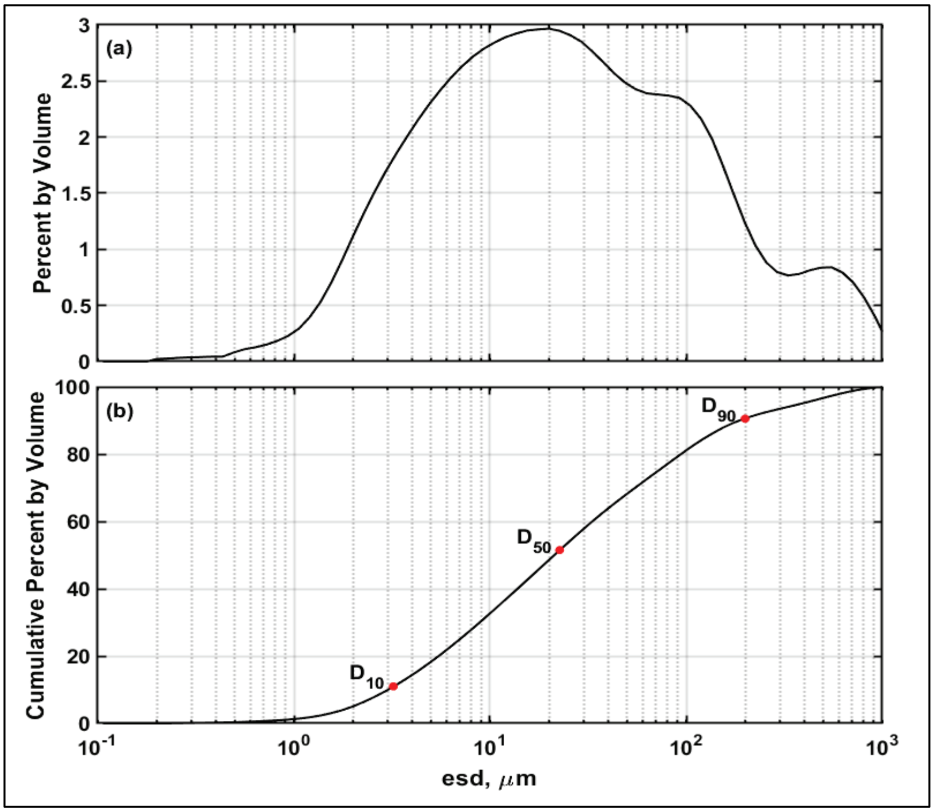
3 Results and Discussion

The physical properties measured for the Pascagoula CDF material are presented in this section followed by the analysis of the erosion testing performed during this laboratory study. The data analysis and parameterization are organized by GAC content. Core descriptions including photographs are provided in Appendix A. A full presentation of the analyzed data set and the erosion parameters for all cores are summarized in Appendix B.

3.1 Sediment properties of the fine-grained sediment slurry

The CDF material from the shipping channel near Pascagoula, MS, was composed of primarily fine-grained sediment (silt and clay) containing 25.9% sand, 58.6% silt, and 15.5% clay with a D_{10}, D_{50}, and D_{90} of 3 µm, 23 µm, and 200 µm, respectively (Figure 3-1). The water content (*w*) of the slurry used to create the cores for erosion testing was 1.50, and the bulk density was 1.33 g/cm^3.

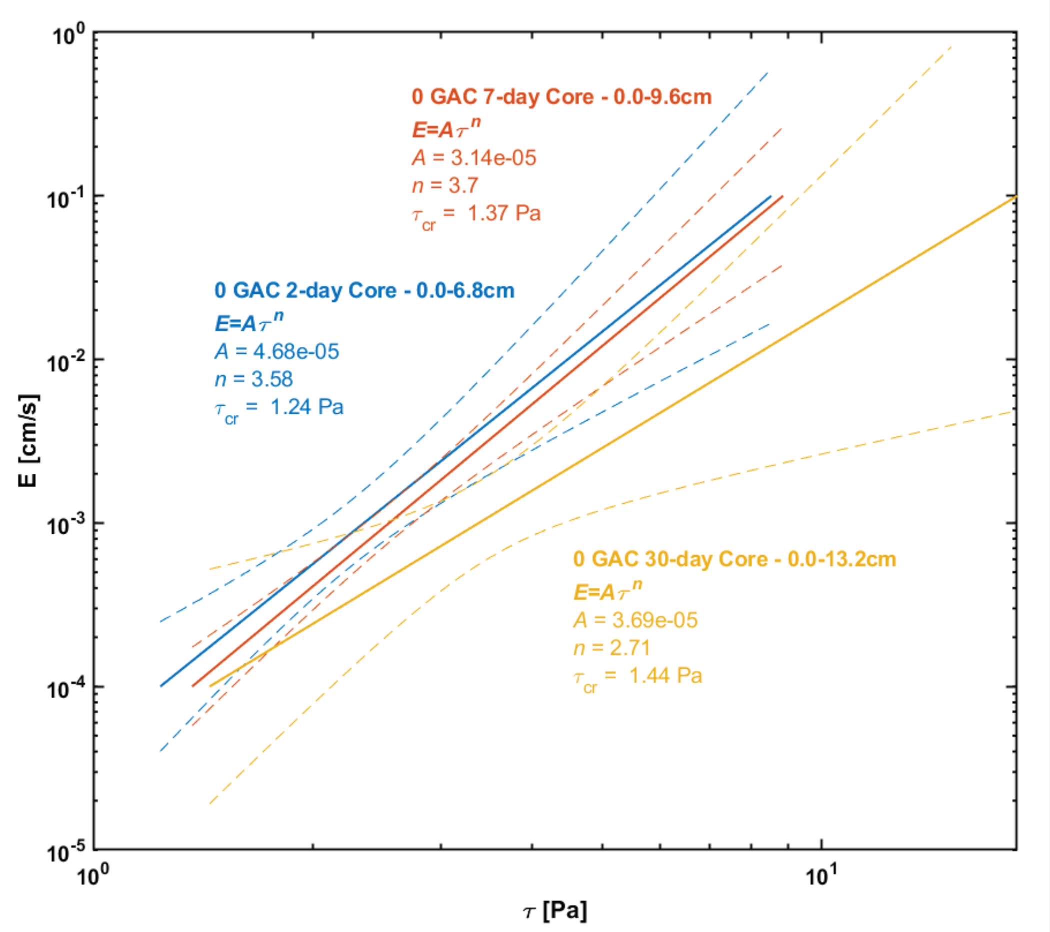
Figure 3-1. The (a) grain size distribution curve and (b) cumulative distribution curve measured by laser diffraction showing the equivalent spherical diameter (esd; µm) and percent of the sample by volume.



3.2 Erosion behavior of the CDF material

Sediment cores containing only the CDF material served as a control for this study. The erosion behavior of this sediment varied slightly with increased consolidation time. However, the variability was not statistically different as indicated by the overlap in the 95% confidence interval bounds in the erosion parameter fits (Figure 3-2). The range of the critical shear stress (τ_{cr}) for the cores without GAC was 1.24–1.44 Pa in which τ_{cr} was highest for the core eroded following 30 days of consolidation. The range of the erosion rates (*n*) from the fits was wider having values of 2.71–3.71. The lowest erosion rate corresponded to the core with the longest consolidation time (30 days) indicating the CDF sediment bed was more stable (less erodible) over time, as expected.

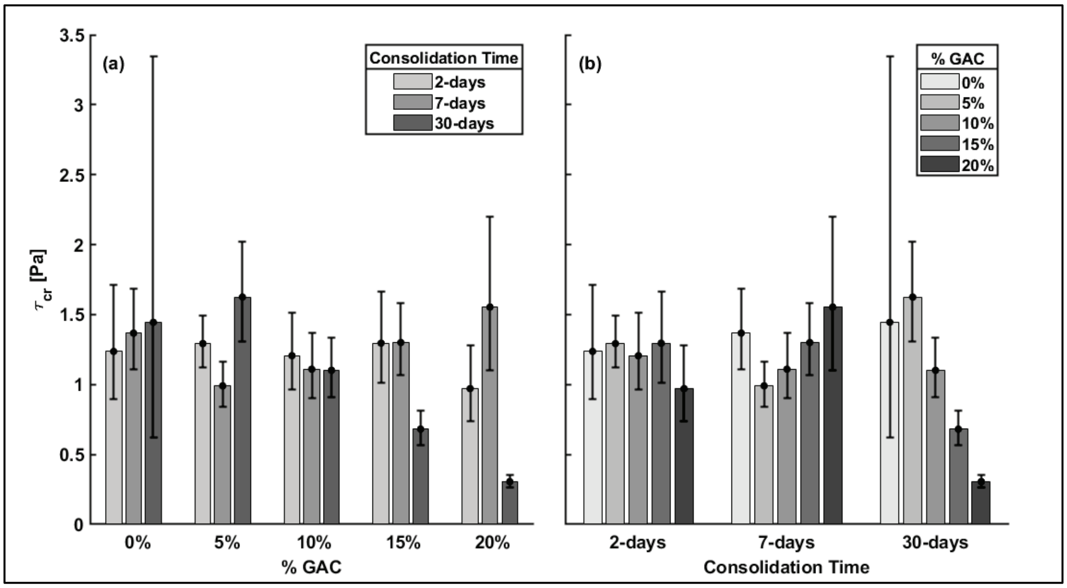
Figure 3-2. Erosion fits (solid lines) with 95% confidence interval (dashed lines) for 0% GAC for consolidation time of 2 days (blue), 7 days (red-orange), and 30 days (yellow).



