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Impact of dikes on the coastal dynamics: Study of the beaches of Saint-Hilaire de Riez (France)

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Abstract:
The French Atlantic coastline is submitted to severe wave conditions. These past few years, this area and especially the region called Vendée went through consequent sedimentary issues. There are a lot of coastal defence structures on the natural beaches of Saint-Hilaire de Riez. Those dikes or ripraps either made with rocks or with concrete material have often been built without any specific impact studies regarding their environment. Nowadays, in France, these dikes are classified "ISC" (Interesting Civil Security). A specific monitoring of these structures is performed. Huge damages happened on these coastal structures these past few years. It is essential to study their influence on the hydrodynamics of the area. It aims to elaborate management solution to restore a stable situation from the coastal dynamics point of view.
Software developed by the CETMEF has been used to study those hydrodynamics and sedimentary issues. The present study aims to numerically ensure the coastline setback strategy recommended to restore the balance considering the coastal dynamics of de Saint-Hilaire de Riez.

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1. Introduction

1.1 Description of the studied coastline

The study area extends from the beach of Les Demoiselles to the beach of Les Mouettes (see Figure 1). Tourism activities are of major economic interest in this area. It requires adapted facilities and equipment. The coastline of Saint-Hilaire de Riez benefits from the natural protection of the island of Yeu which blocks most of western and northwestern waves. It especially protects the north coast of Saint-Hilaire de Riez. However, to maintain facilities on the seafront, defence structures like ripraps were built to stabilize the shoreline where shoreline retreat is obvious.

