Proceedings of the 7th International Conference on Geotechnical and Geophysical Site Characterization
Barcelona, 18 - 21 June 2024

Geotechnical Characterization of Dredged Material from Rio Grande's Port, Brazil

Inácio Soares Ribeiro[1#], *Helena Paula* Nierwinski[2], *Diego* Freitas Fagundes[3], and *Régis* Pinheiro Maria[4]

[1,2] *Federal University of Santa Catarina, Department of Civil Engineering, Florianópolis/SC, Brazil*
[3,4] *Federal University of Rio Grande, Department of Civil Engineering, Rio Grande/RS, Brazil*
[#] *Corresponding author: inaciosr@gmail.com*

ABSTRACT

Dredging works are essential to ensure navigability in Harbors and waterways. However, this crucial activity generates millions of tonnes of waste each year worldwide. Since the disposal of dredged material is responsible for several environmental impacts, entrepreneurs and engineers must find creative uses for it. Therefore, this study aims to characterize a local dredged material to assess its properties and suitability for geotechnical applications. With this knowledge, this paper presents a series of experimental tests on dredged material samples retrieved from Rio Grande's Port, Brazil. The experimental program includes determining Atterberg limits, sieve and sedimentation analysis, pH and SEM analysis, compaction curve, and unconfined compressive strength in a reconstituted state. The results showed that the material is sandy lean clay, with unfavourable strength characteristics for geotechnical work in a raw state. However, with the advent of chemical stabilization techniques, there is potential for enhancing its suitability for geotechnical applications. By exploring methods such as adding binders like lime or Portland cement, the material's strength and stability could be significantly improved, opening up possibilities for its utilization in various engineering projects. This study contributes valuable insights into the potential reclamation and beneficial reuse of dredged material, ultimately aiding in the sustainable management of harbor and waterway dredging operations.

Keywords: Soil Properties; Dredged Material; Sustainability; Unconfined Compressive Strength.

1. Introduction

The Port of Rio Grande is the 3rd most important port in terms of cargo volume in Brazil. Situated in the estuary of Patos Lagoon, the extreme southern region of the country, the port plays a major role in trade and commerce. To sustain its robust activities, the Port of Rio Grande undergoes recurrent maintenance dredging works once every two years.

Each year, hundreds of millions of cubic meters of sediment are dredged worldwide (Bose and Dahr, 2022). For 2023-2024 alone, it is estimated that the maintenance dredging of the Port of Rio Grande will generate 2.7 million cubic meters of sediment (Estado RS 2023). These volumes have increased over the years, driven by larger vessel sizes pressuring the sector to provide deeper drafts (Carse and Lewis 2020). Notably, the Port of Rio Grande underwent a draft deepening in 2020, reaching 15 meters.

At the same time, the straightforward disposal of dredged material has raised concerns in society due to its undeniable environmental impacts (OSPAR 2008). Some examples of these impacts are an increase in water turbidity and a change in properties of the bottom sediments in the dumpsite (Palanques *et al.* 2022), and the burial of benthic communities diminishing drastically the number of species at the dumping site (Katsiaras *et al.* 2015).

Dredged Material from the Port of Rio Grande is currently disposed of in an offshore dumping site located 22 km from the coast. Studies, such as Calliari *et al.* (2020), have linked the dredging activity and the sediment dumping to instances of mud deposition at Cassino Beach. This beach is situated in the hydrodynamic zone after the Patos Lagoon inlet, as illustrated in Figure 1. These episodes have environmental impacts, including changes in wave patterns along the beach (Calliari *et al.* 2007) and socioeconomic implications.

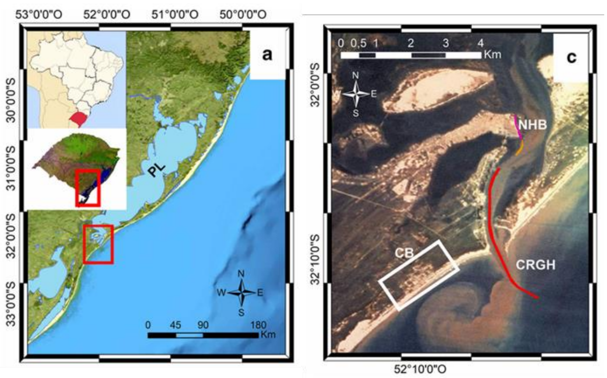

Figure 1. Images of the area of study, adapted from Caliari et al. (2020).