3.3 Erosion behavior and physical properties of GAC mixtures

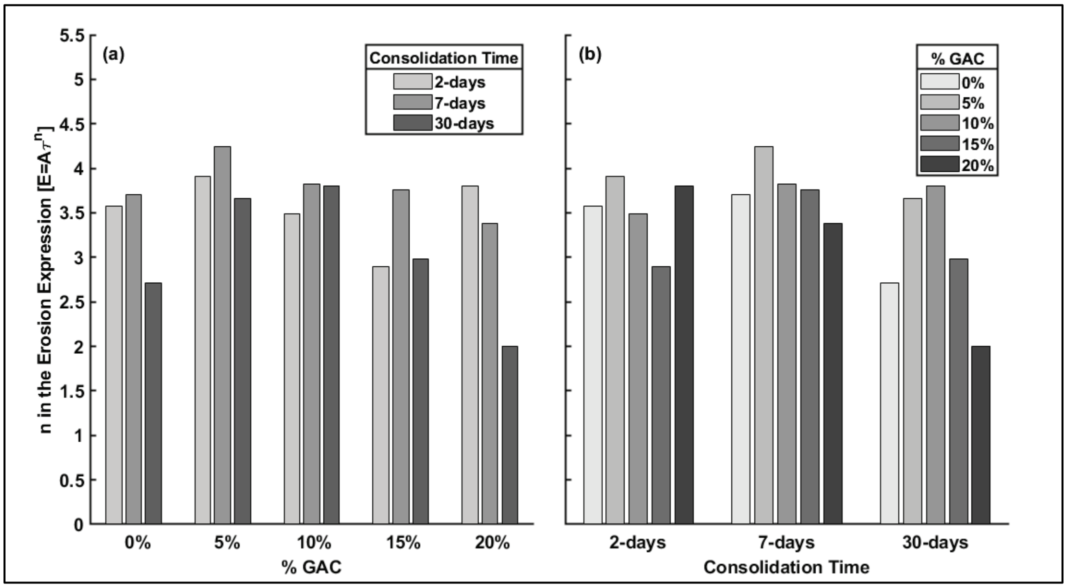
Erosion testing results from this experiment showed that the addition of GAC to CDF sediment had no definitive effect on τ_{cr}. The range in τ_{cr} for all 12 test cores was 0.31-1.63 Pa, excluding the uncertainty bounds (Table B-1, Appendix B). There was no statistical difference observed in cores with GAC contents ≤10% when compared to the control cores over all consolidation times, as indicated by the overlap in the 95% confidence intervals (Figure 3-3). The cores with 15% and 20% GAC content had statistically lower τ_{cr} after 30 days of consolidation when compared to the other test cores (Figure 3-3a). However, due to the large uncertainty observed in τ_{cr} for the 30 day consolidation control core (0% GAC), only the core with 20% GAC content had a statistically lower τ_{cr} (Figure 3-3b) from the rest of the data set. Omitting the 0% GAC core, a general trend of decreasing τ_{cr} with increasing GAC content was observed in the cores following 30 days of consolidation (Figure 3-3b).

Figure 3-3. Critical shear stress (τ_{cr}) with the lower and upper bounds for a 95% confidence interval grouped by (a) GAC content and (b) consolidation time.



As observed with τ_{cr}, the effect of GAC on erosion rates (*n*) did not have a consistent trend across quantities or consolidation times tested. The full range in *n* over all 12 test cores was 2.00–4.25 (Table B-1). Erosion rates for test cores with ≤10% GAC stayed within the range of 3.5–4.25 across all consolidation times (Figure 3-4a). The values for *n* were slightly lower for 15% GAC (2.9–3.75) with no persistent trend over the consolidation times. Cores with 20% GAC showed a decrease in erosion rate as consolidation time increased (Figure 3-4a). Variability in *n* due to consolidation time was more evident in Figure 3-4b. Erosion rates for 2-day and 7-day consolidation times were similar in range for all GAC quantities (Figure 3-4b). After 30 days of consolidation, *n* was found to be more variable. Erosion rates for GAC contents of 5% and 10% were similar to the rates observed in the 2- and 7-day consolidation data while lower rates were observed at 15%, and 20% (Figure 3-4b). However, for the 30-day consolidation period, only the core with 20% GAC had a lower erosion rate than the control (0% GAC).

Figure 3-4. Erosion parameter "n" from erosion expression grouped by (a) GAC content and (b) consolidation time.



The bulk density samples taken during the erosion testing of each core were examined to determine if bed density was a contributing factor to the variability in observed erosion behavior. The range in bulk density in the control core samples was 1.32–1.34 g/cm^3. In comparison, the range in the bulk density was 1.32–1.37 g/cm^3 for all samples from the 12 test cores (Table A-16). The change in bulk density with depth for the test cores was also minimal; of these cores, the maximum change with depth was 0.03 g/cm^3. Overall, the ranges in bulk density for the test cores were minimal, bracketed the bulk density of the CDF material and control cores, and was within expected standard deviation for the method used to determine bulk density (ASTM International 2019). As such, bed density does not appear to be a primary factor that could be associated with any variability shown in the erosion data.

4 Conclusions and Recommendations

Previously published test data indicate that the addition of sand to a muddy sediment matrix can increase the critical shear stress and resiliency of the sediment bed (Mitchener and Torfs 1996). Based on these data, a preliminary investigation into the potential of using GAC to stabilize fine-grained dredged material after placement was conducted. This study performed erosion testing with Sedflume (McNeil et al. 1996) on sediment cores consisting of sediment collected from a CDF near Pascagoula, MS, mixed with GAC ranging in content from 0% to 20% by dry mass. The cores were eroded after 2, 7, or 30 days of consolidation time.

4.1 Conclusions

Experimental testing with sand-mud mixtures has demonstrated that the addition of granular sand (10%–50% by mass) to a muddy bed can potentially reduce the erosion rate and increase the critical shear stress by a factor of 2 (Mitchener and Torfs 1996); similar results were not observed in this test with GAC. The comparison of the erosion parameters, τ_{cr} and n, between the control cores and the ones with a GAC content of 5%–10% indicated the addition of GAC did not strengthen or weaken the sediment bed as there was not a statistical difference in the results. The same was true for GAC content of 15%–20% for consolidation times of 2 and 7 days. However, following 30 days of consolidation, some noticeable differences were observed in cores with GAC contents of 15%–20%.

Data indicated that the GAC had conflicting effects on sediment stability for these cores by reducing both τ_{cr} and n. The incorporation of 15%–20% of GAC to the fine-grained material, lead to a less stable sediment bed in respect to τ_{cr} in that sediment could be removed from the bed at a lower shear stress. However, the smaller n showed this erosion occurs at a slower rate as the applied shear stress increases indicating a slightly more resilient bed. Both behaviors greatly impact the amount of sediment that could be mobilized at the placement site after deposition. Therefore, it was beneficial to examine both parameters with respect to the erosional behavior of the mixed sediment. Note that the trend observed in this study was weak as the only test core to show a statistical difference in erosion behavior was the core with 20% GAC after 30 days of consolidation.

The mechanism responsible for promoting the difference in erosion behavior for GAC content greater than 15% for longer periods of consolidation is not apparent. Examination of the bulk density of the test cores revealed a consistent density across all cores and depths, indicating that this behavior was not likely caused by variability in bulk density.

4.2 Recommendations

As these are preliminary results from a limited data set, additional testing with natural sediment of varying silt and clay content would be beneficial to further evaluate the potential of using GAC as a stabilizing factor in designing muddy sediment caps with dredge material. Standard industry practice when designing an environmental capping is to specifically engineer the cap to remain stable in the hydrodynamic and bathymetric conditions of the placement area (Palermo et al. 1998; USEPA 2005, 2013). The amount of GAC used in an environmental cap is determined by factors such as permeability of the sediment, and type and concentration of the contaminant (USEPA 2005, 2013). The results of this testing indicate that additions of GAC to a muddy sediment on the order of ≤10% by mass may have limited to no impact on the stability of the sediment matrix. Therefore, if hydrodynamic conditions were adequate, the use of muddy dredged material requiring ≤10% GAC by mass for an environmental cap may be feasible with little risk of the GAC impacting the erodibility of the placed dredged material. However, sediment capping mixtures of dredged material requiring >10% GAC might display altered erosion behavior due to the addition of the GAC. Note that the feasibility of utilizing sediments that require GAC content >10% is likely to be limited not only by increased financial costs associated with the higher quantities of GAC required but also the environmental risks involved with using contaminated sediment that has the potential to be mobile.