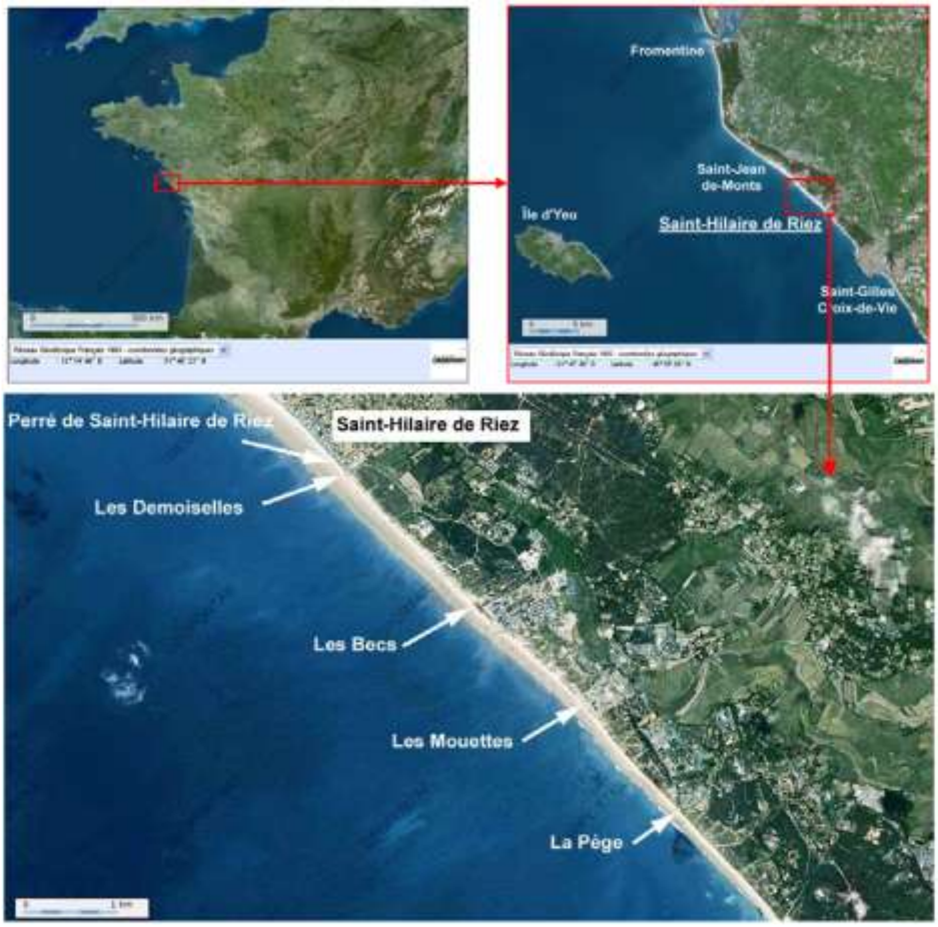

Figure 1. Location of the regions of interest along the coastline of Saint-Hilaire-de-Riez.

The main structures of coastal defence on this area are listed here:

a) The riprap of the beach of Les Demoiselles built between 1974 and 1979; has been reinforced by a rockfill toe in 1996 at its southern end making the transition with the dune.

The masonry wall shows very local signs of weaknesses located in the siding and joints. At its south, there is a riprap made of fill material and resting on an embankment. It was set in response to an erosion problem that typically occurs in the transition zone between the wall of protection from the promenade and the dune. It is also used as a ramp to the beach gear. It is forward on the foreshore when compared to the wall of the boardwalk. Thus erosion mechanisms appear on both the beach and the adjacent dune.

b) The rockfill ripraps in front of the beaches of Les Becs and Les Mouettes have been initially set up to arrange access to the beach before 1989 and then to protect the parking platform since 1998. The slipway of the Les Becs beach acts like a groin. The rockfill ripraps of those two beaches are located way too forward on the foreshore. They are significantly damaged, especially at their ends (see Figure 2).

c) Forty groins were built between 1968 and 1974 from the north of the buildings of Les Becs to the Parée Préneau (located at the south of La Pège). These numerous groins are more or less unstructured. They do not seem to have any effect on sediment transport (see Figure 3). However, their location shows the backward movement of the coastline. Their upper limit is set about 25 to 50 m back of the dune.

d) Some fences protect the natural dunes. They are disposed inline at the foot of the dune to prevent trampling. But they do not protect dunes against the strong erosion phenomena that occur in this area.

(a) *(b)*

Figure 2. North part of the riprap on of Les Mouettes beach:
(a) Erosion; (b) Foot slope.

Figure 3. Groins (from the top of the riprap of Les Becs to the south).

1.2 Classified dikes

A specific regulation is to be applied for ISC dikes (French classification meaning Interesting Civil Security). The rules depend on their protection degree. It is defined depending on the goods and people the dikes have to protect against waves and flooding. Especially in Vendée, attention is paid on the ISC classification of the dikes (RAISON, 2008).

The State lists the dikes protecting against waves and flooding. The degree of classification depends on their geometric characteristics (height) and the number of people they ought to protect (categories A, B, C, D defined by the order December 11, 2007). Depending on each class of dike, requirements are imposed (MISE 83).

The State controls the ISC dikes.

Management and maintenance of those dikes are of the responsibility of the client, either private owner whether or not grouped in associations, or local or state owners. He is fully responsible, in both civil and criminal point of views of the damages that can be induced by the dike and in particular by its rupture.

When an incident or accident occurs, his liability may be engaged for negligence, imprudence, maintenance vice or construction defect (sections 1382 et seq of the Civil Code). The modalities of the implementation of the dikes control are determined by a circular. This control leads to check that the client fulfils its obligations against the proper condition of the dike. It also aims to ensure that the maintenance of the dike is performed regularly and in a proper way.

The ISC dikes of the beaches of Les Becs and Les Mouettes are within the B class. Thus, the client has to achieve the following tasks: a safety diagnostic of the existing dike, a dike record, a thorough technical inspection every year, a periodic monitoring report to perform between each 1 and 5 years, a logbook of the dike. The hazard study is also required to assess the risk of flooding. In this case, considering an ISC dike located in the coastal zone, the flood hazard is defined from the results of the hydrosedimentary study. The present study has been performed as part of those dikes monitoring.

