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The Diagnosis of Maritime Structures, a Management Support Tool: Case of the Sèmè-Podji Wharf in the Republic of Benin

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Abstract

Port structures constitute the main link in the maritime transport chain of coastal countries and therefore contribute to their economic development. But it should be noted that the installation of said works is not without consequences for the countries concerned. Benin, a country in the Gulf of Guinea, is no exception to this phenomenon because, due to its maritime history, it has a heritage of port structures. These structures, built on its coastline, cause a wide variety of environmental problems such as silting and erosion on either side of them. The general objective of this article is to contribute to the proper functionality of port facilities while minimizing environmental problems that may arise. It aims to provide managers with a tool allowing them to fully understand the state of their assets in order to rationalize maintenance actions. In order to achieve this objective, an assessment of the state of the structure, and then a structural diagnosis are necessary and recommendations can be established to restore the level of service of the latter. As a result, two examples were presented: the wharf of the Sèmè-Podji pipeline project and the maritime piles project of the Wasco de Gama bridge (control project), and recommendations adapted to this objective were established. The comparative analysis of the two examples, both maritime works, revealed an under-sizing at the level of the spans of the wharf bridge of the Sèmè-Podji pipeline project (spans of 7 m in length), while these spans vary on average by 45 m to 62 m for the Wasco da Gama bridge. Bringing the piles closer together at the Sèmè-Podji wharf reduces the energy of the current which promotes the accumulation of sediment. The structure no longer experiences a flow capable of setting in motion the sands accumulated since at least 2022. This element appears to be a fundamental characteristic explaining the erosion observed to the east of the structure.

Keywords

Structural Diagnosis, Wharf, Pipeline, Erosion, Sèmè-Podji, Benin

1. Introduction

The commune of Sèmè-Podji and its coastline historically constituted a rich natural environment free from major disturbances. Unfortunately, for several years, after the construction of the wharf (**Figure 1**) by the Chinese company WAPCO as part of the project to export oil from Niger through Benin to other countries, local users have been confronted with a phenomenon of fattening west and erosion to the east of the structure on the coast.

Source: Hountondji Babilas.

Figure 1. Sèmè-Podji wharf.

Coastal erosion is the loss or movement of land along the coastline through the interaction of oceans, waves and beaches, often associated with the impact of human activity. Coastal erosion occurs when wind, waves, longshore currents, tides, surface water runoff, or groundwater infiltration move sand and sediment from the coastline. This sand and sediment moves from place to place and does not disappear from the overall system unless human activities, such as dredging, remove it permanently [1].

A similar phenomenon has been observed in the past at the Salie wharf (**Figure 2**) on the coast of the municipalities of Lège-Cap-Ferret, La Teste-de-Buch and Biscarrosse which is subject to chronic erosion phenomena linked to the direct action of the sea combined with the ebb and flow of the tides at the level of the passes and the spatio-temporal evolution of the passes [2]. Thus, during recent storms (Martin in December 1999, Xynthia in February 2010, etc.) but also during recent winters less marked by events of this importance, erosion has led to setbacks of the order of several meters. At the end of winter 2013/14, it was observed:

- a setback of 40 m in the commune of Lège-Cap-Ferret at the Pointe and the blockhouses;
- a setback of 40 m in the commune of La Teste-de-Buch at the level of the Petit

Nice beach plan;

- a setback of 15 m in the town of Biscarosse.

So today, on the coastline of the municipalities concerned, the situation is such that it could in the short term endanger coastal facilities (beach plans, homes, etc.) and degrade the quality of seaside reception. And therefore, the Syndicate Intercommunal du Bassin d'Arcachon (SIBA) anticipated the sedimentary modifications to the right of the structure in order to plan sustainably and in a relevant manner specific developments on the network. Indeed, if sedimentation is observed in the area of the structure, very strong erosions may have taken place in the past at its roots, leading to work to reinforce the piers of the structure.

Figure 2. Protection of the piers of the Salie Wharf [1].

