Journal of Building Technology, 2026, Volume 8, Issue 1
DOI: 10.32629/jbt.v8i1.5220
ISSN Online: 2717-5103
ISSN Print: 2705-1390

Containment technology: innovation with hexagonal rings and precast concrete blocks

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Abstract: This paper aims to present the coastal erosion containment technology applied on the shoreline of Maceió, utilizing the Dutch methodology with solid concrete blocks and precast hexagonal rings, without the need for reinforcements. Maceiófaces challenges posed by advancing seas onto the mainland, exacerbated by sediment deficit and meteorological variations resulting infrequent storm surges and damage to urban infrastructure, as well as loss of vegetation due to human activities along the coast. In response to this scenario, studies have been conducted to mitigate the impacts of coastal erosion and halt sea encroachment. Among the considered approaches are the use of gabions, granite stone revetments, retaining walls, bagwalls, sandbags,and now the implementation of hexagonal rings and solid concrete blocks as coastal containment measures. The use of hexagonal rings and solid blocks aims to efficiently dissipate wave energy and serve as physical barriers to decelerate erosion and protect coastal soil. This multifaceted strategy represents a promising alternative to address the challenges of coastal erosion along the shoreline of Maceió.

Key words: maritime containment; hexagonal rings; massive blocks; coastal erosion

1 Introduction

Coastal erosion is a growing threat in coastal urban areas, driving the search for innovative and effective solutions to protect coastlines and neighboring communities. Maceió, a coastal city of great economic and social importance, faces challenges related to land loss, infrastructure damage, and environmental risks. In this context, the implementation of coastal containment interventions becomes crucial to protect the city's coastline and ensure the sustainability of coastal areas. According to Souza [1], it is necessary to conduct a preliminary study of the problem before carrying out a feasibility study for the project to be implemented. The innovative methodology used along the Maceió coastline is the first alternative (physical structure), as it consists of installing a ramp made of precast concrete hexagonal rings, capable of withstanding wave energy and mitigating the natural erosion process occurring in these areas. On the other hand, the massive blocks act as physical barriers, slowing erosion and protecting the coastal soil [2].

Coastal protection refers to the techniques and structures designed to protect coastal areas against the effects of erosion, sea advance, and other natural forces. These techniques aim to stabilize the coastal soil, protect urban and natural infrastructure, and preserve sensitive ecosystems. The implementation of coastal protection strategies is essential to mitigate the negative impacts caused by waves, currents, and climate variations in coastal regions. These impacts can include the loss of coastal land, beach erosion, the destruction of natural habitats, threats to urban infrastructure, and risks to the safety of coastal communities.

Various methodologies have been developed and applied to contain coastal erosion and mitigate the impacts of coastal erosion. Each of these approaches has specific characteristics, as shown in Table 1.

The dissipative methods previously employed along the Maceió coastline aimed to reduce damage caused by wave action. However, the existing structures failed to effectively contain the erosion process at the implementation site, highlighting the need for a more in-depth study to develop more effective methods for dissipating wave energy and preventing the erosion process that has impacted the city's coastline [3]. Given this scenario, the technical team of the Maceió Municipal Infrastructure Secretariat (SEMINFRA) identified 23 technological criteria for selecting the most appropriate methodology to mitigate the erosion process along the Maceió coastline, as detailed in Table 2.

Table 1. Description of maritime containment methodologies previously used on the Maceió/AL waterfront. Source: the authors

Methodology	Description
Granitic rock revetment	Consists of the strategic placement of rock blocks parallel to the beach, acting as a temporary protective barrier for buildings near the sea.
Geotextile concrete bags	Uses geotextile bags filled with concrete, forming a resilient barrier that adapts to the marine environment.
Retaining wall	Vertical structures that ensure soil stability, transferring loads to adequate foundations and protecting vulnerable areas..
Sandbags	Stacked sandbags designed to create shields against wave force, easily removable when necessary.
Bagwall	Uses concrete-filled geotextile forms to form solid and stable barriers along the coast.
Gabion	Low-cost flexible structures made of stone-filled wire mesh bags, providing stability to slopes and coastal structures.

