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Potential Reduction of Dredging Volumes in the Access Channel to the Port of Santos through the Use of Jetties

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ABSTRACT: Santos is the most important Brazilian port, handling about 162 million of tons in 2022. In 2010, there was a great capital dredging to deepen the Access Channel to 15 m deep (Chart Datum - CD). This depth was not achieved, due to inefficiency on dredging procedures. Previous studies have indicated that, in order to maintain the bathymetric condition presented by the survey carried out in March 2016, an annual dredging of approximately 4,325,000 m³ would be necessary. This value increases for different project depths, increasing by 15%, 55%, and 80%, considering drafts of 15, 16, and 17 meters, respectively. Considering this situation, this study evaluated the possibility of implementing jetties in the region of the Port of Santos, using a calibrated hydrodynamic and morphological computational model for the area of interest. From the simulation of two different scenarios to represent local hydrodynamic conditions, reductions of approximately 45%, 40%, 35%, and 30% were estimated for the condition presented by the 2016 bathymetry and for draft depths of 15, 16, and 17 meters, respectively.

1 INTRODUCTION

The Port of Santos, officially inaugurated on February 2, 1892, located in the municipalities of Santos and Guarujá, is the largest port in Latin America. In 2022, the Port of Santos handled approximately 162 million tons, the highest volume in its history.

Located in an estuarine region, sheltered from wave action, the Port of Santos was the target of its first major dredging of the Access Channel only in 1964, 72 years after its inauguration. At that time, the intention was to deepen the average natural depths (approximately -10 m CD) to establish a channel with a depth of -14.8 m (CD). This depth was never reached due to insufficient dredging procedures adopted. The average depth of the port channel was approximately -12.5 m (CD).

From 2008, with the improvement in dredging efficiency, the Access Channel to the Port of Santos now has depths closer to the target of -14.8 m (CD). In 2010, a second major deepening dredging was defined, this time for the -15.0 m (CD) depth. On July 10, 2017, the maximum operational draft of the Port of Santos was set at 12.6 m, after depths lower than 14 meters were found in the bar region.

In a scenario of increasing ship dimensions worldwide, associated with the role of the Port of Santos as a hub port, it is estimated that, soon, it will be necessary to implement a new design depth to serve new vessels. Pion and Bernardino [3] indicated that there is an increase in the maintenance dredging volumes required to maintain greater depths in the access channel. For the maintenance of the condition presented by the bathymetric survey of 2016, a maintenance dredging of approximately 4,325,000 m³ per year would be necessary, increasing to approximately 5,000,000 m³, 6,700,000 m³ and 7,900,000 m³ considering depths of 15 m, 16 m and 17 m, respectively, for the Access Channel to the Port of Santos.

Thus, this paper presents the analysis of the potential implementation of jetties in the region of the Port of Santos to reduce the accumulated volumes along the access channel, based on hydrodynamic and sediment transport modelling, considering this possibility as an alternative to reduce spending on maintenance dredging campaigns.

2 STUDY AREA DESCRIPTION

As described in Pion and Bernardino [3], the port of Santos is situated on the south eastern coast of Brazil, as depicted in Figure 1. The city of Santos is located on Sao Vicente Island, within a highly intricate estuarine system with over 60 river outfalls. The port is located on both sides of the estuary outlet, as shown in Figure 2. The access channel to the port is divided into four different areas, illustrated in Figure 3.

Figure 1. Location of the Port of Santos - Brazil (Google Earth).

Figure 2. Port of Santos Area (Google Earth)

The climate of the region can be classified into two distinct seasons. The rainy season typically occurs between spring and summer (from October to March), when around 70% of the annual rainfall takes place. The dry season occurs between April and September and is generally referred to as winter. During this period, high significant wave heights are observed due to the occurrence of cold fronts generated in the oceanic area, known as storm surges, which are less frequent in the summer period.

Figure 3. Scheme of the Access Channel of the Santos Port (Google Earth)

The tide in the region is semidiurnal, with amplitudes ranging from 0.27 m during neap tides to 1.23 m during spring tides. However, meteorological effects can increase the water level up to 1.83 m. The maximum flow speed is around 1 m/s near the estuary outlet, but it does not exceed 0.5 m/s in most of Santos Bay.