References

ASTM International. 2019. *Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass*. ASTM D2216-19. West Conshohocken, PA: ASTM International.

Jepsen, R., J. Roberts, and J. Gailani. 2010. “Effects of Bed Load and Suspended Load on Separation of Sands and Fines in Mixed Sediment.” *J. Waterw. Port, Coast. Ocean Eng*. 136(6): 319–326. https://doi.org/10.1061/(ASCE)WW.1943-5460.0000054.

McNeil, J., C. Taylor, and W. Lick. 1996. "Measurements of Erosion of Undisturbed Bottom Sediments with Depth." *Journal of Hydraulic Engineering* 122(6): 316–324.

Mehta, A.J. 2013. *An Introduction to Hydraulics of Fine Sediment Transport*. Vol. 38. Hackensack, NJ: World Scientific Publishing Company.

Mitchener, H., and H. Torfs. 1996. “Erosion of Mud/Sand Mixtures.” *Coastal Eng*. 29(1–2): 1–25.

Palermo, M. R., J. E. Clausner, M. P. Rollings, G. L. Williams, and T. E. Myers. 1998. *Guidance for Subaqueous Dredged Material Capping*. Technical Report DOER-1. Vicksburg MS: US Army Engineer Waterways Experiment Station.

USACE RSM (US Army Corps of Engineers, Regional Sediment Management). 2021. Accessed July 26. https://www.arcgis.com/apps/MapSeries/index.html?appid=0ea8fc0a956f46068428c862e7497233.

USEPA (US Environmental Protection Agency). 2005. *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites*. EPA-540-R-05-012. Washington, DC.

USEPA. 2013. *Use of Amendments for In Situ Remediation at Superfund Sediment Sites*. EP-W-07-078. Washington, DC.

Wentworth, C. K. 1929. "Method of Computing Mechanical Composition Types in Sediments." *Bulletin of the Geological Society of America* 40(4): 771–790.

Appendix A: Core Descriptions

Tables A-1 through A-16 present core photographs, core descriptions, and analysis of physical samples.

Table A-1. Core description 0% GAC after 2 days of consolidation.

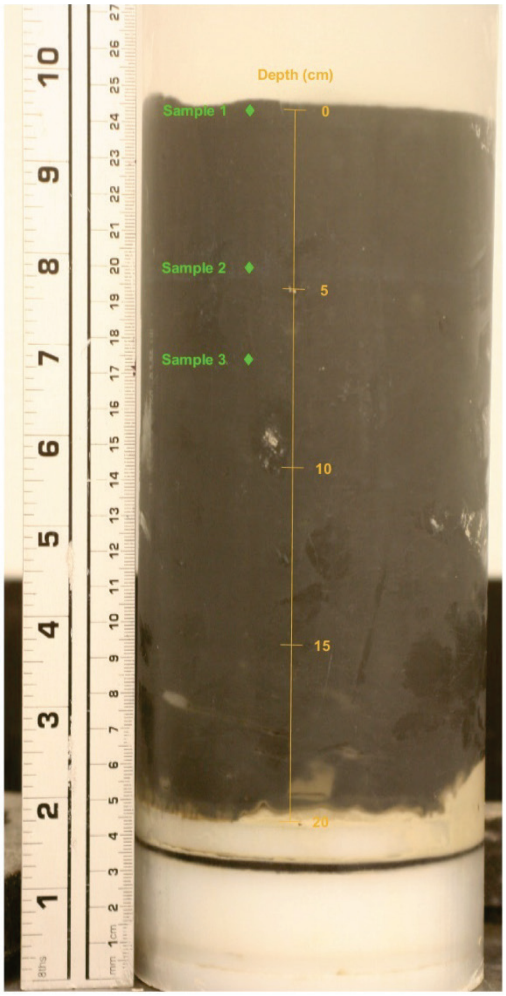
Photograph	Description
	Overlying Water
	Dark grey/black in color throughout core. Slightly uneven and mounded surface in the center. <1mm thick oxidized layer at surface. No visible voids or fractures in core.

Table A-2. Core description 0% GAC after 7 days of consolidation.

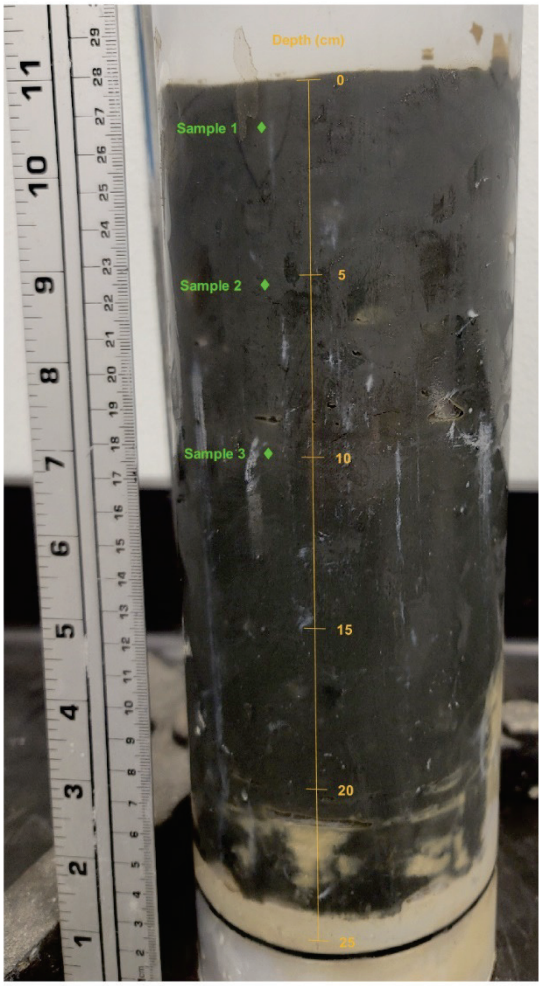
Photograph	Description
	Overlying Water
	Dark grey/black in color throughout core. Visible small voids ~3-10 cm depth. Visible crack near surface and ~10 cm depth. Benzenite clay on the core walls. Linear voids ~1-3 cm from bottom. Slight mound in the center of the surface. Core tube was cut at a slight angle, the high side was positioned on the upstream side of the flume.

Table A-3. Core description 0% GAC after 30 days of consolidation.

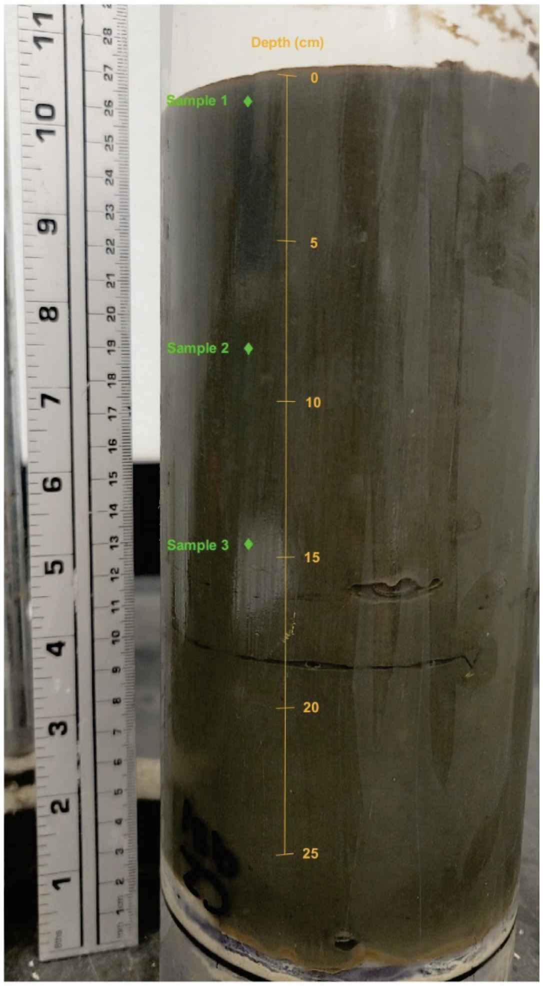
<table>
<tr><th>Photograph</th><th>Description</th></tr>
<tr><td rowspan="2">
</td><td>Overlying Water</td></tr>
<tr><td>Dark grey/black in color throughout core. Visible linear voids ~11 cm depth ~1 cm in width and ~12 cm depth ~1/3 of the core diameter. Small visible voids near the bottom of the core. Oxidized surface with small peak near the center.</td></tr>
</table>

