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Evolution and Dynamic of Itamambuca Beach and Comparative Evaluation of Morphodynamic Studies of Beaches

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ABSTRACT

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There is a worldwide tendency of intensive investigation on beaches with the main purpose of obtaining a better comprehension of the dynamics and evolutive tendency of the environment, and further promote an improvement to the management of this environment. The purpose of this work was to evaluate the space-time variability of Itamambuca beach (north of São Paulo State) as well as the main methodologies of beach studies used in Brazil. The monitoring of beach profiles showed that there are different topographic behaviors under the influence of hydrodinamic and meteorologic parameters, containing good weather atmospheric conditions and the front systems (prefrontal, post frontal and frontal action in the area). The great shaper of Itamambuca beach is the wave system. Concerning the morphodynamic classifications, the two methods presented as predominant the reflective and intermediary morphodynamic states (Low Tide Terrace - LTT). Both of them presented propitious results according to what was proposed. Therefore, with all of this we can conclude that the best method to be used is more related to the purposes of the work than to the method itself.

ADDITIONAL INDEX WORDS: *Coastal environment, morphodynamic state.*

INTRODUCTION

The studies about the variability of the coastal environments have shown the need of proposal solutions to the several environmental problems actually caused by natural or anthropogenic elements on those kind of environment.

Among several applicated models of the coastal studies, the most accepted is the one by WRIGHT and SHORT (1983) that classifies the beach in five different morphodynamic states. This model includes the watching of several existent elements on the emersed and submersed portions of the beaches and also the setting of the W (DEAN, 1973) and Wm (WRIGHT *et al.*, 1985) parameters.

The Wright and Short (op.cit.) model is not so used in Brazil mainly because of the small quantity of systematic studies in beaches and the difficult access to the needed equipment to execute this kind of work. MUEHE (1998) developed a simple method that can be easily applied to determine the evolutive tendency of the coastal line, taking advantage of a worldwide tendency of investigation of the beachface. He elaborated a new parameter called delta (D) for it.

The purpose of this work was to compare how applicable are these two methodologies of studies of beaches and also the evaluation of the space-time variability of the beach environment, precisely the modifications measured in the beach profiles and its relations with the sedimentary processes in beaches exposed to the ocean.

The beach of Itamambuca located in the North of São Paulo State, in the city of Ubatuba, near of the latitude 23º25"S and longitude 045ºW) was chosen for this purpose. (Figure 01).

Itamambuca is a beach that it faces SE, located at a homonym coastal plan with length of 1,650 meters and width between 20 and 40 meters.

It is normally described as a beach with a large breaking zone and a strong inclination of the beach face that grow less into the south together with the mouth of the river Itamambuca, the main drain basin of the beach.