In order to implement a long-term management strategy for the coastal strip like the Syndicat Intercommunal du Bassin d'Arcachon (SIBA) to combat the pronounced erosion phenomenon observed to the east of the Sèmè-Podji Wharf towards Nigeria, the Ministry of Living Environment and Transport in charge of Sustainable Development (MCVT) of Benin wanted to initiate studies to find out under what conditions the operation of the structure could be continued sustainably.

These studies initially include an assessment of the state of the structure, then secondly, following the structural diagnosis, recommendations which must be established to restore the level of service of the structure, with an objective of sustainability.

To illustrate this problem, we have chosen to present two examples: the wharf of the Sèmè-Podji pipeline project and the maritime piles project of the Wasco de Gama bridge (control project), then to establish recommendations adapted to this objective.

2. Methodological Approach

The study is made up of two (02) main parts which are: the analyzes and structural diagnosis of the work on the one hand and the formulation of proposals for the problems detected on the other hand.

2.1. Use of Participatory Tools

The working methodology used to achieve our results is based on the use of several participatory tools from different methods. We made this choice to allow strong involvement of the population and the authorities in the diagnosis of problems and in the formulation of solution approaches.

2.2. Phases of Research Activities and Actions

2.2.1. The Institutional Anchoring Phase

The institutional anchoring phase was based on hearings with the competent authorities of the town hall, the prefecture, the ministry and delegates to the populations. It was necessary to explain in detail the goals, objectives and expected results of our research work in order to benefit from their agreements, their research authorizations and to facilitate the participation of the population in the overall success of the project.

2.2.2. The Documentary Research Phase

The documentary research phase constituted the prelegomena of our project because it made it possible to collect the information essential to the development of our work problem. To achieve this, we first had to list our information needs, then prioritize them. We had to gather documents from other related sciences that could help us achieve this task. The approach consisted of an initial collection of field data from the appropriate administrations (Ministry, University, Prefecture, Town Hall). To carry out the second we used the archives of the WAPCO company.

2.2.3. The Location Recognition Phase

Once the site was chosen, we carried out series of descents on the ground. They allowed us to better familiarize ourselves with our work site, to take ownership of it to know and understand its components and to derive an inventory. During this reconnaissance phase, surveys in public services and interviews with resource people took place. They helped justify the choice of site and theme.

3. Results and Discussion

3.1. Results

3.1.1. Inventory of Maritime Works

- **The wharf of the Sèmè-Podji pipeline project**

Built between 2019 and 2022 by the Chinese company WAPCO, the Sèmè-Podji wharf built as part of the Niger – Benin pipeline project (export of oil from Niger to other countries) has at its end (sea side) a quay allowing the docking of the three launches available to the company, to carry out operations at sea. The structure with a total length of 666.96 meters is made up of:

- a maritime bridge with a length of 257.3 meters and a width of 25 meters comprising three rows of reinforced concrete piles with a diameter of 1.20 meters, each row being crowned by a reinforced concrete beam of prefabricated elements keyed by concreting on the piles;

- a protective dike with a length of 409.66 meters and a width of 18 meters;

- a quay with a length of 60 meters and a width of 25 meters, comprising three rows of reinforced concrete piles with a diameter of 1.20 meters, each row being crowned by a reinforced concrete beam of keyed prefabricated elements by concreting on the piles. Figure 3 and Figure 4 respectively present the plan view of the wharf and the cross section of the maritime bridge of the wharf of the Sèmè-Podji pipeline which is the subject of our study.

