

Coastal protection solutions in a highly energetic wave climate and beach erosion environment: the Furadouro case (Portugal)

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Abstract. Numerical modeling studies of the coastline evolution for the Furadouro coastal stretch (Portugal mainland west coast) were carried out. Four intervention scenarios are compared, involving the maintenance of the existing coastal structures and/or the construction of a detached breakwater, with or without a large-scale, 4 million m³, artificial beach nourishment. This paper contains a brief characterization of the last-decade morphological evolution of the Furadouro coastline, and the methods and results of modeling its coastline evolution. A classical one-line type shoreline evolution model was calibrated and applied for each scenario evaluation. The efficacy of the detached breakwater in enhancing the beach width in front of Furadouro is dependent on its location and can be equivalent to the case of nourishment only. The compound intervention (breakwater plus nourishment) significantly increases the town maritime frontage protection but also induces greater erosion problems downdrift.

Keywords: Erosion mitigation, beach overtopping protection, detached breakwater, beach nourishment, shoreline evolution.

1 Introduction

The town of *Furadouro* is located in the Portuguese northern-central west coast, subject to a high-energy wave climate (e.g., [1]). Its maritime frontage has been subjected to severe coastal erosion, frequent coastal overtopping and flooding events for more than 50 years. This has led to several interventions, mainly leading to armouring of the coast since 1972 by means of a 750 m long coastal revetment and two groins (Fig. 1). Incidents of wave overtopping have increased dramatically in frequency and intensity since 2010, when urban structures, both commercial and residential, were harmed [2].

The small-size groins (lengths circa 135 m) in front of *Furadouro* (Fig. 1) essentially led to accumulating sand at the northern (updrift) side and enhancing erosion at the southern (downdrift) side. The potential yearly net littoral transport is approximately 1 million m³/year. Presently, as the sediment input into this littoral cell from its northern boundary is much smaller than the potential net transport, this potential flux is not achieved at *Furadouro*, and caps at a value of circa 600,000 m³/year. The coastline presents generalized erosion of the beach-dune system north of *Furadouro*.

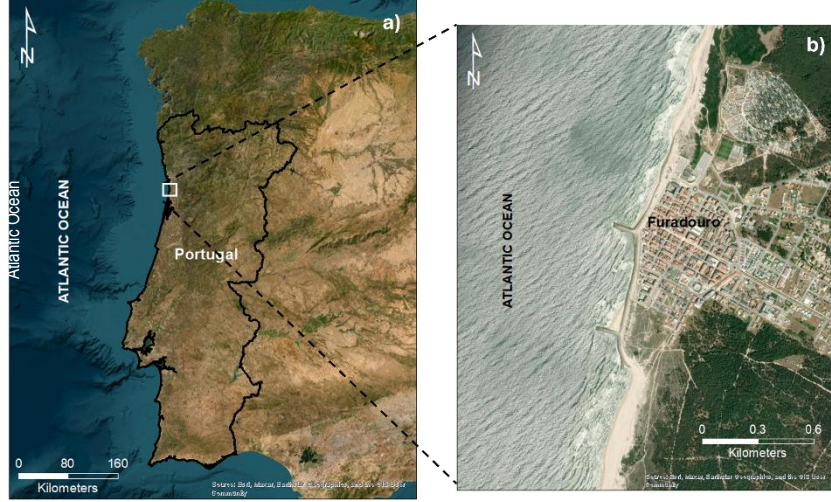


Fig. 1. Portugal mainland (left) and Furadouro locality (right). (Images from Basemap "World Imagery" provided by ESRI. Credits: Esri, Maxar, Earthstar Geographics, and the GIS User Community)