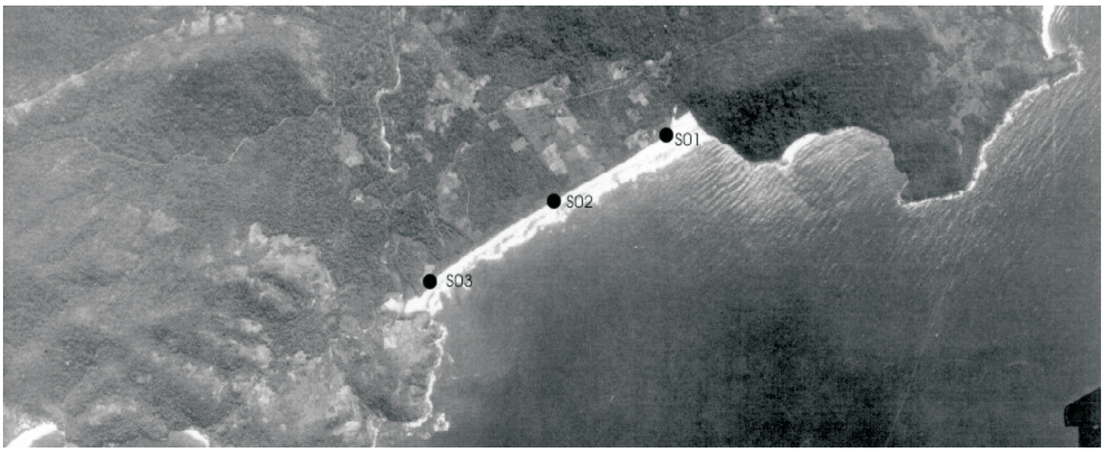

Figure 1. Itamambuca beach - Ubatuba. The first beach profile (S01) is located on the central part of the beach (UTM localization 0499603/7411951), the second one (S02) is on the northeaster portion of the beach (UTM localization 0500296/7412335) and the third one (S03), on the other edge next to the mouth of the river Itamambuca (UTM localization 0499269/7411731). The orientation of the three set beach profiles was N165º.

MATERIALS AND METHODS

Bathymetry

The bathymetric characterization was obtained by the range "A" from the bathymetric chart Nº1613 do DHN (1936). It also used the dates from RODRIGUES (1996) who described details about the bathymetry of this area.

Meteorological Monitoring

The meteorological monitoring was done using the following variables: atmospheric pressure, pluviometric precipitation and its deviation from the historic average, relative air humidity, number of cold fronts, its characteristics and respective action dates over the target area. These parameters were obtained from IOUSP North Base (located in bay of Flamengo, in the south of the area) and also from the synoptic/meteorological chart of DHN - MM (Diretoria de Hidrografia e Navegação do Ministério da Marinha – Directory of Hydrography and Navigation of Navy State Department) as well as from the *Climanálise* bulletin website (http://www.cptec.inpe.br/products/climanalise).

Topographic Monitoring

The topographic monitoring was done in three beach profiles (S01, S02 and S03), located on the borders and in the middle of the beach (figure 01), previous located by GPS. The duration of this activity was 14 months (from March/2001 to April/2002) and was done monthly (new moon phase) using a theodolite. The range between the contour values was 5 meters. In July a detailed monitoring was also accomplished, where six survey fields were done in the period between July 06th (used as reference) to July 21st of 2001.

Sediments

Together with the monitoring of topographic beach profiles some samples of superficial sediments were collected. This was done in a systematic manner in two different positions of the beach profiles (superior portion on the beach face and near to the waterline). The laboratory analysis of the sediments was: content of $CaCO_3$ (hydrochloric acid at 10M) and granulometry by dry seiving (SUGUIO,1973).

Oceanographic Parameters

Visual observations of oceanographic parameters like waves and direction of the longshore currents were also obtained during the survey fields. The wave period (T, in seconds) was obtained from the measuring of the time passed after the movement of eleven consecutive swell over a fixed point, divided by ten. The height of the wave was estimated visually from the height difference between the crest and the base of the wave in the breaker zone and the direction of the waves related to the beach orientation taken by the sight compass.

Definition of the Morphodynamic State

The calculations to define the morphodynamic state of the beach were done according to the work proposition from WRIGHT & SHORT (1983) and MUEHE (1998), with the aid of the software Microsoft Excel (Office 2000 version).

WRIGHT & SHORT (1983) model subdivides the morphodynamic states in six different states, which are: Dissipative, Reflective and four intermediate states between the two first ones: Longshore Bar - Trough (LBT), Rhythmic Bar and Beach (RBB), Transverse Bar and Rip (TBR) and Low Tide Terrace (LTT). These six states were set quantitatively by the parameter (Ω) from DEAN (1973) and this was set by the formula:

$$\Omega = Hb/\varpi s.T \qquad (1)$$

Where Hb is the height of the wave in the breaker zone, ϖs is the average speed of decantation of the grains and T is the average period of the wave.

Wright *et al* (1985) checked that the instant values of W not necessarily show the mean morphologic state of the beach and decided to use a weighted Ω value considering also the past morphodynamic conditions of the beach. This average value is represented by the following formula:

$$m=[\Sigma_i 10^{-i/\phi}].\Sigma(\Omega_i.10^{-i/\phi}) \qquad (2)$$

Where i=1 represents the day of the monitoring and i=D shows the number of foregoing days. The ϕ parameter is the factor of weighing that matches 10% from a preset number of days before the observation.

