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NUMERICAL SIMULATION OF CONSTRUCTIVE SOLUTION FOR CONTAINING MARITIME FLOODS AT PONTA DA PRAIA, IN SANTOS, WITH MINIMUM ENVIRONMENTAL IMPACT

Corrected version

São Paulo

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Thesis submitted to the Graduate Program in Environmental Science Institute of Energy and Environment at the University of São Paulo to obtain the title of Master of Science.

Orientador: Prof. Dr. Joseph Harari

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2020

APPROVAL SHEET

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Epigraph

“Tout ce qu'un homme est capable d'imaginer, d'autres hommes sont capables de le réaliser”[i]

Jules Verne

"Everything that a man is capable of imagining, other men are capable of accomplishing "

Author's free translation

I dedicate this work to God, to my husband Ediglê, to my parents Wanderley and Marta and to the memory of my grandfathers Adão and Pedro.

ABSTRACT

HONORIO JOB, C. M. **Numerical simulation of constructive solution for containing maritime floods at Ponta da Praia, in Santos, with minimum environmental impact.** 2020. 177 f. Thesis (MSc) – Graduate Program in Environmental Science Institute of Energy and Environment at the University of São Paulo to obtain the title of Master of Sciences.

Significant sea level rises have caused major disturbances in Santos, on the coast of the State of São Paulo. Initially, this project surveyed the storm surges that occurred in Santos from 1945 to 2013, including the determination of the levels reached. In this initial phase, characteristics of the storm surges were analyzed, considering their frequency and intensity, as well as their correlations with the tides.

As a short term solution to the flood problem, the purpose of this paper is to analyze the feasibility of constructing a flood containment system that would be activated in case of floods and would have a reduced environmental impact.

Ocean numerical simulations were performed for the years of 2016 and 2017, to determine the hydrodynamic behavior in the region, and thus analyze the feasibility of constructing the containment system. In addition, a outlined environmental impact study was made for the implementation of this type of project.

Keywords: numerical simulation, floods, environmental impact, civil construction

SUMMARY

1. Objectives of the work

The main objective of this research is to propose a sustainable constructive solution for the Ponta da Praia region, in Santos, which has suffered from severe hangovers during times of high tide and fronts that cause intense rains, due not only to the natural effects, but also for the anthropic action of urbanization and soil waterproofing.

In view of a flood scenario (considering the survey of hangovers that have occurred in Santos since 1950, considering the levels reached and flooded areas, and the data obtained from the model), we propose a solution that aims only to protect the population and the environment in which it lives, without having a strong impact on coastal dynamics. It should be emphasized that it is not the objective of our work to solve silting scenarios that occur at the site, but rather to propose a solution to protect the population in cases of floods.

It should be noted that the solution to be proposed aims to be the most adaptable to the environment, aiming to cause the least damage, and to bring innovation in comparison with the solutions already proposed and carried out in other regions of the country, which consist of the construction of jetties, barriers and other construction structures, which, even though they provide flood containment, cause significant damage to the environment and coastal dynamics, and in the long run lose their effectiveness.

2. Introduction

2.1. Characterization of the region

According to Law No. 9,034, OF DECEMBER 27, 1994, which provides for the State Water Resources Plan - PERH, the State of São Paulo is divided into 22 (twenty-two) Hydrographic Units for Water Resources Management - UGRHI.

Figure 1 – Location of the city of Santos, 70km from the state capital.

Source: Prefeitura de Santos website accessed in April de 2020[ii].

The Atlantic Hydrographic Region - Southeast consists of three Water Resource Management Units: 03-Litoral Norte (LN), 07-Baixada Santista (BS) and 11-Ribeira de Iguape and Litoral Sul (RB). Santos is located in the 07-Baixada Santista (BS) region.

In the Hydrographic Region of the Atlantic - Southeast, the most populous municipalities are those of Baixada Santista. This region was one of the first occupied areas in the State of São Paulo and in the country, currently its economic development is linked to the activities of the port of Santos and to summer tourism. The four most populous municipalities in the Atlantic - Southeast region are Santos, São Vicente, Guarujá and Praia Grande.

2.1.1. Geological and geomorphological characteristics of Santos

The municipality of Santos, located at 23 ° 56 ′ 13.16 ″ S, 46 ° 19 ′ 30.34 ″ W, in the State of São Paulo, as a divider between the north and south coast of the State, comprises an area of 280.3 km², forming part of the Coastal Province of Planalto Atlântico. According to IBGE (2017) i, the population measured in the 2010 census was 419,400 people, and the estimate according to the same body, for 2017, is 434,742 people. The demographic density in 2010 was 1,494.26 inhabitants / km², making it a city with a strong demographic density.

According to LIMA & Oliveira (2011) ii, Santos comprises an extension of the Coastal Plain of the State of São Paulo, with altitudes that rarely exceed 20 meters above average sea level. However, the area is also composed of isolated hills, the Massif de São Vicente, whose altitude does not exceed 200 meters above average sea level, and where there is an irregular urban occupation. Santos is limited to the North by the municipalities of Santo André and Mogi das Cruzes; to the south by the Atlantic Ocean and the municipality of Guarujá; to the east by the municipality of Bertioga; and to the west by the municipalities of Cubatão and São Vicente.

According to DIAS et al. (2015) iii, the municipality of Santos is divided into two major geological and geomorphological domains: Serrania Costeira, generally consisting of crystalline basement rocks, with Precambrian to Paleozoic ages, but with important Mesozoic igneous manifestations; and Coastal Plain (IPT, 1981) iv with Baixadas Litorânea, consisting predominantly of Cenozoic sedimentary deposits.

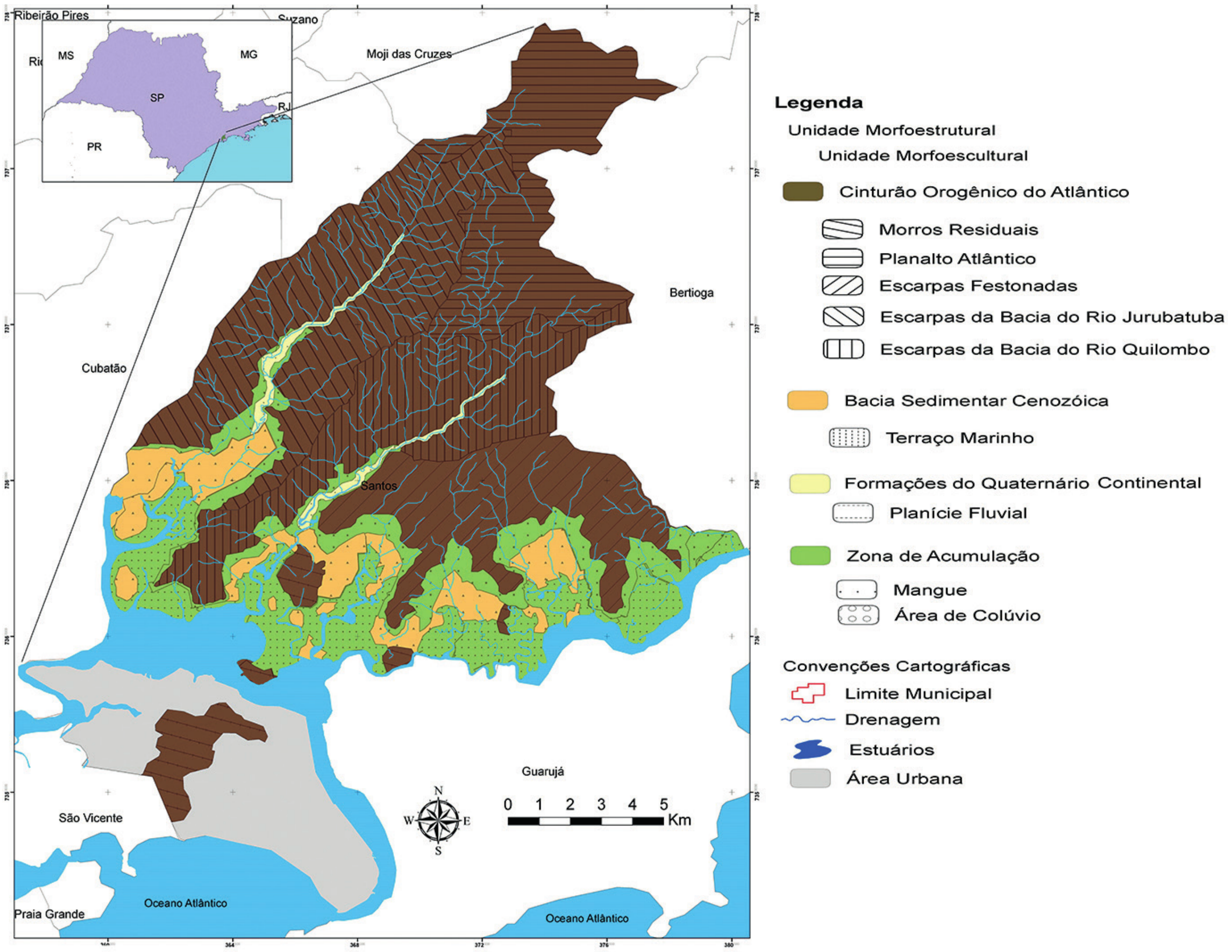
Also according to Dias et al (2015) v, in Serrania Costeira, the Morpho-sculptural subunits Escarpa / Serra do Mar and Morros Litorínios stand out, presenting altimetric variation from 20 to 1,000 meters and slopes above 30%. In these, drainage has a dentritic pattern, adapted to the directions of failures and fractures, leading to a natural adaptation. Litisch Cambisols predominate, also presenting rocky outcrops. Regarding lithology, there are granites, migmatites, gneisses and mica schists. As it is one with large sculpted valleys, high drainage density and sloping slopes, this area has a very high level of potential fragility, being subject to aggressive processes of fluvial erosion, spontaneous and induced mass movements.

According to (IPT (1981) apud DIAS et al. (2015)) vi, other compartments present are the Residual Hills. In the Morphostructural unit of the Cenozoic Sedimentary Basins, the municipality is located in the Morphostructural unit of the Santos Coastal Plains, with altitudes of maximum 20 meters, hydromorphic soils, very small slope (less than 2%) and, regarding lithology, unconsolidated marine and river sediments are found. These areas are basically made up of plain landforms, marine terraces and dune fields.

This set of forms stems from a complexity of morphogenetic processes, in which the interactions of constructive and destructive activities of ocean waters along the coastal strip are confronted with the influences of continental waters, which are also builders and destroyers of wind forms and deposits, which exercise important role in the remobilization of marine sediments. Figure 1 shows the geomorphological compartmentalization chart.

Due to the sediment consolidation and the low slope, this unit is naturally susceptible to flooding and land accommodation, being, therefore, an area of great fragility.

Figure 2 - Geomorphological Compartmentation Chart

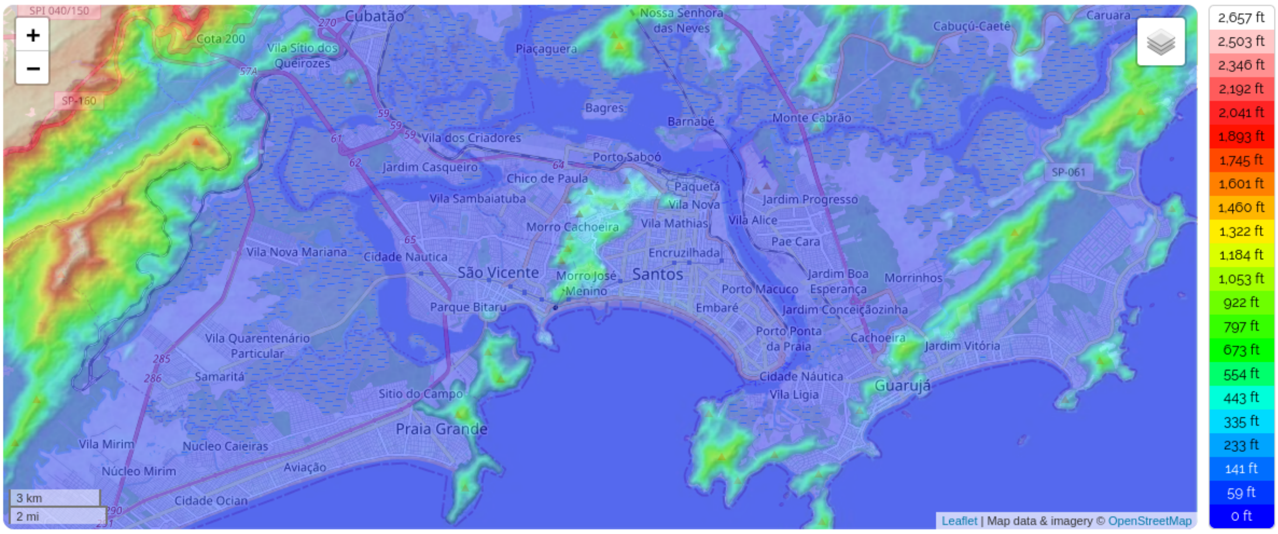


Source: DIAS, RL., BACC, PH., and OLIVEIRA, RC. Baixada Santista: uma contribuição à análise geoambiental, Editora UNESP, 2015[iii]

In the Mangrove Plains, on the other hand, the interaction between ocean and continental waters provides a unique environment for the formation and development of animal and plant species that are extremely important for sustaining the ecosystem. Thus, any environmental imbalance generates direct impacts, making the ecosystem extremely fragile, both in relation to the physical environment and the biotic. These areas are developed on a quaternary sediment package of varying thickness, which obeys the same pattern of distribution throughout the coast of São Paulo (IPT, 1981) i.

The area of the municipality is distributed between island and continental. Two very different natural dynamics of relief formation can be identified: one associated with hill areas located on the continental portion, with denudational actions, and another with lowland areas found in the island region and on the continent in contact with the mountains, with more depositional. The hill areas are characterized by intense chemical and physical weathering. The first is due mainly to the intense humidity associated with high rainfall, and the second due to the great altimetric variation, the number of very carved rivers and the high degree of slope of the slopes. Figure 3 shows the hypsometric map of the region.

Figure 3 - Drainage Hierarchy Chart



Source: OpenStreetMap®, licensed under the Open Data Commons Open Database License (ODbL) by the OpenStreetMap Foundation (OSMF) https://www.openstreetmap.org/copyright. C. Hypsiometric map of Santos, Immediate

Region of Santos, Metropolitan Region of Baixada Santista, Intermediate Region of São Paulo, Southeast Region, Brazil (-23.96083 -46.33389).

Thus, one can get an idea of the complexity of the sediment loading dynamics. The area of interest of our project is already covered by the urban area, but it is still composed of different formations in its soil profile. These factors must be observed in relation to the soundings necessary for the eventual implantation of a containment project, in view of the depth in which structures must be fixed on the coast.

According to DIAS et al. (2015) i Baixada Santista is subject to several environmental problems, which can influence natural processes, intensifying them or making their occurrence more difficult.

2.1.2. Economy

According to Max Weber (1921) ii, cities are characterized as a market and a seat of power, with political autonomy. According to the same author, the new element in modern societies (compared to antiquity) is represented by the productive processes that, based on capitalist rationality and impersonality, fight and replace traditional economic-social forms.

According to Zündt (2011) iii, it can be considered that the Brazilian urbanization started in 1532, and had as a landmark the colonization of the southeast coast of the new land, determined by the king of Portugal, in the current state of São Paulo, having as I mark the foundation of Vila de São Vicente. This urbanization took place after the arrival of the colonizers, commanded by Martin Afonso de Sousa, who installed the Chamber, the Pelourinho, the Jail and the Church, taking into account the measures recommended by the King of Portugal for the organization of the political-administrative system in the new lands. Soon after the foundation of Vila de São Vicente, the nobleman Brás Cubas sought a more sheltered spot for mooring the caravels, on the other side of the island of São Vicente, where the ideal port was installed.

