

Alternative study for the Nautical and Shore Protection Structures in the Estuary of Santos, Brazil

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ABSTRACT: For the enlargement of the nautical dimensions of Santos Port Outer Access Channel (Brazil), training walls crossing the Offshore Bar are needed. The training walls choice to reduce dredging rates also induces to consider a coupling planning between nautical purposes and shore protection measures, as Santos Municipality have serious erosion problems nowadays due to the urban growth in the backshore and sea level rise. For decision support, the Hydraulic Laboratory of Engineering School of University of Sao Paulo was commissioned to study in a composite mathematical and scale model. Results include changes in wave height and direction and current speed analysis to conditions with training walls and segmented breakwaters. The water renewal was also analyzed to the condition with segmented breakwater and compared to current situation, based on hydrodynamics results and considering that this structure can reduce water quality in this area.

1 INTRODUCTION

Santos Port, in São Paulo State Coastline (Fig.1), throughputs approximately 15% of Brazilian maritime cargo, more than 110 million tons per year and is the most important maritime cargo transfer terminal in the Southern Hemisphere. The requirement to enlarge and deepen the Santos Port Outer Access Channel (depth, width and radius) to receive Post Panamax Plus and New Panamax, typically vessels of 12,000 TEUs (LOA = 398 m, B = 56.4 m, T_{full load} = 15.0 m) training walls crossing the Offshore Bar are the best cost-benefit solution to avoid huge dredging rates. This concept was already presented in the first Master Plan of Santos Port, proposed in the sixties, and it is the Phase 1 of the Seaward Conceptual Planning for the Offshore Port (Alfredini, Arasaki & Moreira, 2015).

Furthermore, the sea level rise occurred in the last century (IPCC, 2014) and the increasing rates of extreme events of storm surges require different alternatives concerning sea defenses structures in Santos beaches, mainly in Ponta da Praia location.

According to Alfredini, Arasaki & Moreira (2015), the construction of two training walls, with a total length of 9 km, is an engineering solution for the reducing Santos Port dredging rates in the Offshore Bar. Indeed, this solution would provide a significantly reducing the maintenance dredging OPEX costs, re-designing the channel dimensions in a suitable way for the larger vessels.

Otherwise, due to the storm surge attack in Ponta da Praia area (Fig.1), it is also important to provide a shore protection structure.

For Port and Municipality Authorities decision support, the Hydraulic Laboratory of Engineering

School of University of Sao Paulo was commissioned to evaluate, in a composite mathematical and scale model (Fig. 2), the morphological impacts of the training walls, considering the nautical purposes and a compatible solution for the shore protection structures.

The goal in this paper is to present the first results of two conceptual projects solution, considering the nautical purposes as mandatory, but also trying to find a compatible solution for the shore protection structures.

2 MATERIAL AND METHODS

2.1 Study Area

Santos City is located in the Southern Brazilian littoral and constantly faces negative impacts with storm surge events and consequent inundation of coastal area and erosion due to wave action and sea level rise. The most critical area in this beach is called Ponta da Praia, located in the eastern end of this beach. It is a residential area where is located the Avenue Saldanha da Gama, and is near the maritime entrance to the Port of Santos (Fig. 1). A technical analysis has been developed by Alfredini et al. (2013) who discusses the possible causes of this event and explains the situation against sea level rise.