With the definition of Ωm values, WRIGHT *et al.* (*op.cit.*) quantitatively defined the morphodynamic states showed on the table below:

Morphodynamic State	Ω_m	Standard Deviation
Reflective	≤1,5	-
LTT	2,40	0,19
TBR	3,15	0,64
RBB	3,50	0,76
LBT	4,70	0,93
Dissipative	>5,5	-

Muehe (1998) methodology considered the surf zone as a filter whose efficiency makes the wave lose part of its energy. This capacity is caused by the bottom morphology.

The system is analyzed like a process-answer system where the surf zone is treated as a dissipation energy area and the entrance of the system is characterized by the height and the wave period, in the most external breaker zone, and the exit of the system is analyzed in the swash zone.

The h/Hb relation (where h is the height of the wave and Hb is the height of the wave in the breaker zone) represents the loss of the energy of the wave during its movement through the surf zone set here as a dissipation coefficient.

Muehe (1998) associated both quotients, dissipation and state of flow, into just one formula, obtaining a new parameter which he called delta (Δ). Here follows the formula of this parameter:

$$\Delta=[(\mathrm{sen}\beta.D_{espr})/Hb]/(T_{espr}/T) \qquad (3)$$

where senβ is the angle of the swash zone; D_{espr} is the size of the swash zone; Hb is the height of the waves in the breaker zone; T_{espr} is the total amount of time of the swash (swash-backwash); and finally T is the period of the wave.

By testing this parameter on the beaches of Rio de Janeiro coast, Muehe (*op.cit.*) determined the following numeric ranges for the classification of the morphodynamic states:

Morphodynamic State	**Delta (Δ)**
Dissipative	<0,5
LBT	0,5 – 0,8
TBR	0,8 – 1,0
LTT	1,0 – 2,0
Reflective	>2,0

RESULTS

Bathymetry

The isobaths contiguous to Itamambuca beach are parallel to each other, equally distant to each other with a rectilinear tendency, with a very complex arrangement in the outcrops of the Crystalline Basement.

Meteorology

During the 13 monitoring months, 35 frontal systems passed by Itamambuca, most of them considered as low intensity and with the dissipation right to the ocean in the latitude of the area of the study or near to the north (Rio de Janeiro estate). The cloudiness grew and some fine rain fallen down because of the influence of those fronts. TThe number of frontal systems over the area was smaller than the historical average that caused an increase in the total mean annual precipitation. The cold fronts with moderated to strong intensity in general were associated to other meteorological phenomena as local systems and centers of low pressure, as well as the action of a high level cyclonic vortex.

The most significant meteorological events inside the area of study happened in May/01 (5^{th}) and June/01 (from 18^{th} to 20^{th}). The event on May/01 occurred due to the conjunction of the forthcoming cold front with the low-pressure systems, causing cyclogenesis with strong winds, historical storm waves and pile water in the coast (the biggest one in the last 50 years). This meteorological phenomena happened again on a small scale, on June/01. On July/01 (12^{th}), a cold front passed by Ubatuba and although its intensity was considered low it caused some erosion on the beach.

There were not cold fronts on August/01 over the area of study but a cyclonic vortex of 500 hPa, located into the ocean near São Paulo coast remained still from 15^{th} to 18^{th}, going to the north on 19^{th}.

The most significant stationary front acted over the area of the study on December/01 (between 11^{th}-16^{th}) and the hot front of higher intensity acted on January/02 (15^{th}-20^{th}). Both of them caused large rainfall inputs.

Beach Profiles

The systematic survey on the three beach profiles presented in general an alternation of erosive/depositional processes over the beach and also between the emerse and the submerse portions of the beach profiles. We must remember that the geometry of the beach profiles during the monitoring was defined by a sum of events during the whole month. During the detailed monitoring done on July/01, the same interchange of erosive/depositional processes was noted with the predomination of the depositional processes.

The beach profile S01 was highlighted by the interchange of the erosive and depositional processes but with the predominance of the erosion, considering that the most significant event was measured on June/01. During the detailed monitoring, the beach profile S01 presented also the predominance of onshore – offshore action with a great tendency to deposition.