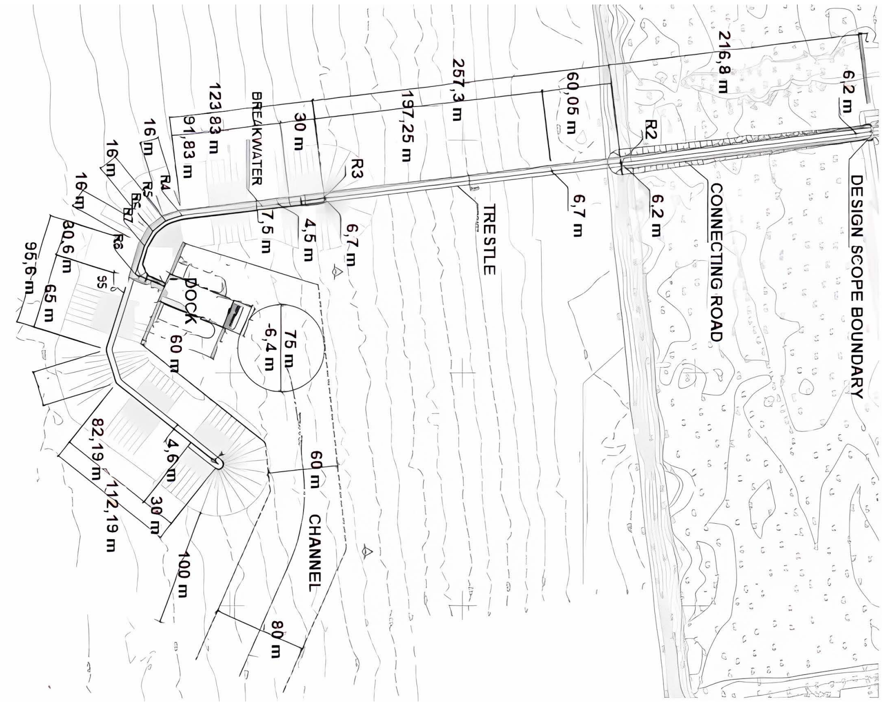


Figure 3. Plan view of the Sèmè-Podji wharf (Source: WAPCO, 2023).

- **The maritime piles of the Wasco da Gama bridge**

Built between 1994 and 1998 by the NOVAPONTE group (Campenon Bernard SGE pilot), the structure with a total length of 12,300 meters is made up as follows:

- a North viaduct, 488 m long (11 spans with an average of 45 m). The piles are built on piles 1 m in diameter.

- an Expo viaduct 672 m long (12 spans from 45 m to 62 m). The piles are built on piles 1.70 m in diameter.

- a main cable-stayed bridge 820 m long, with a central span of 420 m above the main navigable channel. The deck is held transversely by three double piers on each side of the main span. The foundations are made of 2.20 m piles.

- a central viaduct 6531 m long, made up of 09 viaducts of 09 spans of approximately 80 m. Each navigable channel has special spans. The piers are built on piles with a diameter of 1.70 m for standard spans, and 2.20 m for navigation spans.

- a South viaduct, 3825 m long, has a section similar to that of the North viaduct. The piles are built on piles of 1.80 m or 2 m in diameter.

Figure 5 and Figure 6 respectively present the plan views of the project and the general view of said project identified as a control project within the framework of this study.