In the period between 1550 and 1822, the urbanization process in the region basically took place around the existence of the Port of Santos, which, by the standards of the time, can be considered a great infrastructure, more resulting from the natural conditions of the estuary than of man’s own intervention, because the pier, at that time, didn’t yet reach 70 meters in length. From 1822, the scenario changed, due to the independence of Brazil and the opening of ports, generating a growth in business with other nations, which allowed a rapid expansion of export business, which was reflected in the growth of the port. This growth occurred, at first, in a timid way, due to the development of coffee culture in the lands of São Paulo; in 1845, the first major shipment of coffee was registered for countries in Europe other than Portugal, in a period marked by the arrival of the first large steam ships, in the middle of 1856.

For a long time, Santos' economy was centered on the commercialization of coffee; in 1922 the Official Coffee Exchange was inaugurated, where wealth from the coffee market was negotiated for the country, which resulted in the current Coffee Museum, housed in the area currently known as the Historic Center, a space that promotes exhibitions on the product's trajectory in Brazil .

According to Zündt (2011) iv, the Port of Santos underwent a period of restructuring and concession of port areas for private companies, which, in a way, has resulted in successive records of cargo handling, although with a large reduction in jobs .

Also according to Zündt (2011) v, the economic strength arising from port and industrial activities, combined with the construction of energy, supply and accessibility infrastructures to the region, which occurred from the second half of the 20th century, culminating in the construction of the second lane of the Rodovia dos Imigrantes, attracted a large mass of construction workers who, without qualification, finished the works, settled in the region, accommodating themselves in the civil construction industry, mainly that focused on summer tourism.

Although it does not present major revenue and collection problems, due to the region's pole position and the presence of the port, due to its centrality and polarization of jobs and activities, in its hills area, Santos has a large number of invasions, subdivisions illegal immigrants and non-conforming occupations.

Santos currently has the characteristic of a pole of development and attraction of the population of neighboring municipalities, slowly growing the tertiary-based economy, more specifically in the commercial and services sectors.

2.1.3. Population and society

According to DIEGUES (2000) i, there are two situations of exploitation of natural resources by the low-income populations of Baixada Santista: that of traditional populations, who settled in the region before the current phase of regional development, and that of migrants, who came to the region attracted precisely by this development process. The ways in which each of these groups uses natural resources is different, both for their cultural characteristics and for their economic base. According to the author, there is a disruption in the way of life of traditional populations, due to the social changes that occur in the region and the reduction of the capture per unit-effort in the estuaries. In the case of fishing, they form the social group with the greatest knowledge of the ecology of the estuaries and the need for an adequate management of their resources.

According to DIEGUES (2000) ii, the caiçaras communities present a way of life based on itinerant agriculture, small-scale fishing, vegetal extraction and handicrafts. In Brazil, this culture developed mainly in the coastal areas of the present states of Rio de Janeiro, São Paulo, Paraná and northern Santa Catarina. The authors Mourão 1971 and Diegues 1979 apud DIEGUES (2000) iii, consider that the caiçaras communities were formed in the intervals of the great economic cycles of the colonial period, and were strengthened when these export-oriented activities went into decline. The decay of these export activities, especially agricultural ones, encouraged fishing and collection activities in aquatic environments, especially those of brackish water such as estuaries and lagoons. Within this caiçara space, cities such as Parati, Santos, São Vicente, Iguape, Ubatuba, Ilhabela, São Sebastião, Antonina and Paranaguá emerged, which, at various moments in colonial history, functioned as important exporting centers. Caiçara communities maintained economic and social contacts and exchanges with these cities to a greater or lesser extent, depending on them for the supply of goods not produced on the sites and on the beaches. Most of these corresponding coastal centers and rural areas declined in the late 19th century, mainly with the end of slavery, leading to the decline of certain agricultural export activities, such as rice.

Also according to DIEGUES (2000) iv, the caiçaras communities maintained their traditional way of life until the 50s, until the beginning of the migratory flow resulting from the construction of the first highways that connected the coastal areas with the plateau. Caiçara communities have an important historical and cultural contribution to the aberres related to the conservation of biodiversity, knowledge of fauna and flora and traditional systems for the management of natural resources at their disposal. These communities are today threatened in their physical and material survival, due to a series of processes and factors, the main ones being: coastal real estate speculation, mass tourism and the demarcation policies of environmental protection areas.

We will not discuss these factors in depth because it is not the objective of this work, but we will pay attention to the fact that this transformation of their material and social reproduction space in parks and nature reserves has resulted in serious limitations to the traditional activities of caiçaras, of itinerant agriculture, hunting, fishing and extractivism, contributing to the emergence of conflicts with the administrators of these protected areas and to an even greater migration to urban areas; the caiçaras, expelled from their territories, started to live in slums, destined to unemployment and underemployment from the 1980s.

It is possible to observe, from these factors, the intensification of the unplanned occupation of the urban suburbs. Santos, in addition to being very urbanized, as it is a tourist resort town that receives the population of São Paulo for leisure, is also a port metropolis with intense passage of people and goods. Thus, the city is very populous, built in a poorly planned manner in relation to the growth presented over its development.

All these factors contributed intensively to the impermeabilization of the soil in a poorly planned way, resulting in an insufficient rain drainage system for the excess run-off drained during periods of rain, which is intensified by the excess of garbage accumulated in the streets, causing floods of rainwater, intensified by floods from the sea.

2.1.4. Environmental situation

From the characteristics of the region described above, one can have an idea of the complexity of the dynamics of sediment loading. The area of interest of our project is already covered by the urban area, but, still, it is composed of diverse formations in its soil profile, and these factors must be considered, in relation to the surveys necessary for the eventual implantation of a containment project. , bearing in mind the depth to which structures must be fixed on the coast. However, simulations of sediment loading dynamics will not be addressed in this work.

The plains areas have relatively flat and stable relief, which allowed urban development to accelerate, resulting in the modification of the landscape dynamics, establishing new processes of landscape formation. These areas were thus classified as unstable.

In addition to this complexity in its formation, Baixada Santista is subject to several environmental problems, which can influence natural processes by intensifying them or making their occurrence more difficult.

According to DIAS et al. (2015) i, among these processes that take place in Baixada Santista, we have those that have the greatest influence in the region of the present study, namely:

Deforestation, which has been occurring since colonization with economic expansion, but currently occurs mainly in the areas of sandbanks and at the foot of the Serra do Mar, where the native forest is removed to be replaced by new urban settlements.

The waterproofing of the soil occurs in almost all the extension of the Plain, resulting from the process of urban occupation. The island regions of Santos, Guarujá and São Vicente are the most problematic areas, which have undergone an intense urbanization process, largely verticalized, in which the floodplain areas were grounded and the rivers channeled, allowing greater surface runoff.

The alteration of drainage is a phenomenon that occurs mainly in areas of plains with urban occupation, where drainage is channeled, in addition to the waterproofing of the soil in these areas modifying the dynamics of surface runoff, resulting in changing the flow of the rivers supplied in the areas cited. Another impacting phenomenon, especially in the estuary area, is the Port of Santos, where the transit of ships causes the silting up of the main channel, changing the entire dynamics of sediment deposition in this area.

The emission of domestic effluents, which occurs in areas of recent occupation, areas of hillside occupation and areas of Irregular occupation, where there is a lack of basic infrastructure (sanitation, garbage collection and street layout).

The accumulation of solid waste, which also occurs in areas of recent occupation, hillside occupation and Irregular occupation, where access is difficult due to the lack of paved roads.

Floods and floods that occur naturally in river plains and estuarine areas, as a result of the accumulated runoff in these areas. In estuarine zones, tidal variation is also a determining factor. Soil waterproofing, resulting from urban occupation, is an aggravating factor, since it does not allow water to infiltrate, increasing runoff.

The United Nations Development Program, 2010ii, placed the city of Santos in sixth place in the list of Brazilian municipalities with the best human development index, and in third place in the list of municipalities in the State of São Paulo.

Figure 4 – Recent flooding scenario in the region of Ponta da Praia, in 08/21/2016

Source: G1 Santos.

One of the concerns of contemporary society regarding climate projections is related to possible changes in the frequency and intensity of extreme short-term climatic events.

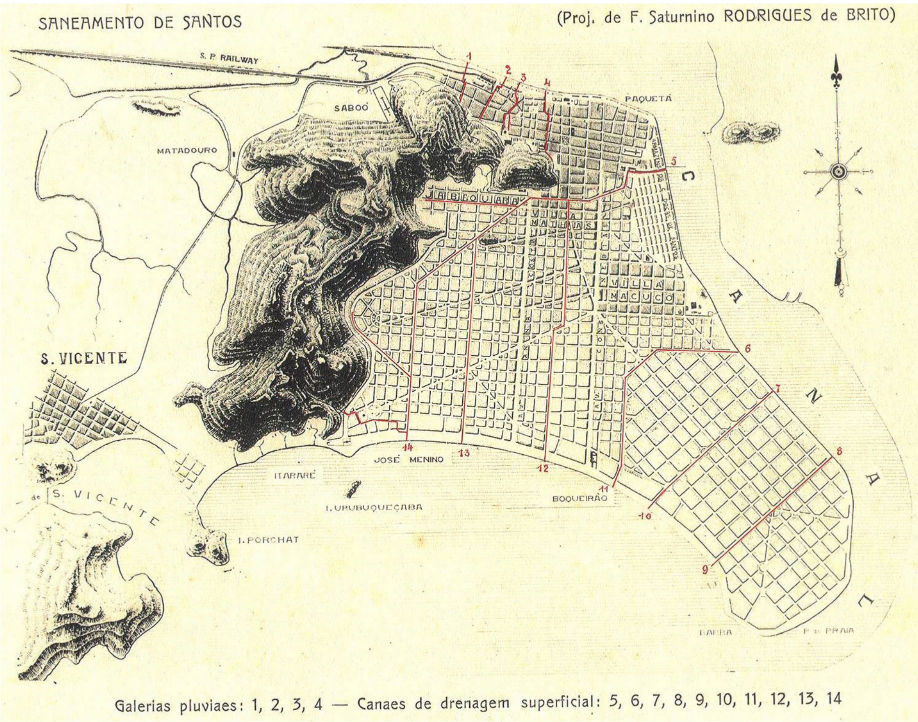
The events of intense precipitation have important effects on society, since floods associated with excessive rains (such as the Figure 4 event in Ponta da Praia - 08/21/2016), even if short, can be the most destructive among the extreme events in Brazil. large urban centers, especially when associated with a sea surf effect. Projections made by the IPCC (2007) i, towards the end of the 21st century, about changes in extreme events due to climate change, also show an increase in the frequency of intense precipitation events over most regions of the planet, considering all possible scenarios emissions of greenhouse gases into the atmosphere.

Strong hangovers have been frequent in Santos and their intensity has been increasing in recent years. These events have been plaguing the city, affecting the population, destroying waterfront structures and causing commercial losses.

There are several causes for this aggravation, which will be explained below. In view of the problems exposed, it is necessary to propose a containment work that prevents damage of great magnitude in the city. This work uses numerical simulations to support the design of a sustainable constructive solution, so that the problem is contained, including its comparison with other solutions, aiming to protect the region's environment in the short, medium and long terms.

2. 2. Urbain drainage system in Santos

Figure 5 – Design of storm galleries and drainage channels in Santos.



Source: Brito (1908) cited by Carriço (2015)[iv].

Santos' urbanization is an old concern; according to CARRIÇO (2015) 18, in the first decades of the twentieth century, Saturnino de Brito developed a sanitation plan for Santos that enabled the expansion of the city, constituting its most important urban reference. The canal system has significantly improved the sanitary standard in the new urbanized areas. However, with the industrialization of Brazil, Santos grew rapidly, making these sanitation conditions worse. This situation resulted in a change in the operation of the system in the 1990s, aiming to recover the bathing of the beaches. However, sanitary conditions have worsened again, leading to rejection of channels by sectors of the population. With regard to the drainage system, the main objective was to dry the marine plain, characterized by the low slope and water courses with many meanders, which contributed, together with the rains, normally intense in the summers, to the formation of large flooded areas, which prevented the dispersion of sewers and enabled the development of vectors of epidemics that plagued the city. Brito's macro-drainage plan was therefore characterized by the central strategy of circulating the water accumulated in the channels, preventing the spread of diseases and creating an extensive area for the development and expansion of the city, which was only fully urbanized in the decade 1970, with the occupation of the Ponta da Praia neighborhood. Figure 5 shows the design of the storm galleries and drainage channels in Santos, prepared by the Sanitation Commission, with the preliminary numbering of the channels, which was later modified.

According to NSW (2009) i, to prevent the flooding of streams and tributaries of a main river system, gates can be installed in the river system of coastal regions. The opening and closing of gates depends on changes in the water level caused by rains, floods or tidal fluctuations. They will remain open or closed, depending on the magnitude of the tides and the volume of water on both sides of the gates. They can be effective in reducing the impacts of small floods and can also be used to drain low humid areas and coastal floodplains for agricultural purposes.

On the other hand, according to NSW (2009) i, the gates can cause a series of negative impacts, such as stagnation and sedimentation upstream of the gates, the deterioration of water quality, including dissolved oxygen levels, pH, temperature, affecting the most forms of aquatic biota; they can encourage conditions for growth of weeds or vegetation not original to the initial ecosystem; reduction in fish passage; harm the drainage of wetlands and coastal swamps that lead to environmental losses (biodiversity), among others.

This work does not aim to carry out a detailed and detailed analysis of the environmental impact of coastal works in the region, as it requires the evaluation of several professionals such as geologists, biologists and environmental engineers.

According to Carriço (2015) 18, Santos' floodgates started to be opened only in case of intense rainfall. However, under normal conditions, the water flowing through the channels is directed to the Terminal Plant, which now receives not only the flow of sewage, but also rainwater conducted by the Interceptor.

This situation made it possible to maintain adequate levels of bathing during the period in which the gates are closed. But after the rains, and the consequent opening of them, the quality of the sea waters usually worsens. Therefore, the bathing of the Santos beaches is effectively associated with rainfall and the operation of the floodgates, which allow or not to transport the contamination of the channels to the ocean, in a situation in which the rainiest period coincides with the summer season and with the greatest influx to the beaches. According to SILVA & PORTO (2008) apud PRIME (1998) ii, polluting loads can be characterized as:

One-off loads - loads whose source can be determined and located, such as domestic sewage, industrial discharges, landfill effluents, etc.

Diffuse or non-punctual loads - generated in a distributed way over the soil surface by numerous polluting agents, which flow into the bodies of water preferably during the precipitation. Diffuse sources of pollutants are most often associated with land use activities. Among these, those that contribute the most are: urban growth, agriculture, urban and rural construction, logging and mining.

LI (2015) iii, carried out a three-year study on the distribution of pollutant loading from rainwater runoff from

mixed commercial and residential water catchments in the watershed of the Tongsha reservoir in the city of Dongguan, a typical and rapidly industrialized urban area in China. This study presented changes in concentration during rain events, average concentrations of events

and pollution loads per event per unit area. Impacts of the characterization of rains and abstractions on the average concentrations of events and on the percentage of polluting loads carried by the first 40% of the runoff volume were evaluated. The results indicated that the flow of pollutants during rain events presents significant temporal and spatial variations. The results of this work were innovative and may be useful for future works that aim to study the mitigation of rainwater runoff pollution in many other urban areas in developing countries, such as Ponta da Praia, Santos.

