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Special Edition

Retaing of dredging waste using geotextile tubes: analysis of the dewatering and undrained shear resistance of the sludge cake

Retenção de rejeitos de dragagem utilizando geoformas tubulares: Análise da dessecagem e resistência não drenada do bolo de lama

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ABSTRACT

The city of Rio Grande has its economy linked to coastal and port activities and has a port complex of high economic importance for the region. To maintain the depth of the port channels, periodic dredging operations are carried out, as occurred in the Port of Rio Grande between 2018 and 2020. Approximately 16 million m³ of sediments were removed from the channel and deposited in disposal zones. There has been an attempt to develop techniques that carry out the reuse and disposal of dredging waste more appropriately, seeking to minimize environmental impacts by avoiding inappropriate open-sea or onshore disposal. Within this context, this work aims to evaluate the potential of the retaining and dewatering process of dredging waste in geotextile tubs (linear geoforms, geobags e etc). This technique reduces the volume of dredged mud through desiccation and allows the geotextile tubs to be installed in sedimentation basins onshore or coastal protection structures. Thus, the present study evaluated the dewatering and filtration efficiency of these systems through tests of small bags. The advantages of adding flocculation polymer and the behavior of undrained shear strength over time of the retained cake were evaluated.

Keywords: Dredging waste, Geosynthetics, Dewatering; Undrained Strength; Costal protection

RESUMO

A cidade do Rio Grande tem sua economia ligada às atividades costeiras e portuárias e conta com um complexo portuário de elevada importância econômica para a região. Para fins de manutenção da profundidade dos canais portuários são realizadas operações periódicas de dragagem, como ocorreu no Porto de Rio Grande entre 2018 e 2020. Aproximadamente 16 milhões de m³ de sedimentos foram retirados do canal e depositados em zonas de bota fora. Têm-se buscado desenvolver técnicas que realizem a reutilização e deposição dos rejeitos de dragagem de forma mais adequada, buscando minimizar os impactos ambientais evitando descartes inadequados em alto mar ou em terra. Dentro desse contexto, esse trabalho objetiva avaliar o potencial de utilização desses rejeitos, após um processo de desaguamento e retenção em geoformas tubulares (Formas Têxteis, Geobags e etc). Essa técnica reduz o volume da lama dragada através da dessecagem e permite que as geoformas tubulares possam ser instaladas em terra ou utilizadas como estruturas de contenção costeira. Assim, o presente estudo avaliou a eficiência de desague e filtração desses sistemas através de ensaios de bolsas de pequena dimensão. Foram observadas as vantagens da adição de polímero floculante e comportamento da resistência não drenada ao longo do tempo na torta de sedimento retida.

Palavras-chave: Rejeito de dragagem, Geossintéticos, Dessecagem; Resistência não drenada; Proteção costeira

1 INTRODUCTION

The maritime and river transport modal is of fundamental importance for the world's economic development due to the capacity to transport large amounts of cargo and low cost considering the long distances traveled. To maintain the depth of the port channels, periodic dredging operations are carried out, as occurred in the Port of Rio Grande between 2018 and 2020 (Ferreira and Freitas, 2019).

Dredging is the landfill process, excavation, and removal of soil, sediments, or rocks from the bottom of rivers, lakes, and other bodies of water through equipment called "dredger". Dredging is usually a vessel designed for these purposes or a floating platform equipped with the necessary mechanisms to remove soil (grab dredgers, backhoes, among others) (Brant, 2012). The main objectives of dredging are the deepening and widening of channels, rivers, ports, and bays and the construction and maintenance of waterways, transport infrastructure, landfills, and soil recovery or mining.

In Rio Grande, the dredging waste resulting from these engineering works was frequently launched at open sea over the years and often caused environmental problems. The environmental impact occurs because of the disposal of dredged waste and the increase in suspended sediments during the process. There are several discussions about the incidence of mud on the beaches close to these regions.

According to Ferreira and Freitas (2019), since 1901, mud incidences have been recorded on Cassino beach in Rio Grande - RS, and just 1998 this issue emerged as an environmental factor. The most recent case occurred in December 2018, when a dredging operation was carried out next to the port access channel.