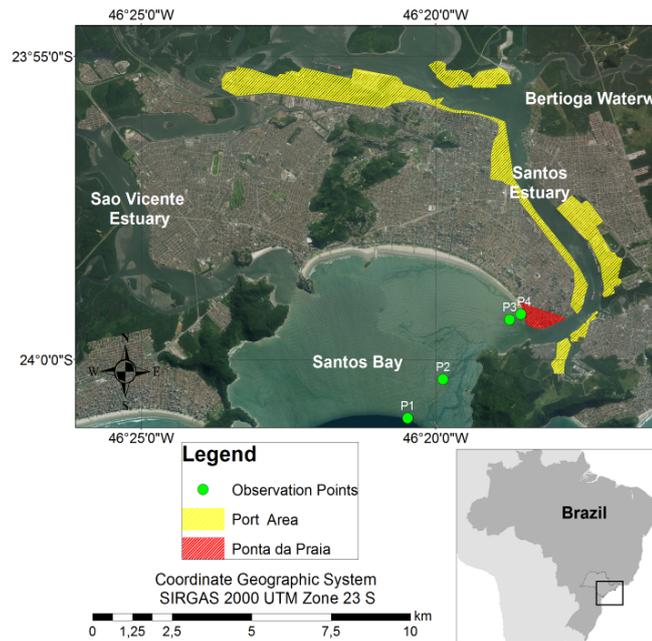


Figure 1. Location map of study area and observation points P1, P2, P3 and P4 (dots).

The data set was obtained with an ADCP gauge from Santos Pilot (2016), located in point P2 (see Fig. 1). Two conceptual projects solutions were studied: the construction of training walls and a segmented breakwater structure (Fig.3).

2.2 Numerical Modelling Description

The effectiveness and efficiency of the cited structures were analyzed using numerical modeling. Delft3D numerical model (DELTARES, 2014), Flow and Wave

modules, was used in the present study with the application of complete formulations for shallow water equation finite-difference calculation, the hydrostatic hypothesis and the Boussinesq approximation. The Boussinesq approximation states that, if density variations are small, the density may be assumed constant in all terms except the gravitational term (Broomans, 2003).

According to Chatzirodou & Karunarathna (2014), Delft3D is a finite difference code that solves the Navier-Stokes equations under the Boussinesq and shallow water assumptions, in 2D or 3D dimensions. For a 3D flow simulation, the system of equations then reads:

$$\frac{\partial(\zeta)}{\partial t} + \frac{\partial[(\zeta+d)\bar{U}]}{\partial x} + \frac{\partial[(\zeta+d)\bar{V}]}{\partial y} = S \quad (1)$$

$$\frac{\partial U}{\partial t} + U \frac{\partial U}{\partial x} + V \frac{\partial U}{\partial y} + \frac{\omega}{h} \frac{\partial U}{\partial \sigma} - fV = -\frac{1}{\rho_0} P_x + F_x + M_x + \frac{1}{h^2} \frac{\partial}{\partial \sigma} \left(\nu_v \frac{\partial U}{\partial \sigma} \right) \quad (2)$$

$$\frac{\partial V}{\partial t} + U \frac{\partial V}{\partial x} + V \frac{\partial V}{\partial y} + \frac{\omega}{h} \frac{\partial V}{\partial \sigma} - fU = -\frac{1}{\rho_0} P_y + F_y + M_y + \frac{1}{h^2} \frac{\partial}{\partial \sigma} \left(\nu_v \frac{\partial V}{\partial \sigma} \right) \quad (3)$$

where f is the Coriolis parameter; U and V are the horizontal velocities in x and y directions; ω is the vertical velocity in relation to σ coordinates; F_x , F_y are the horizontal Reynold's stresses; ν_v is the vertical eddy viscosity; P_x , P_y are the horizontal pressure terms approximated by the Boussinesq assumptions; M_x , M_y are external forces added as source or sink terms in the momentum equations (2), (3); ρ_0 is the reference density; S represents the contributions per unit area due to the discharge or withdrawal of water, evaporation and precipitation; ζ is the water level; d is the water depth in relation to a reference level and h is the total water depth ($h = \zeta + d$).

Delft3D-Flow module grid includes São Vicente Estuary, Santos Estuary and Bertioga Waterway, with 59096 elements. The grid resolution in the study area has 15x15 m and it was used one layer in the vertical direction.