The bottom sediment in Area I is predominantly sand (70%). The sand fraction decreases towards the interior of the estuary. In Area II, the sand fraction is around 50%, whereas in Area III it is around 40%. In Area IV, the innermost area, the bottom sediment is mainly fine sediment (silt and clay).

For areas that are not affected by wave action (II, III, and IV), sediment deposition is mainly associated with the seasonality of rainfall due to the higher river flow and total sediment transport load. Hence, sediment deposition in these areas is expected to be more intense during the summer period.

In contrast, Area I is exposed to wave action and located in an area characterized by low current speeds. The sediment deposition pattern in this area is primarily influenced by the wave climate. Generally, during the winter period, when waves are higher, sediment deposition is more intense in Area I. In periods characterized by higher waves, sediment tends to be removed from the beaches and deposited in the channel area.

3 DATABASE AND MODEL

During this study, the model presented in Pion and Bernardino [3] was used. This model was developed in the Delft3D® platform [2], widely used for the representation of coastal and estuarine processes in studies of this type. The model was calibrated based on data of currents, tidal level, and waves measured in the region of the Santos estuary and bay, in addition to data of suspended sediment concentration used to calibrate the sediment transport model. For boundary conditions, the global models WaveWatch III (waves), NCEP/CSFR (wind and sea level elevation), and TPXO (tidal constants) were used.

More details about the equations used and the calibration of the tool can be obtained in Pion and Bernardino [3]. Figures 4 and 5 illustrate the computational grids of wave, current, and sediment transport used during the study.

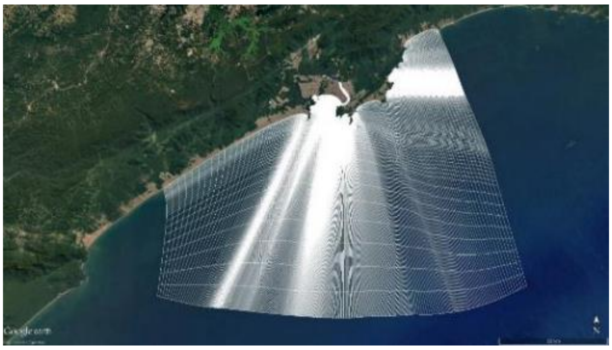

Figure 4. Wave grid of the computational model of the Port of Santos

Figure 5. Flow and sediment transport grid of the computational model of the Port of Santos.

4 DESCRIPTION OF THE JETTIES

To assess the potential reduction of accumulated volumes in the Santos Port Access Channel, a configuration of jetties was designed both in the Santos Bay region and inside the estuary, as shown in Figure 6.

Figure 6. Scheme of the design of the jetties for the Santos Bay and Estuary.

The jetties located in the bay are based on the recommendation of a study carried out by Reis [4] at the Brazilian National Institute of Waterway Research (INPH). These structures serve to confine the stream, increase velocities, and prevent sediment accumulation at the inlet. Additionally, their location protects the Channel Area I (see Figure 3) from littoral transport, which is the main mechanism responsible for sediment deposition in this region. Lastly, their position was defined to ensure safe navigation trajectories for vessels. According to Reis [4], a reduction of up to approximately 50% in sediment accumulation in Channel Area I of the Access Channel was expected, aiming to maintain a depth of -14.8 m (CD).

In the present study, the jetties were extended by 250 m in relation to the original design proposed by Reis [4], as the idea was to evaluate the use of jetties to allow the maintenance of deeper levels in the channel (-15, -16, and -17 m - CD).

The internal jetties were designed to accelerate the flow in the wider areas, so that the flow presents higher competence of transport, reducing the accumulation of material in these areas.

It should be noted that the structures adopted in this document are only a reference for evaluating the potential reduction of dredging volumes using jetties. No alternative or optimization studies of the adopted layout were carried out. It is likely that, depending on the desired depth, it will be necessary to extend the structures in the bay to deeper regions. The choice of internal structures, in turn, was based only on hydraulic aspects and existing terminals and must be further evaluated in accordance with the premises of port expansion and other impacts in the region.

5 SIMULATIONS

The Estuary and Santos Bay region is characterized by two distinct hydrological periods, dry and rainy. The dry period, from April to September, is responsible for approximately 30% of the average annual precipitation in the region. Thus, as the contribution of fluvial sediment has a direct relationship with precipitation, the rainy period, from October to March, represents most of the fluvial sediment contribution to the navigable waterways of the Santos Port.