Table A-4. Core description 5% GAC after 2 days of consolidation

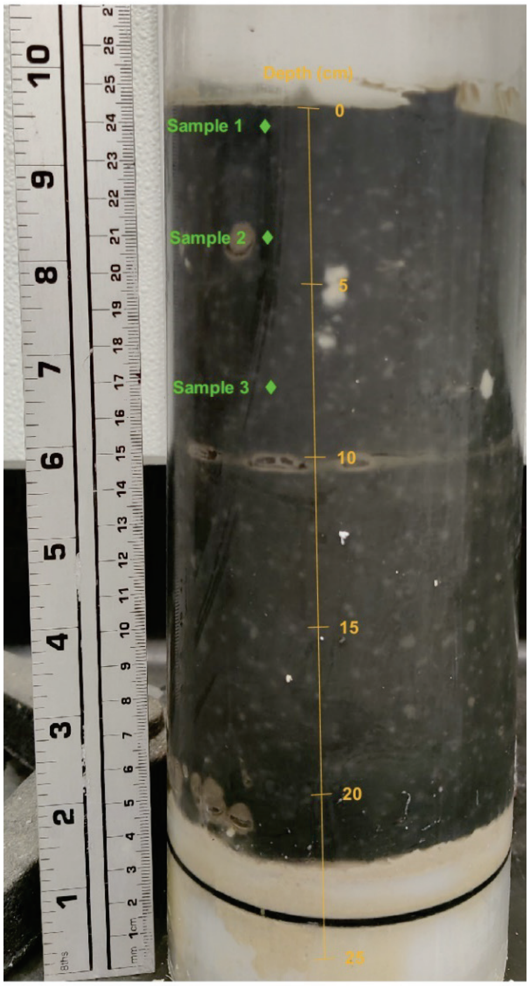
Photograph	Description
	Overlying Water
	Dark grey/black in color throughout core. A few small spots of bentonite visible on core walls. Multiple voids ~5-10 mm in diameter 5-10 cm depth. Linear air gap along the core at ~10 cm depth.

Table A-5. Core description 5% GAC after 7 days of consolidation.

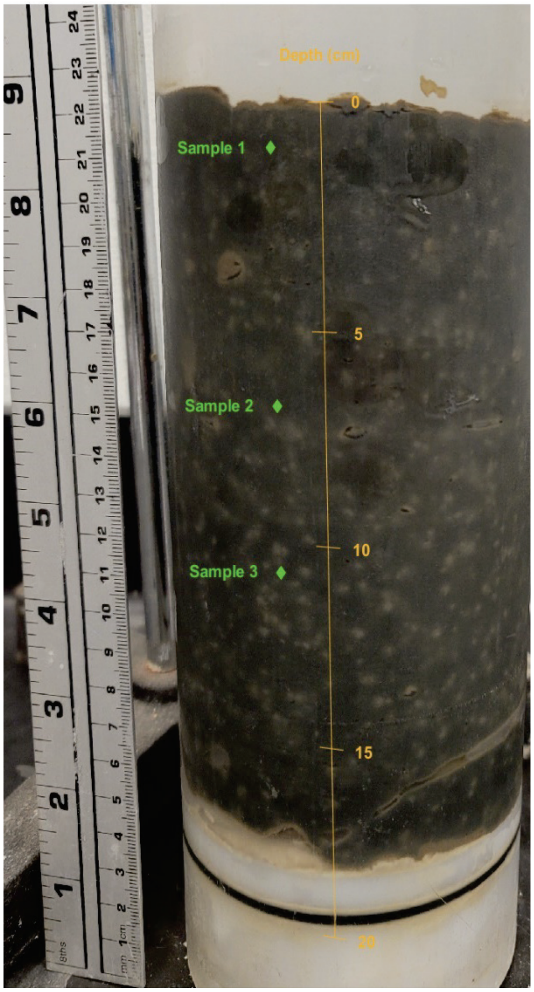
Photograph	Description
	Overlying Water
	Dark grey/black in color throughout core. Visible linear voids ~7-8 cm at ~20 cm depth and a large void at the bottom of the core. Slightly raised surface at the center of the core.

Table A-6. Core description 5% GAC after 30 days of consolidation.

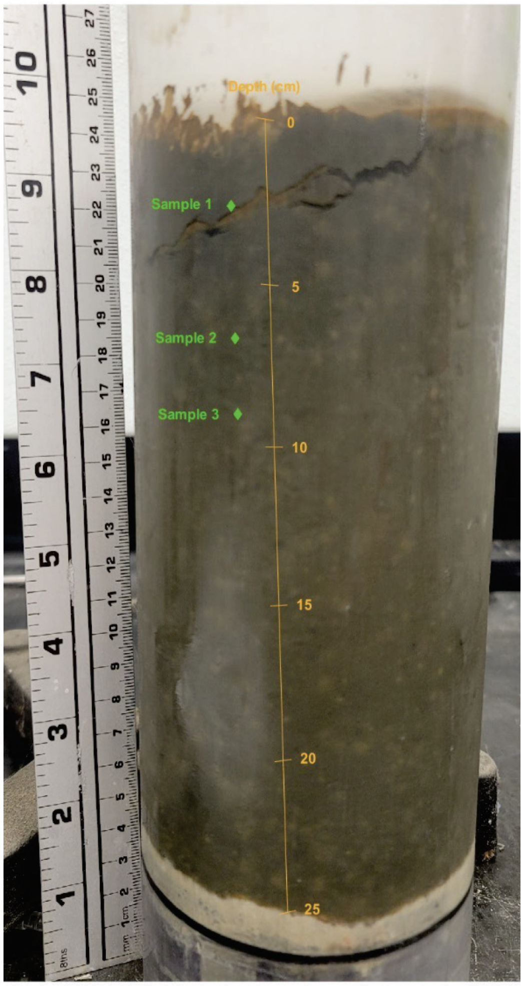
Photograph	Description
	Overlying Water
	Dark grey/black in color throughout core. Oxidized “fluffy” surface ~0.1-0.5 cm thick. Visible small voids <1 cm in diameter throughout the core indicated by lighter brown oxidized material. Visible large crack running ~1/2 of the diameter of the core between the surface and ~5 cm depth.

Table A-7. Core description 10% GAC after 2 days of consolidation.

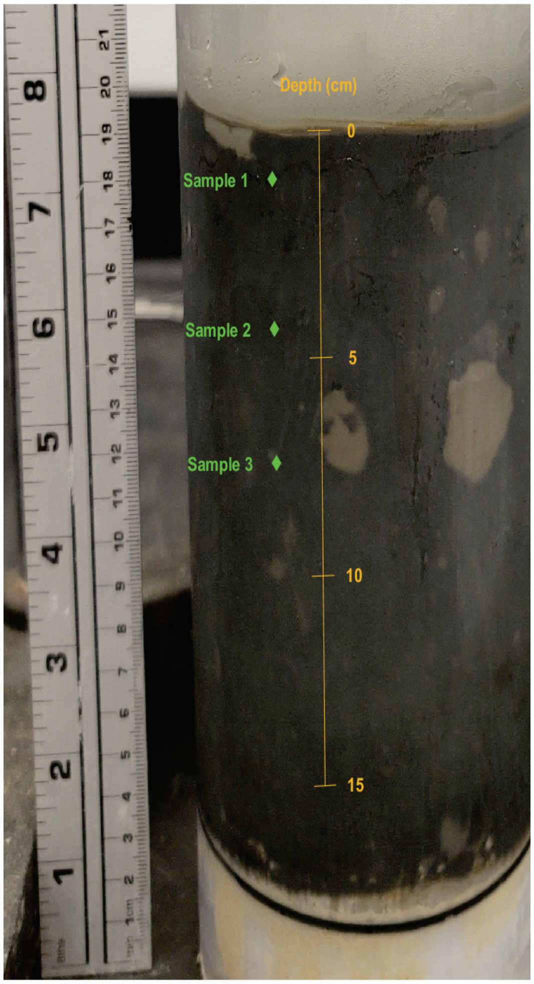
Photograph	Description
	Overlying Water
	Dark grey/black in color throughout core. Brown oxidized surface <1 mm thick. Visible ~1-3 cm in diameter throughout the bottom half of the core with oxidation rings. Slightly sloped surface with small mound near the center.

Table A-8. Core description 10% GAC after 7 days of consolidation.