In this context, the responsibility falls on the academic community to investigate environmentally friendly and practical applications for this abundant material, moving beyond offshore dumping. Some of these alternatives include the use in the restoration of natural habitats, agricultural purposes, and applications in the construction industry (Rakshith and Singh 2017).

The reuse of residues stands as a valid alternative to mitigate the environmental impacts of the construction industry (Huang *et al.* 2020). There are a wide variety of applications for dredged material in that sector, such as concrete production (Achour *et al.* 2019), brick manufacturing (Hamer and Karius 2002), and pavement foundations (Zentar *et al.* 2012). These studies either focus on its use as a partial substitution for noble materials, as in Achour *et al.* (2014), or in attempts to enhance its properties, as in Huang *et al.* (2017).

Dredged material is excavated from the bottom of waterways, primarily consisting of loose material originated from siltation phenomena that commonly undertake sheltered sites, such as ports. It is characterized by being disaggregated, presenting high water content and low bearing capacity (He *et al.* 2020). While grain fractions and mineralogy may vary depending on local geomorphological conditions, it is quite common to observe a prevalent fine fraction, some organic content, and chemical contaminants (Solanki *et al.* 2023).

The objective of this study is to characterize dredged material collected from the access channel of the Port of Rio Grande, identify its geotechnical properties, and assess its potential applications in geotechnical works.

2. Materials and Methods

2.1. Site description

The Port of Rio Grande is situated in the estuary of Patos Lagoon, which spans an extension of 250 km with an average depth of 5 m. This lagoon receives water from significant rivers in southern Brazil and has an inlet to the Atlantic Ocean. The sedimentary characteristics of the inlet bottom of Patos Lagoon vary, with a predominance of silty clay, silty sand, and clayey sand observed in deeper areas (Antiqueira and Caliari 2006).

2.2. Material sampling and preparation

A large quantity of dredged material from the Port of Rio Grande was collected during dredging operations in 2018. Claudio Dias Geotechnical and Concrete Laboratory from the Federal University of Rio Grande (FURG) provided this material. Previous studies by authors such as Araujo e Fagundes (2020) and Larrosa *et al.* (2023) have also investigated this same material.

The material is stored in a tank, preserving high water content. Since it becomes very rigid and lumpy when dried out, the material is spread in thin layers, as shown in Figure 2, and then placed in an oven at 60°C for 24 hours. Following this procedure, the material was easier to break up clumps, and at that temperature, it should preserve its original organic content.

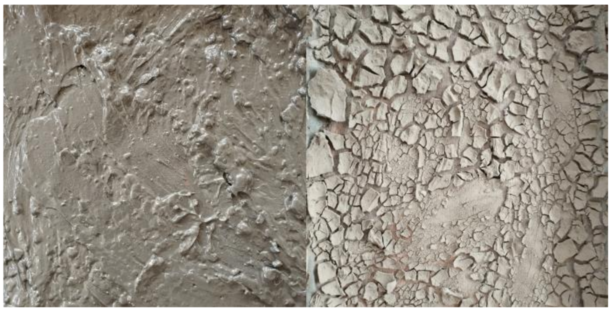

Figure 2. Drying of dredged material.

2.3. Geotechnical Characterization

The dredged material was tested for physical properties, such as initial water content ASTM D2216 (ASTM 2019a), organic matter content AASHTO T267 (AASHTO 2022), specific gravity ASTM D854 (ASTM 2023), Atterberg limits ASTM D4318 (ASTM 2017a), and grain size distribution ASTM D6913 (ASTM 2017b) and ASTM D7928 (ASTM 2021a). These results were used to classify the dredged material by the Unified Soil Classification System, ASTM D2487 (ASTM 2017c), an essential procedure to verify its engineering applications.