On the other hand, the dry period comprises the winter, when cold fronts are generated in the oceanic region, causing swells and the incidence of more intense waves in the Bay region, being the main conditioning factor for sediment transport in Area I of the Santos Port Access Channel (Inlet – see Figure 3).

Thus, to represent the two characteristic periods of the region, two distinct scenarios were simulated: Summer and Winter. The simulations were monthly, aiming to characterize a dry and a rainy period. Directional wave histograms for the average summer conditions and for the selected month are shown in Figures 7 and 8, respectively. Likewise, Figures 9 and 10 show the directional wave histograms for the average winter conditions and for the selected month.

Regarding the river flow, average flow values (winter period) and maximum flows (summer period) available in the Environmental Impact Assessment of the deepening dredging were used.

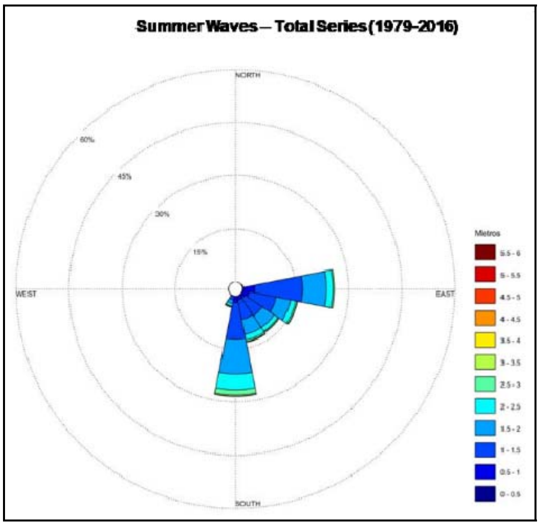

Figure 7. Directional wave histograms for the average summer conditions (data series from 1979 to 2016) in the Santos Bay.

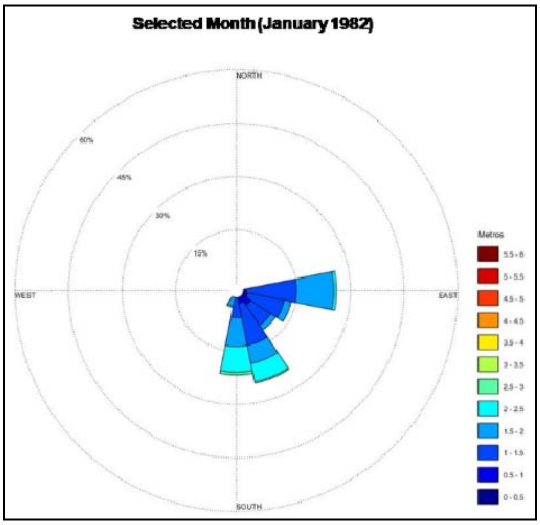

Figure 8. Directional wave histograms for the month selected (January, 1982) to represent summer conditions in the Santos Bay.

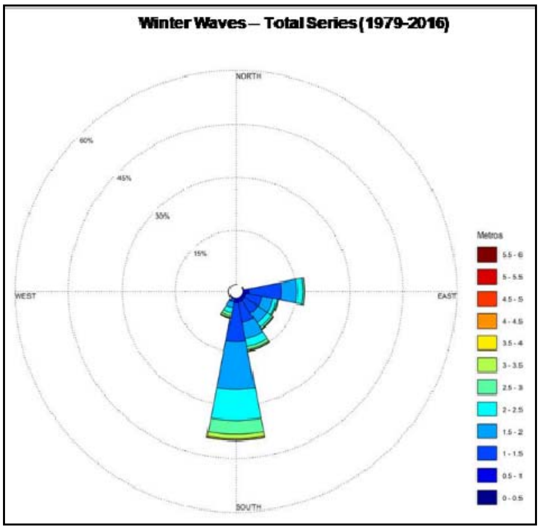

Figure 9. Directional wave histograms for the average winter conditions (data series from 1979 to 2016) in the Santos Bay.