The *in situ* diagnosis shows the dikes are in poor conditions. They provide protection against the sea, but their position, especially in forward of the foreshore, is problematic due to the backward movement of the coastline on both sides of these structures.

Indeed, access to the sea and structures located on the foreshore, lead to a hardening of the shoreline. They have a significant impact on the waves and generate high currents. These hard engineering structures increase the phenomena of sediment transport. Consequently, damages occur on those structures (collapse of rockfill dikes, influence of strong waves and currents, degradation of geotextile, …). In addition, they prematurely deteriorate the coastline and induce significant backward movements of the coastline, especially near those structures.

It is therefore necessary to rethink the coastal management of Saint Hilaire to provide a long-term solution. Note that the authors' findings on the impact of coastal structures on the evolution of the sea bottom are dispersed. This is due to the difficulty of understanding of the phenomena and to the large number of parameters to consider. However, frontal dikes (parallel to the coast) have a negative impact on the surrounding bathymetry and threaten the stability of the structure (SAMAT, 2007).
The second part of this paper introduces the numerical tools used to model the hydrodynamics of the study area. Then, results are presented considering the initial state and the projected one. Finally, conclusions are performed.

2. Methodology

Three main software called REFONDE, REFLUX and REFLUX-SEDIM are used. They are developed by the CETMEF (*http://www.cetmef.developpement-durable.gouv.fr/*). Two areas have been defined for the best cover of the studiednregions. An adaptive mesh was defined to obtain accurate results near the sites. It also aims to reduce the computation time

2.1 Waves modeling

The calculations with REFONDE enable to numerically reproduce and thus study the waves near the coast. It helps to analyse the impact of defence structures on waves. Bathymetric data and wave statistics of the studied area are needed. Random waves can be implemented. It is a finite element model. It solves Berkhoff's equation and thus takes into account wave reflection, refraction and diffraction phenomena. It calculates wave height and phase for each wave train.

2.2 Currents modeling

Currents are studied with REFLUX. It particularly suits to study problems involving navigation, protection against floods. It also helps to assess of the consequences of implementing defence structures. The regions of interest can be located in sea, river and estuary. The finite element code solves St Venant equations. A large number of parameters can be taken into account such as wind, tides and waves (coupling with REFONDE, DEBAILLON *et al*., 2001). A solving mode is chosen with the unsteady calculation method of Newton-Raphson. In nature, the boundary of the wet area varies over time, especially in periods of high tidal range. This is taken into account within the present calculations. Indeed, the boundary of the wet area is detected and modified Saint-Venant equations are solved on partially wet elements.

2.3 Sediment transport modeling

Finally, sediment transport phenomena are considered using REFLUX-SEDIM. It calculates the sand bed evolution and the sediment transport. It uses the mass conservation equation and formula for suspended and bed load transport (principle of Van Rijn). Coupling the hydrodynamic module REFLUX with REFLUX-SEDIM aims to estimate areas of potential deposition or erosion on the studied site after one or several tidal cycles.

3. Results and proposed managements

3.1 Longshore drift

Annual wave characteristics are considered here. They have been calculated from the ANEMOC database. REFONDE calculations shows, that at the north of the site, wave crests are almost parallel to the coastline (<3 °, see Figure 4a). It traduces a slight littoral drift to the north.

At the south of the site, the presence of protection structures freezes the orientation of the coast. It induces destabilization of the coastal dynamics, especially in case of high obliquity (from -1.2 ° to -9 °, see Figure 4b). Consequently, a major transit to the south occurs in this area.