To investigate the optimal water content and maximum dry density of the dredged material, standard proctor tests were performed in accordance with ASTM D698 (ASTM 2021b). Due to the material being desegregated during the dredging process and having high water content, it was not possible to mold specimens in these conditions. Therefore, the material was compacted at its maximum dry density for the Unconfined Compression Test to ascertain its mechanical properties. Unconfined Compressive Strength tests were conducted in line with ASTM D2166 (ASTM 2016). Furthermore, the material pH was measured in conformity with ASTM D4972 (ASTM 2019b). The sample was also subjected to scanning electron microscopy (SEM) to analyze its microstructure.

3. Results and Discussions

The dredged material exhibits a high water content, measured at an average of 110%, contributing to its viscous mud-like consistency, which suggests the presence of clay. The material has a strong organic odor and a grayish, as depicted by Figure 2, indicating significant organic content. According to the findings of Solanki *et al.* (2023), dredged material with less than 20% water content could be used as fill material for foundations and base layers of pavements. However, the current high water content renders the material unsuitable for compaction, necessitating the exploration of methods to reduce moisture content.

Araujo and Fagundes (2020) evaluated the dredged sediment drainage efficiency with geotextile. Additionally, Wang *et al*. (2018) demonstrated that the use of inorganic flocculants contributes to solid-liquid separation, effectively increasing material permeability. Furthermore, the addition of lime and a sandy material is an alternative presented by Siham *et al.* (2008). This approach not only reduces moisture content by introducing more solids but also because of the induction of flocculation and hydration associated with lime and the increase in permeability because of the sand. Some studies propose to work with the material at high water content, using chemical stabilizers, such as ordinary Portland Cement, as in Huang *et al.* (2017), and alternative cementitious materials, as found in He *et al.* (2020).

Organic matter content was measured at 7,71% by weight. The ignition test significantly altered the sample color, as shown in Figure 3. The presence of organic matter could pose serious concerns as it significantly reduces the material's bearing capacity. According to Lang *et al.* (2020), the decomposition of organic matter can generate acids, such as humic acid, which can inhibit the action of chemical stabilizers like Portland Cement, that requires a high pH environment for optimal hydration. To address these challenges, the authors recommend the addition of lime to the mixture to counterbalance these effects and ensure stabilization.

Figure 3. Organic content test.

The material's specific gravity is 2,48. The liquid limit was determined to be 49%, and the plastic limit was found to be 19%, resulting in a plasticity index of 30%, which is relatively high for a construction material. Since the dredged material contains organic content, the liquid limit test was conducted on a sample dried at 110° C to assess whether organic content interferes with its consistency. This test yielded a liquid limit of 43%, demonstrating that organic content does not significantly interfere with its consistency.

Chemical admixtures like Portland Cement and Lime are widely used to reduce soil plasticity. In a study by Wang *et al.* (2012b), it was concluded that these additives increased both the liquid and plastic limit of dredged material, resulting in a reduction in its plasticity index that altered its classification according to the Unified Soil Classification System.

Sieve analysis revealed that 100% of the sample passed in sieve #10 (2mm). The grain size distribution showed 48% sand, 24% silt and 28% clay. The grain size distribution is shown in Figure 4. Although there is a predominance of fine particles, it is important to point out the presence of sand.

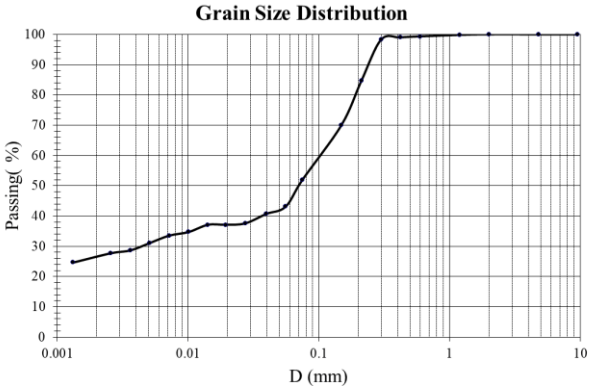

Figure 4. Grain size distribution chart.

With those results, the dredged material can be classified according to Unified Classification Soil System. Since 52% of the material passes through sieve #200 (0,075mm), the material is fine-grained. Once the position of the plasticity index versus liquid limit plot falls above the "A" line, the organic content does not significantly interfere with the liquid limit, and the liquid limit is 49%; the material is a sandy inorganic lean clay. That is consistent with the findings of Antiqueira and Caliari (2006) for the sediment at deeper portions of the Patos Lagoon inlet.