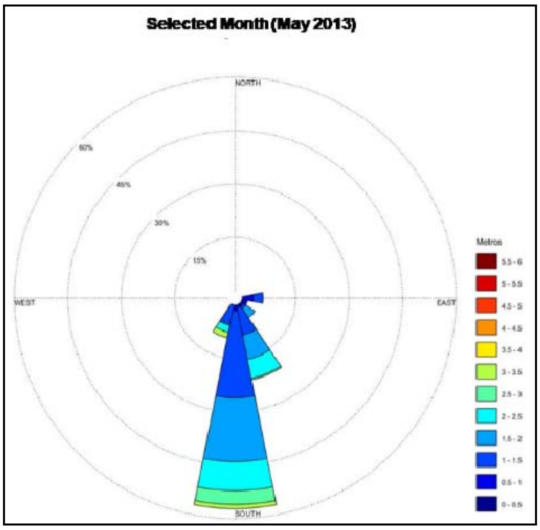

Figure 10. Directional wave histograms for the month selected (May, 2013) to represent summer conditions in the Santos Bay.

The winter and summer conditions were simulated for each of the channel reference scenarios (bathymetry of March/2016, 15, 16, and 17 meters), considering implementation of the jetties.

6 RESULTS AND DISCUSSION

6.1 *Hydrosedimentological effects resulting from the implementation of jetties*

Figure 11 to Figure 17 present the comparison between the scenarios with and without the jetties described in chapter 5, regarding wave incidence, current fields, and sediment erosion and deposition patterns in the areas where the jetties were implemented in the computational model.

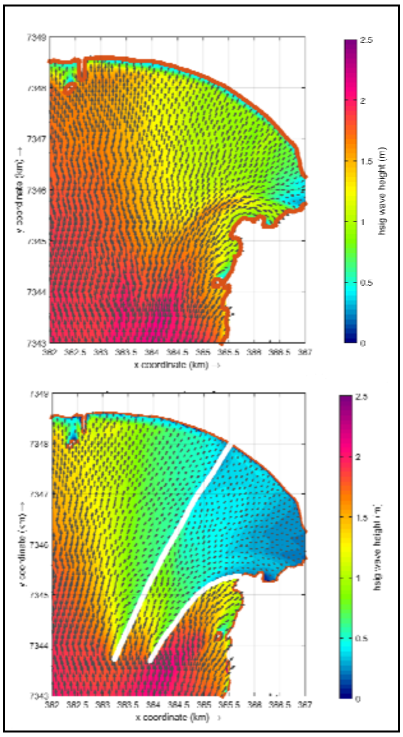

Figure 11. Wave field comparison between conditions: without jetties and with jetties – Area I of the Santos Port Channel.

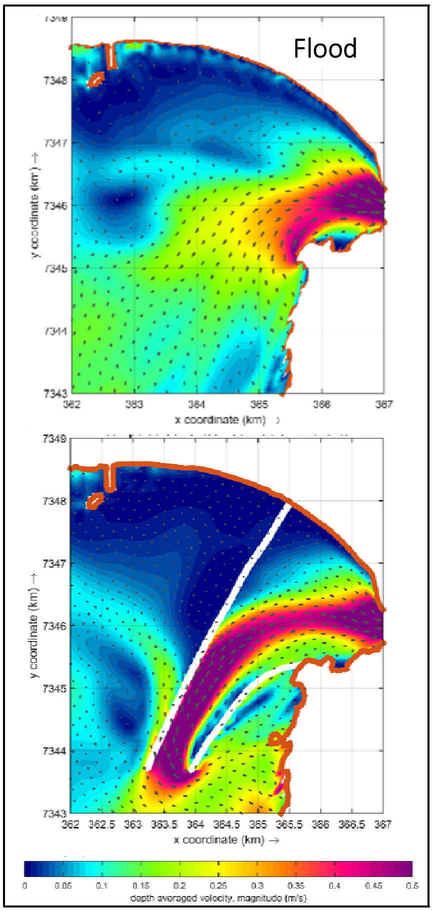

Figure 12. Comparison of the flood tide current fields between the conditions: without jetties and with jetties – Area I of the Santos Port Channel.