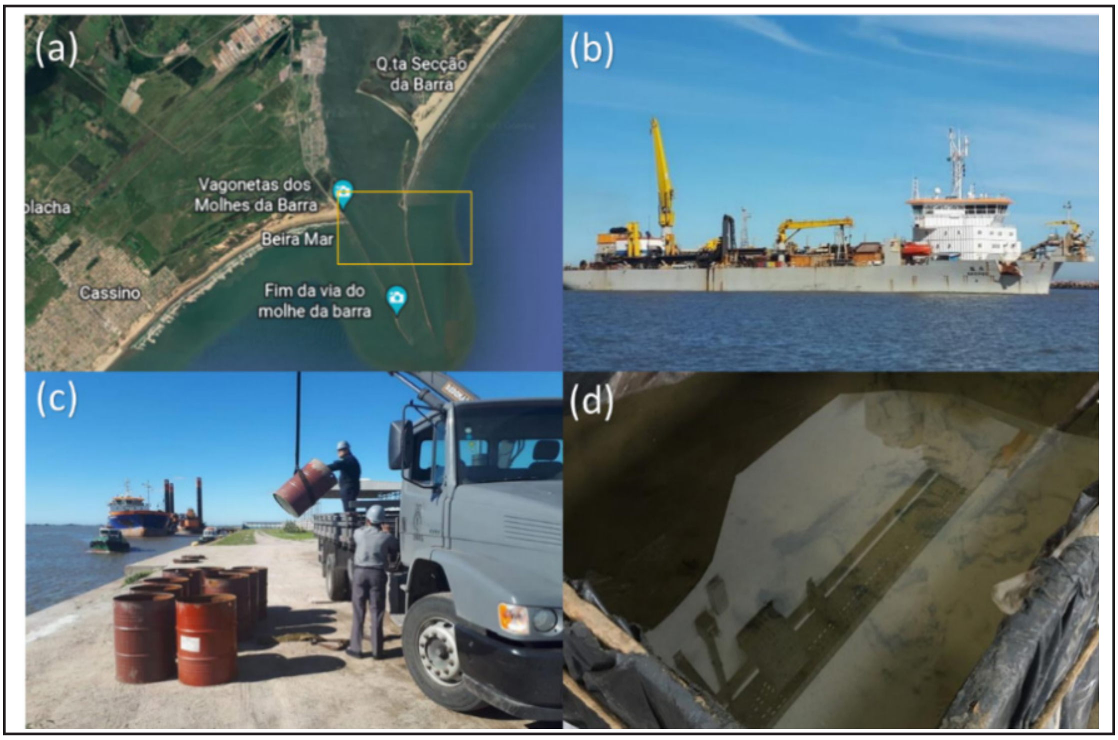
The geotextile tubes, also called linear geoforms, Geobags, large sausages or geocontainers, have been used mainly on applications related to coastal protection and retaining dikes for hydraulic fills, since 1980's years. According to Yee *et al.* (2012) the dewatering process increases the concentration of solids in the dredged sediments, changing its consistency to a solid or semi-solid form, which facilitates its handling and disposal.

The present study aims to analyze the performance of geotextile tubes in retaining dredging waste. Characteristics related to filtration, dewatering, and infiltration efficiency were analyzed, as well as the undrained shear resistance of the sludge cake inside the geotextile tubes.

2 MATERIALS AND METHODS

The sediment used in this study was collected during the dredging carried out across the channel access (near of Porto Novo, Superporto, and the exit of the access channel to the breakwaters). Dredging began in 2018 and was completed in 2020, performing the removal of about 16 million cubic meters of sediment. According to Araújo (2021), this material was disposed of on the open seas in a previously licensed area 30 km from the coast. The samples were transported to the Laboratory of Geotechnics and Concrete - FURG and stored in a closed reservatory. In the reservatory, the natural characteristics of the sediment as the water content, salinity, among others were maintained, as shown in Fig. 1.

Figure 1 – a) Location of the sample collection; b) Dredger Hopper; c) Transport of waste in barrels ; d) Sample storage at the laboratory



Source: Author’s (2022)

2.1 Geotechnical characterization of the sediment

For the geotechnical characterization of the soil, the granulometric curve was performed, through sieving and sedimentation as described in NBR 7181 (ABNT, 2016), and the Pycnometer test to determine the actual specific gravity of soil solids (ɣs) described by NBR 6458 (ABNT, 2016). The Atterberg Limits were also made, as described in the NBR 7180 and NBR 6459 standards (ABNT, 2016).

The percentages of each granulometric fraction according to the classification of NBR 6502 (ABNT, 1995) found in the sample were 6% coarse sand, 12% medium sand, 10% fine sand, 28% silt, and 44% clay%. The organic matter content found in the sediments was 1.45%.