Following previous coastal protection strategies (e.g., [1], [3]), in 2024, the Portuguese Environmental Agency (APA) commissioned a study [4] to analyze and compare several options in terms of coastal protection performance and coastline evolution, contemplating mainly the execution of large-scale beach nourishments and a detached breakwater (DB, in short). Previous works [4] have pointed towards the main geometrical characteristics of one or two DB, in front of *Furadouro*. The intended nourishments would be placed at the dry beach and in the nearshore submerged active profile, totaling $4 \times 10^6 \text{ m}^3$. This paper presents the main results of that study [5]. The “do-nothing” strategy (apart from maintaining the present defenses) is here identified by scenario A; beach nourishment only is B; scenario C refers to DB only; and scenario D compounds beach nourishment with a DB. Scenario C involved three alternative locations – C1, C2 and C3 – of the DB (200 m long, and 350 m seaward the coastline), shifted 100 m longitudinally, in relation to *Furadouro* northern groin alignment.

2 Data and Methods

Coastal topo-bathymetric data were extracted from the COSMO monitoring programme [6], surrounding *Furadouro*. These included beach aerial and orthophoto surveys, upper beach and integral (upper beach and foreshore) cross-shore profiles, and nearshore bathymetric surveys, from 2018 until 2021. Other data included a LIDAR topographic survey from 2011 and orthophotos from 2008 and 2021, all provided by the Portuguese General Territory Directorate (DGT) [7].

The wave climate hindcast data from Dodet *et al.* [8] was used to obtain past annual time series (1952 to 2010) at the region. For the scenario’s evaluation, the 1-yr sequence

of daily events from 2005/08/01 until 2006/07/31 was used and repeated periodically, as this cycle yields a close estimate of the net sediment transport capacity averaged over the whole period.

The morphological evolution of the 16 km coastal sector centered at *Furadouro* was carried out by comparing the coastline position at different dates, digitized from the georeferenced COSMO orthophotos, between 2018 and 2021 (yearly, although not equally spaced in time, yielding 4 shorelines in this period). The observed shoreline evolution rates and other metrics were computed by means of the DSAS – Digital Shoreline Analysis System (version 6.0) software [9].

The shoreline evolution model LITMOD [10, 11] was used to compare the various intervention scenarios. This is a classical one-line model, like the well-known GENESIS model, which allows the user to easily define and evaluate scenarios. The Kamphuis formula was chosen to calculate the alongshore sediment transport from wave breaking parameters, with the calibration transport coefficient equal to 82% of the original value to better fit the shoreline data. This model had been previously calibrated for a 40 km long coastal region surrounding *Furadouro* [11], but a finer re-calibration was carried out locally (over a 10 km long sector) to match the shoreline evolution rates at three cross-shore locations obtained from the 2008 and 2021 DGT orthophotos (for details, see [4]). One important aspect of the modelling was the use of different sediment size in the regions (and cases) where the beach nourishments would be performed as the median grain size (D_{50}) of the native sand (0.30 mm) is smaller than that of the borrow sand (0.84 mm). This was considered through the alongshore variation of the Kamphuis sediment transport formula factor.

3 Results

Fig. 2 (left) shows the shoreline evolution rates over a 16 km long stretch, encompassing *Furadouro*, between 2018-02-09 and 2021-03-03. The measured erosion rates peak at *São Pedro de Maceda* beach (minimum values of -13 m/yr), exceeding greatly those identified by Veloso-Gomes *et al.* [12] (-4.6 m/yr, 1978-1992), and Lira *et al.* [13] (-4 m/yr, 1958-2010). South of *Furadouro* the erosion rates are smaller, with a minimum of -4.2 m/yr. The orthophoto data from DGT allowed to estimate an erosion rate of -7 m/yr from 2008 until 2021 at *São Pedro de Maceda*. Hence, these results indicate that erosion at this beach has increased in the past two decades.

Beach profiles at *São Pedro de Maceda* and *Furadouro* are also shown in Fig. 2 (right). Dune/soft-cliff erosion is evident at the former, whereas the latter evolution is dominated by winter/summer profile changes.