The beach profile S02 was highlighted by the more equilibrated interchange of depositional, erosive and onshore-offshore processes, without the predominance of any one of them during this time. In detail, S02 was noticed the predominance of the onshore – offshore processes.

The beach profile S03 was highlighted by the action of the onshore – offshore processes without any measurement of the larger erosive processes. On the detailed S03, there was the tendency of predominance of depositional processes.

Sediments

The granulometry of the profiles was relatively stable considering that S01 presented during the whole monitoring, mean sand with moderated grade of selection, approximate symmetric and mesokurtic. The difference from S02 to S01 was only in the mode that was a variation of fine sand in the emerse part (during the period between April and October/01). The beach profile S03 was the one, which presented more variation of mode, with fine sand during the monitorings under good weather conditions in the emerse part of the profile, but near to the waterline this granulometry presented medium mode with a tendency to gross because of the passing of the front.

Wave Data

The wave presented larger mean significative heights in front of the beach profile S03 (1 to 2 meters). In front of the beach profiles S01 and S02, the heights were between 0.5 to 1.5 meters reaching 2 meters in S01 just on June/01. The average periods are between 8 and 14 seconds. The predominant direction of the incidence of the wave trains was from quadrant SE. The coastal drift, most of the time, goes direct to the mouth of the river Itamambuca.

Definition of the Morphodynamic States

The Ωm parameter (WRIGHT *et al.*,1985), cannot be calculated because of the absence of past data, giving some preference to the use of the Ω parameter, that illustrates the "morphodynamic moment" of the beach. The beach is normally reflective with gradual passage to the intermediate states right to the mouth of the river Itamambuca. The center of the beach was steeper than the borders after the action of the cold fronts. The most dissipative relief found was on 07/13/2001 when the beach was equal on the morphodynamic state LBT.

Then the parameter Δ (MUEHE, 1998) presented the tendency of evolution of the morphodynamic state of the beach. The tendency of the beach is the variation between the states of LTT and Reflective, considering that in a rough manner, the reflective state was predominant during the months from April to July/01 and in the remaining time of the monitoring, there was a predominance of the state of LTT.

DISCUSSION

In Itamambuca, the monitoring of beach profiles showed that there are different topographic behaviors between the several points of the beach influenced by the meteorological parameters and hydrodynamics (hydrological) that acted during the monitoring.

The 13 months of monitoring embraced atmospheric conditions from the acting of the South Tropical Atlantic Anticyclone – (STAA) and cold and hot front systems (prefrontals, postfrontals and under the frontal action on the area), besides stationary fronts and cyclonic vortex. The beach profiles did not reflect exactly the climatic conditions from the monitoring day, presenting a resultant monitoring from the incidence of the several systems that passed by the area between the periods of monitoring.

During the action periods of the STAA (i.e. good weather), the beach presents different behaviors, influenced mainly by the intensity of the systems and by the past time from the passage of them over the area of study, but in general, a tendency of transport right to the mouth of the Itamambuca river can be noticed. During the prefrontal period, the tendency is to have a transportation of material right to the mouth of Itamambuca river, with the predominance of onshore-offshore on the northeaster portion of the beach, followed by a small magnitude erosion or then, the predominance of onshore-offshore processes in the center and finally, near to the mouth of the river, a tendency of deposition of the sedimentary material.

During the period of the action of the front of small intensity, there is some erosion in the central part of the beach and the predominance of onshore-offshore processes on the borders of it. The transported sedimentary material goes to the fluvial outlet.

In case of more intense fronts like the one occurred in May/01, the coastal arc retract as a whole but the restoration of the beach is easier to be seen near the Itamambuca river, which a month and a half after the passage of this front presented a few changes on this profile (in comparison with april/01 monitoring). It leads us to affirm that this coastal range is more circumspect than the rest of the beach/ or that it can be restored more quickly because of the large delivery of sediments.

This circumspect must occur due to the fluvial influence and by the presence of the Crystalline Basement. The remaining beach profiles were eroded. The cold fronts that acted in May and June/01 made it difficult to restore the beach due to the incidence of high waves and refraction of them all over the beach.