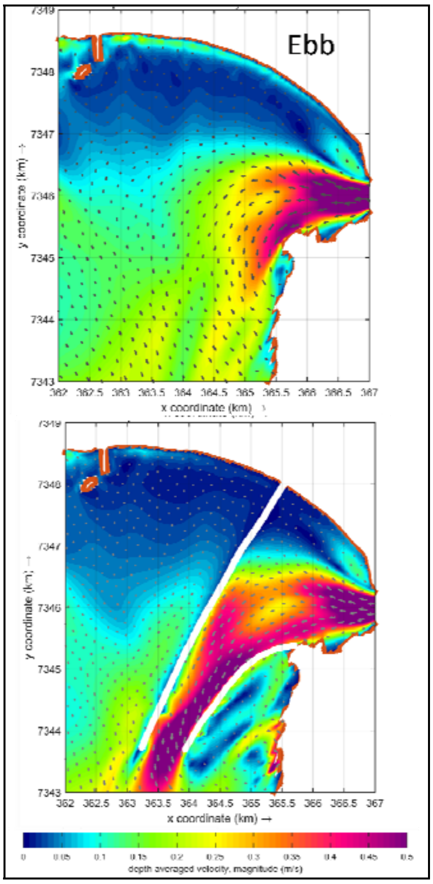

Figure 13. Comparison of the ebb tide current fields between the conditions: without jetties and with jetties – Area I of the Santos Port Channel.

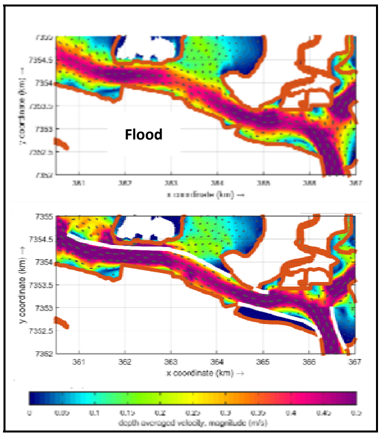

Figure 14. Comparison of the flood tide current fields between the conditions: without jetties and with jetties – Areas III and IV of the Santos Port Channel.

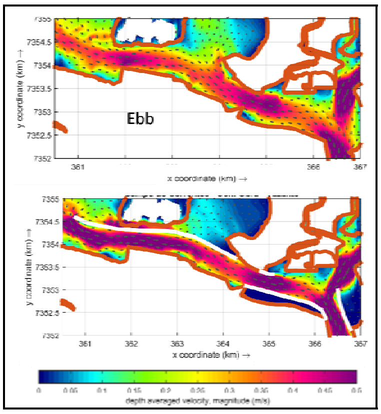

Figure 15. Comparison of the ebb tide current fields between the conditions: without jetties and with jetties – Areas III and IV of the Santos Port Channel.

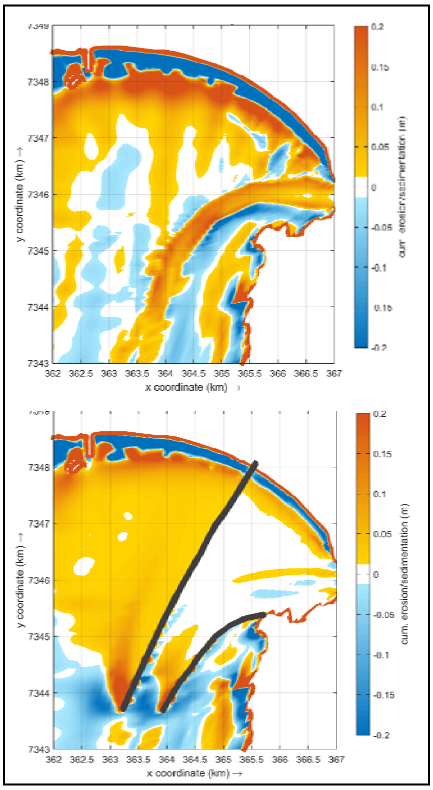

Figure 16. Comparison of the sediment erosion (cold colors) and deposition (warm colors) between the conditions: without jetties and with jetties – Area I of the Santos Port Channel.