Fig. 3 presents the modelled 20-year shoreline position along a 12 km coastal stretch, for scenarios A (“do-nothing”), B (4×10^6 m³ nourishment), C3 (DB) and D3 (nourishment+DB), relative to the 2021 (initial) line. For all nourishment scenarios two simulations are presented: assuming alongshore-uniform D_{50} (cases B_{cte} and D3_{cte}), and alongshore-varying D_{50} (cases B_{var} and D3_{var}), to differentiate the borrow from the native sediments. Fig. 3 shows that in any scenario there will be continued erosion south of *Cortegaça* (at *Maceda* beach) and *Furadouro*, with coastline retreats up to 200 m in

20 years. Secondly, south of *Furadouro*, most of the “do-something” scenarios lead to worse results than the “do-nothing” (A) one. However, at *Furadouro* and updrift, any of those improve the situation relative to scenario A. Immediately updrift the northern groin at *Furadouro*, interventions B and C lead to similar beach configurations. These results therefore indicate that sediment retention (from beach nourishment) at any sector will enhance sediment deficit further downdrift, so one needs to carefully balance the benefits and shortcomings of any intervention.

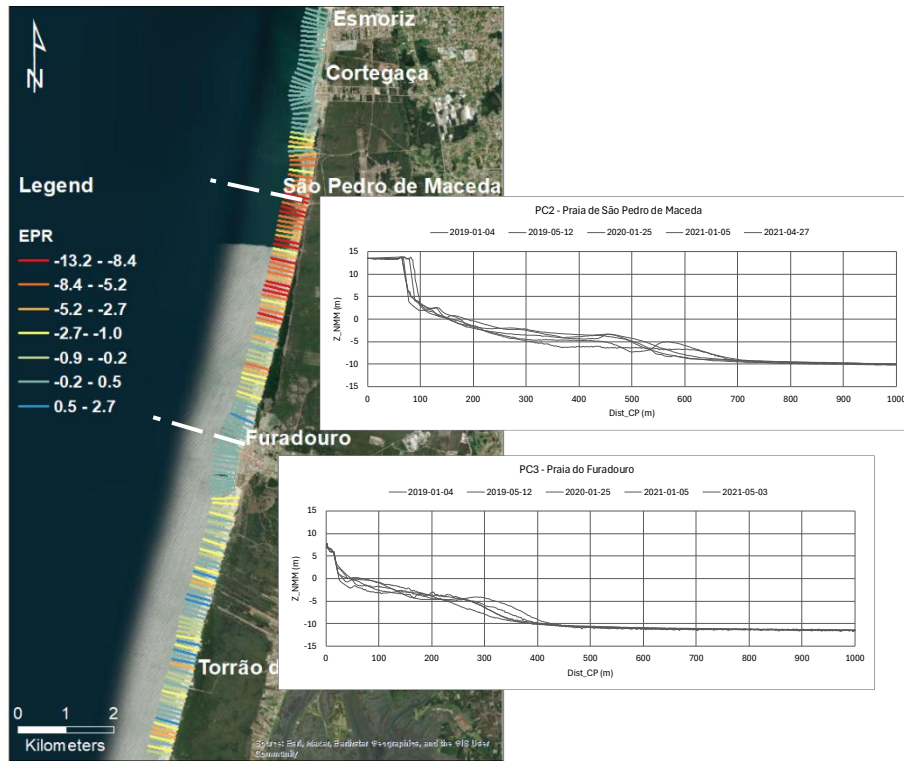


Fig. 2.: Shoreline evolution rates (2018-02-09 to 2021-03-03), and beach profiles at *São Pedro de Maceda* and *Furadouro* (marked in white at left) (from 2019-01-04 to 2021-04-27). (Image from Basemap "World Imagery" provided by ESRI. Credits: Esri, Maxar, Earthstar Geographics, and the GIS User Community)

Fig. 4 reveals the sediment budget over the 20-year simulation period for the coastal cell comprised between $78750 \leq x \leq 89800$ m (see the x-axis of Fig.3), from south of *Furadouro* to *Esmoriz*. Dashed versus solid bars for the same scenario differentiate the uniform from varying D_{50} simulations. Negative values indicate sand loss from the cell. Indeed, the “do-nothing” scenario is the one with greatest loss. Nonetheless, scenarios B and D account for the initial beach nourishment added volume of $4 \times 10^6 \text{ m}^3$. Case D2 is the most beneficial for this cell, with a net gain nearly equal to the nourished volume. However, it is also the one with the greatest erosion south of this cell [4].