Based on water level and water current field data (Santos Pilots, 2016) was possible to calibrate and validate the mathematical model. Boundary conditions, as wave height and direction, wind velocity and direction were obtained with the aid of the WAVEWATCH III® model developed by National Oceanic and Atmospheric Administration, National Weather Service, National Centers for Environmental Prediction and Marine Modeling and Analysis Branch (NOAA/NWS/NCEP/MMAB, 2016).

Data analysis was based on the variation due to the presence of the structures in wave significant height and direction and current intensity and direction. The period simulated started on June 17th, 2012 and finished on July 15th, 2012. It includes the storm event of June 20th, which generated waves with significant higher than 2,5 m in point P1 (Fig1). The scenarios simulated were defined as:

- S1 - No Structure: current situation, without any structure;
- S2 - Training walls: future situation in long-term, with nautical purposes;

- S3 - Segmented breakwater: future situation in short-term with coastal defenses purposes.

The scenario 3 includes an analysis of water renewal. This analysis was included because this structure can affect water circulation and consequently leads to poor water quality in this area, therefore, a constant tracer has been included to S3.

2.3 Scale Model

The Spectral Wave Simulator for Port and Coastal Studies is constructed in a wave basin reproducing in fixed bed, a portion of Santos Bay and Ponta da Praia Beach. It is a facility of Hydraulic Laboratory of Polytechnic School, University of São Paulo.

This facility (Fig. 2), with dimensions of 37 m x 17 m x 1.5 m, has a water reservoir capacity of 650 m³, 10 independent piston wave generators with 1KW for 500 mm piston translation. Irregular short-crested spectral waves can be reproduced with individual wave period above 0.6 s ($f = 1.66$ Hz) and wave heights between 8 and 250 mm.



Figure 2. General view of the Spectral Wave Simulator for Port and Coastal Studies of Hydraulic Laboratory of Polytechnic School, University of São Paulo.

3 RESULTS AND DISCUSSION

3.1 Effects on Wave and Current

Simulation results showed that both structures were effective with the purpose of protecting Ponta da Praia Beach from higher wave height. Figure 4 presents the significant wave height in the storm surge event (July 20th, 2012 at 15h:00).

Comparing Figure 4 (A and B) it is possible to verify the differences between wave significant height without and with training walls, whereas Figure 4 (A, C and D) shows the effect of the segmented breakwater in comparison to current situation. Indeed, it is possible to observe the diffraction effect in breakwater gaps, illustrating the effect on wave direction and height.

Although wave incident direction is parallel to training walls alignment, wave height was reduced. Figure 5 shows the entrance area of training walls, where is verified the influence of the structure in reducing the wave height and direction.

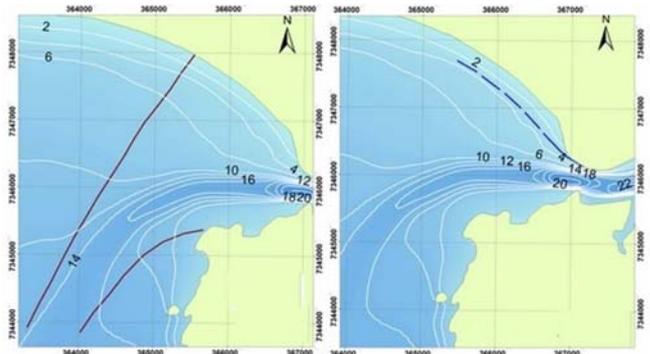


Figure 3. Schematic location of the proposed training walls and segmented breakwater.