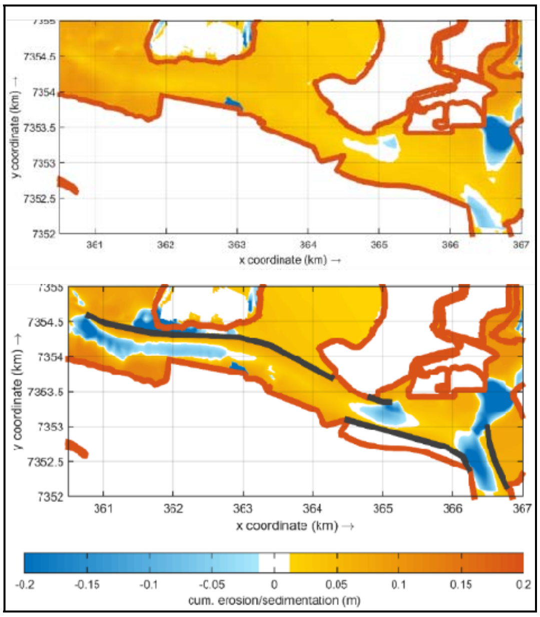

Figure 17. Comparison of the sediment erosion (cold colors) and deposition (warm colors) between the conditions: without jetties and with jetties – Areas III and IV of the Santos Port Channel.

The simulation results indicate that the implementation of the jetties in the Santos Bay reduces wave intensity in the Area I of the Access Channel, sheltering it from littoral transport. Additionally, the implementation of these structures accelerates the currents in this region. Together, these effects cause a significant reduction in sediment deposition in Area I, especially in the curved reach. As an additional positive effect, it is noteworthy that the implementation of these structures reduces wave intensity in the Ponta da Praia region, thus it can be evaluated as an integrated solution for coastal defense in the future.

In the internal region, particularly in Area IV, the introduction of jetties causes an increase in current intensity, leading to a reduction in sediment deposition in this area. In fact, some locations within this area show a reversal in sediment movement pattern after the implementation of the structures, exhibiting erosive tendencies.

6.2 *Estimation of accumulated volume*

According to the hydrodynamic effects caused by the implementation of jetties in the Santos Bay and Estuary, as presented in the section 6.1, these interventions should result in a reduction of sediment accumulation and, consequently, a decrease in the need for dredging in the Access Channel.

Figure 18 shows a comparison between the estimates of sediment deposition volume for the March/2016 bathymetry condition, considering the situations with and without the structures, for each area of the Access Channel to the Port of Santos.

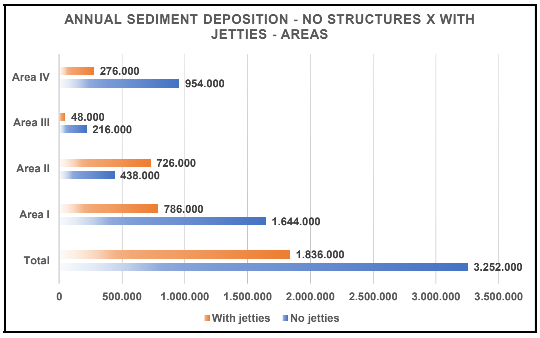

Figure 18. Comparison of the annual sediment deposition between the conditions: with jetties (orange color) and without jetties (blue color), considering the March/2016 bathymetry as the initial condition for simulation. This comparison is considering total area of Santos Port Access Channel and each area (I, II, III and IV) separately.

The implementation of the jetties reduces sediment deposition by 52%, 78%, and 71% in Areas I, III, and IV, respectively. There is an increase of approximately 65% in the accumulated volume in Area II. This increase occurs because some of the material that would be deposited in Areas III and IV considering the situation without jetties, tend to accumulate in Area II region, due to the changes in the local characteristics of currents after the implementation of the jetties. However, the introduction of jetties may result in a reduction of approximately 45% in the overall estimated dredging volume for the access channel, considering the current bathymetry.

Figure 19 shows a comparison between the overall estimates of deposited volume for the current scenario and with the implementation of jetties in the Santos Bay and Estuary, considering the different evaluated drafts for the Santos Port Access Channel.

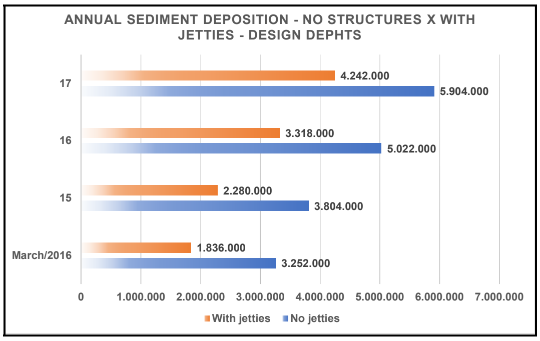

Figure 19. Comparison of the annual sediment deposition between the conditions: with jetties (orange color) and without jetties (blue color), considering the volume deposited in the total area of the Santos Port Access Channel. This comparison is considering different depths as initial conditions for simulation (March/2016 bathymetry and design depths of 15 m, 16 m and 17 m).