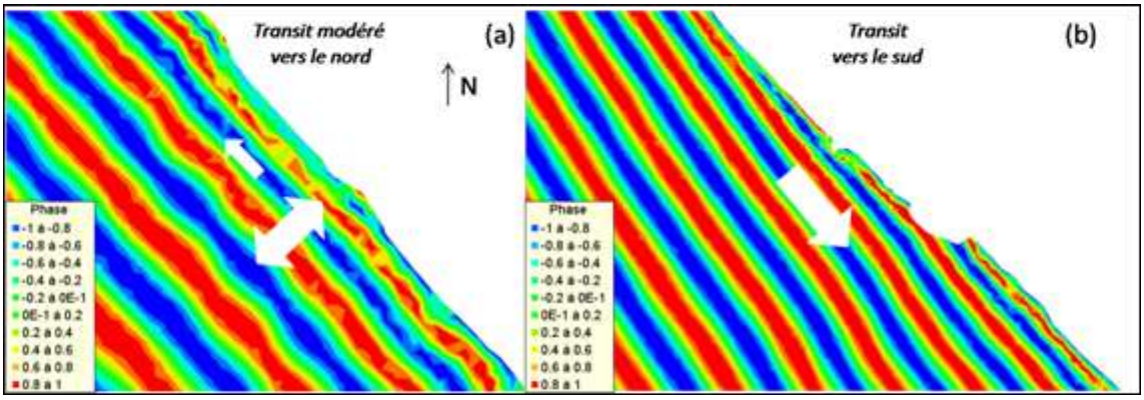

Figure 4. Wave phases from REFONDE calculations considering annual wave conditions (T_p= 12 s;H_s=1.4 m (at-5mCM);θ_{pb}=235 °;θ_{pa}=231°): (a) Les Demoiselles; (b) Les Becs.

Waves have a huge impact on sediment transport, especially near defence structures (BRIERE, 2006). It has been deeply analyzed.

Several wave directions have been considered for these calculations. Wave simulations for annual wave conditions show that the residual wave heights at the coast are relatively large. The order of magnitude of wave heights is of about 1.5 m to 2.1 m (for instance, see Figure 5a). These relatively severe wave conditions put together with the obliquity of the waves and variations in the orientation of structures with that of the coastline induce relatively high sediment transport.

The proposed managements are:

- Rehabilitation of the ISC dikes of the beaches of Les Becs and Les Mouettes, with realignment on the shoreline which presents an asymmetry between north and south;
- Massive beach nourishment along 1100m between the beaches of Les Becs and Les Mouettes;
- Destruction of the dike located on the beach of Les Demoiselles. This dike is way too forward on the foreshore. It aims to restore the dune.

The destruction of the structures located forward on the foreshore enables the coastline to naturally evolve. It aims to restore a stable dynamics along this coast. These managements reduce the negative effects of structures (see Figure 5b). As a result, a decrease of about 25% of the agitation of waves near the structures is measured.

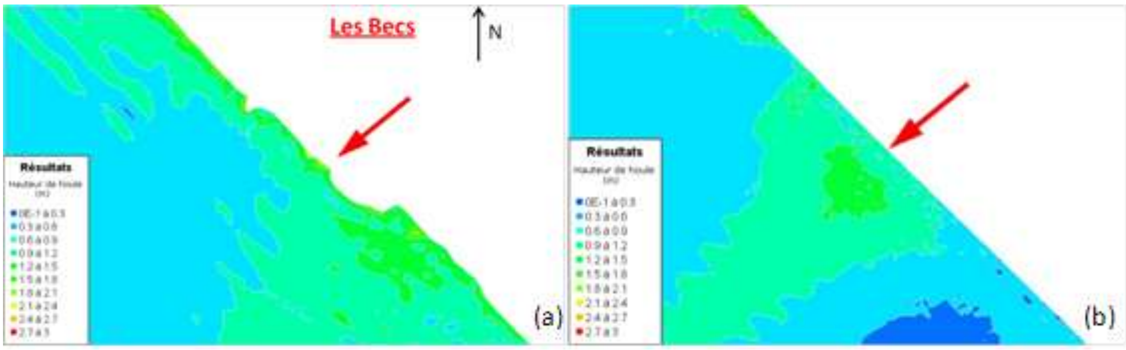

Figure 5. Wave heights (T_p=12s; H_s=1.4; θ_p=232°N): (a) initial state; (b) proposed solution.