The sediment density of the soil measured inside the dredge was approximately 1.1 g/cm³. The determination of the physical index of the soil showed a liquid limit (wl) of 52%, plasticity limit (wp) of 35% and PI = 17%. The plasticity index value PI > 5, characterized the sediment as highly plastic sediment. The colloidal activity index (Ia) obtained was 0.386, indicating the presence of clay minerals 1:1 and classifying the sediment as inactive.

According to Araújo et al (2023), the physical tests that indicated the material with the presence of clay minerals 1:1 and the X-ray diffraction results that also indicated the presence of quartz minerals, k-feldspar, illite and kaolinite.

2.2 Geosynthetics

NBR 12.553 (ABNT, 2002) defines geosynthetics as polymeric products (synthetic or natural) developed to serve various geotechnical works with the function of reinforcement, filtration, drainage, protection, separation, waterproofing, and control of erosion. Souza (2018) says that the mechanical and hydraulic properties of geotextile blankets led to the manufacture of the so-called closed geotextile system, which allows the confinement of solid material and drainage of high liquid content.

According to Saadet and Bulut (2015) when geotextile tubes are used to dewater materials with high water content, dewatering capacity is the main concern including two aspects: dewatering efficiency (how high the final percentage of solids can be obtained) and dehydration rate (how long dehydration will take).

Table 1 – Characteristics of the Geotextile used

Test Method	**Properties**	**GTX – 3 SoilTain PP - 55/55DW**
NBR ISO 9.864 (ABNT, 2013)	Feedstock; Mass per unit área; Density	Polypropylene; 270 g/m²; 0,92
NBR ISO 11.058 (ABNT, 2013)	Nominal flow speed	15x10-3 m/s
NBR ISO 12.956 (ABNT, 2013)	Filtration opening; Color	0,20 mm; Black
NBR ISO 10.319 (ABNT, 2013)	Rated tensile strength; Transverse direction	55 kN/m; 55 kN/m

Source: Author's (2022)

The present study was based on the geotextiles previously tested by Araújo et al (2020), for the same sediment analyzed in this research. To evaluate the system in geotextile tubes, the GTX - 3 type was used, whose characteristics are described in Table 1.

2.3 Flocculation polymer

Polymers are chemical substances known as additives or flocculants that, through chemical reactions, combined with the components of the material to be mixed, in the case of dredging sediments, forming flocs.

Koerner *et al.* (2016) state that most sediments from rivers and sea beds are composed of fine-grained clays and sediments that are easily adaptable to aqueous suspension in the form of dredged mud. Therefore, the portion of fine material in the sediments represents a concern in dewatering processes through geotextile tubes, since seams are usually the weakest points, in addition to forming the so-called filter cake at the bottom of the bag. To minimize these effects, chemicals are added to the dredged mud during pumping, flocculating fine materials, and contaminants.

Table 2 – Flocculation polymer

	Polymers	Ionic Characteristic	Density	Apparent optimal dosage (ppm)
A	SUPERFLOC C-496HMW	Cationic	650-850 kg/m³	280
B	SUPERFLOC C-492HMW	Cationic	750 kg/m³	500
C	SUPERFLOC A-130HMW	Anionic	650-850 kg/m³	350
D	SUPERFLOC A-150HMW	Anionic	650-850 kg/m³	360
E	SUPERFLOC C-498HMW	Cationic	750 kg/m³	200
F	SUPERFLOC A-100HMW	Anionic	650-850 kg/m³	280
G	SUPERFLOC A-110HMW	Anionic	750-950 kg/m³	200
H	SUPERFLOC A-137HMW	Anionic	650-850 kg/m³	200
I	SUPERFLOC C-494HMW	Cationic	750 kg/m³	310

Source: Adapted from Araújo (2021)

Araújo (2021) performed the determination of optimum polymer dosage testing nine different cationic, and anionic polymers. The cationic polymers neutralize the surface electrical charges that surround suspended solids and increase the size of the flocs (Novais, 2012). The anionic polymers form a kind of “bridge” between its chain and the already coagulated particles forming flocs of larger diameters (Novais, 2012). The optimum polymer dosage and the characteristics of the materials are presented in Table 2. The polymer H at a dosage of 200 ppm was chosen to perform the tests of this study.