The implementation of jetties results in a reduction of 40%, 35%, and 30% for drafts at levels of -15 m, -16 m, and -17 m (CD), respectively, when compared to the situation without the jetties. The efficiency decreases when the channel deepens is expected since the greater the distortion imposed on the environment, the greater the difficulty of maintenance. It is worth noting that the proposed structures were based on the 2016 bathymetry and, depending on the draft, should undergo changes to optimize their spatial configuration, such as the extension of the jetties in the Santos Bay.

According to Alfredini [1], the ratio between the volume dredged in the dredger's tank and the corresponding in situ volume is 1.33 for the Access Channel to the Port of Santos. Thus, Table 1 below presents the final values of estimated maintenance dredging volumes for each evaluated depth throughout the study, considering the implementation of the jetties.

Table 1. Annual sediment deposition and dredging prediction for each design depth, considering the implementation of the jetties.

Design Depth	Annual Sediment Deposition (m³)	Annual Dredging Volumes (m³)
March/16	1,836,000	2,441,880
15 m	2,280,000	3,032,400
16 m	3,318,000	4,412,940
17 m	4,242,000	5,641,860

7 CONCLUSIONS

The maintenance of dredged channel depths is one of the most costly and important activities for the development of port activities. As the environment tends to return to its natural state of equilibrium, periodic maintenance dredging is necessary to maintain the required clearance for nautical spaces and ensure safe navigation of vessels.

If the desired clearance depth is significantly greater than the natural depths of the access channel, the necessary frequency of interventions to maintain the levels can be so high that the maintenance dredging becomes unfeasible due to operational or financial reasons. In this case, structures, such as jetties, are presented as a possibility for achieving the desired clearance, as they increase the local flow's competence to transport sediments, creating a tendency for depths deeper than the natural.

The present study, based on results of numerical sediment transport modelling, evaluated the annual estimate of volumes deposited in the Access Channel to the Port of Santos, considering the bathymetry of March 2016 and clearances at levels -15m, -16m, and -17m (CD). These clearances were evaluated to support future studies for decision-making, considering a scenario of demand for the operation of larger vessels at the terminals.

Considering the implementation of jetties, there was a reduction of up to approximately 45% in the accumulated volume in the access channel area, considering the bathymetric survey carried out in March 2016. In the most adverse condition, using a clearance of 17 m depth, the implementation of jetties caused a reduction of approximately 30% in the accumulated volume compared to the situation without the implementation of these structures.

It should be noted that, for this study, only one spatial configuration of jetties for the region was used, based on past studies, with the aim of defining a potential reduction in dredging volumes in the area of interest through the implementation of these structures. From the definition of the desired clearance depth, different spatial configurations of jetties should be evaluated.

It is important to highlight that the simulations carried out to obtain the estimates consider an average scenario of flow characteristics in the Access Channel to the Port of Santos region. This is a complex region, subject to different environmental conditions, such as waves and river flows, which vary significantly according to the local climate behaviour pattern. Thus, the volumes deposited in the channel should show variability according to the flow characteristics presented in the region. In addition, the implementation of new clearances should be evaluated from a geotechnical and structural point of view, in order to verify the stability of the new channel geometry and the need for structural reinforcements at the terminals.

Finally, it is essential to point out the limitations of the modelling performed. Sediment transport models have equations that, when well calibrated, can show significant deviations from variations found in the field, due to the difficulties of fully representing this phenomenon through mathematical equations. In addition, the lack of information about the chronology of dredging procedures, carried out between bathymetric surveys, limits the morphological model calibration procedure, further increasing uncertainties, as the removal of material from the bottom modifies the sediment balance and depths measured in the field. However, it should be noted that despite the limitations mentioned, the study of sediment transport using computational modelling, as developed in this report, is currently the most suitable approach for addressing the studied problem.

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