In addition, accidental loads, such as clandestine sewage, cross-links, failures in the collection system and transportation of solid waste, must be considered.

The canal gates already work as a drainage method for the city, but they need constant maintenance and have been used as a hydraulic control tool.

3. State of the art of the studied subject

3.1. Coastal containment

With advances in Computer Science and the vulnerability of coastal marine environments, the modeling of dynamic coastal processes has grown exponentially, enabling the use of numerical models for forecasting and reproducing phenomena.

It is important to emphasize that, in order to apply a numerical model, one must take into account the processes that act on the phenomenon (or phenomena) to be studied, in view of the compatibility of the equations used in the model and of the errors or uncertainties, for that the result is as close as possible to reality and useful for the intended application.

According to the PPMC 2015-2016 of the Municipality of Santosi, since the year 2012, with the approval of the National Policy for Civil Defense and Protection, Federal Law nº 12608, Brazilian municipalities subject to natural disasters, as in the case of Santos, started to be forced to adapt their respective Master Plans to face this problem. In addition, this law defines the municipal competence to identify and map disaster risk areas, promote inspection and prohibit new occupations in these areas.

To meet the above, the municipality provided, in Complementary Law No. 821/2 013, which instituted the Master Plan for Urban Expansion and Development, in Article 128, “that Risk Management ... will be based on technical studies, including Meteorological Monitoring, Susceptibility Charter, Geotechnical Charts and Municipal Risk Reduction Plan-PMRR, which aim to guarantee the reduction of disaster risks throughout the municipal territory, the minimization of adverse impacts resulting from human activities and natural processes, and constitute strategy of forming a resilient society. ”

Thus, supported by the Geographic Information System (GIS) of Santos, the municipality has been using each of the recommended and available tools, including the Letter of Susceptibility to Mass Gravitational Movements and Floods, the Municipal Risk Reduction Plan and the Geotechnical Map of Morros de Santos and São Vicente, among others. These are actions in the area of planning that are added to the daily work of living with risk, which is the result of the annual implementation of the Preventive Civil Defense Plan, operated with an emphasis on monitoring rainfall data, the evolution of slopes and the preventive removal of the population in sectors of high or very high risk during periods of intense rain and which has significantly reduced the number of fatalities on the hills.

But what the Climate Change Plan emphasizes is the need to build a resilient, sustainable city, which therefore promotes the effective reduction of the risk of natural disasters in its territory.

Time series of sea level and meteorological data in the coastal region of Santos were analyzed by Harari & Camargo (1995) i, Campos, Camargo & Harari (2010) ii and Harari, França & Camargo (2013) iii. Additionally, several works of numerical modeling of circulation and undertow in this area have been carried out over the last few years, such as those by Camargo & Harari (1994) iv, Harari, Camargo & Cacciari (2000) v, Harari, Camargo and Miranda (2002) vi and Magini, Harari & Abessa (2007) vii.

The analysis of time series allowed to obtain information about the variability of the sea level and the great influence of the meteorological conditions, in order to establish the causes of the strong hangovers, in Santos - especially the intense frontal systems in periods of greater tide range (syzygy), which occur when Moon and Sun are in conjunction or opposed, in times of Full Moon or New Moon. The numerical circulation models mentioned above allowed the establishment of coastal circulation patterns in periods of undertow, with strong intrusions of currents and transports on the platform, coming from the Southwest, these being the main responsible for the elevation of the average sea level.

Another cause for the severe hangovers that has occurred in Santos is the increase in the average sea level due to climate changes. Arasaki et al (2008) i analyzed the effects of the elevation of the average sea level in regions of Baixada Santista in the marine environment. One of the interesting points of this work is found in the demonstration of great variations in the estimates of elevation of the average sea level, due to the adoption of relatively short records; this work is complemented with a series of estimates of areas subject to flooding, especially mangroves in Baixada Santista.

Alfredini et al (2014) ii analyzed results from the numerical model of ERA-40 wave propagation for the period from 1957 to 2002, including comparison with buoy measurements off the coastal region of Santos. The analyzes show that, in the last decades, there has been an increase in the frequency of situations with extreme weather conditions, with high waves (with a significant height greater than 3.0 meters), and there is also a tendency to increase the significant heights and the periods of peak of the waves. The authors point out that, due to forecasts of an increase in the average sea level between 50 cm and 1 meter by the year 2100, which should cause flooding of about 50% of the mangrove areas in the Baixada Santista and of about 100 m of the beach strips, there should be an increase of 0.45 m in the significant height of the waves. Other consequences of the rise in the average sea level are listed by the authors of the work, such as, for example, an increase in the low tide level, a reduction in the tidal range, a decrease in the speed of tidal currents due to the decrease in the range, but an increase speed in flooded areas or river areas affected by the flood, and finally increased erosion and coastal drift.

Among the main adverse effects of climate change predicted until 2100, which may be reflected in an unprecedented political, social and economic crisis, in addition to the increase in the average sea level, there is a change in the supply of fresh water, a greater number of stronger and more frequent cyclones, rain and snow storms, and the consequent dryness and depletion of fertile soils (ALFREDINI (2014) 28).

If the projections for future global climate change are confirmed, the impacts could be potentially irreversible; in this case, island countries and coastal urban regions are the most vulnerable, with real possibilities of flooding in the medium and long term.

Other significant consequences can occur in many ecological and socio-economic systems, resulting from long periods of drought and a probable increase in tropical pests and diseases, not excluding the possibility of having affected the supply of food and water resources, damaging immensely. quality of life and human health.

As for engineering solutions for protecting the coastal region from maritime flooding, some solutions are presented, such as the fattening of beaches, the construction of rigid dikes and the insertion of movable arms, as used in the port of Rotterdam.

After the passage of Hurricane Katrina, new containment works were carried out in New Orleans - USA. They are great examples of a containment system (Figure 6), being a junction of protection by dikes with a system for pumping surplus water (NOLA Media Group, 2016) i. Unfortunately, the dike system was not effective in the exceptional event of Hurricane Katrina, and for this reason it has been strengthened, now with a new system for opening and closing gates, similar to that of the port of Rotterdam, but on a smaller scale. However, it must be taken into account that the city has regions that are at levels below sea level (USGS, 2016), as in the case of Rotterdam, and there is a demand for a much more robust system than would be necessary in the case of Santos. Therefore, it is possible to take into account the construction solutions carried out in other locations, so that new solutions are proposed in Santos.

Figure 6 - Mobile flood gates in New Orleans - USA / 2016

Source: www.nola.com.

According to NOVAK et al. (2007) i, coastal engineering has faced a variety of practical problems, such as the provision of ports, with a view to protection against silting, discharges of effluents from rivers at sea, design and construction of coastal protection works taking into account erosive aspects.

Most problems are difficult to solve, due to the complexity of the processes involved, often interacting at the same time.

Waves play an important role in coastal processes, causing erosion, sediment movement, resonance in ports, etc.

The elevation and decrease movement associated with the astronomical tide is produced by the gravitational field created by the interaction between the Earth, the Moon and the Sun, considering its rotation and its orbital movement. The time scale of tidal oscillations is much larger than the waves generated by the wind. These movements cause periodic forces on the Earth's surface, introducing a large number of known periodicities in the movement of tides. In addition, the tidal flow is strongly influenced by the Coriolis acceleration, the bathymetry of the place and the characteristics of the coastline. It can also be amplified by the resonance in the bays and estuaries. The accurate prediction of tides by theoretical means is not very accurate, and therefore, in practice, data measured at a given location are expressed as a “sum” of the periodic components, the number of which depends on the duration of the data collection. Once a periodic component is computed, it can thus be used in the “sum” to predict the water level of the location in the future.

Sea water levels are also increased significantly by strong winds and by suction due to low atmospheric pressure. In addition to generating waves, the wind causes the water surface to move, due to the wind shear, thus forming storm waves (undertow), which are generally affected by the topography of the coast.

Also according to NOVAK et al. (2007) 31 water level in a given location depends on tidal and wind conditions. The design of the structures must take into account the tide level to be added to the depth due to the increase in the storm. The combined effects of high water level and large waves are the cause of coastal flooding or damage to coastal structures. Observations made along the coast over a period of time could provide a useful basis for statistical analysis to determine individual probabilities of wave heights and water levels. However, today, the joint probability of a given water level with a given height wave, at the same time, forms the basis for specifying the design conditions for coastal structures.

Coastal currents can be generated by differences in specific mass in the ocean, wind tensions, tidal flows, rivers that flow into the sea and waves. The currents produced by breaking waves are important with regard to the transport of sediments along the beaches. River flows that discharge into the sea can cause currents close to the coast. The currents caused by flooding and refluxing of the tide and by wind tensions, particularly in shallow waters, can lead to the formation of vortices following immersed structures. As with offshore structures, flow-induced vibrations from structures, such as piles, can also occur that threaten structural integrity.

The trends in sea level rise that have been observed over the years, of which it is not the scope of our work to discuss the origin, may make the effectiveness of some of the current flood defense structures questionable in the future. Thus, it begins to introduce future water levels in project calculations.

Recent flood-related catastrophes (mainly from maritime sources) around the world have spawned a large number of projects aimed at developing stronger and more "intelligent" flood protection systems. Many projects, including FLOODsite, FloodControl 2015, International Levee Handbook, attempt to solve some of the flood control problems. One of the most challenging problems is the design of flood prevention and disaster management warning systems (EWS-Early Warning Systems) (Krzhizhanovskaya et al.,

2011) i. These systems are not part of the scope of this work, but will have an essential function if this project is applied. For this, it is indicated that the best developed alert systems, such as the one mentioned above, be used so that the system we propose is activated when necessary and adequately fulfills its function.

3.2. Dry Dykes

According to Alfredini & Arazaki (2014) i the construction of dry dykes requires the best contemporary resources for design and execution. These are normally built for fairing in shipyards.

To relieve pressures in a dry dock, partial relief alternatives are available, total or without pressure relief. For solutions with relief, cut-off diaphragm curtains isolate the radier or the entire dike, while the appropriate self-weight and / or anchoring systems support stability in the solution without relief. Structurally, the relief solutions reduce the thickness of the radier and wing walls, while excellent soil conditions are necessary for the solution without relief (which would not be the case in Ponta da Praia / Santos). In terms of maintenance, relief solutions require a pumping system. In economic terms, the partial relief solution is the best balanced, due to the reduction of the radier cost and less pumping than in the total relief solution.

Also according to Alfredini & Arazaki (2014) 33, protection works are basically intended for their defense, providing protection or stabilization of the land without changing the channel's free current conditions in plan and profile. The defense of the margins consists of the execution of works that prevent their sliding by dynamic action of the river currents (distribution of the tensions in the margin and in the bottom), or by the undermining produced by the action of transverse waves generated by the wind (most important effect in stretches more or lakes) or transit of vessels. In addition to these hydrodynamic causes, there are those originated in the reduction of soil resistance, linked to the oscillation of the water table: saturation reduces the angle of equilibrium of the soils, percolation due to abrupt variation in the water level can produce slip of soil wedges, and the dragging of fines (piping) can favor destabilization. Thus, the defense must be designed with greater resistance up to the level of maximum annual floods, and can be conveniently alleviated for the highest quotas, up to the maximum flood level and free edge.

3.3. Locks

According to Alfredini & Arazaki (2014) 33, the navigation lock consists of a chamber bounded by two doors (upstream and downstream), which give access to the vessels, where, by specific hydraulic circuit, the water level varies between levels upstream and downstream extremes, overcoming the necessary gap (Figure 7). In some locks, the potential energy of the water is used to overcome the gap, causing a transfer of water downstream in a filling-emptying cycle of the chamber. The raising or lowering of the water level, together with the vessels, is carried out by means of a set of interconnected aqueducts, with the flow control performed through gates or valves installed in the aqueducts or in the doors.

Figure 7 - Lock wall structure being built in Kentucky - United States of America.

Source: New York Times [v].

In locks, hydraulic issues, such as vortexes next to the water intake, pressure and cavitation losses, agitation inside the chambers, among others, act to induce efforts. The pressures along the aqueducts are one of the main parameters of analysis, aiming at the definition of operational conditions of technically satisfactory and economically viable hydraulic behavior, aiming mainly at cavitation control.

The locks have wing walls that contain the volume of water in which the vessels float, resisting hydrodynamic thrusts and, eventually, of land in buried stretches, guiding the vessels in their elevation movement and supporting the efforts of mooring and mooring. Structurally, the wing walls can be embedded in the terrain, projecting completely above the terrain or mixed. In the inlaid, the walls essentially resist earth pushes, while the hydrodynamics are largely absorbed by the rock. In protruding locks, the walls behave like dams, resisting hydrodynamic thrusts.

The bottom sill is designed to distribute the weight of the hydraulic column to the terrain, and must have the support and waterproofing capacity to do so. Hydraulic distribution and dissipation systems are often incorporated into the threshold. The maintenance of thresholds that are at a lower level than the downstream level, should provide for a chamber drainage system, with doors and valves closed. When dimensioning the threshold, underpressure must always be checked with permeable terrain and in an empty chamber condition, when the lock is located in the reservoir. Anchoring, or thick sills, are possible solutions in these conditions.

The control of the operation of the locks is performed by valves that always operate submerged, installed in independent filling and emptying aqueducts. Its sealing tightness is obtained by rubber or neoprene gaskets, admitting a loss of up to 0.2 L / s per meter of gasket.

There are many types of doors used in locks, such as flat vertical movement doors, as they are the ones that most resemble the coastal defense structure that we want to propose in this work. These doors can be lifted or lowered. In the first case, they are moved, in general, by gantries that must be of great height, to allow the passage of the vessel. Flat gates are generally moved by cables, and it is almost always possible to have counterweight systems, which reduce the energy needed for movement, do not have delicate parts constantly submerged and in the drawcocks, their maintenance can be done outside the water. The biggest drawbacks of this type of door are related to the maintenance of the cables, which are requested by great efforts and must have great lengths, high weight in comparison to the equivalent search doors, complicated maneuvering systems, requiring maneuvering frames and, in the case of drawcocks , they drop water on the boats.

What we propose in this project is a containment of floods that mixes the functioning of a dry dock and a lock. Since it is planned for the boardwalk in Santos, its foundation should be fixed with a frame in deep rock, below the sand layer of the region (after geological study and surveys carried out by geology professionals); and it is composed of a set of floodgates that rise and fall according to the height of the sea level at the site, but in this case only to protect the site.

3.4. Containement projects around the world

Due to the large extensions and heights to be controlled, the flood containment and surge protection project is a major challenge in the design, installation and operation of gates.

In the Netherlands, Maeslantkering, a part of the Europoortkering project (Port of Rotterdam), was built. The Delta's main surge protection barrier operates at Western Scheldt in the Netherlands; completed in 1986, it has 62 elevation gates from heights of 5.9 - 11.9 meters and 42 meters in length (Figure 8). The Maeslant storm barrier on the navigation channel (Nieuwe Waterweg) to Rotterdam, completed in 1997 and which is part of the same general scheme, has two horizontal floating / radial gates capable of closing the channel 360 meters wide. Each gate is 21.5 meters high, 8 meters wide and 210 meters long; the two horizontal arms of each gate are 220 meters long. The gates have a single sphere (pivot) 10 meters in diameter. Under normal conditions, the gates are "parked" on two dry docks (one on each bank). To operate the gates, the docks are flooded, the gates float and return to the position on the waterway. When contact between the gates is established, they are flooded and sink by closing the channel. After the danger of the flood has passed, the whole process is reversed and the gates are towed back to their "parking" position.