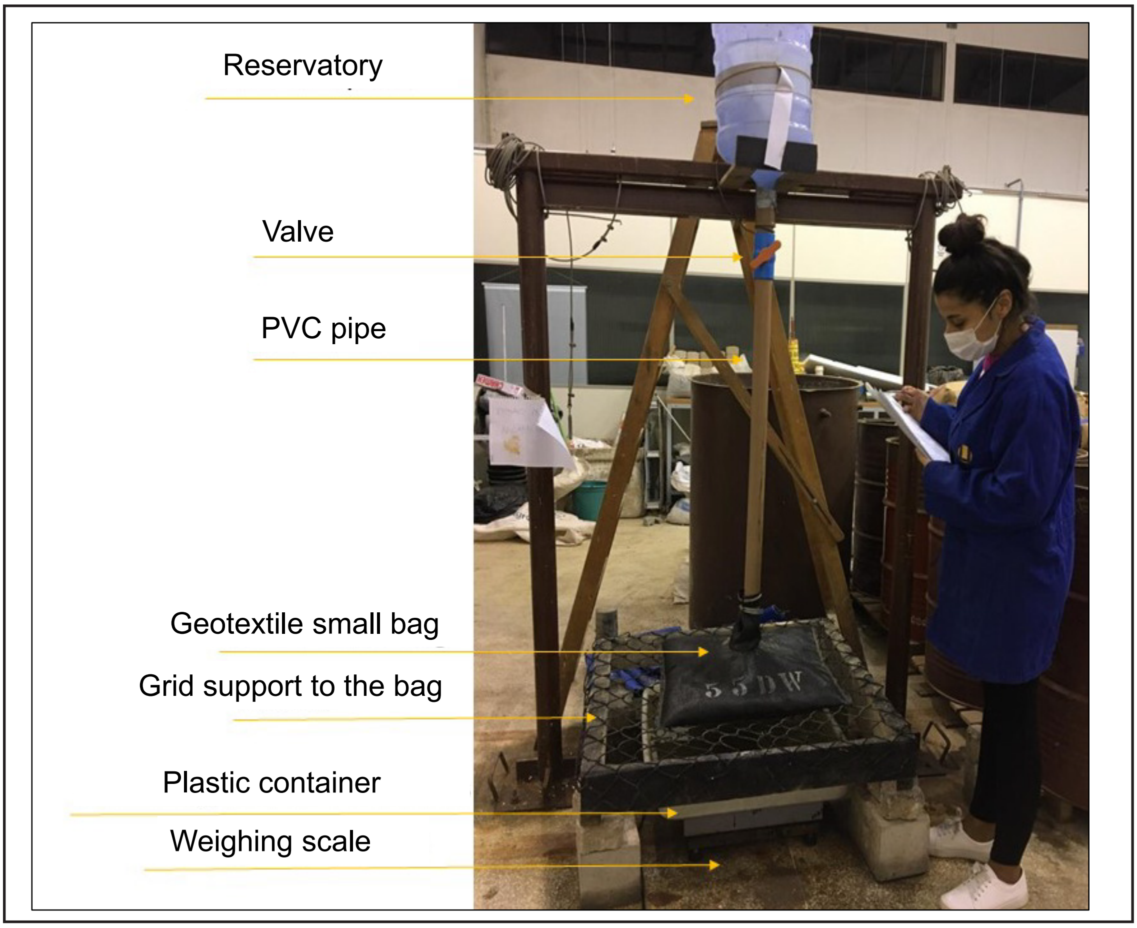
2.4 Dewatering test in small geotextile bags

To evaluate the behavior of the geotextile tubes, the dewatering test was carried out in a geotextile small bags. The test consists of filtering the sediment in a geotextile tube of reduced dimensions (carrying out the test at a laboratory level) and evaluating the capacity of the system (sediment x polymer x geotextile) for draining the liquid portion and soil retention during the time. ASTM D7880 (2013) standard describes the procedures for this test.

The dewatering test equipment showed in Figure 2, counts with a structure support to the reservatory were the dredging waste was launched, a valve to control the flow trought the PVC pipe, grid support for the small bag, a plastic container to collect the effluent and a weighing scale.

The first step was to launch the dredging waste mixed with the flocculation polymer in the reservatory. Next, the valve was opened at 45º to control the flow in the PVC pipe. Then, readings of the volume discharged were performed in times 1, 5, 15, 30, 60, 120 minutes, and finally in the 24 hours. The small bag was filled in 6 cycles with a time interval of 48 hours between them. The tests were performed with and without the addition of polymer.