The optimal water content for the material was about 25%, and the maximum dry density was 1465 kg/m³. Those values were important to mold the specimens for unconfined compressive strength tests. The specimens for UCS tests were molded with 50mm diameter and 100mm height at optimal moisture content and maximum dry density. They were loaded at a pace of 1mm per minute. The tests were performed under unsaturated conditions once test specimens would completely disintegrate under saturated conditions.

The stress-strain relationship for one of the test specimens is shown in Figure 5. The average unconfined compression strength at failure was 300 kPa. This is a typical value for a very stiff clay; however, it is important to notice that some resistance is due to matric suction developed under loading on unsaturated conditions. Since the soil voids contain air and water, some pressure differences exist between those two phases. This phenomenon causes an increment in cohesion because meniscus water increases intergranular forces (Chae *et al.* 2010). With this in mind, it is possible to infer that the strength of the material is lower than the measured.

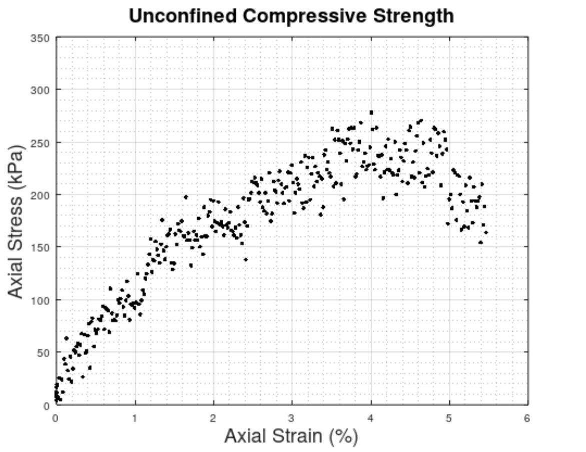

Figure 5. Stress-strain relationship for a UCS test.

The soil pH test produced a result of 7.89, which means that this dredged material has a basic nature. The dispersion of clay particles, such as smectite and kaolinite, typically requires a higher pH environment (Mitchell and Soga 2005). Considering this, it is plausible that the material contains disperse clay. Furthermore, the elevated pH facilitates potential treatment with binders, such as lime and Portland cement. The efficacy of this treatment depends on establishing a basic environment that promotes the dissolution of clay and the formation of cementitious products.

Analyzing SEM images, it is possible to observe that the sample is composed of a coarser fraction (sand) and a finer fraction. Figure 6 illustrates that the sand grains exhibit angular shapes. There are larger grains with very porous structure, which may be shell fragments, as depicted in Figure 7. Finer particles accumulate on the surface of the coarser particles, which is evident in Figure 8. Clay particles appear to have a very dispersed structure, as shown in Figure 9.

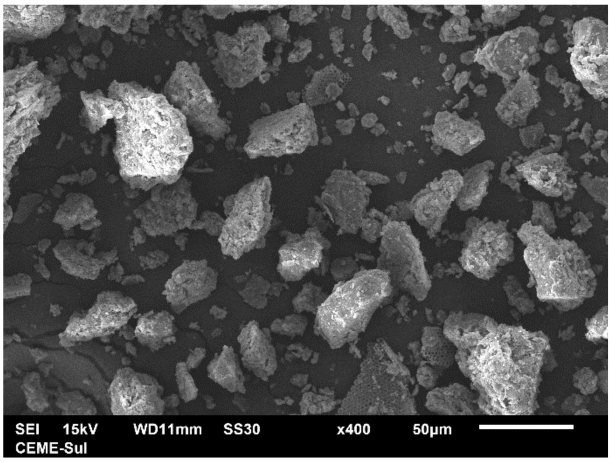

Figure 6. SEM image - shape of sand grains.