In the 1980s, it was clear that this project would take at least 30 years and would be extremely expensive. However, the adopted solution is characterized as a resistant work, and that has been very effective for the established purposes.

Figure 8 - Mechanized flood containment barrier and physical model of the mechanized barrier.

Source: Website do Porto de Rotterdam[vi]

According to NOVAK et al. (2007) 31 Large vertical lift gates need a high superstructure necessary to raise the gate and allow sufficient space for navigation. This elevated superstructure is not only expensive, but also intrusive to the environment; in addition, the gate in its elevated position can be subjected to high wind loads. A solution adopted for this type of problem, at the tidal barrier of a single gate on the River Hull (United Kingdom), is to rotate the gate 90 ° to a horizontal plane when parked in the raised position. Another possibility is the use of different types of gates, for example, in the River Tees tidal dam (United Kingdom) completed in 1994, where 4 13.5 meter long floating mouth gates were used, 8 , 1 meters high and 2 meters thick.

Protecting Venice from flooding is a major engineering challenge. To avoid pillars in the navigation channels that connect the Lagoon of Venice and the Adriatic, it is proposed to use, on the three channels, four 400 meter wide barriers with a 20 meter wide bottom float, 18-28 meters long and flap of 3.6-5 meters deep. Gates lowered in closed position in reinforced concrete crates with a hydraulic system of sediment ejectors. In their operating position, the gates are at an angle of approximately 45 °; they are not connected and move independently under the action of the leaking waves between the gates (and the hinges). A full scale experimental module was built and operated 1988-92; In 2003, an agreement was reached to proceed with the project.

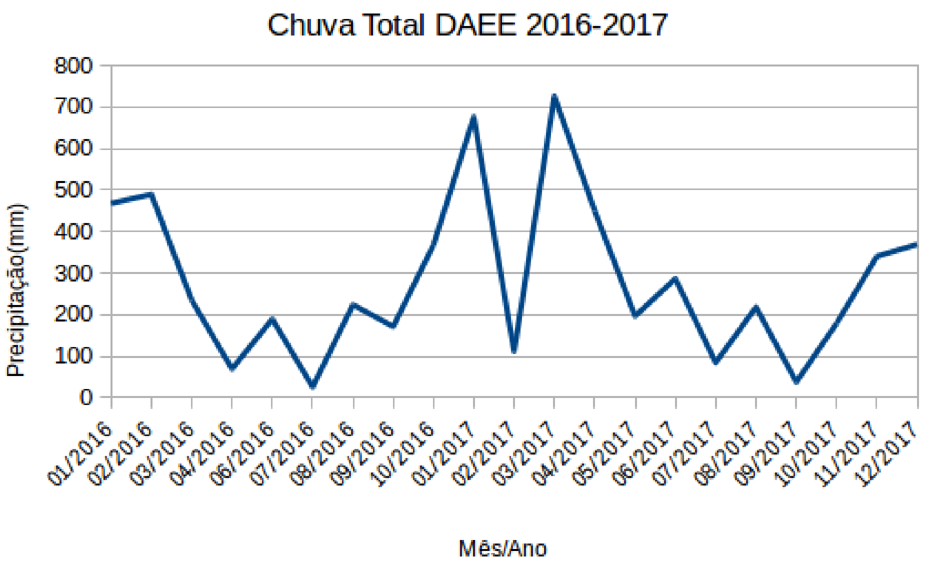
If something similar to Dutch or Italian work was implemented in Santos, it would be a very costly project to solve a minor problem compared to cities with quotas below sea level. Thus, we can say that the work to be implemented must also have a cost proportional to the size of the problem. This cost will not be negligible, but it cannot be absurd.

4. Justification of the originality of the work

In view of the damage caused by the strong hangovers in Santos, this work aims to propose a sustainable constructive solution to contain the effects of hangovers.

Hangovers in Santos are caused by several factors together. The last major hangovers, which occurred on 08/2016, 10/2016, 08/2017 and 10/2017, were caused by cold fronts coming from the South, together with the high tide of full moon. In addition, urbanization, generated by the anthropic action on the floodable banks of Ponta da Praia, profoundly affects the coastal dynamics that would happen in the absence of buildings and the impermeable cover present there. These conditions affect the occurrence of floods, worsening their intensity.

Graph 1 - Total monthly rainfall

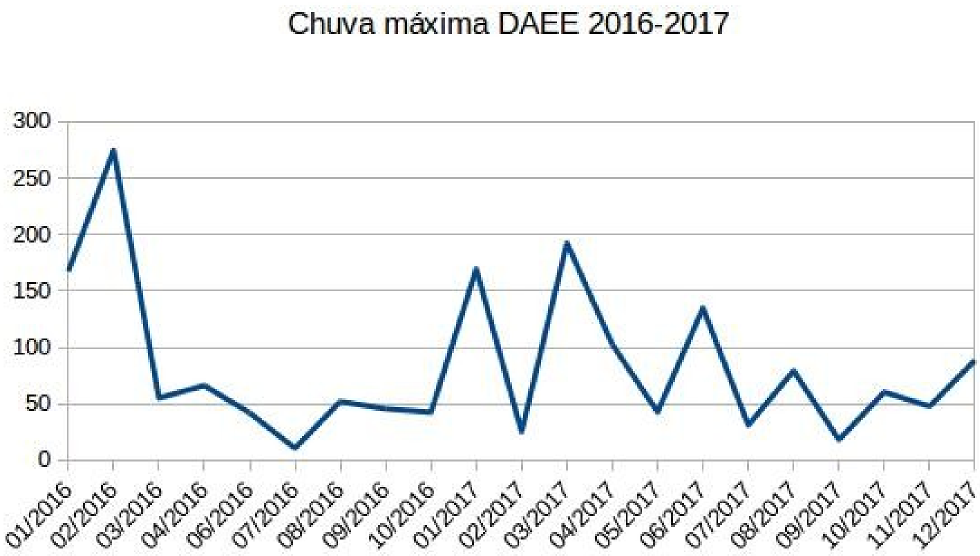


Source: Produced by the author based on data provided by DAEEi.

It should also be noted that the occurrence of maritime flood events can be aggravated by critical rainfall events if they are coincident. In our case, there were some rainfall events coinciding with the hangover events, however they were not the most extreme rainfall events of the studied period (2016-2017). These significant rainfall events may have aggravated the flood scenario. In figures 1 and 2, we observe the pluviometric data of total rain and average rain of the post with the lowest quota in the municipality of Santos provided by DAEE.

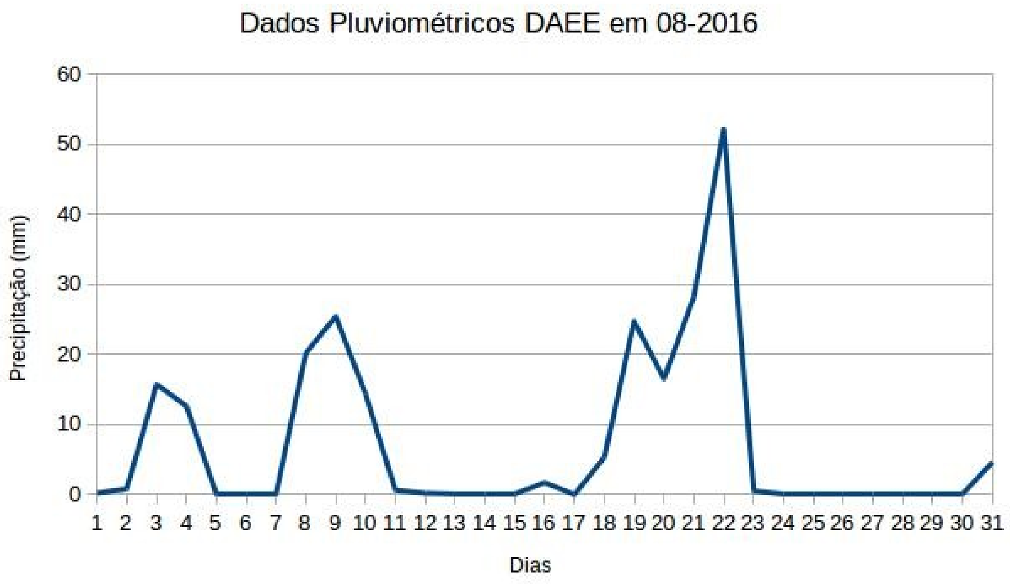
In figure 3 we observe the critical rainfall event on 19-21 / 08/2016 coinciding with the floods that were observed in this work and will be addressed below. As in figures 4, 5 and 6, we observe the critical rainfall events on 21-25 / 10/2016, 20-22 / 08/2017 and 22-27 / 10/2017, coinciding with floods that were observed in this work and will be discussed below.

Graph 2 - Maximum monthly rainfall.



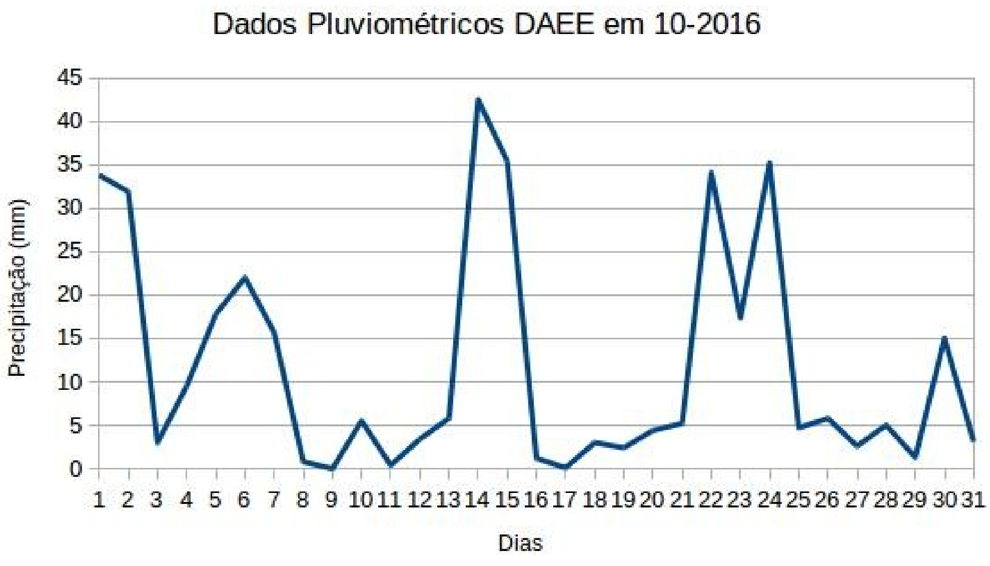
Source: Produced by the author based on data provided by DAEEi.

Graph 3 - Monthly rain 08/2016



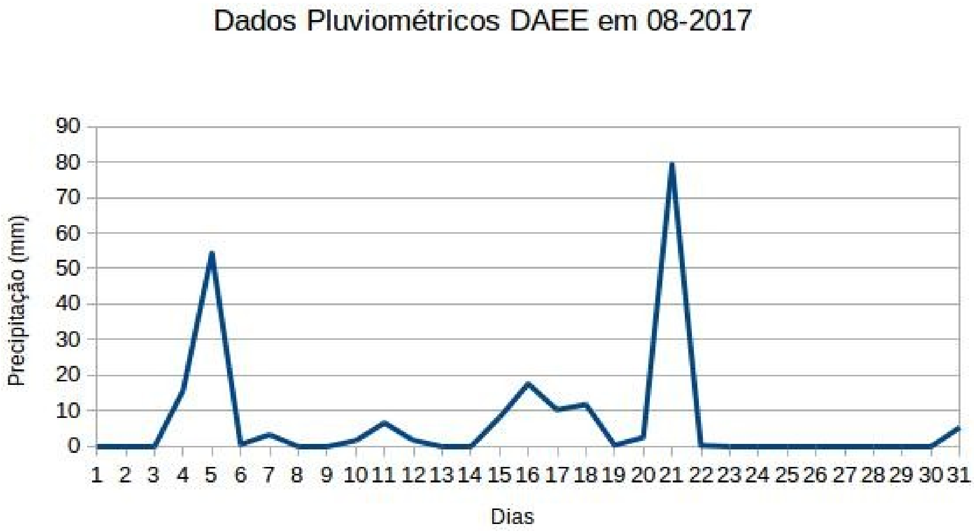
Source: Produced by the author based on data provided by DAEEi.

Graph 4 - Monthly rain 10/2016.



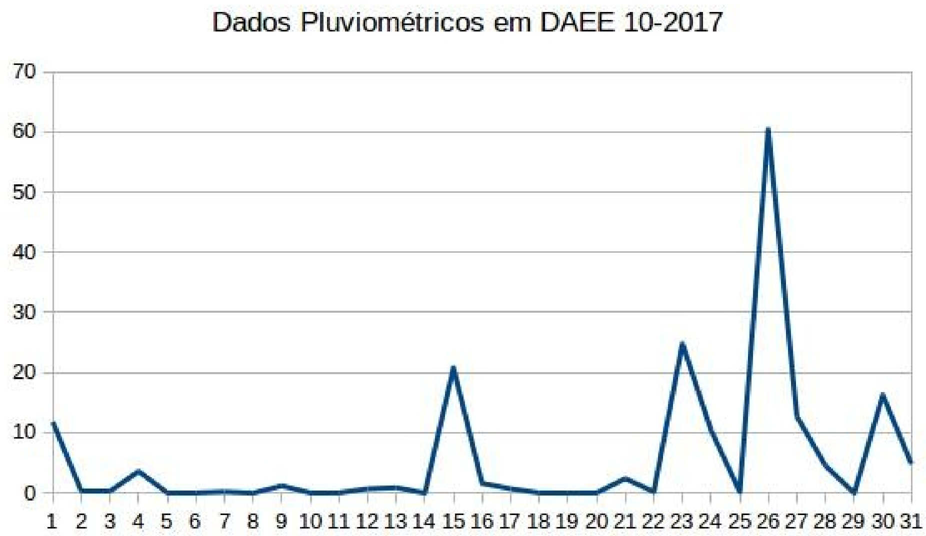
Source: Produced by the author based on data provided by DAEEi.

Graph 5 - Monthly rain 08/2017.



Source: Produced by the author based on data provided by DAEEi.

Graph 6 - Monthly rain 10/2017.



Source: Produced by the author based on data provided by DAEEi.

Human experience shows that the more man adapts to nature, the less likely it is to be catastrophic. However, most of the constructive solutions proposed for the case of floods, both sea and river, have been intrusive in the natural processes of sediment loading, and also for ecosystems. Jetties, spikes and barriers are common solutions that are reputed to have a significant environmental impact.

Therefore, it is necessary to propose a constructive solution that contains floods, does not significantly affect the environment and is feasible for a medium-sized city hall in the Brazilian context.

The research justification is found in the need for a coastal containment project, in view of the damage caused to the population and the environment by the floods associated with hangovers. In addition, the coastal containment works carried out in Brazil have, for the most part, a very significant environmental impact. Thus, sustainable containment works are necessary.

According to PIKLEY et al. (1985) i, coast erosion, in its natural state, is not a threat to coastal sandy strands, but part of the evolution of these systems. When the beach retreats towards the continent, this does not mean the disappearance of the coastal features, but the migration of systems.

Thus, it can be observed that the retreat of the coast is a natural process, which only becomes a disturbance when permanent structures are built in areas liable to erosion or the impact of the waves. According to DIAS (2002) ii, unconsolidated beaches, dunes or escarpments are temporary features that will often be transformed by the forces of waves and tides. The retreat of cliffs and the erosion of beaches do not necessarily occur regularly, but there are geological indications that a large part of the coastline is constantly changing, with different proportions in certain regions. The faster or more frequent these changes are, the greater the potential impact of constructions in these environments.