Figure 2 – Drainage test in a small bag



Source: Author’s (2022)

2.4.1 Parameters evaluated in the dewatering tests

To analyze the system’s filtration capacity, Moo-Young et al. (2002), suggest that filtration efficiency is obtained by comparing the final total solids of the effluent (TSfinal) with the initial total solids (TSinitial), as shown in Eq. (1)

$$FE = \frac{TS_{initial} - TS_{final}}{TS_{initial}} \times 100\% \qquad (1)$$

Where:
FE is Filtration efficiency [%];
TS final is the final total solids [mg/L];
TS initial is the initial total solids, [mg/L].

Dewatering efficiency is calculated through comparisons between the initial solids percentage and the final solids percentage, according to Eq. (2).

$$DE = \frac{PS_{final} - PS_{initial}}{PS_{initial}} \times 100\% \tag{2}$$

Where:
DE is Dewatering Efficiency [%];
PS final is the final solid percentage;
PS initial is the initial solid percentage.

Similarly, analyzing the initial moisture and the final moisture of the sample after opening the bag, the calculation of the infiltration efficiency was performed, described in Eq. (3).

$$IE = \frac{w_{initial} - w_{final}}{w_{initial}} \times 100\% \tag{3}$$

Where:
IE is the Infiltration Efficiency [%];
w initial is the initial humidity [%];
w final is the final moisture [%].

Finally, for the polymer efficiency analysis, the results of the effluents obtained from the dewatering test with and without the polymer were compared. The polymer efficiency is obtained with Eq. (4).

$$PE = \frac{P_{sludge} - P_{sludge,polymer}}{P_{sludge}} \times 100\% \tag{4}$$

Where:
PE is Polymer Efficiency [%];
Ps ludge is the dry weight of percolate without polymer [g];
Ps ludge, polymer is the dry weight of percolate using polymer [g].

2.5 Undrained shear strength of the cake

After 48 hours of the last fill cycle, the geotextile small bag was opened and tests were carried out to verify the behavior of the undrained shear strength (Su) of the retained sludge cake. The Su was also measured during the time to evaluate the influence of the water content. Laboratory VaneTest equipment and the test procedure are present in Fig 3.

Figure 3 – Laboratory VaneTest equipment

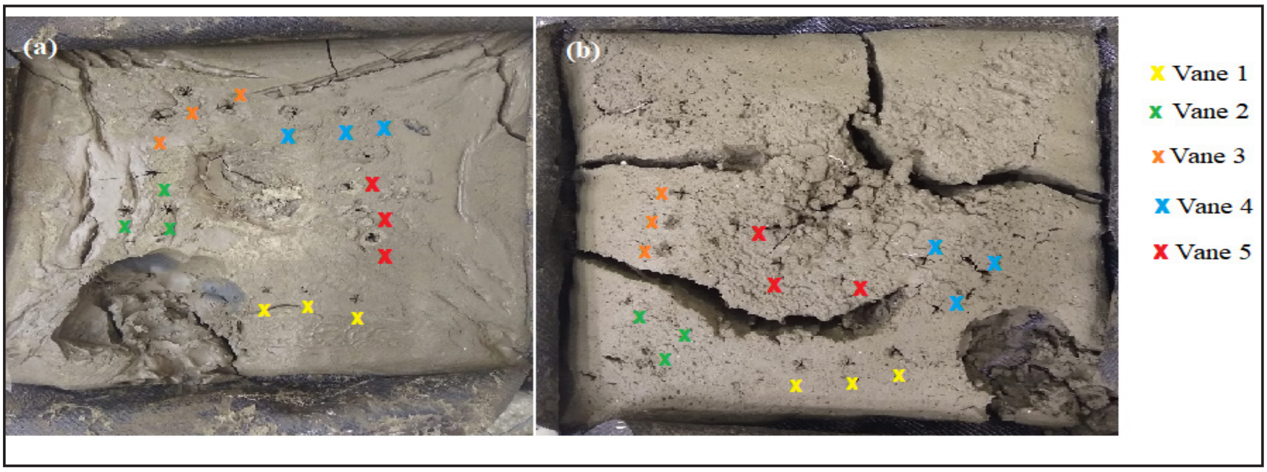
Source: Author's (2022)

Five tests were performed at different points of the sludge cake, all in triplicate, with intervals of 7 days. The location of these points is shown in Fig. 4(a) and (b). With the torque results measured in the test, the undrained shear strength was calculated through the correlation between the spring constant (Kmv), provided by the equipment manufacturer, and the measurement of the maximum torque angle presented in Eq. (5) NBR 10905 (ABNT, 1989).

$$S_u = \frac{K_{mv} \times \theta_f}{4{,}29} \quad (5)$$

Where:
K_{mv} is the spring calibration constant;
θ_f the maximum measured angle.