Table 2. Technological assumptions for selecting the maritime containment system used on the Maceió/AL waterfront. Source: the authors

Premise	Description
1	Meet the desired objective, which is: to protect public roads and utility networks through the installation of coastal maritime containment
2	Structural resistance to the forces to which the structure will be subjected – The areas to be protected are located in areas in contact with the sea subject to wave action
3	Have the foundation set below 0.00 m (hydrographic zero)
4	The upstream geometry must be in the form of a "staircase" or ramp to dissipate energy of the waves
5	Semi-rigid structure designed to dissipate wave energy within the structure itself
6	Have a dual function: upstream maritime containment and downstream retaining wall to also withstand the forces that the terrain will exert on the structure
7	Longitudinal rather than transverse silhouette so as not to influence local sediment dynamics
8	Counteract wave vortices so as not to accelerate the maritime erosion process
9	Do not interfere with the local flora and fauna
10	Do not alter the wave dynamics
11	Accessibility (NBR 9050/2015 standard)
12	Do not alter the bathymetric conditions of the sea
13	Do not alter sea currents
14	Do not alter the geotechnical conditions
15	Structure without the use of steel reinforcement
16	Low maintenance cost
17	Modular construction options
18	Full reversibility in case the structure needs to be removed
19	No vector propagation
20	No interference with the use of beach sand
21	Shorter execution time
22	Simplified supervision during construction
23	Simple construction plan

After analysis, it was found that only two of them met all the criteria: those using hexagonal rings and precast solid concrete blocks. Both methodologies were approved and recommended, according to studies conducted by the team from the Maceió Municipal Infrastructure Secretariat [2].

2 Description of the approach using hexagonal rings and solid blocks

Hexagonal rings (Figure 1) are modular structures made of corrosion-resistant materials, such as concrete or fiberglass-reinforced polymers. These rings are designed to form a barrier similar to a breakwater. The hexagonal geometry of the rings is specifically designed to dissipate wave energy, reducing the erosive force of the water and protecting the coastline [3].

Figure 1. Precast concrete hexagonal rings. Source: the authors

Massive blocks (Figure 2), in turn, consist of large concrete or rock structures that are strategically placed along the coast. These blocks help dissipate wave and current energy, reducing erosion of the beach and the adjacent shoreline. This methodology serves a dual purpose, as the upstream (sea-facing) side acts as a seawall and the downstream (land-facing) side functions as a retaining wall, that is, it supports the weight exerted by the terrain on the retaining wall [2].

Figure 2. Interlocking precast concrete blocks. Source: the authors

2.1 Characteristics of the technology using precast concrete hexagonal rings

The coastal retaining structure is constructed using precast hexagonal concrete rings, and there is no on-site concrete pouring; thus, the wall's foundations can be built even in the presence of saltwater.

This is a methodology of Dutch origin, which consists of promoting natural beach accretion through the construction of a diagonal ramp formed by precast concrete hexagonal rings and free of rebar, which fit together perfectly and, when combined, form a structural honeycomb sufficient to contain the advance of the sea by absorbing wave energy within the structure itself and in the voids, while promoting natural beach accretion through the process of sedimentation [2].

This coastal containment system (Figure 3) features a ramp-shaped geometry designed to dissipate wave energy, eliminate backwash and water spray after contact with the structure, similar to pouring water onto a mattress [2].

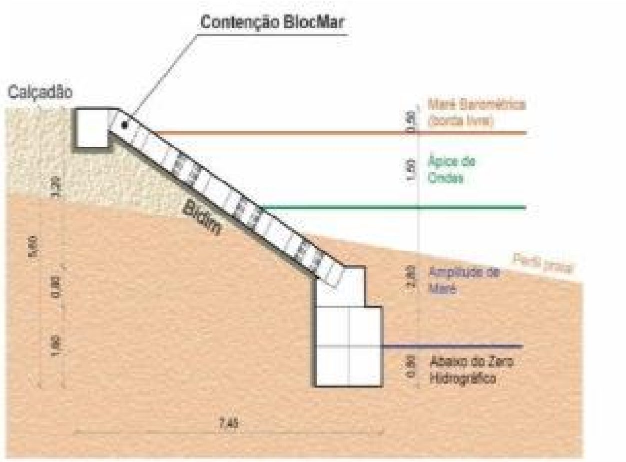

Figure 3. Illustration of the containment system using hexagonal rings. Source: BlocMar Collection

The precast concrete hexagonal rings have the following dimensions: Height = 50 cm, Edge length = 50 cm, and internal diameter = 47 cm, and each weighs 600 kg. The marine retaining structure features a ramp-shaped upright geometry designed to dissipate wave energy, eliminate backwash and water spray after contact with the structure, similar to pouring water onto a mattress. The entire interior of the structure is lined with a geotextile membrane to prevent the passage of sediments. The structure's foundation is constructed below the hydrographic zero level, using massive precast concrete blocks, Figure 4.

The Municipal Secretary of Infrastructure, Lívio Lima, reports that the methodology used at all construction sites ensures a sustainable future, supported by cutting-edge technology, with a potential lifespan of up to 200 years [4].