In a postfrontal situation, the tendency of the longitudinal transport is right to the mouth of the river, considering that the northeaster and central portions of the beach can suffer the erosion or the predominance of onshore-offshore processes. There is an accumulation of sediments on the coastal rangeoccurs next to the river.

In a prefrontal situation as of December/01, there was a predominance of onshore-offshore processes in the central portion and near the river Itamambuca. In this case the tendency of the coastal drift was to the northeast border of the beach where an accumulation of sediments occurred.

BARROS (1997), who studied the dynamics of Itamambuca beach, affirms that this beach presents a balance between erosive and depositional events, considering that there is no difference in the intensity between them. The standard sediment of this beach was fine to mean sand (except on the waterline, where the tendency is mean to gross mode), selected moderately, approximately symmetric and mesokurtic. In general, the tendency of the granulometry is to be smaller in the direction of the northeast border of the beach and on the superior part of the coastal line. FOLK & WARD (1957) parameters also indicate the existence of more than one resource of sediments in this beach.

The anthropic interference on this beach can yet be considered minimal, with small changes as the compression of the sand on the beach face. Bigger changes were also noticed with the clearing of the vegetation near the beach and dredging (with archaic methods) to explore the sand all over Itamambuca river.

The use of the morphodynamic states was very useful to the analysis of the evolution tendency and the characterization of the beach. The classification of WRIGHT & SHORT (1983), that proposes to show immediate morphodynamic tendencies, show a similar evolution as seen by topographic theodolite.

The predominant tendency on the beach profile S01 was the interchange of the states from the TBR with the reflective state, showing an accumulation of sand on the shoreface, which during the action of cold fronts are transported to the beach face. With good weather, the sediments are accumulated again in banks on the shoreface.

The beach profile S02 is more stable due to its tendency to a reflective state and presents a small morphologic variation. Intermediate states were registered only 5 times, which means that the profile is characterized by high coastal gradient, high berm and low stock of sand in the submerse zone.

In the extreme border of the beach, beach profile S03, it was registered a beach with tendency to intermediate states, where there is a most active migration of sand banks compared to the rest of the beach, and whose answer from the modulator agent is more efficient.

The morphodynamic classification generated by Δ is about the tendency of the bewach evolution which result consists of predominance of intermediate state on beach profiles S02 and S03, showing that these parts can be easily restored. The beach profile S01 shows an interchange between reflective and LTT states, showing more difficulty to accumulate/receive sediments. The parameter Δ showed also that during the action of prefrontals, cold fronts and cyclonic vortex, the direction of the drift was to the northeast, this means, for S01. In the case of postfrontals with intense fronts, the beach presented an homogeneous reflective state, which led to insufficient time for restoration.

CONCLUSIONS

It can be assumed that the system of waves is the biggest conditioner and modulator of Itamambuca beach and they act with different incidence standards, causing different changes to the beach. Under good weather, the beach changes according to the intensity of cold fronts that had occurred previously. Under the action of great magnitude of frontal systems, the beach tendency is to create a general erosion except in the range near the mouth of Itamambuca river, saved by the presence of the river itself and the Crystalline Basement. Under the action of small intensity of cold fronts, prefrontals and postfrontals, the action of the drift is reduced and the action of onshore – offshore processes can be easily seen. The granulometry was relatively stable with minor variations during the monitoring. Concerning the morphodynamic classifications, both of them presented propitious results according to what was proposed. Overall, the best method to be used to study a beach is most related to the purposes of the work than the method itself. If the purpose of the study is to determinate the morphologic tendency on the instant, the best method is the WRIGHT & SHORT (1983). But if the study involves the determination of a longer evolutive tendency the best method is the one from MUEHE (1998). Both methods are trustful and if used together they give an excellent view of the beach evolution.

It's obvious that the applicability of both methods should be remembered. WRIGHT & SHORt (1983) needs systematic studies of the beach and the acquisition of equipment (like waverecorders) that make possible to define the Ωm. This makes this method expensive and difficult to be used. On the other hand, Muehe´s method (1998) is easier to be used and demands less cost and time. Therfore, this is the most recommendable method to be used for the Brazilian beaches.

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