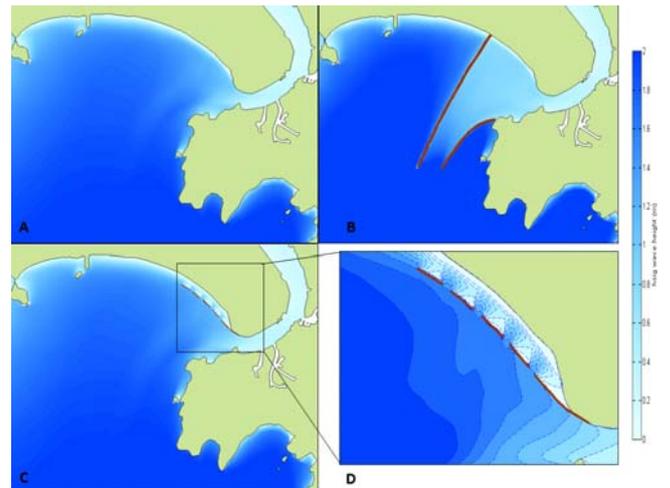


Figure 4. Significant wave height (m) during the storm surge event on July 20th, 2012 at 15h:00, for three different scenarios: A - S1 - Current situation; B - S2 - Training walls; C - S3 - Segmented breakwater; D - Zoom S3.

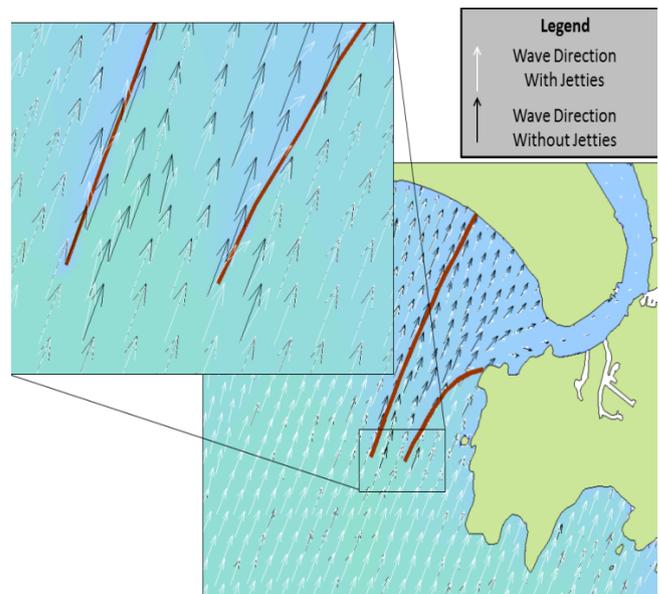


Figure 5. Wave peak direction to S1 (black vector) and S2 (white vector).

Figure 6 shows current intensity and direction for the time of maximum flood and ebb velocities in spring tide conditions for scenarios S2 and S3.

3.2 Water Renewal on the Beach

Considering that the hydrodynamics of the area will change as presented on item 3.1, there is another issue to be considered, the water renewal on the beach area. This aspect was analyzed to the condition with segmented breakwater based on the results obtained from current intensity (Fig. 6 A and C), from where was observed lower currents to the condition with breakwater in comparison to the condition with training walls.

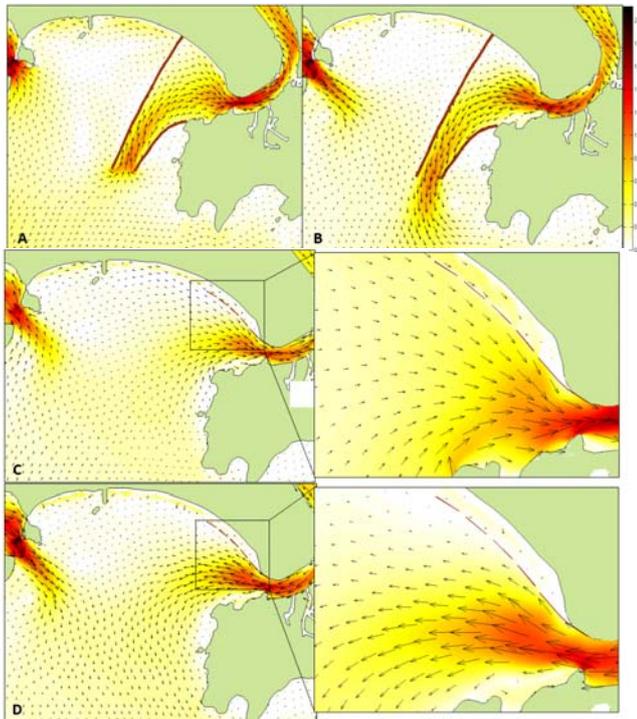


Figure 6. Current intensity (m.s-1) and direction for Scenario 2: A - flood; B – ebb. Scenario C – flood; D – ebb.