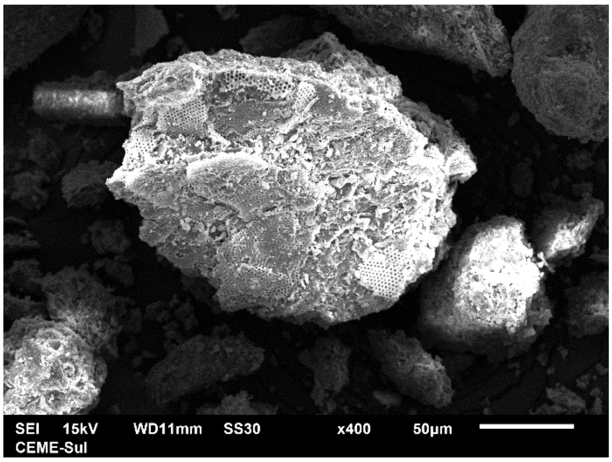

Figure 7: SEM image - Grains with porous structure.

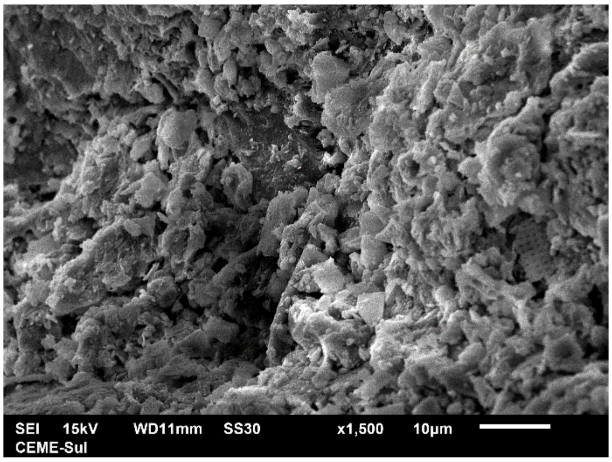

Figure 8. SEM image - Finer Particles accumulating on top of coarser particles.

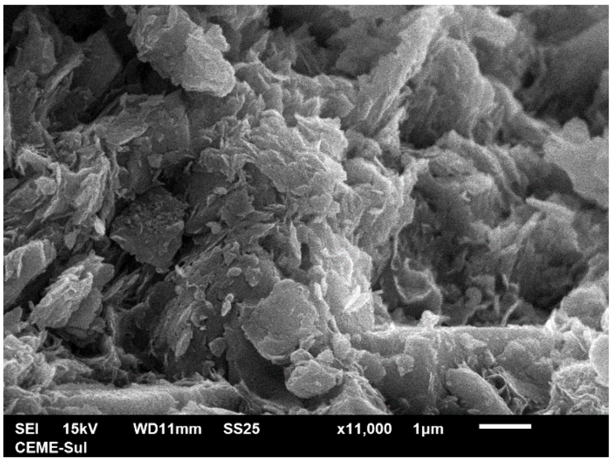

Figure 9. SEM image - Clay particles.

Concerning chemical analysis, it is notable that 85% of the sample is composed of silicates and aluminates because of the presence of oxygen (O), silicon (Si), and aluminium (Al), which are commonly found in soil mineral composition. Chlorine (Cl) and sodium (Na) may be attributed to the presence of sea salt, while carbon (C) could be attributed to organic matter and shell fragments. This analysis does not show evidence of contaminants; however, further standard tests may be required to affirm it. Table 1 presents the element distribution in sample analysis.

Table 1. Chemical Analysis.

Element	**Percentage**
C	3.23%
O	50.01%
Na	1.24%
Mg	1.25%
Al	9.46%
Si	25.47%
Cl	1.93%
K	0.46%
Ca	0.51%
Ti	0.51%
Fe	5.37%

The main findings of this study are summarized in Table 2.

Table 2. Main results

Parameters	**Values**
Water Content	110%
Organic Matter content	7.71%
Specific Gravity	2.48 g/cm³
Liquid Limit	49%
Plastic Limit	19%
Plasticity index	30%
Fine Sand (Diameter < 0.063mm)	48%
Silt (0.002mm<Diameter > 0.063mm)	24%
Clay (Diameter < 0.002mm)	28%
USC	CL
Wopt	25%
Pd	1465 kg/m³
UCS	300 kPa
pH	7.89

As was revealed by the characterization program, the material exhibits specific characteristics that deem it unsuitable for engineering applications. With this in mind, a brief literature analysis was conducted to explore potential alternatives for utilizing the investigated material for engineering applications. The analysis examined how similar materials were treated and utilized in previous studies.