Doyle et al. (1984) iii, analyzing changes in the east and west coasts of the United States, established a series of findings, which they call “truths of the shore line”, established as follows:

1- There is no erosion problem until a structure is built on the coastline. Beach erosion is a common and expected event, not a natural disaster. If the beach is growing or shrinking, it does not affect the bather, the surfer, the hiker or the fisherman. When man builds a permanent structure in this zone of change, the problem arises.

2-Fixed buildings cause changes to the coastline. On sandy beaches there is a delicate balance between the supply of sand, the shape of the beach, the energy of the waves and the variations in sea level. All of these factors are in dynamic balance. Rigid constructions interfere with this balance and reduce the natural flexibility of the beach, causing changes that often threaten the installed structures themselves. Dune removal, which is usually done prior to construction, interrupts the supply of sand used by the beach to adjust its balance profile during storms.

The construction of a current guide at the mouth of the Flexa channel, south of the Cape of São Tomé, Rio de Janeiro, is an example of intervention on the coastline that resulted in major morphological changes and serious environmental impacts (DIAS (2002) [2]). Figure 9 shows the current guide in Rio de Janeiro, in 1987 and in 2001: in addition to no longer fulfilling its long-term containment function, it also causes real environmental catastrophes, such as silting, changing the dynamics of water and sediment transport, in addition to major changes in the region's ecosystems. It can be seen in the figure the silting present inside the current guide structure, demonstrating that the internal depth planned for this guide no longer exists, considering that the sediments were carried by the hydrodynamics of the region and tended to return to the bathymetric configuration corresponding to the natural course prior to the work.

Figure 9 - Current guide work in Barra do Furado, Rio de Janeiro, in 1987 (left) and in 2001 (right)

Fonte: DIAS (2002)

Thus, the justification for this work is found in the need for a flood water containment solution that adapts to natural geomorphological changes, thus reducing environmental impacts and eliminating the effects of silting and invasion of the coast.

In contrast to the inefficient solutions presented above, around the world, there are examples of containment structures that have a much smaller influence on the natural coastal dynamics, but are not yet adopted in Brazil on a large scale.

The purpose of this work is innovative, as it aims to adapt to the environment instead of being a structure independent of the environment in which it is inserted. In addition, the proposed work takes into account the socio-environmental value of the region affected by the floods.

As a methodology, it uses computational tools that can give results very close to reality, thus replacing the physical models that would be of high cost.

The design of the structure was based on the protection of the society that lives on the site, especially in the region affected by the floods, always with a view to building at the limit of the areas of natural erosion on the coast, not significantly influencing these areas.

It should be noted that this project simulates a protection tool for the local population and that, in order to be really implemented, several studies of soils and boreholes must be made, which are not within our reach at present, due to the lack of resources for this end and the need for geology professionals who work on this topic. The project we propose has nothing to do with resolving issues such as silting or sediment loading dynamics. The only solution that we want to propose is the design of a protection system for the population in the event of floods, which with the current perspectives has become increasingly a reality in the life of the population.

5. Hypotheses to be tested

The initial hypothesis of this work is that the floods that occur during times of hangovers at Ponta da Praia, in Santos, are mainly caused by the following factors: weather conditions, high tide levels and rising sea levels due to climate changes caused by pollution atmospheric, urbanization and soil sealing.

The main hypothesis of the research to be developed is that the physical containment of the rise in sea level associated with hangovers, through a system of mobile panels, will be efficient, for the protection of the inhabitants and their goods, producing minimal environmental impact.

6. Methodology

6.1. The containment structure

According to NOVAK et al. (2007) 31, the main operational requirements for valves and gates are flood control, tightness, minimum lifting capacity, convenience of installation and maintenance and, above all, fault-free performance, avoiding risks security for operational personnel and the public. Despite the robust design and precautions taken, failures can occur and works must be able to tolerate these failures without unacceptable consequences.

The execution of this work plan initially involves the analysis of time series of sea level, wind, atmospheric pressure and air temperature, from the Santos region, from 1950 to the present - available in the Database of the Simulation Laboratory and Hydrodynamic Numerical Forecast (LABSIP), from USP's Oceanographic Institute, coordinated by the supervisor of this proposal. These series were subjected to statistical and spectral analysis, including correlations of oceanographic and meteorological information, as performed by Campos, Camargo & Harari (2010); in addition, specific analyzes were carried out on selected cases of extreme sea level rises.

Next, a proposal for the construction of ditches in the Ponta da Praia region will be analyzed, on the line not influenced by geomorphological changes in the beach sediments, with the insertion in these ditches of resistant panels, which can be raised in case of undertow, in order to protect the metropolitan region from flooding, without influencing the natural dynamics of the coastal area, which is always under the influence of sediment transport and morphological changes, due to cyclical natural phenomena. Currently, a boardwalk has been built in this area, which would need to be reconfigured in the event of the implementation of this flood containment.

Figure 10 - Beach tip region - the proposal is to build the ditches on the line not influenced by geomorphological changes in the beach sediments. This area would be the strip present after the rockfill and before the cycle path, illustrated in this figure.

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Source: Santos City Halls[vii].

The mechanism used to lift the barriers would be based on the mechanism used in locks, together with the construction techniques of dikes. A sluice is a hydraulic engineering work that allows boats to go up or down rivers or seas, in places where there are very large gaps, such as dams, waterfalls or rapids (DNIT, 2016) i.

For the Ponta da Praia region, panels driven by a pneumatic piston would be used. The panels would be lifted by means of a pneumatic piston system, which would lift the panels made of resistant material (we propose high-strength steel). In addition, a drainage system would be installed at the bottom of the trenches. Thus, the floodgates would only rise in the event of a flood hazard and return to their initial position soon after the normalization of sea level rise conditions. The piston system that would move the panels would be activated when receiving a radio signal from a weather station informing of the danger of flooding. In addition, a case study is necessary, together with the fire department, of the security systems for people who transit on the shore, so that the area can be evacuated before the floodgates are fully surveyed. It would be like the construction of dry movable dikes, which would have little impact, being triggered only in cases of floods.

In addition, it is necessary to perform a good drainage system at the bottom of the ditches, requiring a study of the best mechanism to be used. In principle, it is possible to propose the insertion of pipes with the Archimedes screw mechanism, which would return excess water to the stabilized region of the sea without causing significant effects. One can think of using a foot valve with a sieve at the end of the pipe to prevent reflux of sea water, in which case a more detailed study of the power of the pump to be installed and its best disposition should be made.

It should be noted that it is not the objective of this work to address the problem with regard to sediment transport and morphological changes, due to cyclical natural phenomena in the region. There are works being developed at an advanced stage, such as the work of GARCIA et al (2018) ii that has been monitoring the Ponta da Praia region for some years also, identifying causes and consequences of coastal erosion for works proposals that mitigate this effect in a way efficient. According to the work of GARCIA et al (2018) iii a major difficulty observed is the dynamics of waves and currents in this region, which is very complex due to the proximity to the mouth of the Santos estuary Given the complex coastal dynamics of the region the aforementioned author has proposed the use of pilot structures for the insertion of geotubes to better understand its effect on the surroundings, before proposing definitive works.

6.2. What makes the structure of low environmental impact

According to the IPCC (2007) i, determining which impacts of climate change are potentially "key" and what is really "dangerous" is a dynamic process that involves, among other things, the combination of knowledge with factual and regulatory elements. In general, the effective or objective criteria include the scale, magnitude, time and persistence of the harmful impact. Normative and subjective elements are incorporated in the assessment: the specific characteristics and the importance of the threatened system, the equity of the considerations on the distribution of impacts, the degree of risk aversion and assumptions regarding the feasibility and effectiveness of potential adaptations. The normative criteria are influenced by the perception of risk, which depends on the cultural and social context. Some aspects that ensure the relationship between climate change and impact are effective, while others are subjective.

In addition, the choice of which effective criteria to be used in the impact assessment has a normative component. Some criteria were listed by the 2007 IPCC report37:

- Magnitude of impacts
- Duration of impacts,
- Persistence and reversibility of impacts;
- Probability (uncertainty estimates) of impacts and
- vulnerabilities and reliability level of these estimates,
- Adaptation potential,
- Distributive aspects of impacts and vulnerabilities,

- Importance of the system (s) at risk.

6.3. Forças Hidrodinâmicas que atuam na estrutura

Hydrodynamic forces acting on the structure

According to NOVAK et al. (2007) 31, the main force acting on gates is generally due to hydrodynamic pressures caused by uneven turbulent flow, with subsidiary forces caused by waves, ice, impact of floating bodies, etc.

In their closed position, the doors and valves are subjected to hydrostatic forces determined by standard procedures for forces acting on flat and curved surfaces. For radial or sectional gates, the resultant force vector must pass through the gate pivot and, therefore, its moment will be zero; it can also be converted into one, tending to open or close the gate, placing the pivot above or below the center of curvature of the cover plate.

The most important factors of the flow over and under the gates will depend on the geometry and position of the gate and its accessories, such as fences, supports, etc., the flow of Froude and Reynolds - and possibly even Weber's numbers, the degree of turbulence of the incoming flow and the aeration of the space downstream of the gates.

Generally, the design of the gate is a difficult task, partly due to the complexity of the hydraulic conditions indicated above, and partly because the project must satisfy conflicting demands: vibration dampening can conflict with maintaining forces for the operation of the gate. gate to the minimum; the need to avoid vibrations can conflict with the optimum shape and strength required by flow and load conditions; the ideal shape of the edges and seals may conflict with the tightness of the closed gate, etc. It is often useful to perform a potential flow analysis and use it to determine the hydrodynamic force that, in some simpler cases, can also be obtained using the equation of the moment.

According to NOVAK et al. (2007) 31, in closed positions, the hydrostatic forces determined by standard procedures will be applied again. For vertical lift gates, the hoist lift force must be dimensioned to overcome the weight of the gate, the resistance to friction and, most importantly, the reduced contraction forces resulting from the fact that, during the operation of the gate, the pressure along the lower edge of the gate is reduced (at atmospheric or even lower pressures), while the pressure acting on the upper part of the gate is practically the same as under static conditions (ie, total pressure of the reservoir). This condition applies both to gates located inside a conduit or on the upstream face of the dam or to an entrance (it should be noted that the fences for the gates at the entrances must be on the downstream side and, generally, the gates in ducts are in the same position). The lifting forces acting on a gate with a given frame and sealing geometry, and the vibrations of the gate, must be analyzed under various operational conditions, using theoretical considerations and field testing experiences, as well as experiments with models, if necessary.

The lifting force of a gate will also be influenced by the geometry of the lower edge and the seal. To avoid negative and elevating pressures, there must be no flow separation until the limit downstream of the gate is reached.

According to NOVAK & ČÁBELKA apud NOVAK et al. (2007) iCavitation, air demand and vibration of gates are closely linked and influence each other. In principle, the danger of cavitation exists in any situation where the flow is separated without sufficient air supply, and in the case of flow under a gate in a high wave crest situation. The determination of air demand and the associated design of the ventilation openings is important for all types of containment gate designs.

The vibration of the gates, if it occurs, can be dangerous - leakage in the seal, intermittent flow connection - inadequate ventilation being the main causes. Therefore cases of vibration must be anticipated and repaired quickly.

There are two aspects of automation in connection with ridge gates of containment: gates that move automatically according to the level of the reservoir and installations with automatic control of the movement of the gate. The first category includes drum and sector gates, some types of screens and flap gates, and ridge gates using fluid dynamics systems (gates with flotation tanks connected by radial arms channeled to an upstream shaft). Automatic gates are advantageous in remote locations, but are not restricted to these.

In control systems, electromechanical controls have been largely replaced by closed-loop electronic systems. Programmable logic control (PLC) is currently general, with duplicate controllers for controlling critical functions. The requirements for remote control are that two independent means of communication are available to transmit important information, which determine the operation of the gates and monitor the condition of the equipment.

Thus, there are many layouts to be examined, in order to propose the ideal for the region of interest, such as the Sluice gate, which is widely used in water supply and drainage, and works to cut the flow within the channel; with adaptations, it could be used in our case (see Figures 11 and 12).

Figure 11 - Steel lock door.

Source: Supplier Maezawa Industries[viii].

Figure 12 - Lock door with suspension mechanism.

Source: Watch Technologies Supplier [ix].

According to NEVES et al. (2012) i, the forces acting on a maritime structure can be classified into two groups:

• Hydrostatic, resulting from the pressure that the fluid at rest exerts on the structure, since the structure is totally or partially submerged;

• Hydrodynamics, resulting from changes in the speed of the water mass associated with agitation.

There are other types of forces that also request the structure, which are the forces due to the action of the wind, impacts of ships, earthquakes, tsunamis, etc.

Hydrodynamic forces depend on the characteristics:

• the fluid medium, in this case, water (volumetric mass, ρ, dynamic viscosity, μ and temperature, T),

• sea waves (wave height, H, period, T, or the respective wave length, L, at the depth of the water, h) and

• of the work (of a characteristic dimension, D, for example, the frontal horizontal dimension of the structure, and of the work's own oscillation frequency).

The formulations to be used for the calculation of forces depend on the force regime to which the structure is subjected.

Also according to NEVES et al. (2012), there are four regimes of forces depending on the wave profile, when it reaches the structure with normal incidence:

1. Stationary regime: the work is subject to the action of a standing wave resulting from the interaction of the incident and reflected waves. The reflection coefficient is approximately equal to the unit and there is no bursting or overtopping, so dissipation and transmission

are negligible. In this case, the wave has a belly in the wall (total reflection) and the pressure distribution varies in phase with the increase of the free surface elevation in the structure, which can be calculated from the wave theory that is representative of the slope, H / L, and the relative depth, h / L, concerned.

2. Partially stationary regime: the wave is almost breaking and has a flat and slightly inclined front over the structure. The wave rises over the structure quickly, transforming its velocity field, just before reaching the structure, from a horizontal direction to a vertical direction.

It is precisely after the impact that very short-term pressure spikes are generated. The result of the forces acting on the structures found in this regime can be calculated by applying theories or models that take into account both the effect of the burst without impact and that of reflection. There are some semi-empirical approaches that give good results for these conditions (for example, Goda, 1974, or Nagai, 1973); however, it is recommended to check the pressure distribution experimentally.

3. System with the occurrence of a burst and impact: the wave's breaking on the structure is the main contribution to the result of the forces acting on it. The wave reaches the structure during the breaking process and the impact occurs with air trapped between the water column and the structure. In this case, a first pressure peak of very short duration occurs, followed by a strong oscillation with a very high frequency (Peregrine, 2003). There are analytical and numerical models that give a good approximation pressure distribution in this regime.

4. Wave regime after surf. The waves reach the structure already broken, either by the effect of the bottom or by the interaction of the incident wave with the wave reflected in the work, behaving like a turbulent water mass. Some semi-empirical approaches give good results for these conditions; however, it is recommended to check the pressure distribution experimentally.

It should be noted that in this work, geotechnical and geological effects will not be considered, only the static balance of forces related to the fluid in contact with the structure.

According to Neves et al. (2012), to analyze the stability of sliding and tipping, one can consider the static balance of the system, assuming that the action is constant. Thus, several simplifying hypotheses are considered:

- The maximum instantaneous forces acting on the structure are constant over time;

• The structure-foundation system is considered rigid until the previous moment when the ruin occurs by sliding or knocking down, that is, there is no accumulation of damage but only instant ruin.

