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Emergency recovery of Macumba Beach, Rio de Janeiro – RJ, using synthetic structure composed of tubular and flat textile bags.

P.H. Marcondes, Huesker Ltda, São Paulo, Brazil - pedro.marcondes@huesker.com.br
S.P. Gomes, Galbeg Grouting, Rio de Janeiro, Brazil - galbeg@galbeg.com.br

ABSTRACT

This paper describes the works carried out in an emergency recovery on the Macumba beach in Rio de Janeiro/RJ. The degradation of the area started after the El Niño and La Niña effects in previous years, caused a strong change in the sea currents regime, leading to excessive beach sand removal, and causing damages to the buildings along the beach in 2017. A protection and erosion control structure was installed as an emergency measure. The structure was constructed with layers of geotextile tubes on top of a concrete geotextile mattress. The tubes were made of woven geotextile fabric filled with colloidal grout, while the matresses were made of woven and non-woven geotextile fabric filled with sand or grout. The construction was divided in 3 sections along the beach. For every section, geotextile mattresses were laid at different elevations, and the technical specifications of these mattresses varied as a function of elevation and geometry of the beach in that section. At the end of the implementation of the synthetic structure, a backfill was constructed, reestablishing the beach aesthetics. The successful emergency construction, which took a period of 6 months to be completed, guarantees a stable structure for the hydraulic energy that will be imposed by a new sea swell event, as well as geotechnical stability. A definite solution for the Macumba Beach must include an extension of the canal on the west of the beach to the sea, as well as restoration of the sediment dynamics at the shore, with an enlargement of the beach.

Key words: Geotextile, Erosion control, Geotextile tubes

1. INTRODUCTION

Pontal de Sernambetiba Beach, popularly known as Macumba Beach, is located in Rio de Janeiro / RJ between Recreio Beach and Prainha Beach, in the Recreio dos Bandeirantes neighborhood. It is an extensive beach with great tourist influence, especially for surfing.

In 1999, there was a big swell in the sea due to the change in South Atlantic wave patterns, caused by the influence of the very strong El Niño in the previous year. In this period, there were no buildings along the sand in which the wave energies were dissipated, and despite no major impact on the population, sedimentation dynamics were already present in the region.

In 2005, an urbanization project called “Eco Praia da Macumba Beach” was implemented, where structures such as bike lanes, boardwalk, beach kiosks, streets and retaining walls were built along the beach.

In September 2017, there was a major swell in the sea at the site, causing a significant erosion and the collapse of buildings built along the area of dissipation.

According to Rosman (2018), “the phenomenon in 2017 was very similar to that of 1999 with the same cause occurring a year after a very strong El Niño which changed the pattern of South Atlantic waves. Because the Macumba Beach faces the south, there is a cyclic movement of sand during spring and summer. The waves come from the southeast, pushing the sand from east to west, in front of the rocky shore that separates Praia da Macumba from Prainha. In autumn and winter, the waves come from the southwest, causing the sand to be pushed in the opposite direction i.e. westward. When there is a very strong El Niño, they come from the southeast all year round, shifting the sand from the beach to the west.”

West of the beach, the Sernambetiba artificial canal, used for the macro drainage of the Vargem Grande neighbourhood, requires constant dredging, thus contributing to the sand removal in years of swell in the sea.

Souza (2011) concludes that beaches and coastal areas are the regions where the energetic action of the sea is most felt on the continents, with the coast being the obstacle into which the waves end up dissipating all their energyies Assessing the events along the Macumba beach stretch, the construction of the buildings in 2005 and the constant dredging of the artificial canal west of the beach, there was the potentiation of energy, which was previously dissipated at the coast of the beach, causimg severe impacts on the buildings. This resulted in the need for emergency intervention.

2. EMERGENCY SOLUTION

The city of Rio de Janeiro, through its secretary of Conservation and Environment - SECONSERMA, needed a quick emergency solution in order to protect buildings near the erosion zone.

As a solution, tubular woven geotextile filled with grout and flat non-woven geotextile filled with grout and sand were specified. Jet Grouting columns had been installed on the existing walls to ensure protection and stability.

As the Jet Grouting columns were installed only in section 2B as an emergency treatment that make up a small part of the construction (60m), its dimensioning method is not detailed in this article.

2.1 The project and the execution

The company Geomecânica S.A. was responsible for the execution of the work and relied on the consultancy of Eng. Marcio Rodrigues and Eng. José Filipe Caldas in the project conception. The supervision was the responsibility of the municipality of Rio de Janeiro / RJ.