Figure 4 – Position where the Laboratory Vane test was performed (a) Dewatering test with only dredging waste (b) Dewatering test with dredging waste and polymer



Source: Author's (2022)

3 RESULTS

Dewatering tests were carried out in a small bag, with and without the addition of polymer to the sediment. Each of them had 6 filling cycles spaced 48 hours apart. The results of the parameters evaluated in the dewatering tests are shown in Table 3.

Table 3 – Parameters evaluated in the dewatering tests

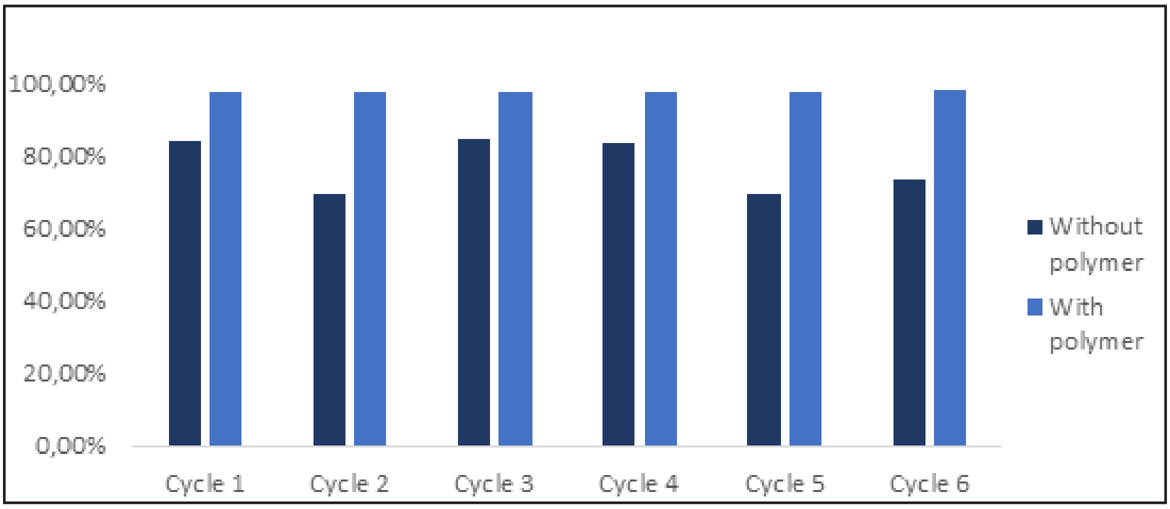
		Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
FE (%)	Without Polymer	84,11	70,82	85,66	79,37	70,50	61,73
	With Polymer	87,05	86,59	85,34	87,15	86,75	88,34
DE (%)	Without Polymer	83,94	69,09	84,59	83,12	68,97	73,13
	With Polymer	97,50	97,36	97,11	97,47	97,39	97,70
IE (%)	Without Polymer	-	-	-	-	-	81,79
	With Polymer	-	-	-	-	-	83,66
PE (%)	-	55,63	63,74	32,13	58,30	70,93	81,72

Source: Author's (2022)

With the results obtained, it is possible to observe that the filtration efficiency (FE), that is, the ability of the geotextile to retain solids in the bag, increases with the addition of polymer, this behavior is more pronounced in the sixth cycle. It can be seen that the average EF without the addition of polymer is 75.36% while the average EF with the addition of polymer is 86.87%, increasing by 11.51%.

The dewatering efficiency (DE), which evaluates the final solid percentage as a function of the initial one, had an average increase of 20.28% in the test with polymer compared to without polymer, as expected. Another important consideration is that the DE practically does not vary between the filling cycles of the system with polymer addition, showing a practically constant behavior of the system's drainage capacity between cycles, as can be seen in Fig. 5.