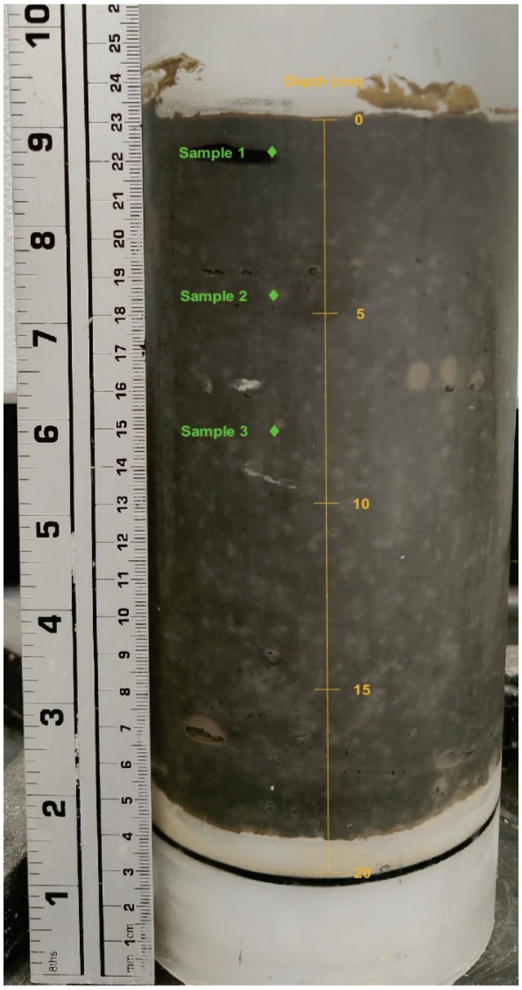
Photograph	Description
	Overlying Water
	Dark grey/black in color throughout core. Light brown oxidized surface <1 mm thick. Visible voids ~0.2-1 cm in diameter with oxidized rings throughout the core.

Table A-9. Core description 10% GAC after 30 days of consolidation.

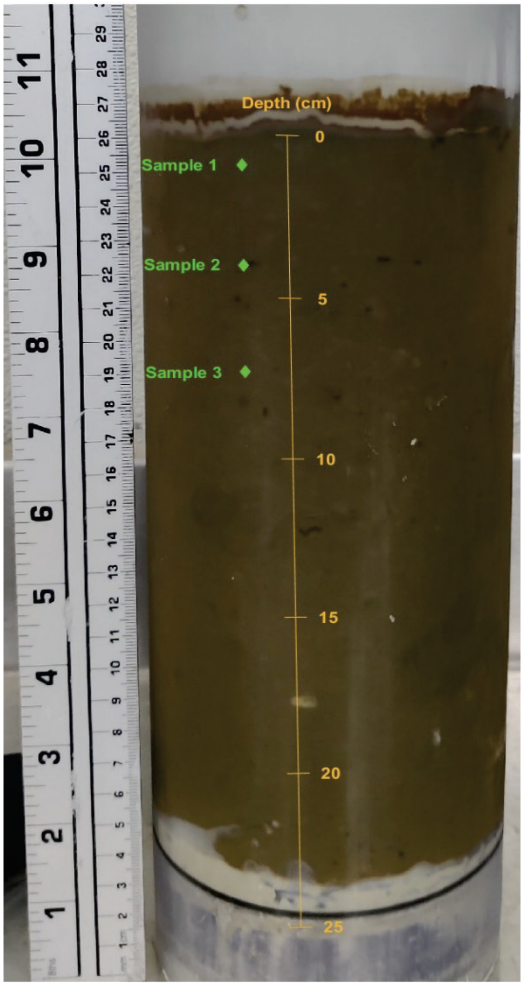
Photograph	Description
	Overlying Water
	Dark brown in color throughout core. Uneven surface with a mounded center of core. Small voids 1-2 mm in diameter dispersed throughout core. No large cracks or fissures visible.

Table A-10. Core description 15% GAC after 2 days of consolidation.

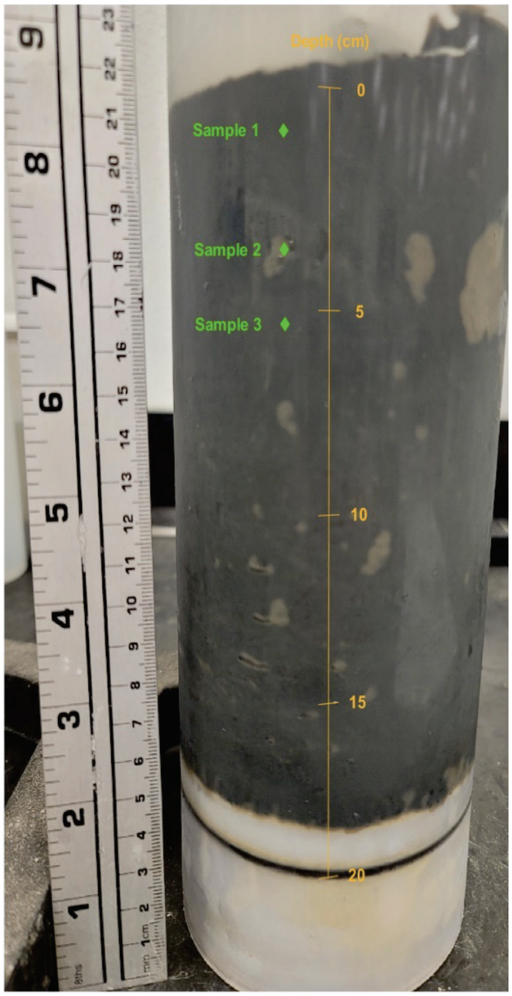
<table>
<tr><th>Photograph</th><th>Description</th></tr>
<tr><td rowspan="2">
</td><td>Overlying Water</td></tr>
<tr><td>Dark grey/black in color throughout core. Brown oxidized surface layer <1 mm thick. Visible voids ~1-3 cm in diameter ~3 cm depth and voids ~1-2 cm in diameter ~7-10 cm depth with oxidized rings. Slightly sloped and uneven surface.</td></tr>
</table>

Table A-11. Core description 15% GAC after 7 days of consolidation.

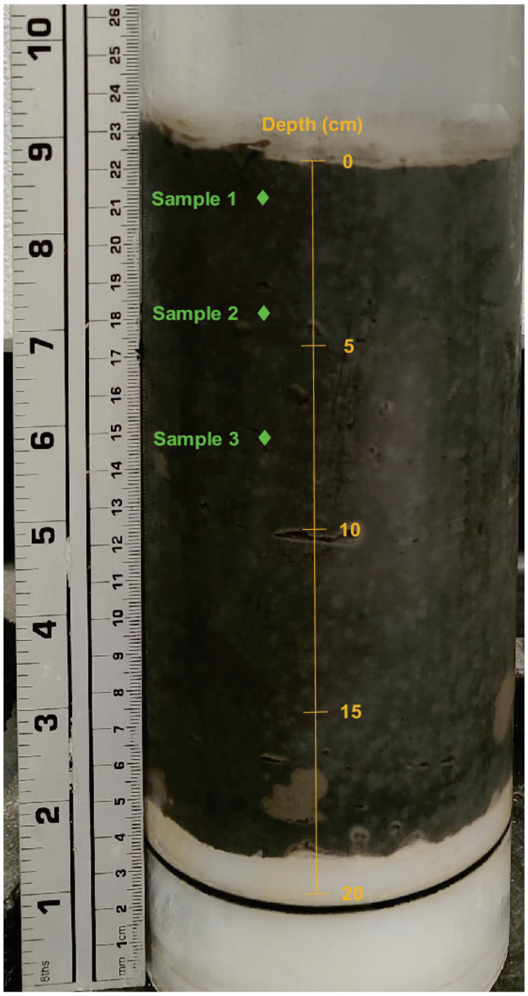
Photograph	Description
	Overlying Water
	Dark grey/black in color throughout core. Brown oxidized layer at surface <1 mm thick. Visible voids ~0.2-1 cm in diameter throughout core with oxidized rings. Slightly sloped surface.

Table A-12. Core description 15% GAC after 30 days of consolidation.

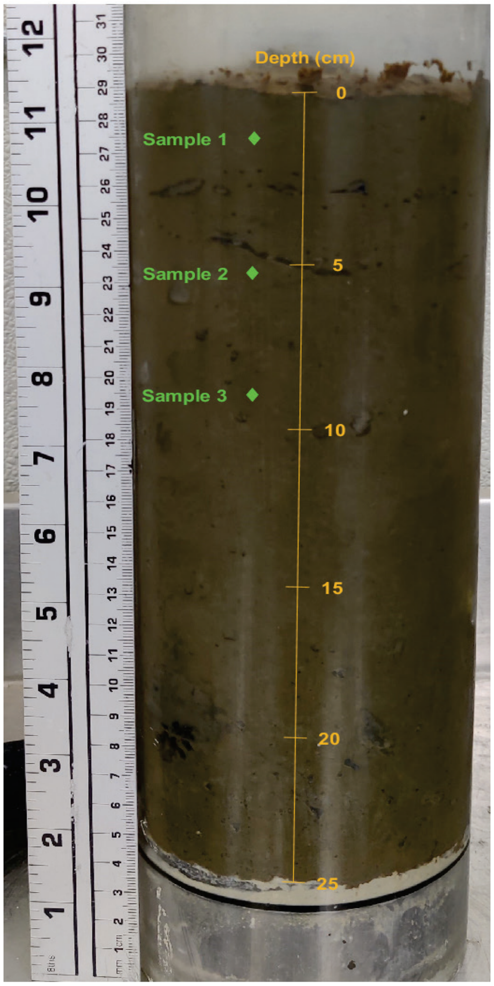
Photograph	Description
	Overlying Water
	Dark brown oxidized coloring throughout core. Uneven surface with mounded center. Visible voids 1-5 mm in diameter dispersed throughout core. Linear pattern of voids/cracks visible ~3-4 cm depth.