The work was divided into 3 sections, as shown in Figure 1. Four distinct sections were defined.

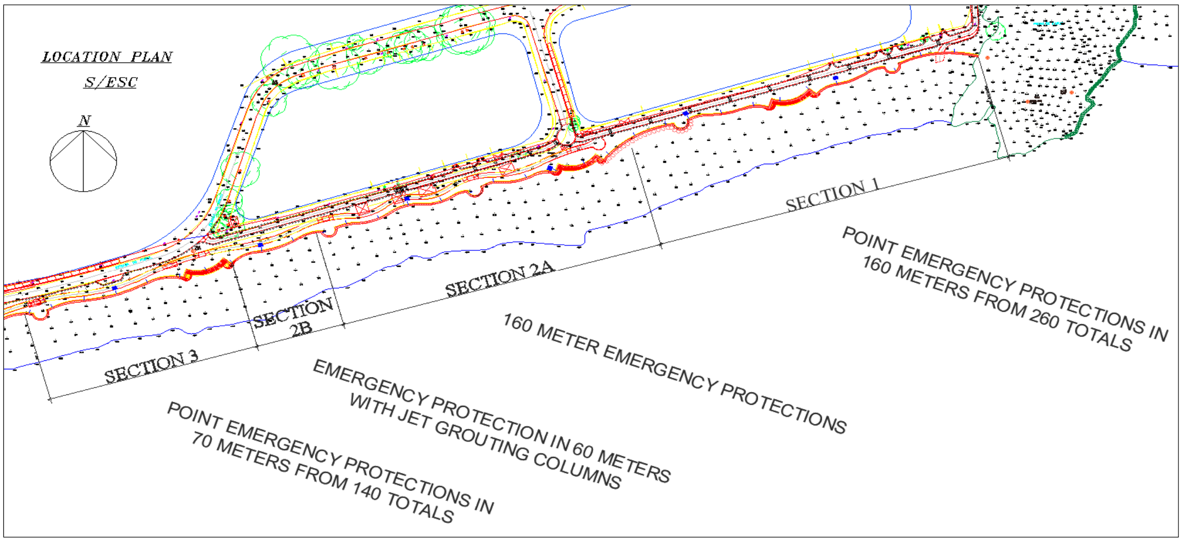

Figure 1 - Macumba Beach Project – Rio de Janeiro / RJ

In most of the work, the technique of synthetic structure with bags was chosen as the structure for energy dissipation and protection of buildings.

The construction of a synthetic structure with bags is a widely used technique, mainly for temporary works, with granular material filling (especially sand) or grout. Lawson (2006) describes several concepts of installation of the bags in standard arrangements, organizing them in a way that improves their performance and overall stability.

In general, sand is the most suitable material for filling, since a more flexible structure is achieved, and the energies caused by waves and currents are better absorbed by the structures. However, to avoid vandalism, few structures of this kind are filled with sand, grout being the most chosen material for these types of work.

Synthetic structures with geotextile bags usually have two main geometries, as shown in Figure 2.

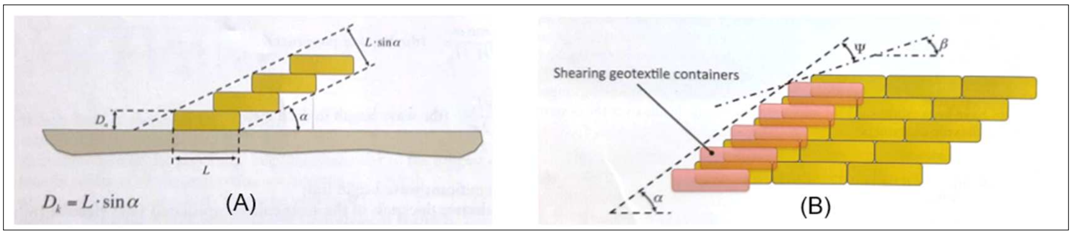

Figure 2 – Main geometries: (A) Stacking on local soil; (B) Stacking systems with overlapping bags (adapted from Bezuijen, 2013).

The Stacking on local soil systems (A) are carried out in regions where excellent geotechnical stability is achieved and a great drainage system can be guaranteed. Stacking systems with overlapping bags (B), on the other hand, are carried out on projects that aim to guarantee good geotechnical stability, but this system represents higher cost of implementation, since it demands 2 to 3 times more bags and filling material.