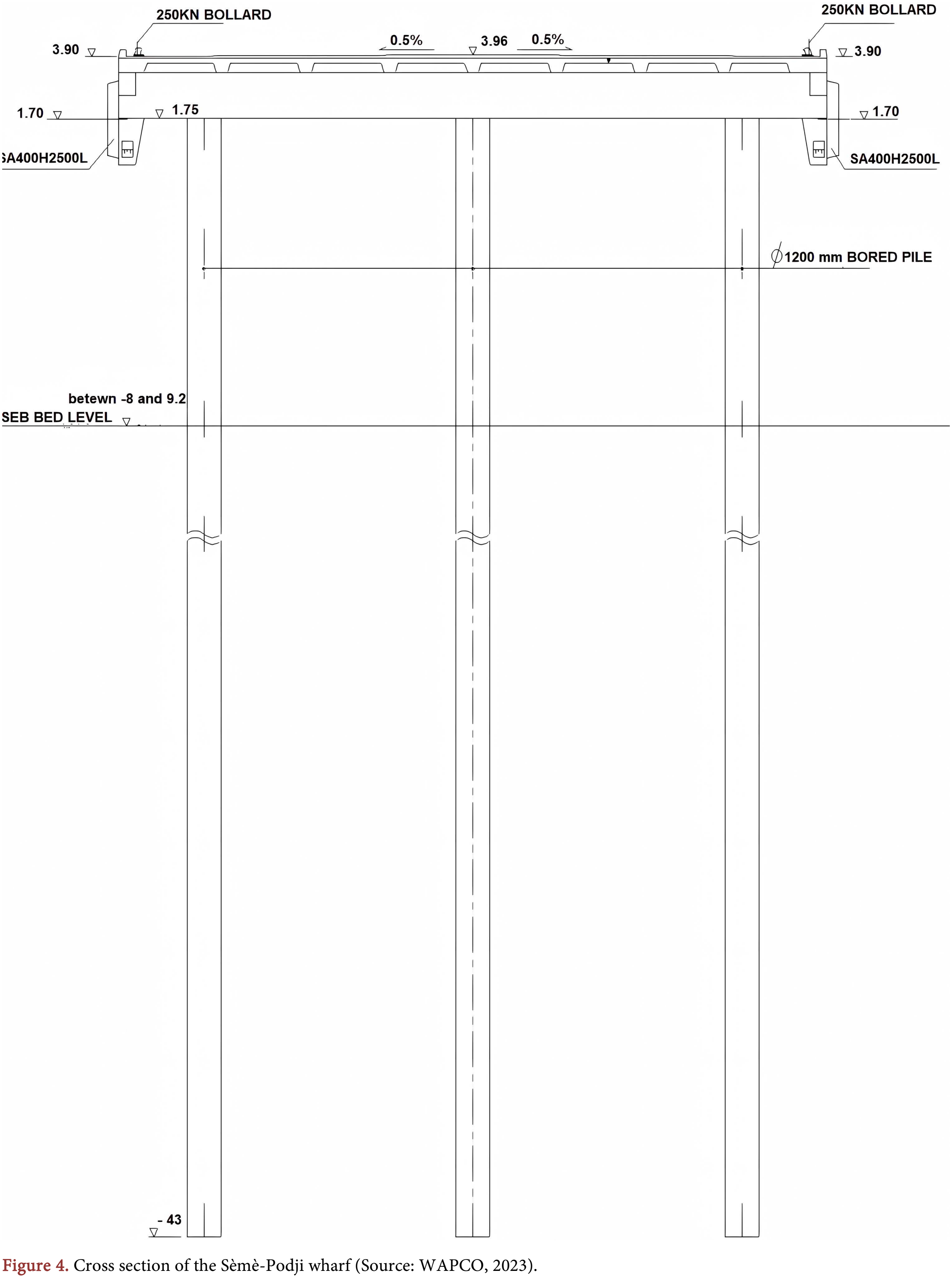


Figure 4. Cross section of the Sèmè-Podji wharf (Source: WAPCO, 2023).