Wang *et al.* (2012a) explored the use of admixtures and compaction to stabilize a dredged material with similar plasticity. They concluded that compacting dredged material with the addition of Portland cement rendered it suitable for road construction. Similarly, Achour *et al*. (2014) investigated a similar approach to stabilize a dredged material with comparable plasticity, employing Portland cement, dredged sand, and compaction. Their findings highlighted the compatibility of fine dredged material with road works.

In another study, Huang *et al.* (2017) investigated a dredged material with high water content, marking China's first large-scale engineering application of Dredged Material solidification treatment. They identified the solidification of dredged slurry with Portland cement as the most appropriate technique for stabilizing the material intended for the foundations of a Science and Technology Industrial Park.

Those studies demonstrated that the use of Portland cement can enhance various properties of the dredged material, such as ICBR (Wang *et al.* 2012a), tensile strength (Achour *et al*. 2014) and CPT strength (Huang *et al*. 2017). This enhancement in strength can be attributed to the formation of crystalline products resulting from the cement hydration process and the pozzolanic interaction between the clay portion of the dredged material and the binder.

The addition of Cement admixture could potentially make the dredged material analyzed in this study suitable for application in geotechnical work. Consequently, it is crucial to investigate how the dredged material will interact with chemical admixtures and determine the feasibility of achieving similar results.

4. Conclusion

In this study, an in-depth analysis was conducted to characterize the dredged material from the Port of Rio Grande. Through various tests and examinations, key properties of the material were identified. Based on the findings, potential applications and challenges associated with utilizing the material in engineering projects were explored. Some of the major findings are summarized below:

- The dredged material was classified as a sandy inorganic lean clay based on the Unified Classification Soil System.
- The material exhibited a grain size distribution of 48% sand, 24% silt, and 28% clay.
- The material showed a basic pH of 7.89, suggesting potential compatibility with binders like lime and Portland cement for treatment.
- Chemical analysis revealed that the sample was primarily composed of silicates and aluminates, with no evidence of contaminants.
- Despite certain characteristics rendering the material unsuitable for engineering applications, potential alternatives for utilization were explored through a literature analysis, and that showed that with the advent of chemical stabilization this material could be suitable for application in geotechnical work such as road base material and building foundation.

These conclusions provide valuable insights into the properties and behavior of the Port of Rio Grande dredged material, paving the way for further research and potential applications in sustainable geotechnical projects. As suggestion for further research, it is important to investigate if the material presents contaminants, and how the dredged material will interact with chemical admixtures such as Portland Cement and Lime.

Acknowledgements

The authors are grateful for the financial support provided by funding agency CNPQ. The project presented in this article is supported by Claudio Dias Geotechnical and Concrete Laboratory from the Federal University of Rio Grande (FURG) and by The Graduate Program in Civil Engineering (PPGEC) at the Federal University of Santa Catarina (UFSC).

References

American Association of State Highway and Transportation Officials. T267: Standard Method of Test for Determination of Organic Content in Soils by Loss on Ignition. Washington, DC, 2022.

American Society for Testing and Materials. D698: Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft3 (600 kN-m/m3)). West Conshohocken, PA, 2021.

American Society for Testing and Materials. D854: Standard Test Methods for Specific Gravity of Soil Solids by the Water Displacement Method. West Conshohocken, PA, 2023.

American Society for Testing and Materials. D2166: Standard Test Method for Unconfined Compressive Strength of Cohesive Soil. 2016.

American Society for Testing and Materials. D2216: Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass. West Conshohocken, PA, 2019.

American Society for Testing and Materials. D2487: Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System). West Conshohocken, PA, 2017.

American Society for Testing and Materials. D4318: Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils. West Conshohocken, PA, 2017.

American Society for Testing and Materials. D4972: Standard Test Methods for pH of Soils. West Conshohocken, Pa, 2019.

American Society for Testing and Materials. D6913: Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis. West Conshohocken, PA, 2017.

American Society for Testing and Materials. D7928: Standard Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis. West Conshohocken, PA, 2021.