3.2 Impacts of the defence structures on currents and sediment transport

The model calculations show the significant impact on currents (induced by waves and tide) of the defence rockfill structures located on the beaches of Les Becs, Les Mouettes and Les Demoiselles. Indeed, these structures constitute a setback from the shoreline to the foreshore. As a result, the currents are very disturbed close by. Strong local currents and vortex movements are generated (see Figure 6a). It reflects a significant risk to destabilize the toe of the dike, and to erode the upper beach downstream.

In this region, the setback of the dikes is preconized, together with massive sand nourishment. Currents generated in such a situation ought to decrease (see Figure 6b). It might reduce sediment transport (see Figure 7) and improve the stability of the structures. Indeed, it results in better damping of waves, the recirculation and accelerations observed in the initial state disappear. The beach might reach a stable profile. The reduction in currents is about 20% for the beach of Les Demoiselles and up to 70% on the areas of Les Becs and Les Mouettes.

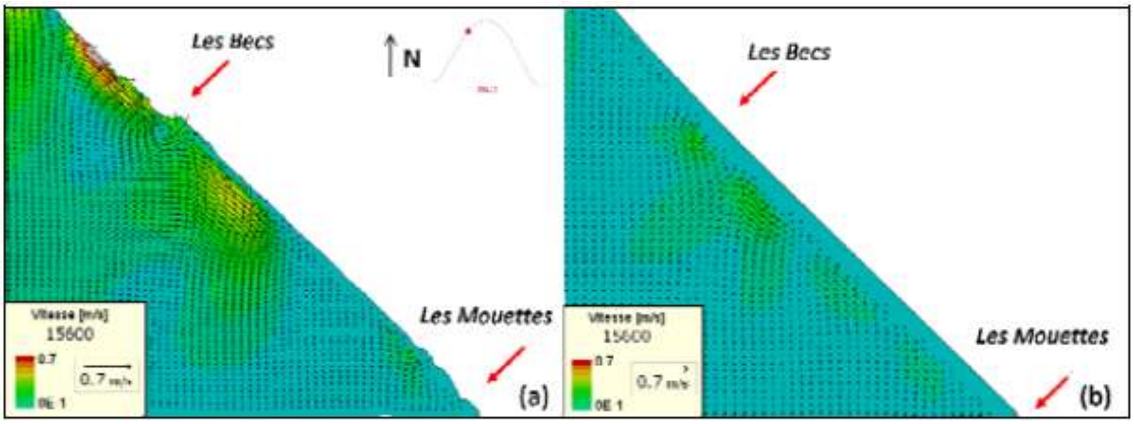

Figure 6. Currents: (a) initial state; (b) proposed solution.

REFLUX-SEDIM was used to estimate potential areas of deposition / erosion over time. It detects the actual scour at the foot of the dikes and areas of sediment disturbance on the foreshore in the case of the current situation. Empirical formulas are used involving among other parameters the wave breaking angle. The longshore transport rate is estimated with for instance Kamphuis formula (KAMPHUIS, 1991):

$$Q = 2.27 H_{sb}^{2} T_{p}^{1.5} \tan\beta^{0.75} d_{50}^{-0.25} (\sin 2\alpha_b)^{0.6}$$

In which: Q [m^3/s]: transport rate; H_{sb} [m]: significant wave height at breaking; T_p [s]: peak wave period; $tan(\beta)$: beach slope; d_{50} [m]: median grain size; α_b: wave breaking angle.