Figure 5 – Dewatering efficiency

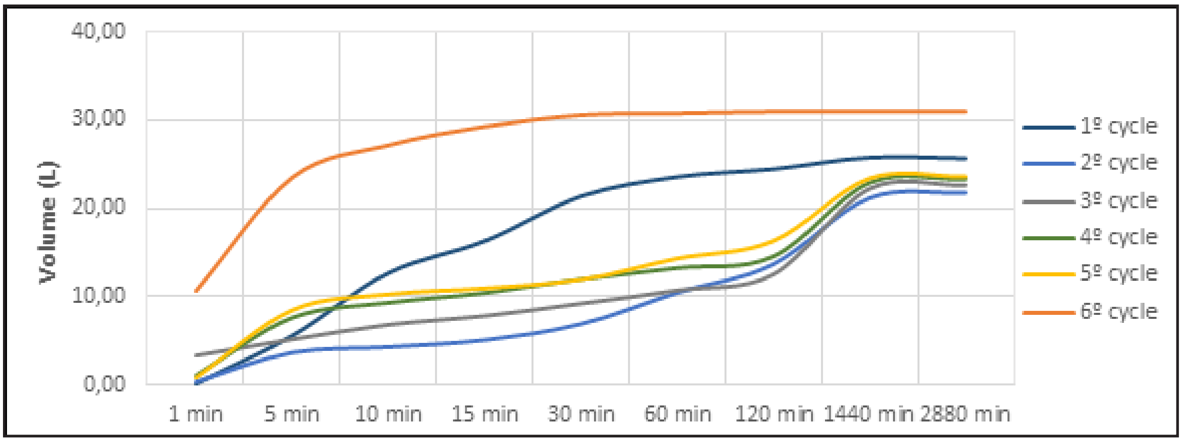


Source: Author's (2022)

The infiltration efficiency (IE), takes into account the variation in system humidity. The results show a little variation with the addition of the polymer in the sediment. In all filling cycles, the polymer efficiency (PE) was around 60.41%, with the highest percentage obtained for the sixth filling cycle at 81.72%, and the lowest percentage of PE in the third cycle filling at 32.13%. It is possible to observe in Figures 6 and 7 that the DE is higher in the system with the addition of the flocculant polymer for all filling cycles.

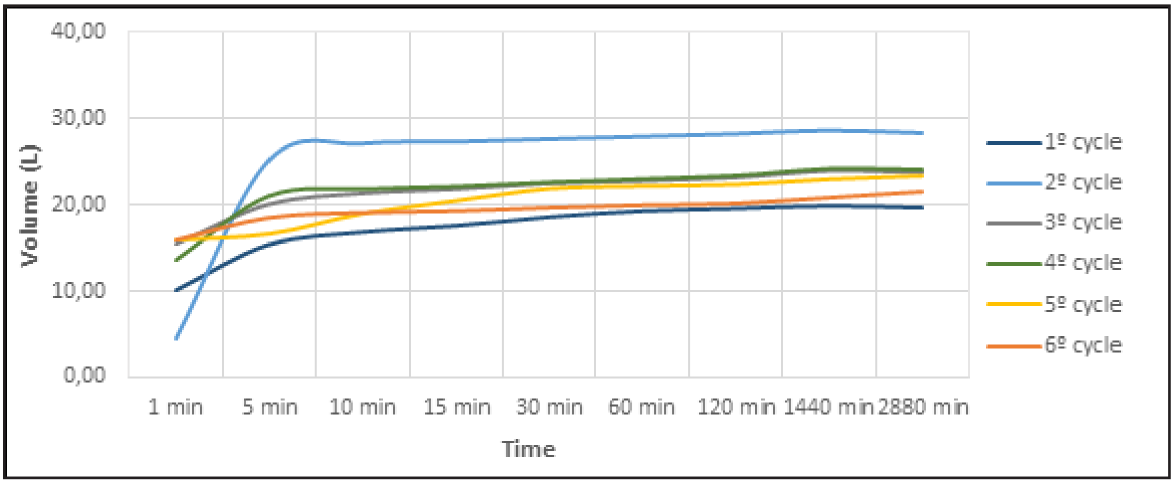
Another important characteristic evaluated is the dewatering rate over time, that is, the accumulated effluent passing volume over the test time, resulting in the mass curve. Fig. 6 and Fig. 7 present the mass curves resulting from each filling cycle for both tests, with and without the addition of polymer.