For the emergency project at Macumba beach, the synthetic structure with stacking and overlap was chosen as the executive design method, as it guaranteed greater geotechnical safety and security regarding the energy imposed by an eventual swell in the sea.

In a stacking situation, the biggest concern with the structure is the shear between the bags, especially the tallest bag. Bezuijen (2013) highlights that bag shear can be a limiting factor in relation to the stability of the highest bag, when the slope is steep and the bag is large in comparison to the height of the wave. In addition, the stability of the foundation can be important, as a soft clay foundation may deform considerably when a bag is positioned on it and can be susceptible to plastic deformations due to compression and excessive settlement.

The greatest challenge to the stability of the structure is when there are waves lower than the one provided in the dimensioning, because the low water pressure on the side facing the sea and the high pressure of the external water on the side of the slope results in a large pressure gradient of the external water in the structure's slope, the narrower the width of the the structure, the bigger the external pressure gradient. For this reason, as the emergency synthetic structure of Praia da Macumba will basically only be required hydraulically by the action of waves in times of swell in the sea, the project has provided long and large structures in the sections, also ensuring good performance regarding the shear.

Lawson (2006) points out that there are ten failure mechanisms to be analyzed in geotextile bag structures. Figure 3 shows the possible internal failure mechanisms analyzed in the sections developed for the structures used at Macumba beach.

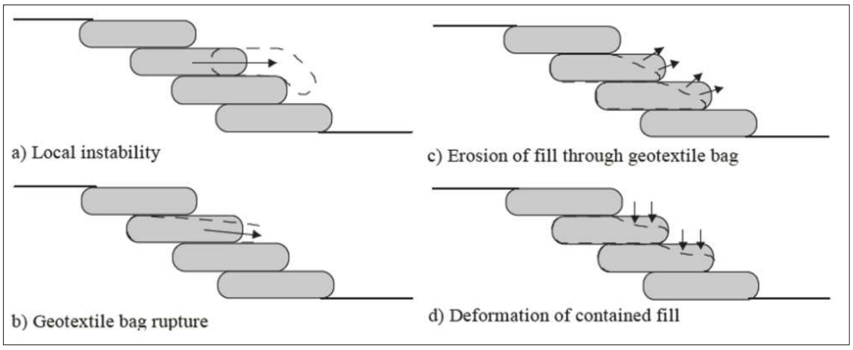

Figure 3 – Internal failure mechanisms (from adapted from Lawson, 2006).

To guarantee local stability (a): the stacking system with overlapping model was chosen. To avoid rupture of the woven geotextile of the bags (b): bags made of woven geotextile with a bidirectional tensile strength of 60 kN / m were installed. To avoid erosion of the filling through the geotextile bag (c) and deformation of contained fill: in addition to the biaxial resistance, the modules presented deformation in the nominal longitudinal resistance of 16% and 11% in the transversal direction, which allows control over the deformation of the structure. The low flow rate ($15x10^{-3}$) contribute to a greater stiffness of the smaller bags. And the large modules were installed with the help of temporary wooden frames.

Figure 4 shows mechanisms of external failure, according to Lawson (2006).

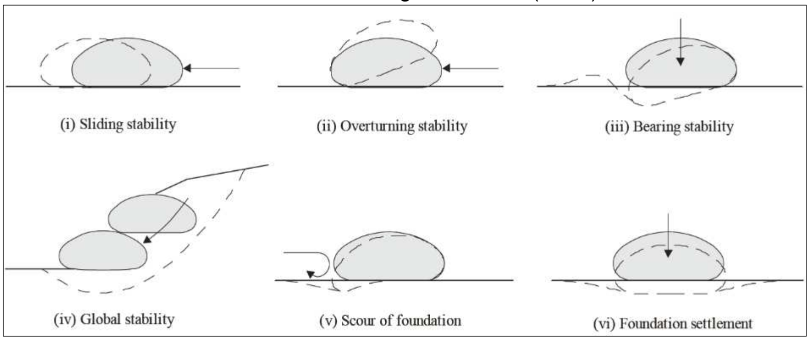

Figure 4 – External failure mechanisms (from adapted from Lawson, 2006).

The external failure mechanisms are linked to the boundary conditions in the installation area. The sliding stability (i) was controlled with the temporary frames and the confining of the structure between the coast and the existing buildings. Overturning stability (ii) and Global stability (iv) were guaranteed by the stacking geometry in a pyramid shape. Bearing stability (iii), To avoid Scour of foundation (v) and Foundation settlement, an anti-scour mattress was placed.