Figure 4. Manufacturing of the hexagonal rings. Source: the authors

This technology offers unique advantages and beneficial characteristics compared to other methods of containing coastal erosion. One of these advantages is the promotion of natural beach nourishment, as the hexagonal ring system reduces the intensity of waves penetrating the voids in the structure, interrupting the longitudinal flow of water—the primary cause of coastal erosion—and filling these voids with sand, thereby widening the beach. Furthermore, another highlight of this system is its complete reversibility due to its modular construction; if urban changes need to be made or the structure needs to be repositioned, it can be dismantled and reinstalled at another location. Other benefits include low maintenance requirements, partial functionality, and a shorter construction timeline compared to other commonly used containment systems [3].

2.2 Characteristics of the technology using precast solid concrete blocks

A coastal sea defense methodology of Dutch origin, consisting of the construction of a wall formed by precast concrete blocks without metal fittings that fit together perfectly and, when combined, form a semi-rigid structure sufficient to contain the advance of the sea by dissipating wave energy within the retaining structure itself [3].

This methodology serves a dual purpose, as the upstream side (toward the sea) acts as a seawall, while the downstream side (toward the land) functions as a retaining wall, that is, it supports the weight exerted by the terrain on the retaining wall. [2]

As Cavalcante [2] describes, this type of marine structure is not built in the sea but rather at the edge of the land, on the mainland.

The structure is constructed by interlocking precast concrete blocks without the use of rebar, much like Lego blocks. The interior of the structure is lined with a geotextile membrane, preventing sediment flow while also providing accessibility. The base of the structure is built below ground level, Figure 5.

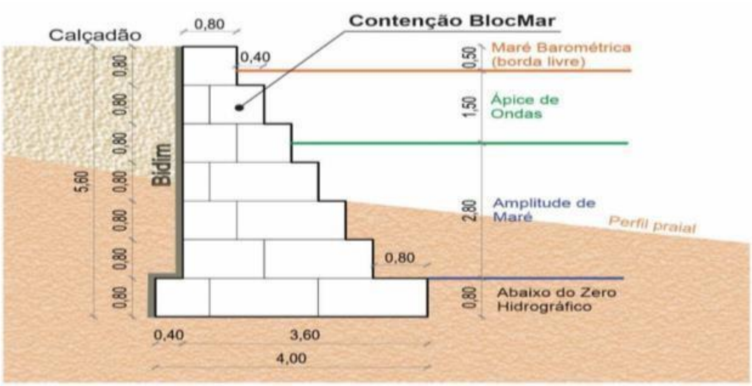

Figure 5. Illustration of containment using solid blocks. Source: BlocMar Collection

Precast concrete blocks (Figures 6, 7, and 8) come in various sizes, but the standard module measures 0.80 x 0.80 x 1.60 meters and weighs 2.5 tons each. The seawall provides the necessary strength to withstand the forces to which it is subjected [2].

Figure 6. Assembly of metal molds for manufacturing solid blocks. Source: the authors

Figure 7. Vibration of the concrete poured into the molds. Source: the authors

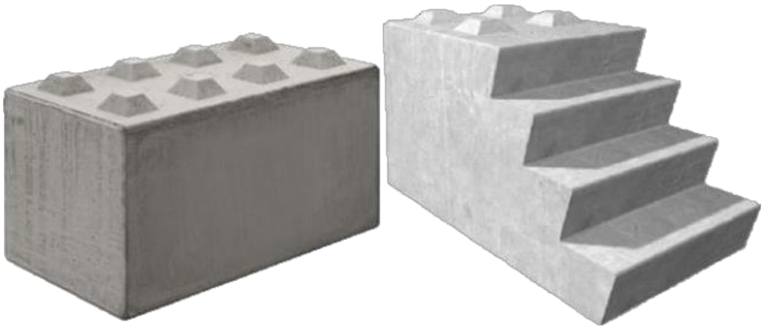

Figure 8. Model of precast concrete blocks. Source: the authors

The methodology that uses overlapping precast solid concrete blocks, without the use of metal reinforcements and with a perfect fit, has characteristics that must be considered when comparing it to other retaining methods. For example, its partial functionality is notable, as this marine retaining system is constructed in an integrated manner, from the foundation to the superstructure. As construction progresses, the wall becomes fully operational, providing partial seawall functionality and protecting the already built area. Furthermore, its full reversibility is a significant advantage.