In order to analyze this aspect, a constant tracer source was included on the hydrodynamic simulation. The source has a constant concentration of 10 kg.m^{-3} and its outputs are located at 5 points on the lee of the breakwater segments. After one week of constant dispersion of tracer on the beach, results of its concentration were analyzed.

From Figure 7 it is observed that the tracer concentration increases in the situation with the segmented breakwater, as expected. Besides, it was observed a variation on tracer concentration along the beach. The highest concentration is located on the lee of the spur breakwater, reaching values near the 10 kg.m^{-3} , whereas the lowest concentration is located at the last breakwater, with concentrations near 0.1 kg.m^{-3} .

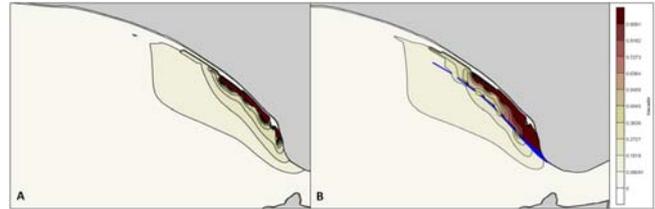


Figure 7. Tracer concentration next to the coastline (kg.m^{-3}) and direction for Scenario 1: A, and Scenario 2: B.

3.3 Time Series for Waves Height

Figure 8 presents time-series from June 17th, 2012 and finished on July 15th, 2012 for wave height in P4. The significant reduction in wave height shows the effectiveness of the segmented breakwater (S3) in protect Ponta da Praia Beach.

3.4 Storm Surge Event Registered in August 21st, 2016

In Figure 9 is presented the location map showing the curve of the Offshore Bar Channel.

The Santos Pilots ADCP gauge, located in the P2 (Fig. 1), records sea level and significant wave height (Figs. 10 and 11), according to Santos Pilots (2016). The Meteorological Station of Santos Pilots anemometer records the wind intensity (Fig. 12) and direction (Figs. 9 and 13).

Confirming that the environmental premises considered in this study are adequate as extreme events for design purposes, in this item is described a recent storm surge with at least 10 years of recurrence period.