The angle of inclination of the structure must follow the angle of incidence of the waves, not exceeding 1:1, conveniently remaining V:H = 1:3 or V:H = 1:2.

2.2 Detailing of sections

2.2.1 Type 1 Section – 260 m stretch along the beach, as shown in Figure 05.

Synthetic structure composed of woven geotextile tubes, filled with colloidal grout with a fck of ~ 20 MPa.

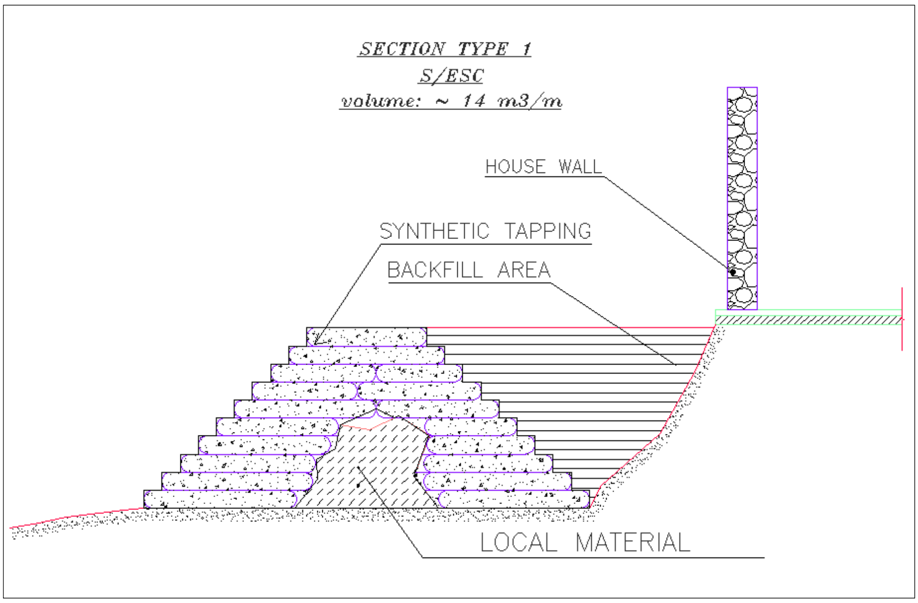

Figure 5 - Type 1 Section - Macumba Beach – Rio de Janeiro / RJ

According to Das Neves (2003), larger bags are more stable under the action of cyclical and high-energy loads than smaller ones, but they are the most difficult to install. At Praia da Macumba, to ensure resistance against wave actions, landslides and falls, large shapes (5m wide x 5m long x 0.5m high) were used. There is a difficulty in preparing or filling in locally, as it was necessary to carry out works in low tides at some points. Also, it was necessary to use temporary frames to Guarantee a Specific Geometry in the Project, as shown in Figure 6.

Figure 6 - Type 1 Section - Macumba Beach – Rio de Janeiro / RJ

As an anti-scour measure of the structure, an excavation was carried out to the minimum tidal level and a sand-filled mattress made with Nonwoven Geotextile was placed.

The executive procedure for building the structure consisted of the following steps:

1. Excavation of the eroded area to the minimum tide level;
2. Leveling the area that received a structure;
3. Installation of nonwoven geotextile mattress filled with sand;
4. Assembly of temporary wood frames;
5. Filling to the determined elevation;
6. Dismantling of wooden frames;
7. New assembly of temporary molding frames on the upper level, filling the bags and disassembly of molding frames until reaching the design elevation.
8. Finishing the synthetic structure.

2.2.2 Type 2A Section - 160m stretch along the beach, as shown in Figure 7.

For the types 2A and 3 sections, to guarantee the stability of the synthetic structure foundation, geotextile mattresses filled with grout were installed, representing the concept of articulated concrete mattress, which perform the function of dissipating stresses throughout the mattress, thus avoiding differential settlements and also providing protection against the scour of the structure, since the mattress allows a certain movement of adaptation to small deformations in the free area (mattress area without the positioning of bags).