7. Data Analysis

7.1. Data Collection

To obtain sea level data for the preparation of tidal time series indicators, the work of Harari & Camargo (1995) i was used for data from 1945 to 1989; and for the data from 1990 to 2013, the work of Harari & C bitter (2010) ii was used, as well as separate data from the tide gauge of Torre Grande in the Port of Santos. In the analyzes, the harmonic tide method (Tidal Liverpool Institute) was used, resulting in a semi-daytime tide with daytime inequality (according to the classification of NR Almirante Santos Franco, under the responsibility of the Navy of Brasiliii).

The coastline and bathymetry of the studied region were obtained by digitizing the nautical charts "Porto de Santos (southern part)", with reference 1713, filed on 12/08/2017, "From Santos to Paranaguá", with reference 23200 (INT.2125), filed on 02/16/2017. And “Proximities to the port of Santos”, with reference 1711, filed on 11/29/2016, provided by the Navy of Brasiliv.

GlobalMapper 18.2 and QGIS 3.0 software were used to digitize the maps. For the interpolation of bathymetry data, the RFGRID module of the Delft 3D 4.03 software was used, with a concession for academic use.

7.2. Data Processing

7.2.1. Sea level time series

For data processing, Matlab 2015 software was used, transforming sea level data into text format in graphs that facilitate observation. In addition, it was possible to observe the trend (increase or decrease) of sea level, which will be shown in the respective results section of the present work.

7.2.2. Initiation of numerical simulation of sea level in the region to implement the work

According to NOVAK et al. (2007) 31, the base of numerical and computational models is a mathematical model, that is, a set of algebraic and differential equations that represent the flow. They are general equations of continuity and Navier-Stokes equations for turbulent flow (including terms for turbulent stresses) and / or shallow water and Saint Venant equations (involving variation in speed and / or concentration in space and time).

The simplest partial differential equations that occur frequently in engineering are second order linear equations, which in fluid dynamics generally take the form of hyperbolic (waves), parabolic (diffusion) or elliptical (Laplace) equations. For the solution of these, initial and / or boundary conditions must be given.

The solution of partial differential equations (EDPs) requires, in most cases, the use of numerical solutions, based on finite difference methods, finite elements or finite volumes, with explicit or implicit solutions. Numerical stability, convergence, dissipation and dispersion are important aspects of numerical models. The characteristic method turns PDEs into common differential equations over certain characteristics, resulting in simplified step-by-step solutions.

There are many computer packages available for troubleshooting hydraulic engineering, but their successful use requires a good basic knowledge of underlying physical, mathematical and hydraulic principles.

According to Deltares®, Delft 3D is a set of integrated computer software for a multidisciplinary approach, with 3D calculations for coastal, river and estuarine areas. This software can perform flow simulations, sediment transport, waves, water quality, morphological developments and ecology. The Delft3D set is composed of several modules, grouped around a mutual interface, being able to interact with each other. Delft3D-FLOW, which is one of these modules, performs

multidimensional (2D or 3D) hydrodynamic (and transport) simulations, calculating non-stationary flow and transport phenomena, for rectilinear or curvilinear grids. In 3D simulations, the vertical grid is defined following the σ coordinate approach. Examples of Delft3D - FLOW processing for the coast of Estado de Segundo can be found in YANG (2016) v.

According to DELTARES (2013) vi, the D3D-FLOW uses the Arakawa C grid for hydrodynamic modeling. The hydrodynamic equations for the flow and transport of substances are solved using the finite difference method, allowing the simulation of transports resulting from tides, river discharges and meteorological effects, including the effect of specific mass differences due to river flows and gradients horizontal temperature and salinity fields.

The D3D-FLOW solves equations derived from the Navier-Stokes equations: equations for the movement of sea water in the x and y directions, to obtain the zonal and meridional components of the currents; equation for the movement of sea water in the z direction, approximate to the vertical coordinate σ, which is reduced to the hydrostatic relationship; continuity equation for obtaining sea level rise and for obtaining the vertical component of currents; and temperature and salinity diffusion equations.

$$\frac{\partial U}{\partial t} + U\frac{\partial U}{\partial x} + V\frac{\partial U}{\partial y} + \frac{W}{H}\frac{\partial U}{\partial \sigma} - fV = \frac{-\nabla P_x}{\rho} + \nabla F_x + \frac{1}{H^2}\frac{\partial}{\partial \sigma}\left(A_v\frac{\partial U}{\partial \sigma}\right)M_x \quad (1)$$

$$\frac{\partial V}{\partial t}+U\frac{\partial V}{\partial x}+V\frac{\partial V}{\partial y}+\frac{W}{H}\frac{\partial V}{\partial \sigma}+fU=\frac{-\nabla P_y}{\rho}+\nabla F_y+\frac{1}{H^2}\frac{\partial}{\partial \sigma}\left(A_v\frac{\partial V}{\partial \sigma}\right)M_y \tag{2}$$

$$\frac{\partial P}{\partial \sigma}=-g\rho H \tag{3}$$

$$\frac{\partial \eta}{\partial t}+\frac{\partial HU}{\partial x}+\frac{\partial HV}{\partial y}-Q=0 \tag{4}$$

$$\frac{\partial HT}{\partial t}+\frac{\partial HUT}{\partial x}+\frac{\partial HVT}{\partial y}+\frac{\partial WT}{\partial \sigma}=H\left[\frac{\partial}{\partial x}\left(\frac{D_H}{\sigma}\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{D_H}{\sigma}\frac{\partial T}{\partial y}\right)\right]+\frac{1}{H^2}\frac{\partial}{\partial \sigma}\left(\frac{A_v}{\sigma_{mm}}\frac{\partial T}{\partial \sigma}\right)+F_T \tag{5}$$

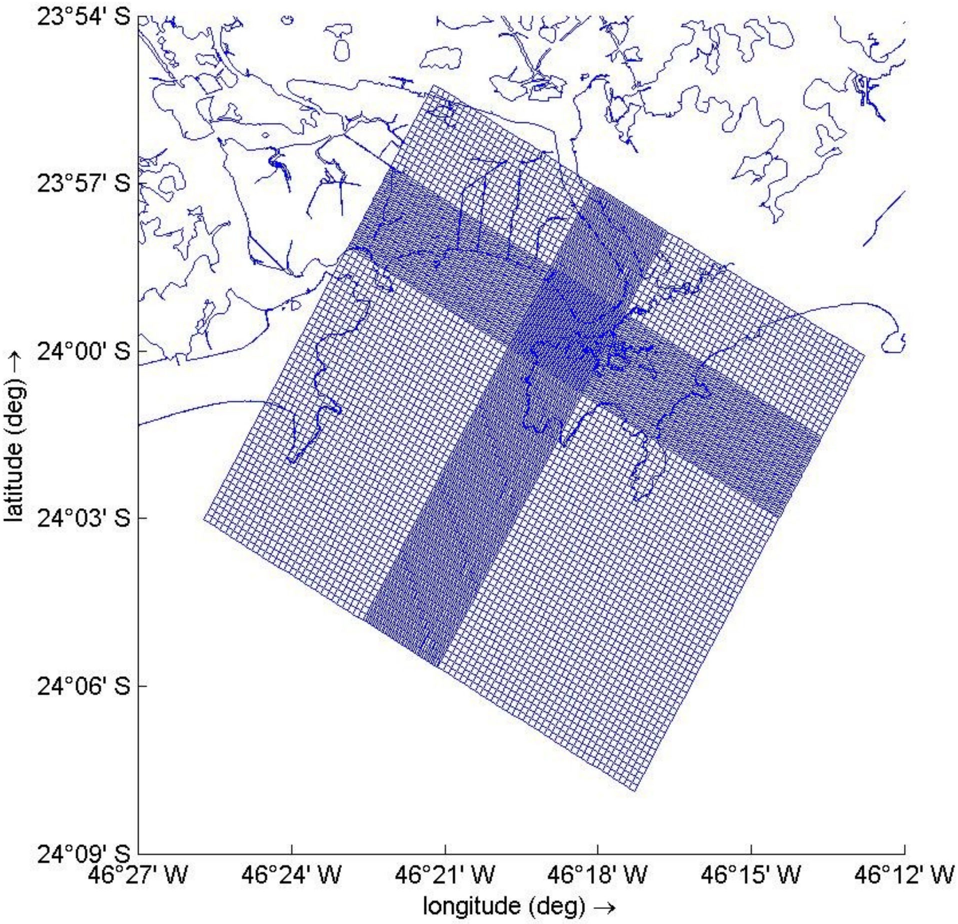
$$\frac{\partial HS}{\partial t}+\frac{\partial HUS}{\partial x}+\frac{\partial HVS}{\partial y}+\frac{\partial WS}{\partial \sigma}=H\left[\frac{\partial}{\partial x}\left(\frac{D_H}{\sigma}\frac{\partial S}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{D_H}{\sigma}\frac{\partial S}{\partial y}\right)\right]+\frac{1}{H^2}\frac{\partial}{\partial \sigma}\left(\frac{A_v}{\sigma_{mm}}\frac{\partial S}{\partial \sigma}\right)+F_S \tag{6}$$

U, V and W being the zonal, meridional and vertical components of the currents, respectively; t the time; H the depth; f the Coriolis parameter and ρ the specific mass of the water.

∇Px and ∇Py are hydrostatic pressure gradients in the x and y directions, respectively; ∇Fx and ∇Fy radial stress gradients in the x and y directions, respectively; AV is the vertical turbulent viscosity coefficient; Mx and My are additional sources of movement in the x and y directions, respectively; P hydrostatic pressure; g the acceleration of gravity; η is the rise in sea level; Q represents sources of contributions per unit of river discharge area; T is the temperature; S is salinity; DH is the horizontal diffusion coefficient; σmm is the Prandtl-Schmidt number for molecular mixtures; and, finally, FT and FS are additional sources of temperature and salinity, respectively.

For the simulation, a -30 ° inclined grid was made, considering that, in this way, we would be able to cover the Ponta da Praia region in a position where the grid would be refined in the region with a lot of flood influence, without wasting time. of refined processing in areas of less influence (Figure 13). The grid limits were in latitude between 23.93 ° and 24.13 ° South and in longitude between 46.45 ° and 46.20 ° West, approximately (Figure 13). With a spacing of about 0.002 ° in Δx and Δy, and a refinement was made in the vicinity of Ponta da Praia to obtain a spacing of approximately 0.0002 °, therefore, about 25 meters.

Figure 13 – Grid used for numerical simulations.



Source: Made by the author with the aid of the Delft 3D RFGRID module.

With the aforementioned grid and the bathymetry points of the nautical charts, the bathymetry was interpolated to the grid points, with the aid of the Delft3D RFGRID module for insertion in the numerical model.

Five observation points were used to generate the time series of the model results, which were inserted through the Delft3D Flow module, as well as the dry points in the region (land points). The observation points were selected as follows: the first at the entrance to the canal near Ponta da Praia; the second near the navigation channel, a little further from Ponta da Praia; and the other 3 furthest from the coast, so that one could observe the progressive behavior of hydrodynamics along the depth. Initially, a 2D hydrodynamic simulation was performed, only for the astronomical tide forcing; in this simulation, calculations were performed for the entire grid considering a single layer, so that at each grid point the average values were obtained in the water column. After carrying out the tide simulation with the 2D version, other simulations were carried out, considering all the forces of circulation, in 3D pattern.

To obtain conditions in the open contours (BND format) representative of astronomical forces (BCA format), the Delft DashBoard software was used, which uses the TPXO 7.2 Global Inverse Tide Model. After obtaining the BND and BCA files, the MDF file was prepared in the FLOW module of Delft3D. This Delft3D-FLOW input file, called the “Master Definition Flow” file (MDF file) is the one that contains all the information (data and simulation parameters) to perform a flow simulation.

To start the work, we performed 2D simulations, to observe the behavior of the sea in the region only under the effect of the tides. In the 2D hydrodynamic simulations, only the tides in the open contours of the grid were used as forcing (Table 1). All tide level components (M2, S2, N2, K2, K1, O1, P1, Q1, Mf, Mm and Ssa) were selected. These forces were also maintained in later simulations (3D), when meteorological and specific mass forces were included.

Modo	Componente	Descrição
Semi-Diurna	M2	Lunar principal
	S2	Solar principal
	N2	Lunar elíptica
	K2	Declinação lunar-solar
Diurna	K1	Declinação lunar-solar
	O1	Lunar principal
	P1	Solar principal
	Q1	Lunar elíptica
Longo Período	Mf	Lunar quinzenal
	MM	Lunar mensal
	Ssa	Semi-anual solar

Table 1 - Tidal components considered by Delft DashBoard, based on data from TPXO. Source: YANG (2016) i

The month of August 2016 was simulated, which was characterized by the occurrence of extreme events associated with intense cold fronts. Greenwich Mean Time (GMT) was used, with a one minute time step. Before the August 2016 simulation, the months June and July 2016 were simulated, starting from the initial resting condition (elevations and currents equal to zero throughout the grid), to obtain the model's hydrodynamic balance in the period of interest. As a result of the model, sea level rise values and currents were obtained.

Results in the form of time series and spatial distributions were obtained, both in 2D and 3D simulations. For the statistical analysis of time series of the variables involved in the hydrodynamic simulations, 20 monitoring points were selected, which are located within the grid along four radials, containing five points each.

7.3. Working with the Delft 3D WAVE module

The Delft3D-WAVE module can be used in order to simulate the evolution of waves generated by wind in coastal waters. This module takes into account the generation of waves by the wind, the non-linear interactions and the dissipation of waves, for a determined bottom topography, wind field, water level and current field in deep, intermediate and shallow waters.

The WAVE module can use the output files from previous FLOW module simulations or it can be simulated independently. In our case, we performed the joint simulation of FLOW data for WAVE simulation, with a view to simply ensuring that the FLOW and WAVE data were compatible.

Currently, two wave models are available in Delft3D (both of the phase average type). They are the second generation HISWA wave model (Holthuijsenet al., 1989) and, its successor, the third generation SWAN wave model (Booijet al., 1999; Riset al., 1999). The SWAN wave model is currently the standard option within Delft3D, having been used in the present work.

This model takes into account the following effects:

- Propagation of waves in time and space, refraction due to current and depth, frequency shift due to currents and non-stationary depth.
- Wind wave generation.
- Interactions of three and four waves.
- Whitecapping, lower friction and depth-induced breakage.
- Dissipation due to aquatic vegetation, turbulent flow and viscous fluid mud.
- Propagation of laboratory to global scales.
- Transmission through and reflection (specular and diffuse) against obstacles.
- Diffraction

SWAN calculations can be made from a regular, curvilinear grid or a triangular mesh, in a Cartesian or spherical coordinate system. In this work, a rectangular grid with variable spacing was used.

SWAN provides the following main output information (numeric files containing time series and spatial distributions):

- One-dimensional and two-dimensional spectra,
- Significant wave heights and wave periods,
- Average wave direction and directional propagation,
- One and two-dimensional spectral source terms,

- Square-medium root of the orbital movement,
- Dissipation,
- Force induced by waves.