Table A-13. Core description 20% GAC after 2 days of consolidation.

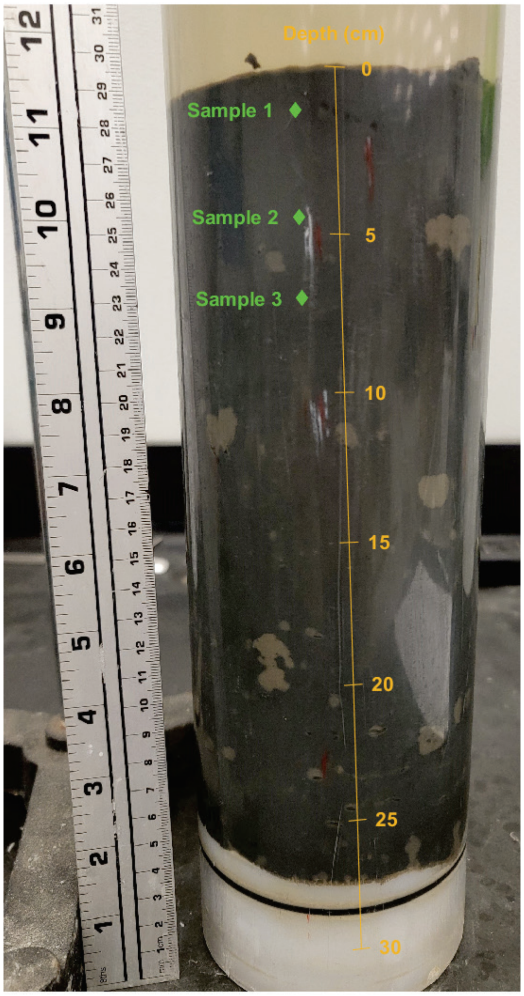
Photograph	Description
	Overlying Water
	Dark grey/black in color throughout core. Brown oxidized surface layer <1 mm thick. Visible voids ~1-3 cm in diameter throughout the core with oxidized rings. Slight mound in center of the surface and a thin “fluff” layer on the surface.

Table A-14. Core description 20% GAC after 7 days of consolidation.

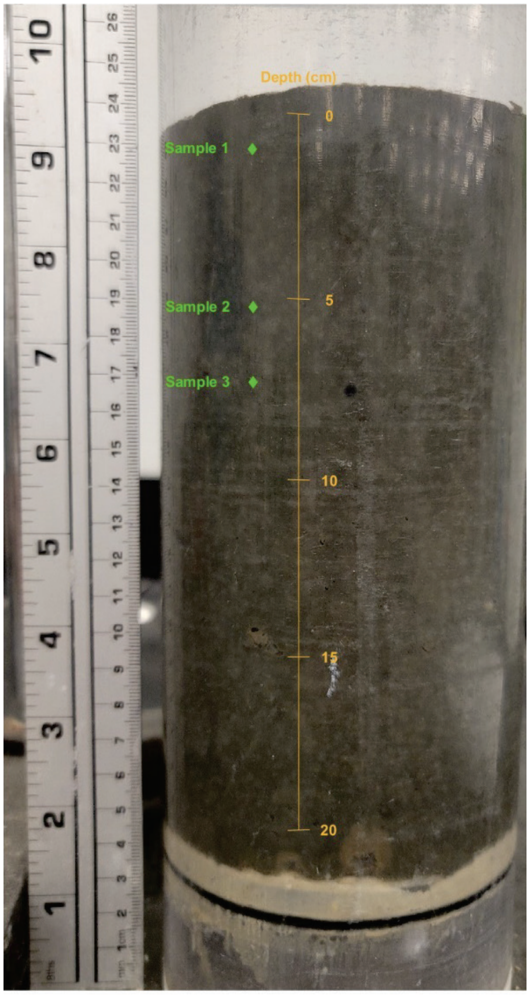
Photograph	Description
	Overlying Water
	Dark grey/black in color throughout core. Brown oxidized surface layer <1 mm thick. Visible small voids <1 mm in diameter throughout core and larger voids ~1-3 cm in diameter in the bottom half of the core with oxidized rings. Mound in the center of the surface.

Table A-15. Core description 20% GAC after 30 days of consolidation.

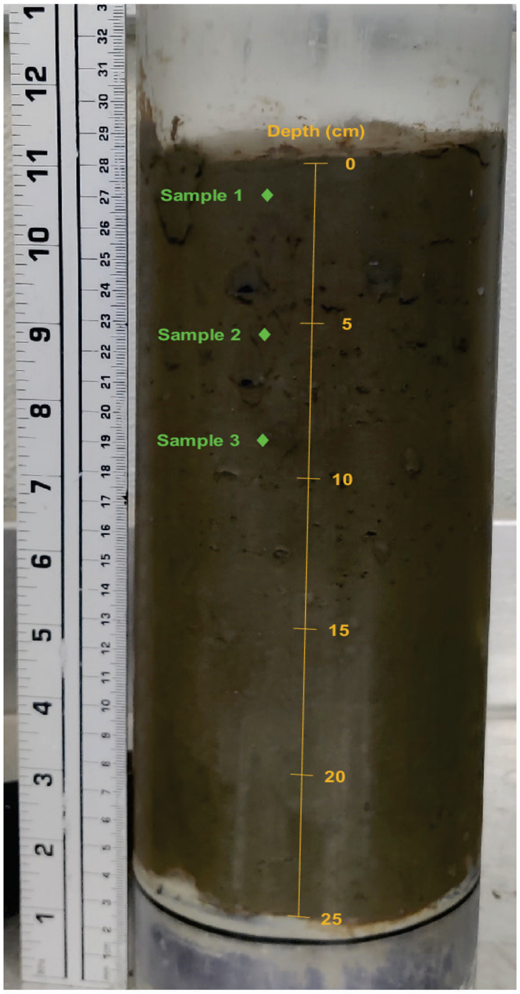
Photograph	Description
	Overlying Water
	Dark brown oxidized coloration throughout core. Slightly sloped surface (~1 cm). Visible voids/fissures 1-3 mm in diameter dispersed throughout the core but most of the voids are in the upper ~10 cm.

Table A-16. Bulk density summary.

GAC Content [%]	Consolidation Time [days]	Bulk Density Sample 1 [g/cm³]	Bulk Density Sample 2 [g/cm³]	Bulk Density Sample 3 [g/cm³]	Depth of Sample 1 [cm]	Depth of Sample 2 [cm]	Depth of Sample 3 [cm]
0	2	1.34	1.33	1.33	0.075	4.450	7.000
0	7	1.33	1.33	1.33	1.150	5.250	9.900
0	30	1.32	1.33	1.34	0.875	8.350	14.550
5	2	1.34	1.33	1.33	0.575	3.725	7.975
5	7	1.33	1.34	1.34	0.950	6.750	10.725
5	30	1.33	1.33	1.35	2.725	6.700	9.000
10	2	1.33	1.32	1.34	1.025	4.325	7.350
10	7	1.32	1.34	1.35	0.800	4.525	8.075
10	30	1.34	1.34	1.35	0.950	4.000	7.300
15	2	1.34	1.35	1.35	1.000	3.625	5.325
15	7	1.34	1.34	1.34	1.000	4.100	7.475
15	30	1.33	1.34	1.34	1.300	5.250	8.950
20	2	1.35	1.36	1.35	1.325	4.500	7.000
20	7	1.37	1.35	1.34	1.025	5.275	7.325
20	30	1.33	1.34	1.35	0.975	5.375	8.800

Appendix B: Sedflume Erosion Data and Analysis

Appendix B contains Sedflume erosion rate data and analysis results for the DOER GAC-Mud mixture Sedflume experiments (Figures B-1 through B-4; Table B-1). The appendix has erosion data fits to cohesive sediment erosion function, $E = A\tau^n$.

Figure B-1. Erosion fits (solid lines) with 95% confidence interval (dashed lines) for 5% GAC for consolidation time of 2 days (blue), 7 days (red-orange), and 30 days (yellow).

