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Uncertainty in the application of the parabolic bay shape equation: Part 2

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ABSTRACT

This paper attempts to highlight issues that are relevant in the application of the Parabolic Bay Shape Equation (PBSE) to a non-equilibrium bay. For this case, the bay of Imbituba in southern Brazil was chosen. The construction of a breakwater to shelter the port of Imbituba in the south of the bay was accompanied by an increase in sedimentation to the port area from an eroding downdrift beach. Superimposed plots of the coastline of the Bay of Imbituba from different years confirm a general trend of accretion of the southern part of the bay accompanied with a retreat of the coastline in the northern part. After the application of the PBSE it became clear that the breakwater caused a change in the equilibrium state of the bay. Between 1947 and 2001 the Bay of Imbituba has changed from a dynamic equilibrium to a natural beach reshaping or self-reshaping. The tendency of the sedimentation of the southern part of the bay can be explained by the SEP associated with the new updrift diffraction point (tip of the breakwater): The seaward position of the SEP predicts a need for additional sediment in order to achieve a stable plan form.

1. Introduction

This paper discusses issues that are relevant in the context of the application of a Parabolic Bay Shape Equation (PBSE) to a non-equilibrium bay. The results were generated in the framework of our work on investigating the uncertainty associated with application of the PBSE to the equilibrium bay of Taquaras–Taquarinhas (Lausman et al., 2010-this issue). Similar to this accompanying paper, we have selected the Parabolic Bay Shape Equation (PBSE) developed by Hsu and Evans (1989). For a more elaborate discussion on the application of the PSBE we refer to the accompanying paper (Lausman et al., 2010-this issue). Our case study is the Bay of Imbituba. This embayment, in contrast to the Taquaras–Taquarinhas Bay that is in static equilibrium, represents a more complex situation, which has undergone several changes by human intervention due to coastal construction works. It has been in a natural beach reshaping or self-reshaping stage.

2. Bay of Imbituba: history of coastal works construction

The Bay of Imbituba is located in the state of Santa Catarina, southern Brazil. The strategic location of the bay was the main reason for the construction of a port in 1919 and works started in the south of the bay to accommodate the export of coal from the mainland. To protect the port against the southerly incoming waves an attached breakwater was built. The construction was carried out in two phases, initially a breakwater of 550 m was constructed in 1972 and later it was extended to its present length of 850 m. The history of the major coastal works construction is described in Table 1.

With the construction of the breakwater an increase in sedimentation of the port area was noticed. The breakwater has changed the wave diffraction pattern in the bay, exposing the soft Pleistocene sedimentary rock in the north of the bay to increased wave attack. It is the erosion of this cliff that is considered to be a major contributor to the sedimentation of the port. The port authority commissioned the construction of three groins in 1980 on Do Port Beach to combat the sedimentation. A cutter suction dredge, owned by the port authority, performs periodic dredging of the basin and access channel and recently, the port authority has decided to extend its operation to the handling of containers with the construction of an 800,000 m^2 container terminal in the south of the bay.

3. Evolution of the Imbituba coastline

Different data, ranging from bathymetric charts to aerial photographs from as early as 1947 to 2001 were obtained at the Companhia Docas de Imbituba (CDI), Imbituba's Port Authority. An overview of the data is given in Lausman (2006). The data covers a time span of 54 years. In this period large morphological changes took place between 1972 and 1982, most importantly due to breakwater extension to 850 m in the south of the bay and the three groins on Do Porto beach, around the middle of the embayment (see Fig. 1).

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Table 1
History of major coastal works for the Port of Imbituba.
(source: Personal communication of Eng. Candido, Companhia Docas de Imbituba).

Date	Construction phase
24/10/1972	Start of construction of the breakwater
17/09/1975	End of construction: 550 m
15/08/1980	Start of extension of the breakwater and construction of 3 groins on Do Porto Beach
03/12/1982	End of construction works. Total breakwater length: 850 m

To analyse the effect of the coastal structures on the morphology of the bay, preparation of the data was needed. This included using the GIS software program ArcGIS 9.2® to designate the correct UTM coordinates to the images (georeferencing) and to digitise the coastline. A chart from the Secretaria do Patrimônio da União (SPU) was used as basis for the georeferencing. The projected coordinate system applied was: South American 1969 UTM Zone 22S and the average error of the aligning was 1.57 m (r.m.s.). Once georeferenced the coastline could be digitised and the coastlines from different years could be superimposed on each other, yielding a visual representation of the morphological evolution of the bay. Coastlines of the Bay of Imbituba in 1966 and 2001 can be seen in Fig. 1.

Immediately clear from Fig. 1 is the accretion in the southern part of the bay. According to the port authority this accretion is not entirely due to natural causes such as sediment transport. During the construction of the berths material from the port basin and access channel was dredged and used as landfill material behind the berths. Nevertheless, after the completion of the first 550 m of the breakwater, sedimentation into the port area was experienced and in 1981 three groins where built with the purpose to stop further sedimentation into the harbour basin. The port authority suspected that the material needed for this sedimentation came from the northern part of the bay. This seems plausible when looking at Figs. 1 and 2.