Figure 6 – Mass curve without Polymer



Source: Author’s (2022)

Figure 7 – Mass curve with polymer



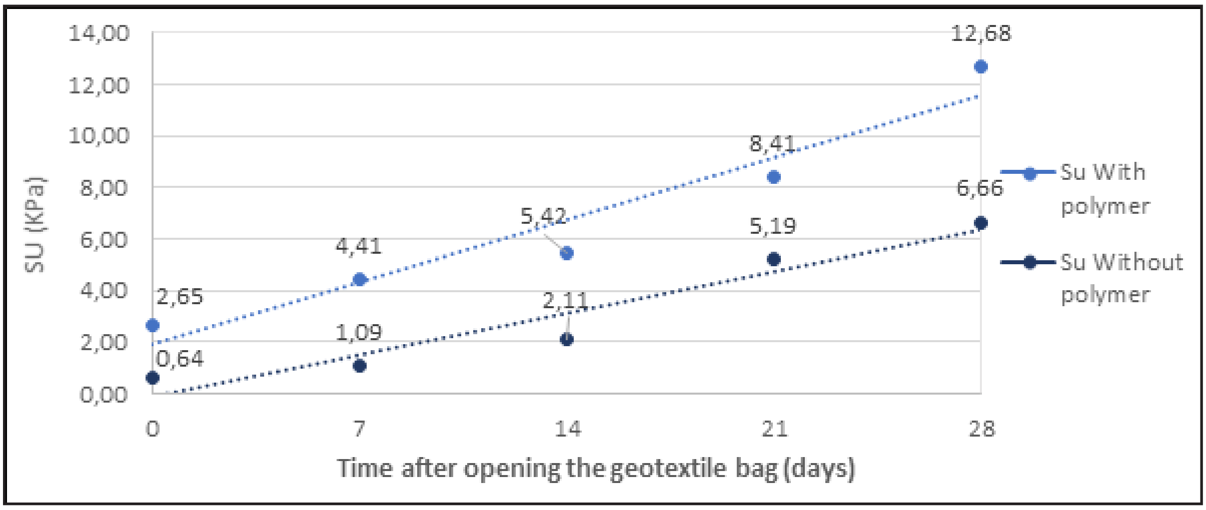
Source: Author’s (2022)

It can be seen that the mass curves in the test with the addition of polymer have less variation in the volume drained over time, which demonstrates that the drainage occurs more quickly compared to the test without the addition of polymer.

The behavior of the mass curves of cycles 5 and 6 of the system without polymer addition is due to the complete filling of the bag, causing the effluent to percolate through the upper part of the bag more quickly when compared to the other cycles which the greater part of the effluent percolates through the sediment cake.

After opening the small bag, the laboratory Vane test was performed to evaluate the undrained shear strength of the retained sludge cake (Fig. 8).

Figure 8 – Undrained shear strength (Su) along the time



Source: Author's (2022)

With the analysis of the results of the Su, it is possible to observe an increase with the addition of polymer to the sediment, since the initial Su without polymer resulted in 0.64 kPa and with polymer 2.65 kPa in the bag opening, and from 6.66 kPa to 12.68 kPa after 28 days. An increase of 185% was observed in Su. There is also a significant increase in Su over time in both tests. In the test carried out with the cake retained with polymer, a resistance of 12.68 kPa was reached 28 days after opening the bag, approximately five times greater than the initial one.

4 CONCLUSIONS

The sediment under study, from the dredging of the access channel to the port of Rio Grande, presented a large amount of fine material, characterized as a sandy clay whose granulometric curve presented a uniform behavior, and also a highly plastic behavior.

The dredging waste study was collected in the access channel of the Port of Rio Grande. the sediment presented a large amount of fine material, characterized as a sandy clay whose granulometric curve presented a uniform behavior, and also a highly plastic behavior.

The dewatering test in small bags was essential for evaluating the behavior of the sediment in closed geotextile systems. In general, there was a considerable gain in system efficiencies by adding the polymer to the sediment, increasing the Dewatering efficiency (DE) by an average of 20%, reaching a maximum value of 97.70%, which is satisfactory for this study. As for filtration efficiency, it was possible to observe an improvement of approximately 11%. Therefore, analyzing the results obtained, it is possible to conclude that the use of a flocculant polymer is necessary to optimize the dewatering process in geotextile tubes.

The understanding of the undrained shear strength of the sludge cake retained in the bag is an important parameter to evaluate the applications of this system as a coastal protection structure. It was possible to observe a significant increase of Su with time, reaching 12.68 kPa, as well as, it was noticed that the addition of polymer to the sediment also contributes to the increase of Su, reaching 186% on average.

The results presented are preliminary and are part of an extensive testing program to understand the Geotextile tube behavior by the analysis of different geotextiles and polymers.

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