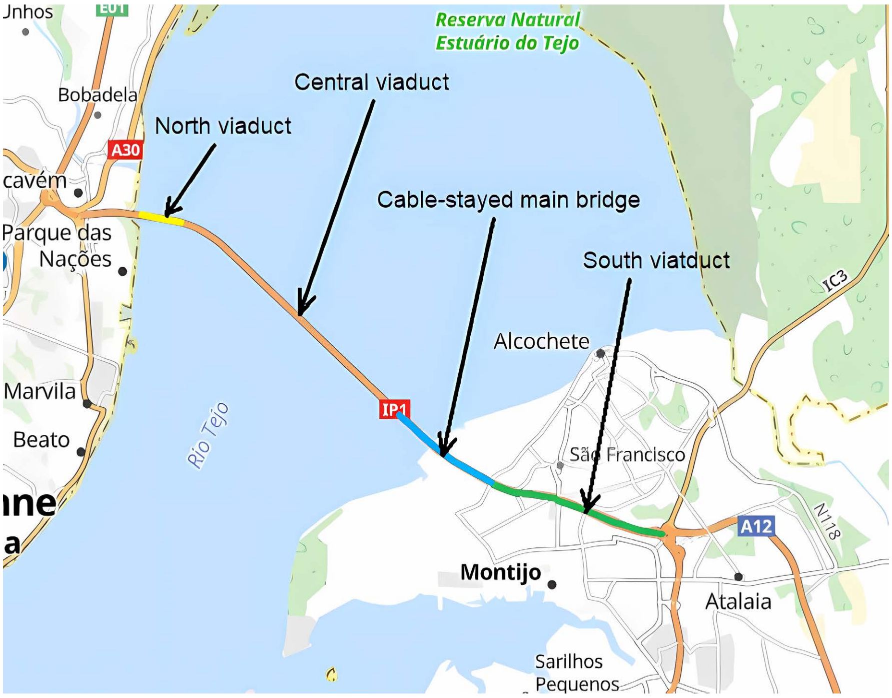


Figure 5. Schematic plan view of project [3].

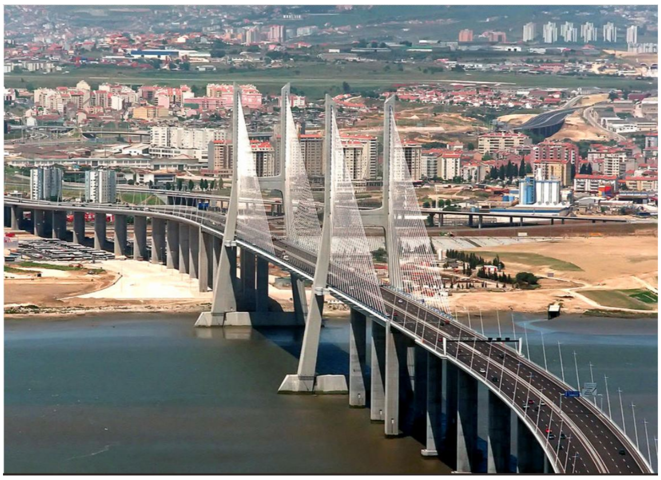


Figure 6. General view taken form central viaduct towards main cable stay bridge [3].

3.1.2. Problems and Impacts

The wharf of the Sèmè-Podji pipeline project being a recent work (carried out between 2019 and 2022), the diagnosis of the latter was made based on the structure because no disorder was observed in the materials. The program for this diagnosis is established from the analysis of available input data—execution plans—bathymetric data—discussions with the manager and a preliminary visit to the site.

3.1.3. Diagnostic Results

The comparative analysis of the geometric measurements of the quay of the Sèmè-Podji pipeline project and the maritime piles of the Wasco da Gama bridge, both maritime works, revealed an under-dimensioning at the level of the spans of the quay bridge of the Sèmè-Podji pipeline project. Podji, especially since for the Sèmè-Podji quay on spans of 7 m in length, a value which is well below 45 m and 62 m considered as minimum and maximum values recorded at the Wasco de Gama bridge taken as project witnesses.

Bringing the piles closer together (small spans) reduces the current which promotes the accumulation of sediment.

The wharf of the Sèmè-Podji pipeline project has completely modified the natural hydrology. It no longer experiences a flow capable of setting in motion the sands accumulated since at least 2022. This element appears to be a fundamental characteristic explaining the erosion observed to the east towards Nigeria.

3.1.4. Solution Approaches

The main action is to promote the transport of sediments by removing all the sediments accumulated under the wharf bridge. Two other means of action can be cited: increasing the quantities of missing sediments and moving the quantities of excess sediments.

- **Short-term action**

It seems necessary to define the state that is desired for the Sèmè-Podji coastline in the different sectors of the pipeline project wharf.

It appears essential in the short term to return to the initial state of the coastline (**Figure 7**), that is to say, to remove all the sediments accumulated under the wharf bridge in order to once again promote the achievement of the state of balance.

Figure 7. Steady state: short-term action (Source: WAPCO, 2023).