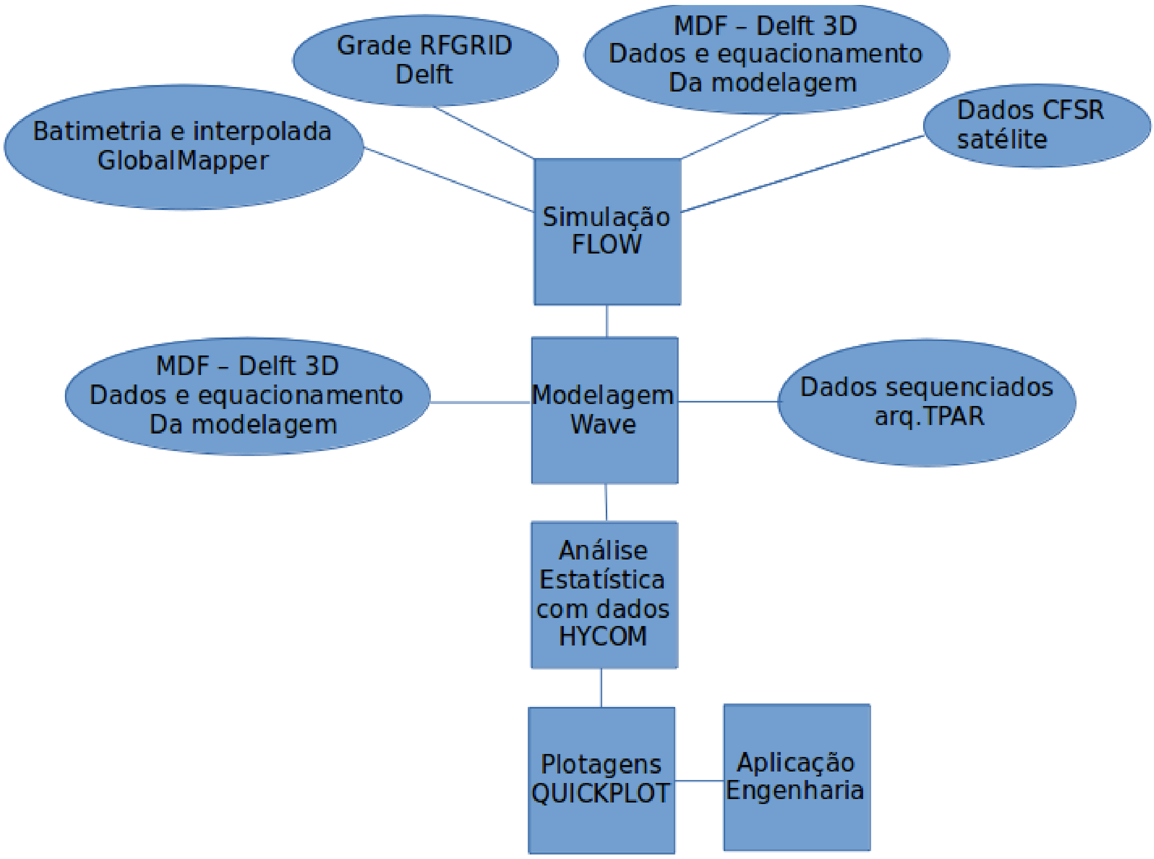
As an observation, SWAN does not consider Bragg scattering and wave tunneling. The SWAN model is based on the equilibrium equation of the discrete spectral action (in all directions and frequencies). SWAN calculates the evolution of random short wave waves in coastal regions with deep, intermediate and shallow waters and ambient currents. The model also considers propagation (refractive) due to current and depth and represents the processes of wave generation by wind, dissipation, background friction and depth-induced wave breaking, in addition to non-linear wave-wave interactions explicitly, with state-of-the-art formulations. The blocking of waves by currents is also explicitly represented in the model. To avoid excessive processing time and obtain a robust model in practical applications, fully implicit propagation schemes were applied. The SWAN model has been successfully validated and verified in several field and laboratory cases.

To prepare the WAVE processing we use the file called TPAR, which specifies the boundary conditions that vary in time and space.

TPAR files contain non-stationary wave parameters. A TPAR file is for only one section of the boundaries; so, for each edge we make a TPAR. The TPAR file has the TPAR string in the first line of the file and each line contains 5 information:

- The first is time (ISO notation)
- The second is Hs - significant wave height
- The third is the average or peak period, depending on the choice given in the Swan Spectral Spaceunder.
- The fourth is the peak direction
- The fifth is the directional distribution

In summary, the steps adopted were:



7.4. Norms that direct the resistance of the building elements

Numerous constructive solutions can be proposed to build flood containment. Maritime. The NBR 11682 (2006) i, defines the studies related to the stability of slopes and to the lessening of the effects of its instability in specific areas.

This standard indicates that preliminary procedures must be carried out before carrying out a slope stability and protection project. These preliminary procedures aim at the knowledge of the characteristics of the place, the consultation of maps and available surveys, the verification of legal and environmental restrictions, the preparation of a geologist survey report (preliminary geotechnical and / or instrumental investigations can be programmed to consolidate the report survey), the assessment of the need to implement emergency measures and the scheduling of geotechnical and geological investigations.

According to the norm, also, due to the risk present in the region where the work is to be carried out, in the elaboration of the flood containment project, the implementation of emergency measures for the protection of lives and property, in situations of imminent risk, according to the evacuation project issued by the fire department. Emergency passages and an alert system linked to weather information should also be considered. Thus, in case of detection of waves and winds with higher than average intensity, an alert can be launched and evacuation procedures from risky places must be carried out.

The main objective of the investigations is to define transversal and longitudinal sections to the slope that represent, with the greatest possible fidelity, the topographic and geological-geotechnical characteristics of the slope under study, emphasizing the stratigraphy and geomechanical properties.

According to NBR 8044 (2013) i, the following studies must be carried out before carrying out any work on slopes:

a) geological-geotechnical sections resulting from the interpretation of the investigations .;

b) solution for eventual treatment of dam foundations and attached structures;

c) basic specifications for the dam massif and foundation of the massif and attached structures;

d) identification of the loan area (s);

e) definition of the crest width and slope slope;

f) internal drainage of the earth mass;

g) protection and surface drainage of the slopes;

h) river closure and diversion system;

i) instrumentation of the massifs (landfill and foundation), defined in sufficient detail to allow the quantification of the works;

The investigations and surveys necessary for the development of a geotechnical project, before the implementation of the system, must therefore obey the NBR 8044 standard.

The geological-geotechnical profile obtained from the investigations of the terrain, and comprising the layers of soil and rocks, with their physical and mechanical characteristics, constitutes a mandatory element for the study / project of stabilization of the slope.

According to Coutinho and Severo (2009) ii the investigation and obtaining of project parameters for the analysis of slope and slope stability is essential, as it is part of the process of geotechnical characterization and the obtaining (in the field and laboratory) of the properties and / or relevant parameters for the execution of engineering projects, with a view to obtaining the required stability for materials and soils susceptible to landslides. It is important, based on these data, to obtain a geotechnical characterization, with risk analysis and consideration of factors of causes. Basic aspects of soil behavior in general, and in particular, residual soils, colluviums and sediments, should be discussed; with emphasis on aspects related to characterization, voids index, permeability, saturated (peak and residual) and unsaturated resistance, and influence of suction on soil behavior.

Thus, for the implementation of a project, a topographic survey must be carried out, which must clearly indicate the contour of the slipped area (if applicable), the location of geotechnical investigations (if available), any existing constructions and any other structures, roads water courses and emergencies, outcrops and rock blocks, as well as cracks, cracks and

In addition to carrying out surveys and subsequent laboratory analysis, to characterize the slope and determine the stratigraphy of the terrain. The number of soundings must be such that it allows an adequate interpretation of the massif, especially of the regions potentially unstable or affected by the works to be carried out.

The rock cores obtained through rotary drilling should be classified by geologist, identifying the type of rock, degree of alteration and fracturing. Field geotechnical investigations should be directed towards obtaining the geotechnical profile that will guide the stability calculation model.

The monitoring of a slope at a preliminary stage, or during the actual development of the project, can, in certain cases, be an important data for investigating the terrain. In this case, the installation of instruments to control the piezometric level and the movements (horizontal and vertical) of the slope must be programmed together with the geotechnical investigations.

In special cases, in which the designer identifies the need for monitoring after the completion of the investigations on the slope, he must specify it in the project or in additional documentation during the service or construction phase.

Also according to the recommendations of the standard, at the end of the work, the developer must prepare a manual / tutorial to be sent to the owner. In this manual, all the measures in terms of maintenance of the work to be followed by the owner must be included. Both the type of service to be performed and its frequency should be defined in the manual.

The recommendations in the manual should aim to maintain the characteristics of its design and use.

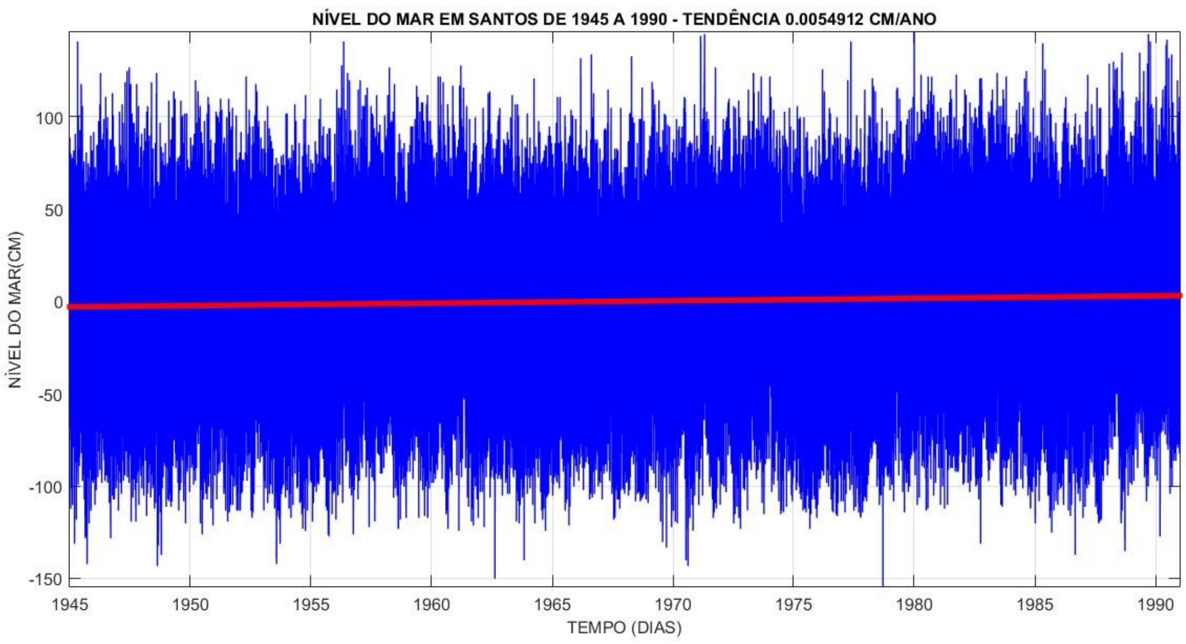
If there is an indication of a project, or need defined during or after the slope stabilization works, to monitor its behavior with instrumentation, the entire service must be performed according to specific planning.

8. Results obtained

8. 1. Time series analysis of data

The first study carried out was the analysis of sea level time series obtained from 1945 to 1990, using tide gauges, and from 1993 to 2013, using altimetric satellites. With the aid of programming in Matlab language, used with a license kindly granted to the USP community for the purposes of scientific research, it was possible to obtain the series of tide gauge data shown in Figure 14.

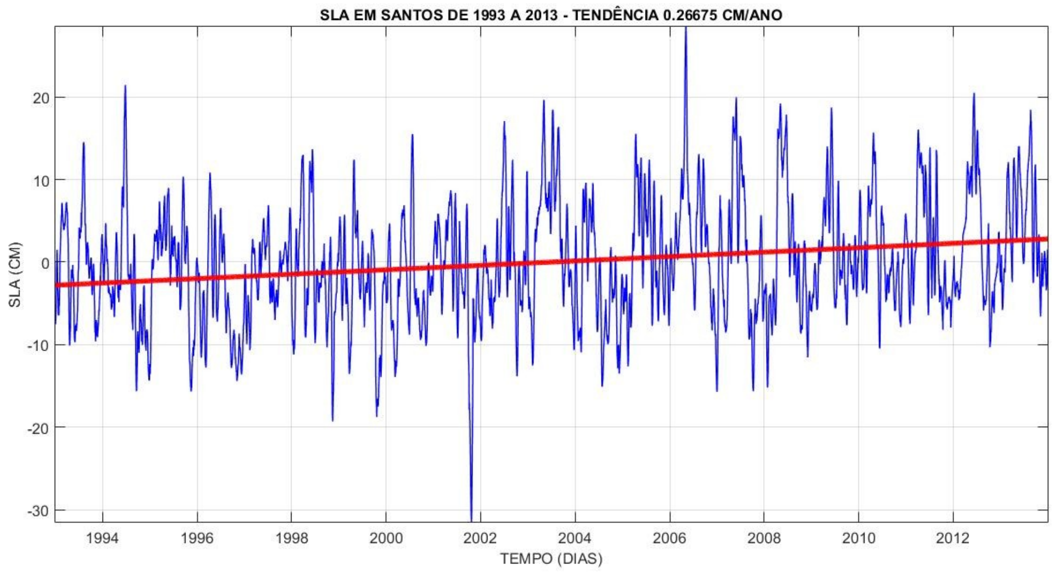
Figure 14 - Sea level data (in cm) from 1945 to 1990, obtained using a tide gauge in the Santos region and trend (in cm / year).



Source: Produced by the author.

It is observed that the tendency to increase sea level, for the period from 1945 to 1990, was 0.0054912 cm / year.

Figure 15 - Sea level data (in cm) from 1993 to 2013, obtained using altimetric satellites, in the Santos region and trend (in cm / year).



Source: Produced by the author based on data from HARARI (2013).

It is observed that the tendency to increase sea level, for the period from 1993 to 2014, was 0.266675 cm / year.

The rate of increase in sea level in the period from 1993 to 2014 was much higher than from 1945 to 1990, it can be inferred that this occurred because the series were obtained for different periods. The methods of obtaining data were also different methods, the first using tide gauge data and the second using altimetric data, since the region's tide gauge was disabled after 1990 and it was no longer possible to obtain data from it.

These rates of increase indicate that air pollution, urbanization and soil sealing have been worsening in recent decades.

This brief analysis of sea level rise may serve as a starting point for further work on the causes of rising sea levels. It is not possible, at this moment, to relate this increase in sea level directly with Global Warming. Therefore, a detailed study on the CO2 concentrations in the region in this period would be necessary, linked to a study of the predictions of the natural cyclical increase or decrease in sea level in the region according to the natural hydrodynamics of the region. In addition to a detailed analysis of the ocean-atmosphere interactions in this period. Thus, it could be possible to make significant insertions on this subject, which is so important for the current scientific scenario and of direct connection with society.

It must be emphasized that it is not possible to deny that the sea level has an upward trend in this region and this is an alarming scenario.

According to MORETTIN (2014) i, Fourier analysis can be seen as the algorithm to be used when dealing with stationary stochastic processes, as this analysis is the ideal tool to determine periodicities in such processes. In the analysis of time series, resulting from the observation of stochastic processes, a basic objective is to approximate a function of time by a linear combination of harmonics (sinusoidal components). In the case of the tides, we know the frequencies and we want to estimate the amplitudes and phases. Classical Fourier analysis is used to study deterministic functions or signals.