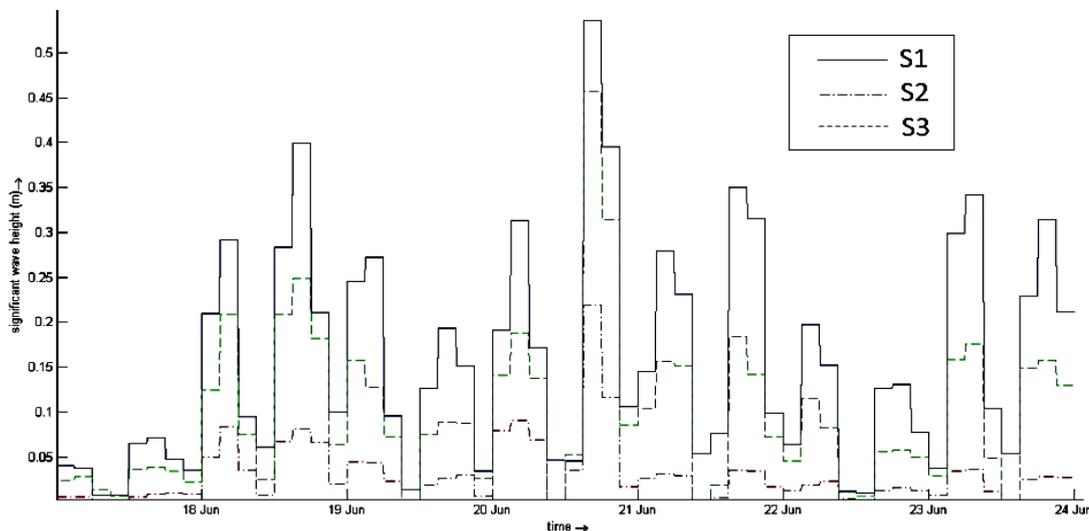


Figure 8. Significant wave height in P4 to S1 (continuous line), S2 (dashed line) and S3 (dotted line).

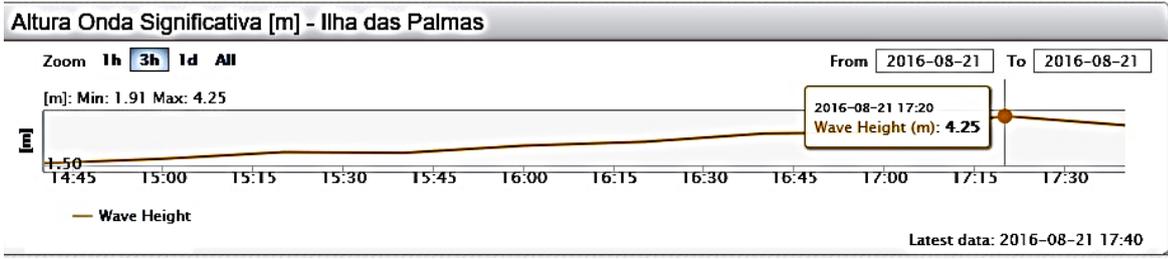


Figure 11. Significant wave height in P2 during the storm surge of August 21th, 2016.

In August 21st, 2016, an extreme event was recorded in the ADCP (Figs. 10 and 11) and in the Meteorological Station (Figs. 12 and 13). The storm surge was induced by wind blowing more than 12 h from SW fetch (Fig. 13), with maximum velocities from 20 to 58 knots (Fig. 12), rising more than 1 m the predicted astronomic sea level in Santos Bay and inducing sea waves up to 4.25 m (see Fig. 11).

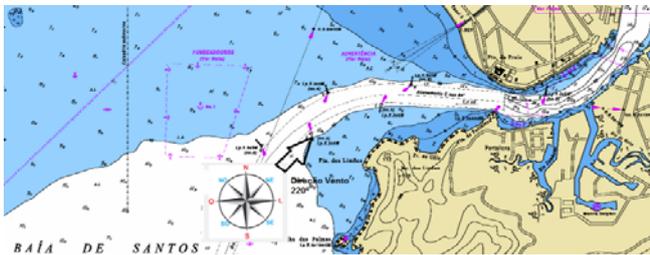


Figure 9. Location map with wind direction during the storm surge of August 21st, 2016.

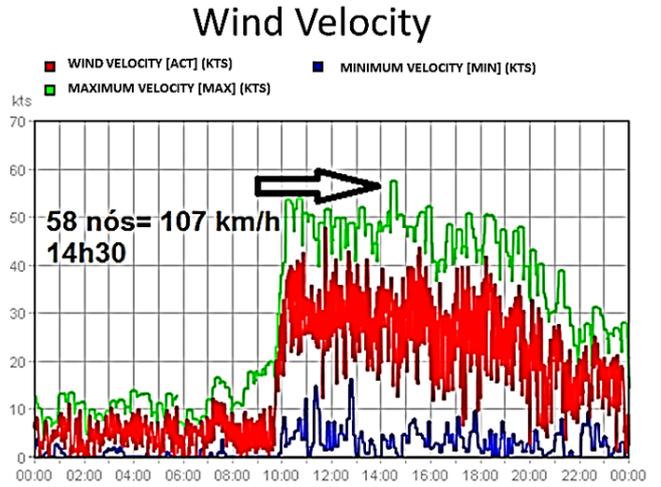


Figure 12. Wind intensity during the storm surge of August 21st, 2016.