- **Medium-term action**

We can increase the quantities of missing sediment and move the quantities of excess sediment, by using nautical means such as dredges (**Figure 8**). This action was proposed by the wharf manager, the Chinese company WAPCO. The company has identified five sand sampling areas for a volume of 398,024 m^3 (**Figure 9**). The coordinates of the points delimiting these zones, their surfaces and the volumes of sand which can be dredged there are presented in **Table 1** and **Table 2**. These volumes of sand will only allow part of a beach of length 600 ml to be recharged on an average width of 67 ml (**Figure 9**). The coordinates of this recharged part are presented in Table 3. These five identified areas are easy to access and are in the vicinity of the areas to be recharged.

Table 1. Coordinates of the points delimiting the dredging zone.

S.N	Point	Coordinates (*X*)	Coordinates (*Y*)	Comments
1	A	704,311.542	464,101.140	
2	B	704,186.221	462,800.033	
3	C	704,222.933	464,153.963	
4	D	704,075.995	464,324.389	
5	E	703,923.216	464,374.819	
6	F	704,034.814	464,503.436	
7	G	704,346.115	464,444.069	
8	K	704,194.667	464,239.423	
9	L	704,174.328	464,299.438	
10	M	704,075.995	464,324.389	
11	N	704,093.950	464,492.158	

Source: WAPCO, 2023.

Table 2. Area and volume of dredging zones.

S.N	Scope	Area (m^2)	Volume (m^3)	Comments
1	A-B-C	55,169.1	75,433	
2	A-C-K-L-G	36,866.67	158,629	
3	G-L-K-M-N	32,652.39	77,275	
4	D-E-F-N-M	19,795.57	39,436	
5	C-D-M-K	21,813.58	47,251	

Source: WAPCO, 2023.

Table 3. Coordinates of the points delimiting the erosion zone (backfilling).

S.N	Point	Coordinates (*X*)	Coordinates (*Y*)	Comments
1	G	704,346.115	464,444.069	
2	H	704,472.7880	464,902.7975	
3	I	704,467.0989	464,793.7274	

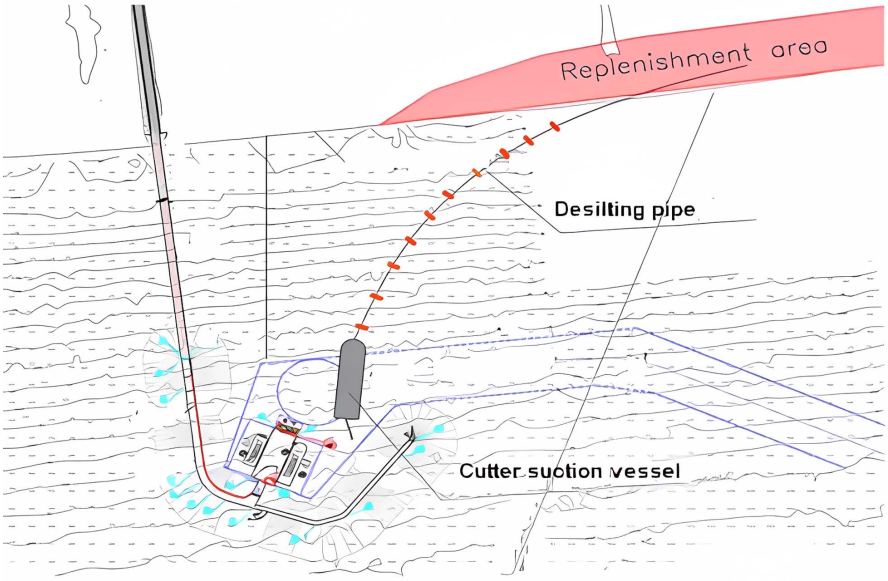
Source: WAPCO, 2023.

- **Long-term action**

Depending on the direction of the incident swell, breakwater or groyne batteries can be used.