Achour, R.; Abriak, N.; Zentar, R.; Rivard, P.; Gregoire, P. Valorization of unauthorized sea disposal dredged sediments as a road foundation material. Environmental Technology, v. 35, p. 1997-2007, 2014. http://dx.doi.org/10.1080/09593330.2014.889758.

Achour, R., R., Zentar; N., Abriak; P., Rivard, P., Gregoire. Durability study of concrete incorporating dredged sediments. Case Studies In Construction Materials, v. 11, p. 244-261, 2019. Elsevier BV. http://dx.doi.org/10.1016/j.cscm.2019.e00244.

Antiqueira, J., L., Calliari. "Características Sedimentares da Desembocadura da Lagoa dos Patos", Sedimentary Characteristics of Patos Lagoon Inlet. Gravel, Porto Alegre, v. 3, p. 39-46, 2005. (in Portuguese).

Araujo, M., D., Fagundes. "Avaliação da eficiência de desague de sedimentos dragados no Porto de Rio Grande com a utilização de geotêxteis", Efficiency evaluation of drainage of a dredged sediment from Port of Rio Grande with geotextile. In: Congresso Brasileiro de Mecânica dos Solos e Engenharia Geotécnica, 20, 2020. Proceedings [...]. Campinas, SP: 2020. (in Portuguese).

Bose, B., M., Dhar Dredged Sediments are One of the Valuable Resources: A Review. IJESKA. 2022; v. 4, p. 324-331.

Calliari, L., T., Holland, P., Pereira, R., Guedes, R., Santo. The Influence of Mud on the Inner Shelf, Shoreface, Beach, and Surf Zone Morphodynamics — Cassino, Southern Brazil. Coastal Sediments, v. 7, p. 1-8, 2007. American Society of Civil Engineers. http://dx.doi.org/10.1061/40926(239)112.

Calliari, L., A., Machado, P., Marroig, S., Vinzon, N., Gianuca. Mud deposits at Cassino beach: role of dredging. Geo-Marine Letters, v. 40, p. 1031-1043, 2020. Springer Science and Business Media LLC. http://dx.doi.org/10.1007/s00367-019-00619-6.

Carse, A.; J., Lewis. New horizons for dredging research: the ecology and politics of harbour deepening in the southeastern united states. Wires Water, v. 7, p. 1-16, 2020. Wiley. http://dx.doi.org/10.1002/wat2.1485.

Chae, J.; B., Kim, S., Park, S., Kato. Effect of suction on unconfined compressive strength in partly saturated soils. Ksce Journal of Civil Engineering, v. 14, p. 281-290, 2010. Springer Science and Business Media LLC. http://dx.doi.org/10.1007/s12205-010-0281-7.

Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR), 2008. Literature Review on the Impacts of Dredged Sediment Disposal at Sea. OSPAR Commissions, Reviews Literature and Arts of the Americas.

ESTADO. RS. "Contrato de dragagem do Porto do Rio Grande assinado nesta quinta (26) prevê investimento de R$ 94,5 milhões", Dredging Contract of the Porto f Rio Grande signed this Thursday (26) foresee investment of R$ 94,5 millions. 2023. Available on: https://estado.rs.gov.br/contrato-de-dragagem-do-porto-do-rio-grande-assinado-nesta-quinta-26-preve-investimento-de-r-94-5-milhoes. Accessed on: January. 2024. (in Portuguese).

Hamer, K., V., Karius. Brick production with dredged harbour sediments. An industrial-scale experiment. Waste Management, v. 22, p. 521-530, 2002. Elsevier BV. http://dx.doi.org/10.1016/s0956-053x(01)00048-4.

He, J., X., Shi, Z., Li, L., Zhang, X., Feng, L., Zhou. Strength properties of dredged soil at high water content treated with soda residue, carbide slag, and ground granulated blast furnace slag. Construction And Building Materials, v. 242, p. 118126-118135, 2020. Elsevier BV. http://dx.doi.org/10.1016/j.conbuildmat.2020.118126.

Huang, Y., C., Dong, C., Zhang, K., Xu. A dredged material solidification treatment for fill soils in East China: a case history. Marine Georesources & Geotechnology, v. 35, n. 6, p. 865-872, 2016. Informa UK Limited. http://dx.doi.org/10.1080/1064119x.2016.1257669.