If the municipality plans to make urban changes or, in the future, the contractor decides to relocate the wall due to sediment transport or other needs, it is possible to dismantle the wall and reinstall it at another location. Another important feature worth mentioning is the system's low maintenance requirements. Inspection is also simplified due to the limited materials required for the structure's construction, which include the rings, the geotextile mat, the precast stair components, and the drainage layers. This simplifies project oversight by environmental agencies and contractors, contributing to more efficient management of the seawall project. This coastal protection system does not alter the conditions of use of the beach and its sandy strip; there are no obstacles for users, as the structure is always built at the boundary of public or private land, without encroaching toward the sea.

3 Sections of the coastline that were addressed using these methods

Faced with the urgency caused by advancing erosion, especially during periods of high tides, as warned by the Municipal Civil Defense, and with growing concern that the coastline could compromise the integrity of the roadways, immediate action was necessary. In response to this critical situation, emergency action was required to address the situation. The contracting of the chosen methodologies, involving the use of hexagonal rings and massive concrete blocks, was carried out on an emergency basis. The contractual process was formalized through a contract established with the municipality of Maceió.

Supervision of the work was entrusted to an official designated by the Municipal Department of Infrastructure, in accordance with regulatory provisions, ensuring the compliance and effectiveness of the services performed. This contract was executed in 2022, with the aim of immediately preserving the coastal infrastructure and ensuring the safety of the local population. Table 3 presents the sections of the waterfront that were addressed and the methodologies applied based on wave dynamics.

Table 3. Sections of the Maceió waterfront with coastal protection using precast concrete hexagonal rings and solid blocks. Source: the authors

Sections	Location	Dynamics	Methodology used
7	Assis Chateaubriand Avenue, Sobral Beach, between Ary Pitombo Street and Roberto Pontes Lima Avenue	Due to the beach profile being less low and the wider sand strip area allowing for better placement of the rings.	Precast concrete hexagonal rings
10	Waterfront, Jatiúca Beach, in front of Jatiúca Hotel & Resort		
11	Waterfront, Jacarecica Beach, at the end of Litorânea Avenue, in front of Evolution Sea Park		
8-9	Álvaro Otacílio Avenue, Jatiúca Beach, between Dr. Júlio Marques Luz Avenue and Empresário Carlos da Silva Nogueira Avenue	Due to the beach profile being very low, with insufficient sand strip for the placement of rings, and because the waves approach the continent and will break on top of the designed containment structure, thus requiring a sturdier structure.	Precast interlocking concrete blocks

4 Results

Originating in the Netherlands, methodologies using hexagonal rings and massive blocks emerged in a country that pioneered containment techniques due to the coastal erosion it faced. This Dutch origin is relevant, as the Netherlands is a low-lying country vulnerable to coastal erosion, which makes its containment techniques highly reliable. The structure is estimated to have a life expectancy of 200 years, with low maintenance requirements, withstanding both wave impact and the weight of the terrain. As noted by Cícero Rocha [1] , each of the 23 assumptions studied and applied could be verified in practice with the start of construction, confirming their effectiveness. Partial functionality, for example, can be observed immediately after the construction of the retaining wall's foundation, demonstrating that the structure protects the coast even before it is fully completed.

5 Conclusion

The methodology presented represents an important contribution to coastal engineering, especially considering the situation in Maceió, where several previous approaches to coastal protection were not as effective as expected. The retaining works using hexagonal rings and massive precast concrete blocks yielded significant benefits.

This approach not only acted as an effective barrier against coastal erosion but has also promoted the natural accretion of the beach. Furthermore, unlike certain structures that proved vulnerable to weathering, these new techniques demonstrated a fundamental focus on the foundation, thereby ensuring greater long-term effectiveness.

The advantages were not limited to technical performance alone. The methodology adopted was also considered environmentally friendly, preventing the proliferation of pests such as rats and cockroaches, generating less waste during construction, and minimizing harm to marine life, as the structures were built without directly impacting the water.

Despite limitations regarding prior knowledge of these methodologies, the innovative approach implemented by the City of Maceió shows significant potential for replication in other coastal regions. The positive results obtained so far, including an estimated lifespan of 200 years, lower costs compared to traditional methods, and simplified execution, highlight the success of this project.

These achievements not only offer a lasting solution to the challenges of coastal erosion but also set a standard for future interventions across the country, demonstrating the positive impact that an innovative and well-thought-out approach can have on coastal engineering.

However, it is important to consider the need for additional studies to more fully assess the effectiveness, durability, and potential future interventions, especially given that the methodology was recently implemented in Maceió.

Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

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Note

[1] Cícero Rocha de Almeida Barros, a civil engineer, was appointed by the Maceió Municipal Infrastructure Secretariat as the supervisor of the coastal protection works along the city's waterfront, which involve the use of hexagonal rings and massive blocks.