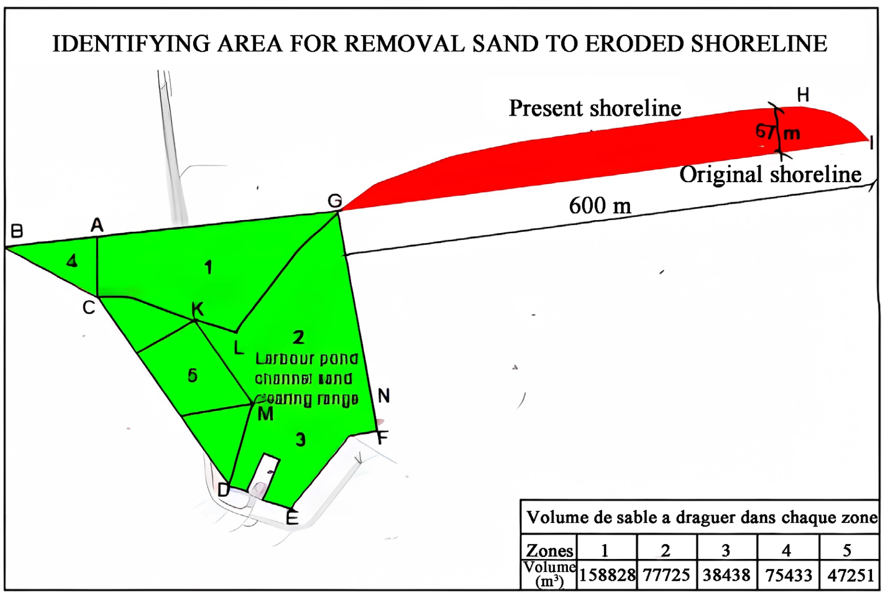
➢ **The breakwater**

The breakwater is a tool for managing the longitudinal coastline to protect the coast from transverse swells (**Figure 10**). Placed on the foreshore or further offshore, the breakwater aims to break swells perpendicular to the coast in order to attenuate their force.



(Source: WAPCO, 2023).

Figure 8. The maritime by-pass: medium-term action.



Volume de sable a draguer dans chaque zone					
Zones	1	2	3	4	5
Volume (m³)	158828	77725	38438	75433	47251

Source: WAPCO, 2023.

Figure 9. Sediment sampling sites to recharge eroded areas.

➢**The groyne**

Groynes are coastal structures designed to retain sediment by preventing it from moving along the shoreline and to help maintain wide beaches by minimizing or slowing erosion [5]. It is a transversal shoreline management tool (**Figure**

11) relying on currents to modify the coastline. Placed on the foreshore, the groyne aims to break the dynamics of coastal drift. Cross-shore currents are not affected by this type of structure.

Figure 10. Breakwater battery: long-term solution [4].

Figure 11. Groyne battery: long term solution [4].

3.2. Discussion

The solutions proposed by the manager of the Sèmè-Podji wharf, the company WAPCO, in order to combat the phenomenon of erosion to the east of the structure are not sustainable. In-depth studies will have to be carried out in order to define, depending on the direction of the incident swell, other solutions such as the use of breakwater batteries, groynes, etc.

A combination of all the solutions defined in this article will make it possible to effectively combat the phenomenon of growing erosion that we are currently observing in the commune of Sèmè-Podji towards Nigeria, with the aim of avoiding diplomatic incidents.

4. Conclusions

The "structural" diagnosis established from the analysis of a record of anomalies detectable by visual inspection and local or global geometric measurements, made it possible to propose the following solutions:

- resize the structure so as to enable it to ensure its sediment transit function;
- recover the initial state of the coastline, that is to say, remove all the sediments accumulated under the structure in order to once again promote the achievement of the state of equilibrium (short-term solution);
- increase the quantities of missing sediments and move the quantities of excess sediments, through the use of nautical means (dredgers), a solution proposed by WAPCO (non-optimal). This solution can be adopted concomitantly with the previous one (medium-term solution);
- Carry out a feasibility study to erect either breakwater or groyne batteries (long-term solution).

Acknowledgements

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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