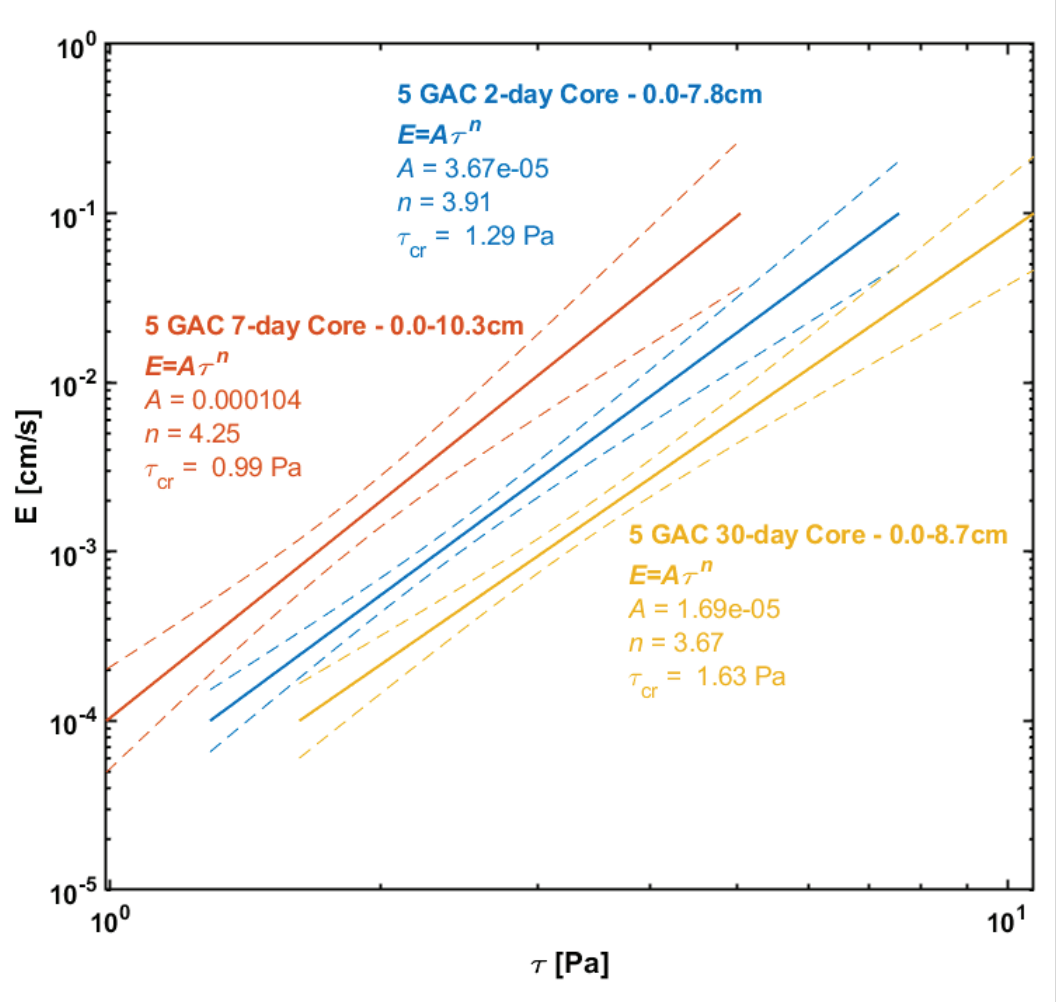


Figure B-2. Erosion fits (solid lines) with 95% confidence interval (dashed lines) for 10% GAC for consolidation time of 2 days (blue), 7 days (red-orange), and 30 days (yellow).

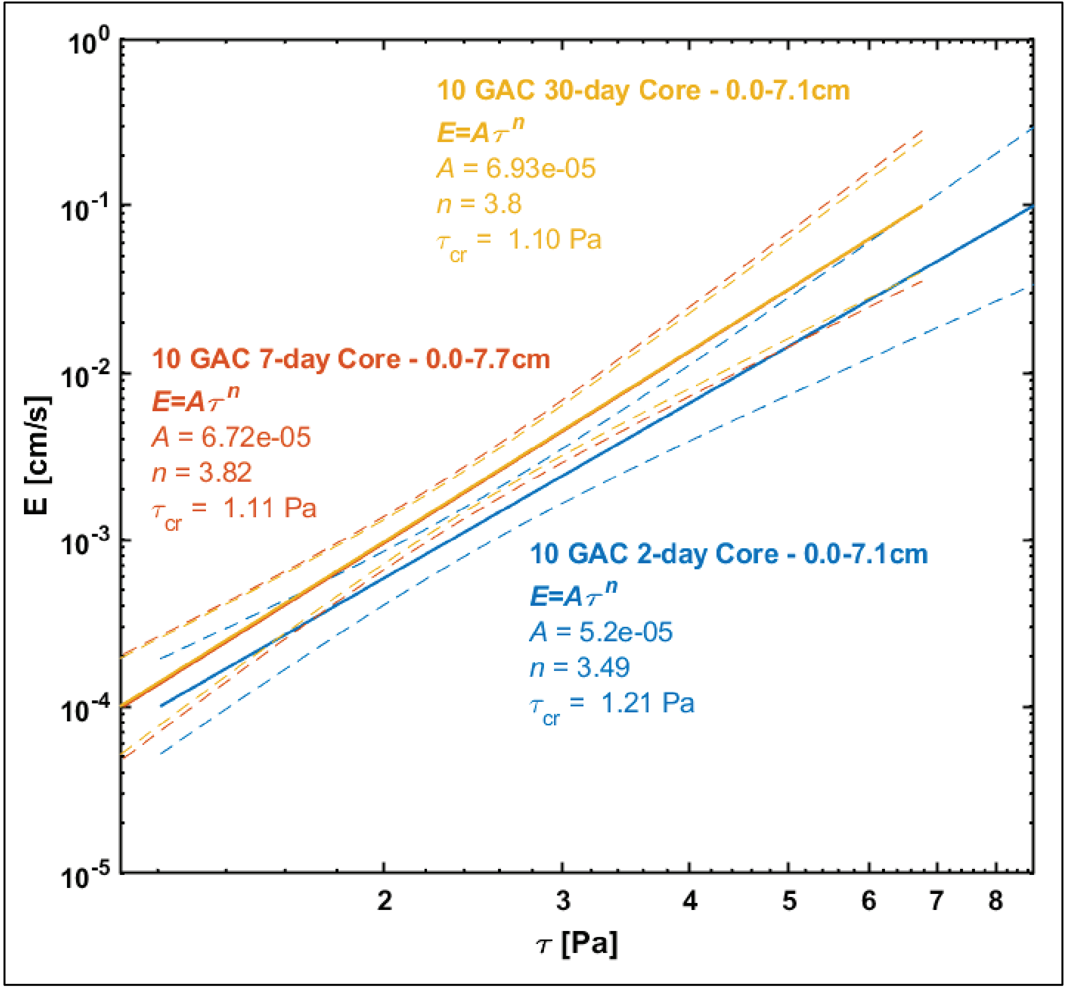


Figure B-3. Erosion fits (solid lines) with 95% confidence interval (dashed lines) for 15% GAC for consolidation time of 2 days (blue), 7 days (red-orange), and 30 days (yellow).

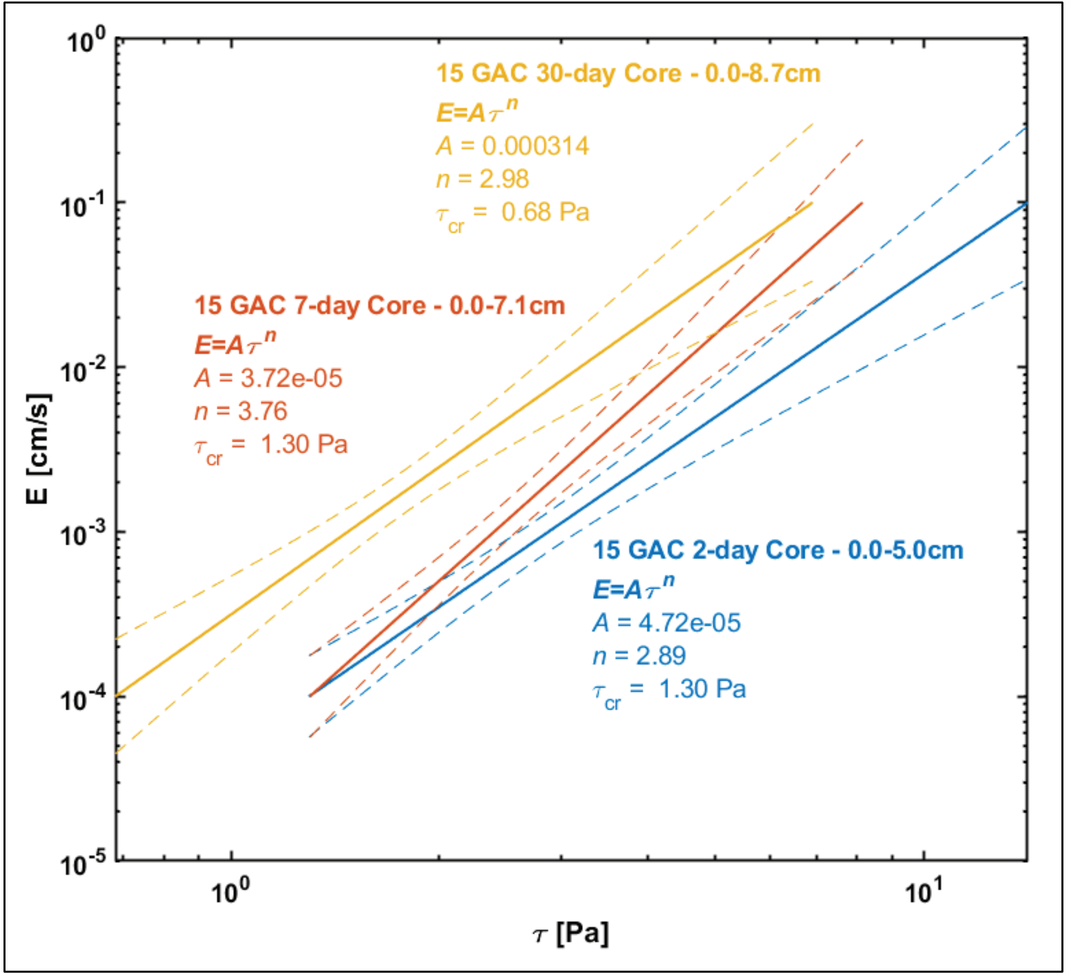


Figure B-4. Erosion fits (solid lines) with 95% confidence interval (dashed lines) for 20% GAC for consolidation time of 2 days (blue), 7 days (red-orange), and 30 days (yellow).