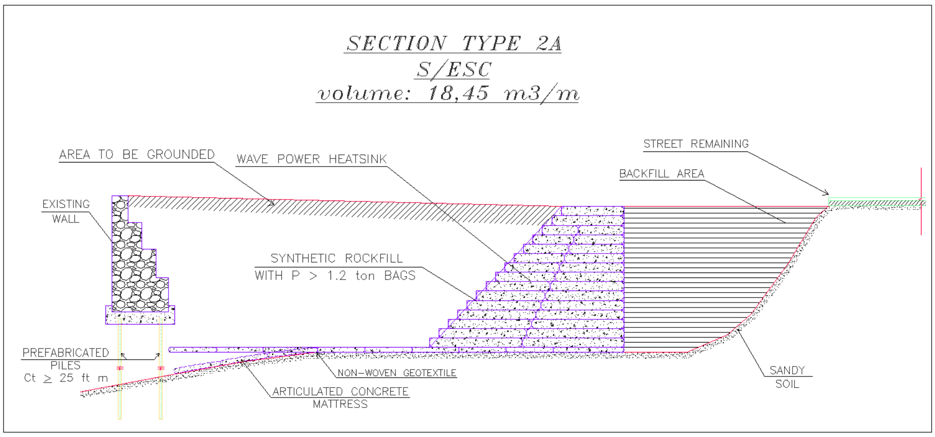

Figure 7- Section 2A - Macumba Beach - Rio de Janeiro / RJ

Figure 8 presents a picture of the mattress filling with the concept of articulated concrete mattress.

Figure 8 - Mattress filling with the concept of articulated concrete mattress – Macumba Beach – Rio de Janeiro

Unlike Type 1 Section, in this case a flexible flat shape made with a double layer of geotextile fabric connected by spacers that determine the thickness of the fill was installed. The mattress has a filling height of 0.2 m, allowing a dissipation capacity according to the energies imposed by the structure on the base. The concept of installation at the minimum tide level was guaranteed, preventing the base of the structure from being solicited.

The executive procedure follows the same standards presented in section 2.2.1, changing only the material of the third stage of execution, and the mattress made with non-woven geotextile being replaced by the mattress made by articulated woven geotextile.

2.2.3 Type 2B Section - 60m stretch along the beach, as shown in Figure 9.

As a demonstrative character, Figure 9 shows the type 2B section – where the Jet Grouting columns were applied along 60 meters of beach protection.

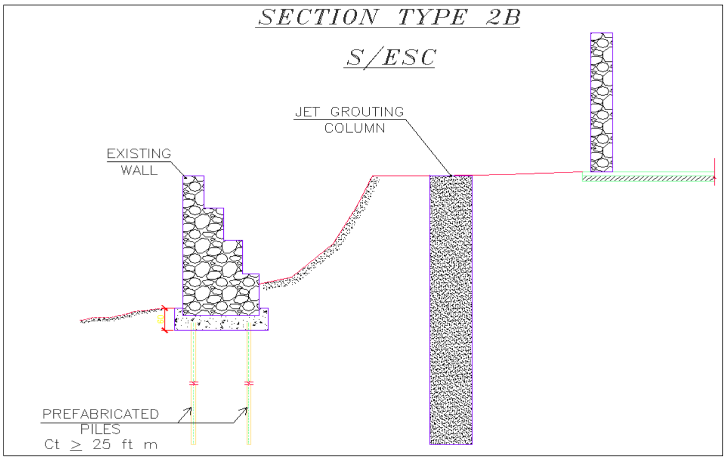

Figure 9 - Section 2B – Jet Grouting Column Macumba Beach – Rio de Janeiro / RJ

2.2.4 Type 3 Section – 140 m stretch along the beach, as shown in Figure 10.

This solution is similar to that used in Section 2 and Section 2A, with the flexible geotextile mattress and the tubes made of woven geotextile, as shown in Figures 8. The flexible mattress and tubes filled with colloidal grout with a fck of ~ 20 Mpa were used to perform the function of protection and erosion control.