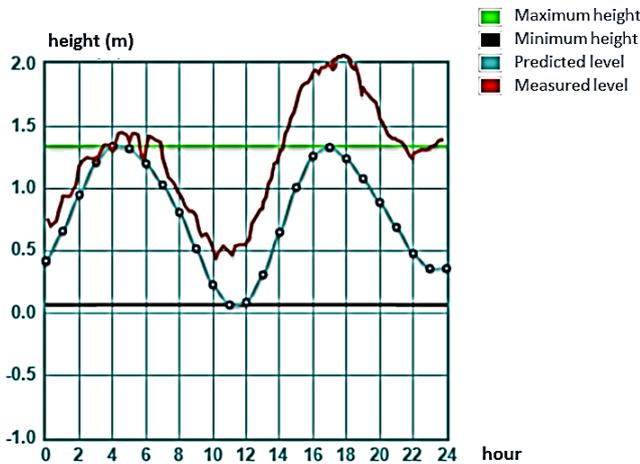


Figure 10. Measured sea level in P2 during the storm surge of August 21st, 2016: maximum height (astronomical high water); minimum height (Chart Datum); predicted level (dotted); measured level (continuous line).

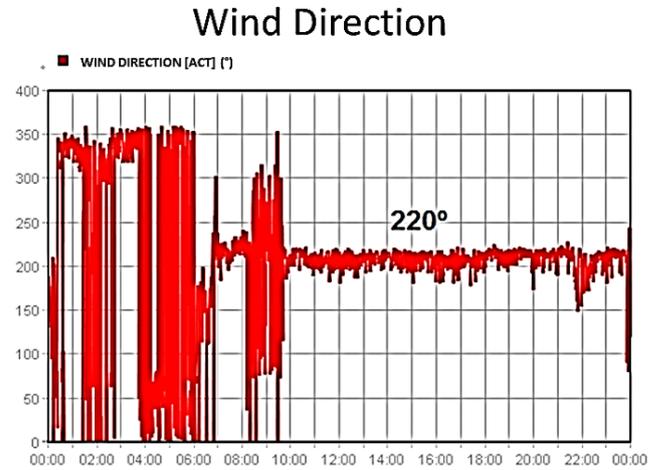


Figure 13. Graphic of wind direction during the storm surge of August 21st, 2016

3.5 Scale Model Results for the Segmented Breakwater

The tests in the scale model of scenario S3, with a storm surge similar to the simulated in the numerical model, is showed in Figure 14. It is possible to observe the similarity of the diffraction pattern comparing with Figure 4D.



Figure 14. Zenithal picture of the diffraction pattern with the segmented breakwater in the scale model.

4 CONCLUSIONS

This paper showed the studies that have been made in Hydraulic Laboratory of Engineering School of University of Sao Paulo, with the goal to analyze the best solution for Santos Bay nautical and shoreline protection issues.

Two structures were simulated at this area, showing alternatives to improve the navigation demands and also the shoreline protection with classical structures, like training walls and segmented breakwater.

Model simulations with segmented breakwater showed the effectiveness in reducing wave height more than 50% in Ponta da Praia Beach, which means wave energy reduction of 75% in a storm surge event. The presence of the segmented breakwater has

affected the capacity of water renovation at the beach area, suggesting that this is an issue to be considered if this alternative is applied.

For the training walls model simulations, the current velocities in the Access Channel increased, showing the real possibility to reduce the dredging rates here. Moreover, results obtained also indicated that the structures reduce wave height in Ponta da Praia Beach, which would enhance the protection against shore erosion in this critical area.

Therefore, both structures showed to be efficient in protect Ponta da Praia Beach against wave erosion.

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