The difference in size of the erosion and accretion area can be explained by the fact that the erosion area consists of an eroding active sea cliff (+40 m height) and the accretion area consists of a flat beach (Fig. 2).

4. Results of the application of the PBSE on the bay of Imbituba

It is clear that the coastal structures in the Bay of Imbituba have had a significant impact on the morphology of the bay. After application of the PBSE to the Bay of Imbituba it was observed that as a consequence of the construction of the breakwater and groins the equilibrium status of the bay has changed from dynamic to close to static in the north and unstable in the south, in other words to the natural reshaping stage (Table 2). Noticeable is also that β changes over time (Fig. 3). This is understandable since with the construction of the breakwater the diffraction point has moved northwards into the bay, decreasing the length of the control line (Fig. 4).

If the beach would not adapt itself to the new situation, *i.e.* if position of point *E* (e.g. as in the MEPBAY output for Tarquaras–Taquarinhas in Fig. 5 - Lausman et al., 2010-this issue), remains the same, then β would increase just by the translation of the updrift diffraction point *H* alone, since β is defined as the angle between the wave crest line and the control line. However, as can be observed in Fig. 1 the orientation of the beach has indeed changed. This complicates the matters because it implies that the position of point *E* did not remain the same throughout time. If one looks at Figs. 5 and 6 (coastlines in 1988 and 2001) the increase in β by the translation of the diffraction point is left out. In theory the only factor influencing the change of β now would be the adaptation of the beach plan form. This can be observed in Fig. 3 where after completion of the extension of the breakwater in 1982, β seemed to decrease as the beach planform adapted itself to the new diffraction point.

Besides the translation of the diffraction point and the adaptation of the waterline to the presence of the breakwater, the cause for the variations in β could also be:

1. Inaccuracies in the plotting of the coastline. Poorly visible sections of beach on the aerial photographs make identification of the waterline difficult.
2. Round-off error of MEPBAY 2.0 when determining β. (According to Andre Raabe, co-developer of MEPBAY 2.0; this error could be up to 1%).
3. The Port of Imbituba operates its own cutter suction dredge, which performs regular dredging of the access channel and port basin. The effect of this dredging on the coastline is not taken into account by PBSE (via MEPBAY 2.0).

The tendency of the sedimentation around the port can be explained by looking at the SEP belonging to the new updrift diffraction point (the tip of the breakwater). To reach this new SEP the southern part of the bay requires massive accretion (Figs. 5 and 6).

5. Expert elicitation results for the Bay of Imbituba

To investigate the behaviour of the PBSE when applied to an unstable situation, the Bay of Imbituba was also included in the expert elicitation described in our accompanying paper (Lausman et al., 2010-this issue). It is important to note that for the investigation of the uncertainty of the PBSE only bays in static equilibrium must be used. However, even though the results from the expert elicitation regarding the Bay of Imbituba may not be used to determine the uncertainty of the PBSE, some useful comments can be made regarding the behaviour of MEPBAY 2.0 (or the PBSE) when applying it to a bay where coastal structures have been placed.

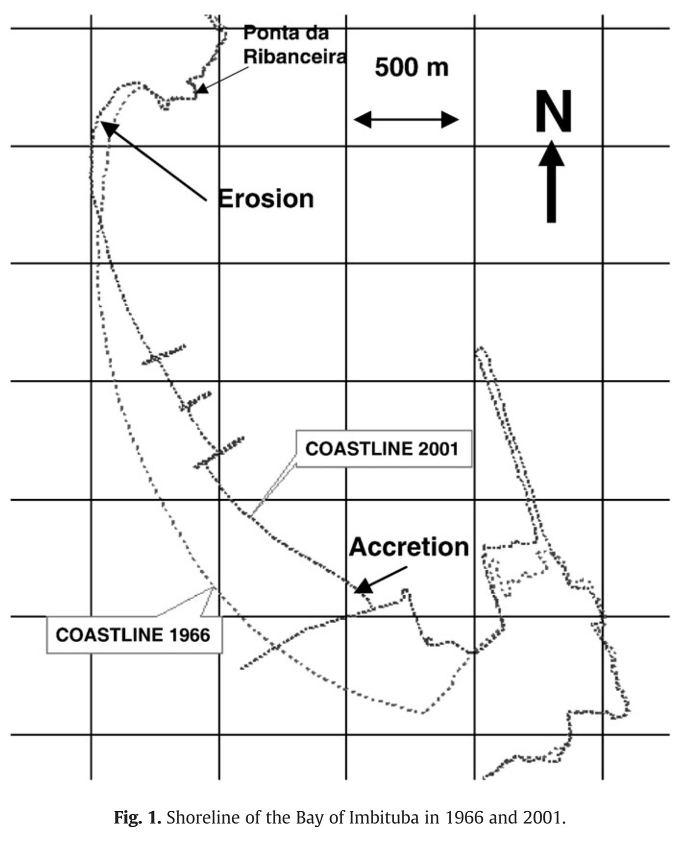

Fig. 1. Shoreline of the Bay of Imbituba in 1966 and 2001.