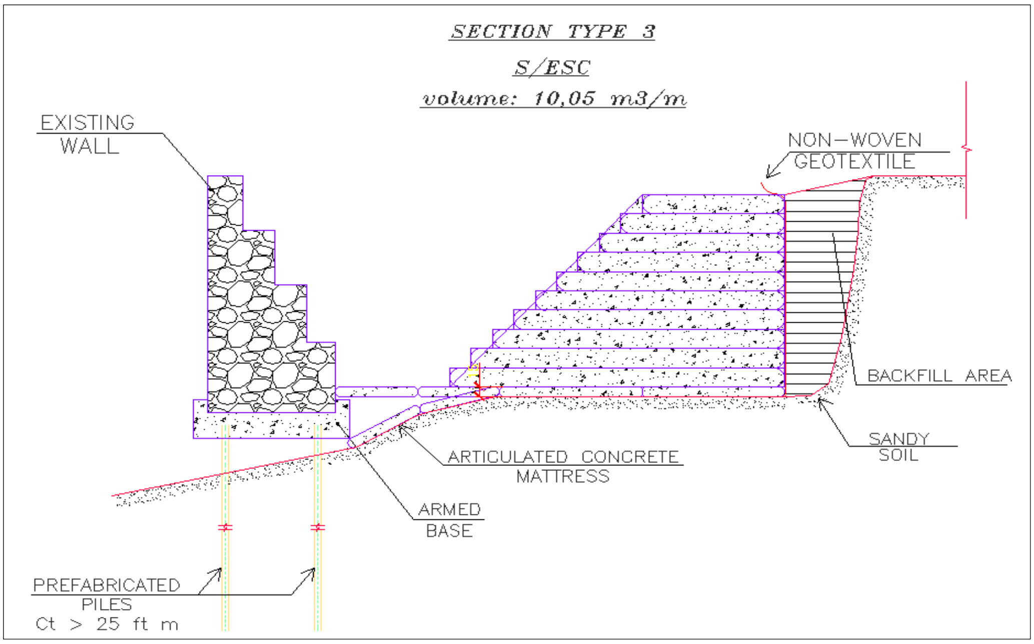

Figure 10 - Excerpt 3 - Type 3 Section - Macumba Beach – Rio de Janeiro / RJ

Figure 11 shows the synthetic structure in the finished Type 3 Section, ensuring the protection of buildings on the beach.

Figure 11 - Section 2A - Macumba Beach - Rio de Janeiro / RJ

At specific locations, where there was an existing wall, smaller modules were used, being adapted to the spaces and angulation of wave energy dissipation, as shown in Figure 12.

Figure 12 - Type 3 Section - Macumba Beach – Rio de Janeiro / RJ

At the end of the construction of the structure, a sand embankment was executed to guarantee the aesthetics requested in the project.

In total, 383 m of Jet Grouting (corresponding to 2,304 m of column), 8.844 m³ of protection with geotextile and 28,560 m³ of embankment were constructed.

2.3 Project quality control

To ensure the efficiency of the emergency project, SECONSERMA carried out a Project Quality Control (CQP), having as one of its consultants Dr. Paulo Rosman, professor of the Coastal Engineering area at Coppe / UFRJ.

2.4 Interventions outside the project

In about half of the work, it was necessary to perform a protection of the foundation of a specific building, which presented greater damages and consequently greater risks. As a punctual work solution, metal piles, Jet Grounting columns, geotextile tubes and flexible geotextile mattresses were used, limiting the structural damage to the building, caused by wave actions, as shown in Figure 13.

Figure 13 - Protection of foundation - Praia da Macumba - Rio de Janeiro / RJ

3. ADVANTAGES OF USING GEOSYNTHETICS

The main reasons for the implementation of geosynthetics and the advantages observed in this project are listed:

- Shorter execution time of the project, due to the easy positioning of the tubes and mattresses, ensuring the stability and geometry of the structure;

- Speed of execution, due to the possibility of filling several tubes at the same time;
- Remote injection of concrete, with the use of a concrete pump, not requiring machinery access in the middle of the beach;
- Accommodation of any movements of the flexible mattress made of woven geotextile, installed at the minimum tidal level in some parts of the beach;
- Lower impact on the nearby population, with the emergency works being carried out in 6 months.

4. CONCLUSION

The emergency works on the edge of Macumba beach was successfully completed, ensuring the temporary security of the buildings next to the site.

The use of geosynthetics enabled a quick response to the emergency situation, ensuring geotechnical and hydraulic stability for the structures. However, the dredging activity in the artificial canal located west of the beach continues to occur, which will lead to changes in the sediment mechanics of the beach, which may result in future problems resulting from coastal erosion.

The constructive methodology chosen for the synthetic structure of the project - Stacking systems with overlapping bags - resulted in a safer structure to resist the energies that would be transmitted, especially the wave energies.

Conventional methodologies, such as grout and stone walls, tend to have a very steep angle when subjected to wave energy, tending to collapse and generating composite waves, amplifying the problem of swell in the sea.

Obtaining a minimum tide level and constructing the base of the synthetic structure at this level guarantees that no erosion will happen at the structure's foot. Also, the use of flexible mattresses, even those filled with grout, allowed a dynamic way to monitor eventual movements by settlement or erosion at the base of the structure.

Finally, for the definitive solution for the protection and rehabilitation of the shore of Macumba beach, according to Rosman, 2018, needs to stabilize the west canal, by extending it to the sea; and restoring the dynamic range of the beach with sand recovery (> 600,000 m^3).

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