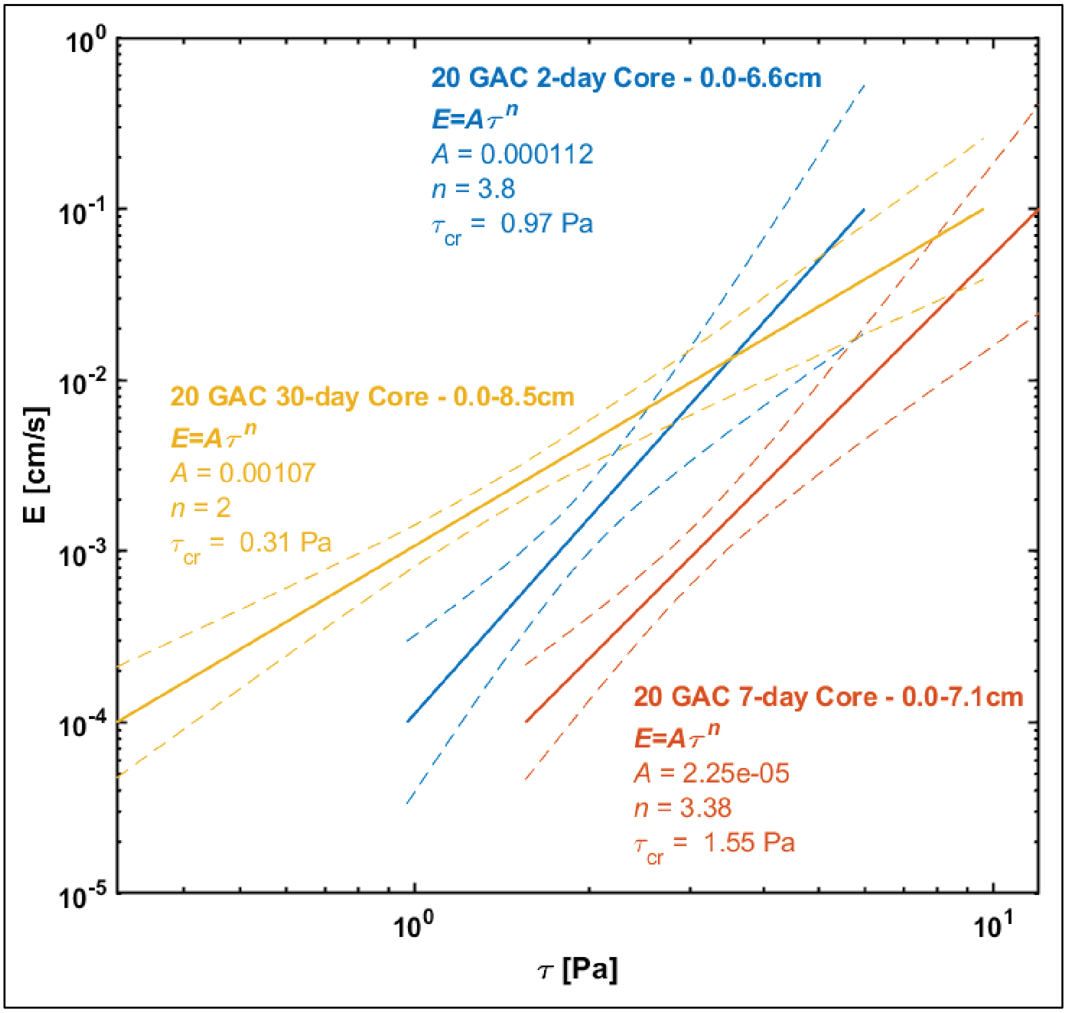


Table B-17. Summary of erosion fit parameters including the length of the core eroded (Erosion Thickness), critical shear stress (τ_{cr}) with the lower and upper bounds of the 95% confidence interval, and the erosion rate parameters A and n.

Core ID	Erosion Thickness [cm]	τ_{cr} [Pa]	τ_{cr} lower [Pa]	τ_{cr} upper [Pa]	A	n
0% GAC 2-day	6.8	1.24	0.89	1.71	4.68E-05	3.58
0% GAC 7-day	9.6	1.37	1.11	1.68	3.14 E-05	3.70
0% GAC 30-day	13.2	1.44	0.62	3.35	3.69 E-05	2.71
5% GAC 2-day	7.8	1.29	1.12	1.49	3.67 E-05	3.91
5% GAC 7-day	10.4	0.99	0.84	1.17	1.04 E-04	4.25
5% GAC 30-day	8.7	1.63	1.31	2.02	1.69 E-05	3.67
10% GAC 2-day	7.1	1.21	0.96	1.51	5.20 E-05	3.49
10% GAC 7-day	7.7	1.11	0.90	1.37	6.72 E-05	3.82
10% GAC 30-day	7.0	1.10	0.91	1.34	6.93 E-05	3.80
15% GAC 2-day	5.0	1.30	1.01	1.66	4.72 E-05	2.89
15% GAC 7-day	7.2	1.30	1.07	1.58	3.72 E-05	3.76
15% GAC 30-day	8.8	0.68	0.57	0.82	3.14 E-04	2.98
20% GAC 2-day	6.7	0.97	0.74	1.28	1.12 E-04	3.80
20% GAC 7-day	7.1	1.55	1.10	2.20	2.25 E-05	3.38
20% GAC 30-day	8.5	0.31	0.27	0.35	1.07 E-03	2.00

Unit Conversion Factors

Multiply	By	To Obtain
microns	1.0 E-06	meters
millimeters	1.0 E-03	meters
centimeters	1.0 E-02	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
liters	1.0 E-03	cubic meters
cubic centimeters	1.0 E-06	cubic meters
grams	1.0 E-03	kilograms

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
July 2022	Final Report	FY21–FY22

4. TITLE AND SUBTITLE
Impacts of Granular Activated Carbon (GAC) on Erosion Behavior of Muddy Sediment

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Danielle R. N. Tarpley and David W. Perkey

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Coastal and Hydraulics Laboratory
US Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
ERDC/CHL TR-22-11

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Dredging Operations Environmental Research Program
US Army Engineer Research and Development Center
Vicksburg, MS 39180-6199

10. SPONSOR/MONITOR'S ACRONYM(S)
DOER

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
Funding Account Code U4381626; AMSCO Code 089500

14. ABSTRACT

Recent policy changes regarding the placement of dredged material have encouraged the USACE to increase its beneficial use (BU) of the sediments dredged from the nation's navigation channels. A good portion of this material is fine grained (<63μm), which traditionally has limited use in BU applications, in part due to its dispersive nature. A need exists to evaluate the potential of stabilizing and using fine-grained sediment (FGS) in BU projects. Previous studies have shown the addition of granular sand to FGS reduces the mobility of the bed. The potential of using Granular Activated Carbon (GAC), an amendment commonly used in environmental capping involving FGS, as a similar bed stabilizing material was explored in this study. A series of laboratory erosion tests using Sedflume were performed on FGS-GAC mixtures that ranged from 5% to 20% GAC by mass. Results suggested that GAC content ≤10% had no influence on the stability of the bed while GAC content ≥15% appeared to reduce both critical shear stress (τcr) and erosion rate (n). However, when compared to control cores, those without GAC, clear evidence of bed stabilization of FGS from the addition of GAC was not observed.

15. SUBJECT TERMS

Carbon, Activated, Dredging, Dredging spoil—Erosion, Materials—Erosion, Sedimentation and deposition, Sediment transport

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Danielle R. N. Tarpley
					19b. TELEPHONE NUMBER *(Include area code)*
Unclassified	Unclassified	Unclassified	SAR	46	601-634-3826