The beach nourishment lifetimes (time to erode the beach nourishment) were also calculated for the above littoral cell, yielding values between 7.5 yr (B) and 12.5 yr (D1 and D3). Case D2 yielded a project lifetime greater than the 20-year simulation period.

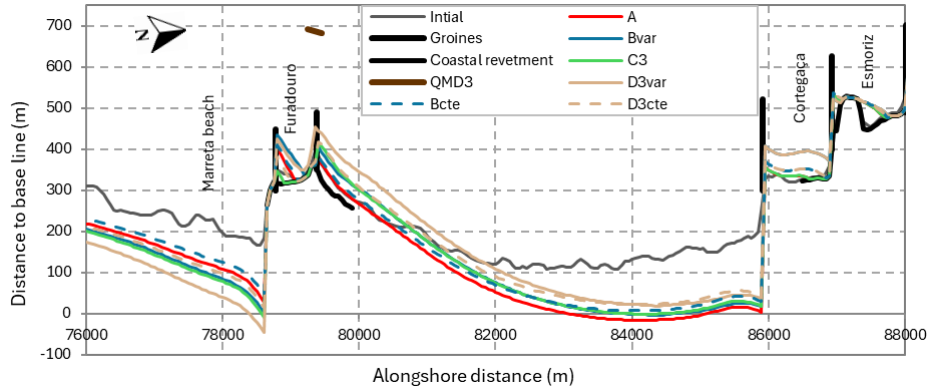


Fig. 3. Modelled 20-year shoreline evolution from 2021 position, for scenarios A, B, C1 and D1 (horizontal/vertical scales distorted)

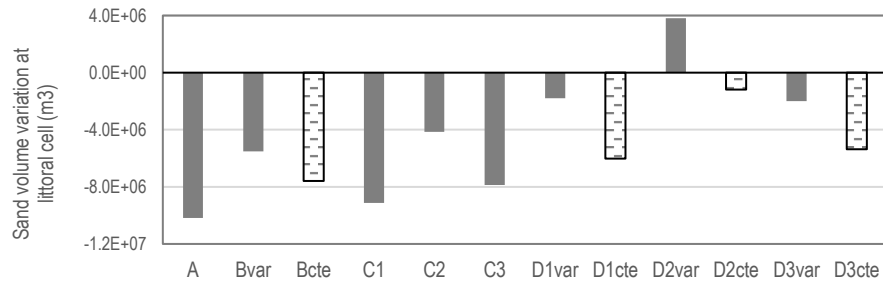


Fig. 4. Sediment budget over 20 years at the littoral cell $78750 \leq x \leq 89800$ m (see x-axis values of Fig. 3; from *Marreta* beach to *Esmoriz*), for all scenarios.

4 Conclusions

This work compares different intervention scenarios to protect the coastal town of *Furadouro*, at the Portuguese coast. The shoreline evolution past a large magnitude ($4 \times 10^6 \text{ m}^3$), spatially distributed, beach nourishment is compared with the no-intervention case and with the placement of a detached breakwater (DB).

Both alternatives provide similar (long-term) protection to the town, although, for the nourishment case (B) the protection lifetime would be shorter than the one offered by the DB (provided this worked effectively as designed, which is expected to be hindered by structural deterioration and maintenance difficulties).

Given the strong negative impacts caused by the DB downdrift of *Furadouro*, it is recommended to undertake the beach nourishment option, monitor the coastline evolution, and re-evaluate the situation past 2 years of the initial nourishment project.

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