Another formulation used is defined by the CERC (CERC, 1984):

$$Q = K \frac{\rho\sqrt{g}}{16\sqrt{\gamma}(\rho_s - \rho)(1-n)} H_{sb}^{5/2} \sin(2\alpha_b)$$

In which K: empirical coefficient ($K=0.39$ CERC, 1984; $K=f(d_{50})$ DEL VALLE *et al.*, 1993); $n=0.4$: sand porosity; ρ et ρ_s [kg/m^3]: weight of water and sand; γ: breaker index.

The results obtained from the different formulations can be very scattered. The empirical coefficients significantly vary from an author to another (ROSAT *et al.*, 2002). Therefore, the transport rate results should be used carefully.

The calculations are performed for the initial state and the proposed solution. It aims to estimate a difference of sediment transport between the two configurations. Considering the present study, the proposed managements might reduce of about 20% the transport rate in front of the beach of Les Becs.

4. Conclusions

The numerical modeling of the proposed management solution clearly shows an improvement of the situation in terms of currents and sediment transport. Consequently to the massive sand nourishment, the low agitation generated by the structures will be reduced. *In situ* observation and expertise are essential for the success of this kind of

project. However, numerical modeling is a valuable tool, if *in situ* updated and good quality measurements are available. The used software can quantify the improvements performed with the proposed management solution and also provide visual support.
The ISC dikes of the areas of Les Becs and Les Mouettes need a whole rehabilitation in order to secure people and urban facilities. The safety of the camping facilities located at the south of La Pège is no longer guaranteed considering the backward movement of the coastline.

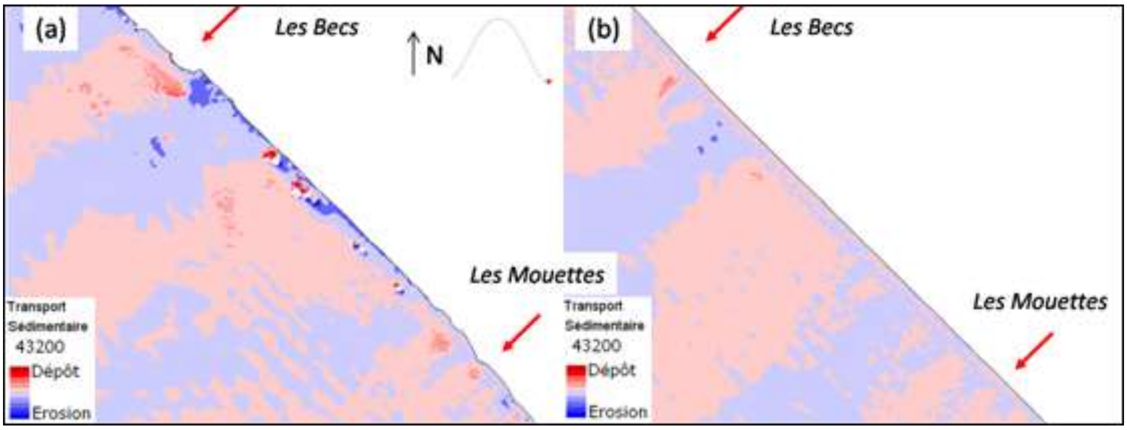

Figure 7. Estimation of sediment transport: (a) initial state; (b) proposed solution.

The location of the camp facilities will be modified so that its boundary is located 100 m from the coastline. The rehabilitation of the ISC dikes and the massive sand nourishment works might reduce the flood hazard to a low level.
The adopted strategy consists in a retreat of the coastline i.e. make the structures forward on the foreshore vanish. It is not intrusive to the coast and might restore a stable profile. As a consequence, it helps to secure in a sustainable manner goods and people upstream.
This strategy is one of the requirements of a French summit entitled "Grenelle de la mer". One of the commitments (number 74) consists in the following tasks: "Anticipate and prevent natural and technological risks", and "develop a methodology and a national strategy for the shoreline management, for the strategic retreat of the coastline and the protection against the sea".

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