Huang, B., X., Gao, X., Xu, J., Song, Y., Geng, J., Sarkis T., Fishman, H., Kua, J., Nakatani. A Life Cycle Thinking Framework to Mitigate the Environmental Impact of Building Materials. One Earth, v. 3, p. 564-573, 2020. Elsevier BV. http://dx.doi.org/10.1016/j.oneear.2020.10.010.

Katsiaras, N., N., Simboura, C., Tsangaris, I., Hatzianestis, A., Pavlidou, V., Kapsimalis. Impacts of dredged-material disposal on the coastal soft-bottom macrofauna, Saronikos Gulf, Greece. Science Of The Total Environment, v. 508, p. 320-330, 2015. Elsevier BV. http://dx.doi.org/10.1016/j.scitotenv.2014.11.085.

Lang, L.; N., Liu, B., Chen. Strength development of solidified dredged sludge containing humic acid with cement, lime and nano-SiO2. Construction And Building Materials, v. 230, p. 116971, 2020. Elsevier BV. http://dx.doi.org/10.1016/j.conbuildmat.2019.116971.

Larrosa, C., A., Lotero, C., Bastos, S., Servi, N., Consoli. Stabilization of Dredging Material from Rio Grande Harbor with Alkali-Activated Cements to Produce Masonry Elements. Journal Of Materials In Civil Engineering, v. 35, 2023. American Society of Civil Engineers (ASCE). http://dx.doi.org/10.1061/(asce)mt.1943-5533.0004677.

Mitchell, J., K., Soga. Fundamentals of Soil Behavior. 3. ed. Hoboken, NJ: John Wiley & Sons, Inc., 2005. 560 p.

Nicholson, P. Soil Improvement and Ground Modification Methods. Kidlington, Uk: Butterworth Heinemann, 2015.

Palanques, A., J., Guillén, P., Puig, R., Durán. Effects of long-lasting massive dumping of dredged material on bottom sediment and water turbidity during port expansion works. Ocean & Coastal Management, v. 223, p. 106113, 2022. Elsevier BV. http://dx.doi.org/10.1016/j.ocecoaman.2022.106113.

Rakshith, S., D., Singh. Utilization of Dredged Sediments: contemporary issues. Journal Of Waterway, Port, Coastal, And Ocean Engineering, v. 143, p. 1-13, 2017. https://doi.org/10.1061/(ASCE)WW.1943-5460.0000376.

Siham, K., B., Fabrice, A., Edine, D., Patrick. Marine dredged sediments as new materials resource for road construction. Waste Management, v. 28, p. 919-928, 2008. Elsevier BV. http://dx.doi.org/10.1016/j.wasman.2007.03.027.

Solanki, P., B., Jain, X., Hu, G., Sancheti. A Review of Beneficial Use and Management of Dredged Material. Waste, v. 1, p. 815-840, 2023. MDPI AG. http://dx.doi.org/10.3390/waste1030048.

Wang, D., N., Abriak, R., Zentar, W., Xu. Solidification/stabilization of dredged marine sediments for road construction. Environmental Technology, v. 33, p. 95-101, 2012. Informa UK Limited. http://dx.doi.org/10.1080/09593330.2011.551840.

Wang, D., R., Zentar, N., Abriak, W., Xu. Experimental investigation on consistency limits of cement and lime-stabilized marine sediments. Environmental Technology, v. 33, p. 1197-1205, 2012. Informa UK Limited. http://dx.doi.org/10.1080/09593330.2011.633565.

Wang, J., R., Zhao, Y., Cai, H., Fu, X., Li, X., Hu. Vacuum preloading and electro-osmosis consolidation of dredged slurry pre-treated with flocculants. Engineering Geology, v. 246, p. 123-130, 2018. Elsevier BV. http://dx.doi.org/10.1016/j.enggeo.2018.09.024.

Zentar, R., D., Wang, N., Abriak, M., Benzerzour, W., Chen. Utilization of siliceous–aluminous fly ash and cement for solidification of marine sediments. Construction And Building Materials, v. 35, p. 856-863, 2012. Elsevier BV. http://dx.doi.org/10.1016/j.conbuildmat.2012.04.024.