According to MORETTIN (2014) ii the discrete Fourier transform is very important in physical applications, to estimate the spectrum of a stationary process. The direct calculation of the transform involves N^2 complex operations; however, using an algorithm called fft (Fast Fourier Transform), it can be calculated. This transform is formulated in discrete time and discrete frequency. With λn being the Fourier frequencies in the sequence fj, assuming a finite number of sampled values from f (t), for 0 <t <T, namely, f0, f1,…, fN-1, at points tj = (t / N) j, j = 0, 1,…, N-1 the discrete Fourier transform is given by:

$$F_n = \sum_{j=0}^{N-1} f_j exp(-i\lambda_n j) \quad (7)$$

The inverse transform is:

$$f_t = \frac{1}{N}\sum_{n=0}^{N-1} F_n exp(-i\lambda_n t) \quad (8)$$

According to Parseval theorem:

$$\sum_{t=0}^{N-1} |f_t|^2 = \frac{1}{N}\sum_{n=0}^{N-1} |F_n|^2 \quad (9)$$

With the following relationships, for n = 1, 2 ,… , N; e k any integer:

$$cos\left((kN \pm n)\frac{2\pi}{T}t_j\right) = cos\left(\frac{2\pi n}{T}t_j\right) \quad (10A)$$

$$sin\left((kN+n)\frac{2\pi}{T}t_j\right)=sin\left(\frac{2\pi n}{T}t_j\right) \quad (10B)$$

$$sin\left((kN-n)\frac{2\pi}{T}t_j\right)=-sin\left(\frac{2\pi n}{T}t_j\right) \quad (10C)$$

It is possible to obtain a relationship between the true Fourier coefficients and the discrete ones

Thus, we used this discrete Fourier transform to analyze the spectrum of the process observed in the sea level data obtained from the tide gauge from 1945 to 1990 (Figure 16). We observed, in this spectrum, the predominance of the annual component, with an amplitude around 5 cm.

We also used the discrete Fourier transform to analyze the spectrum of the process observed in sea level data obtained from satellites, from 1993 to 2014 (Figure 17), which again indicates the predominance of the annual component, with a 5 cm amplitude..

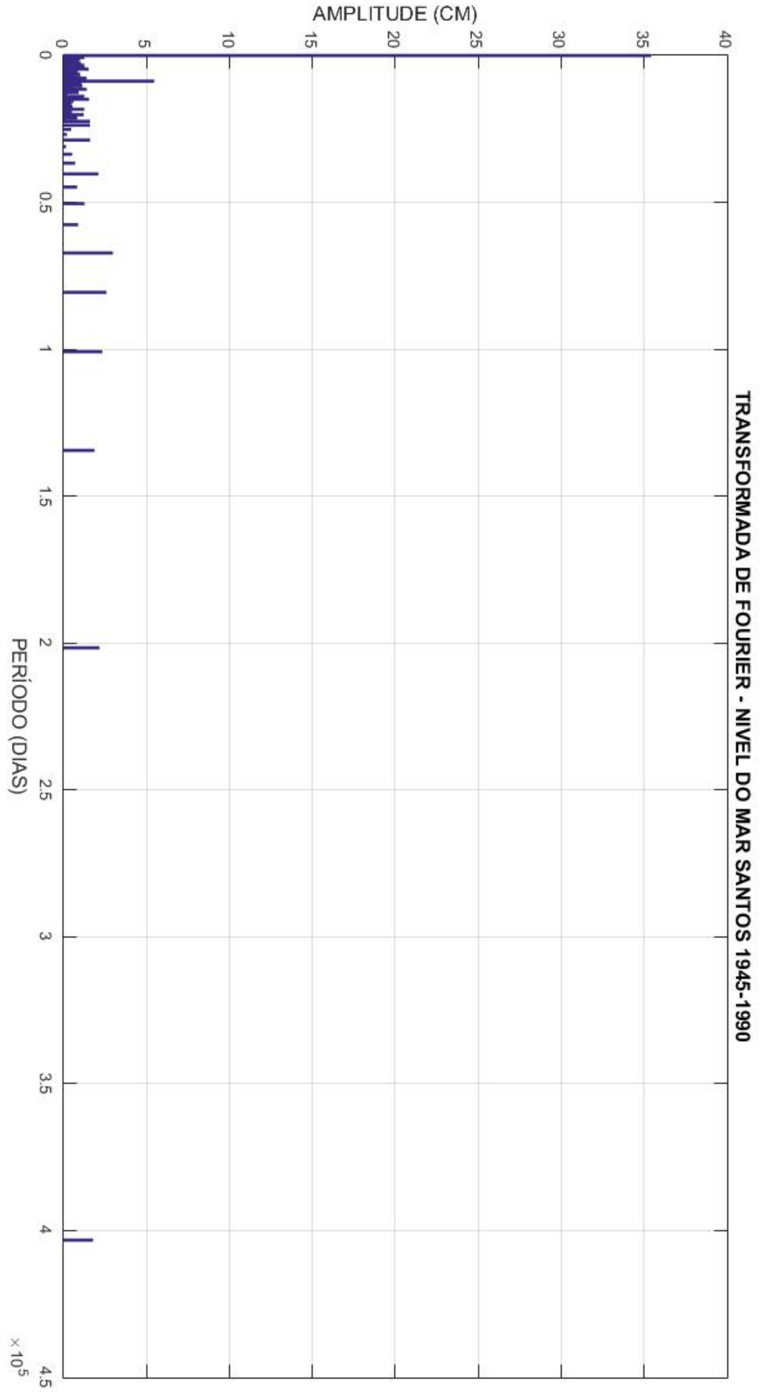


Figure 16 - Discrete Fourier transform based on sea level data obtained by a tide gauge in Santos, from 1945 to 1990. Source: produced by the author.

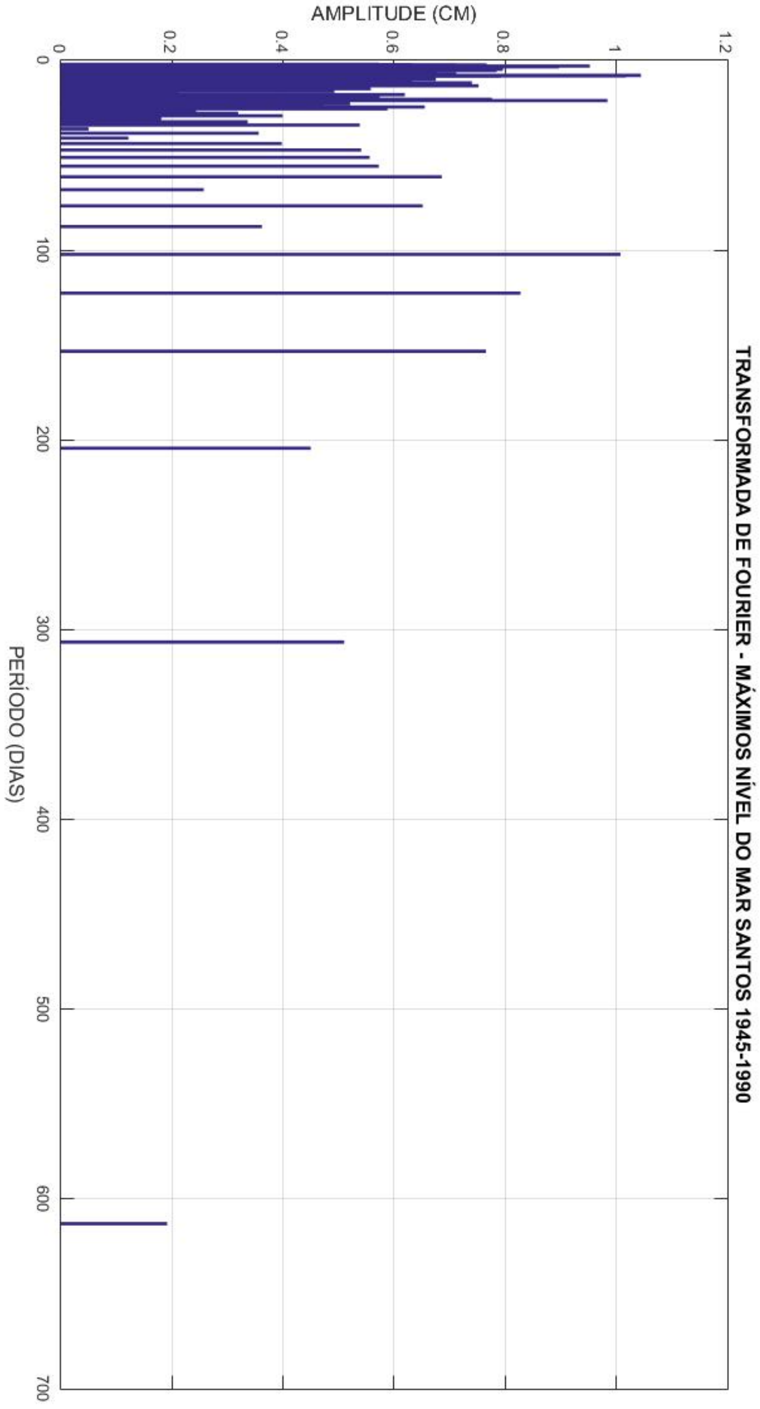
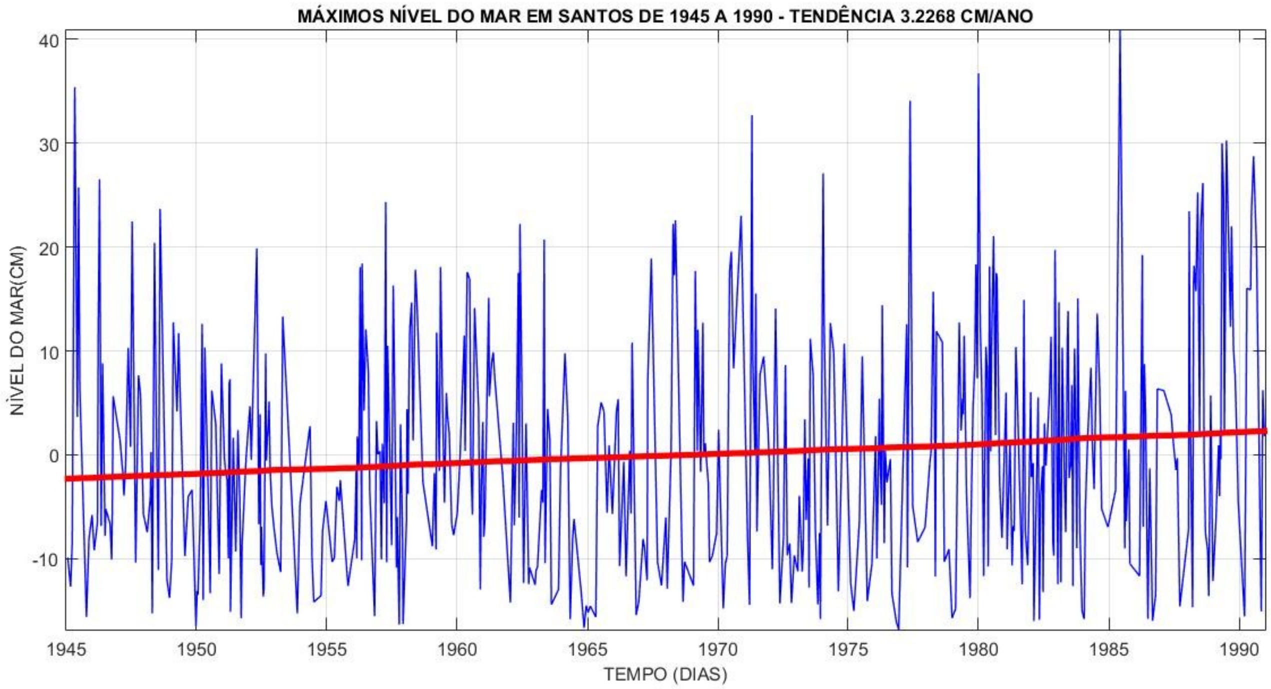


Figure 17 - Discrete Fourier transform from sea level data obtained by altimetric satellites in Santos, from 1993 to 2014. Source: produced by the author.

In addition to the sea level data, it was possible to analyze maximums observed in the sampled periods.

For the period from 1945 to 1990, we have the maximum time series in Figure 18. It can be seen that the trend of increasing sea level maximums for the period from 1945 to 1990 was 3.2268 cm / year.

Figure 18 – Series of sea level maximums (in cm) from 1945 to 1990, obtained using tide gauges, in the Santos region and trend (in cm / year).



Source: produced by the author.

The series of maxima obtained by the tide gauge was resampled for constant time intervals and subjected to analysis by the discrete Fourier transform, obtaining the result shown in Figure 20, with different intervals between 0.5 cm and 1.0 cm.

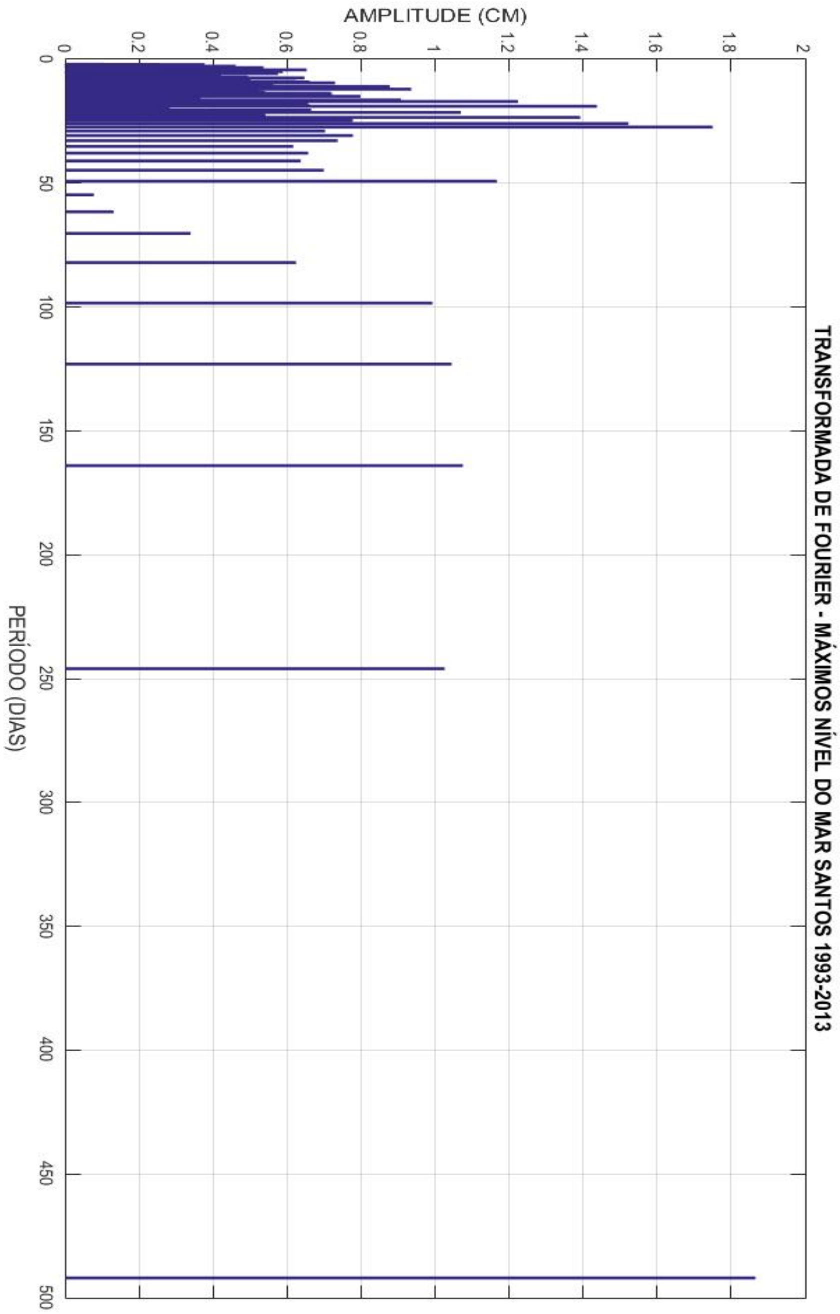
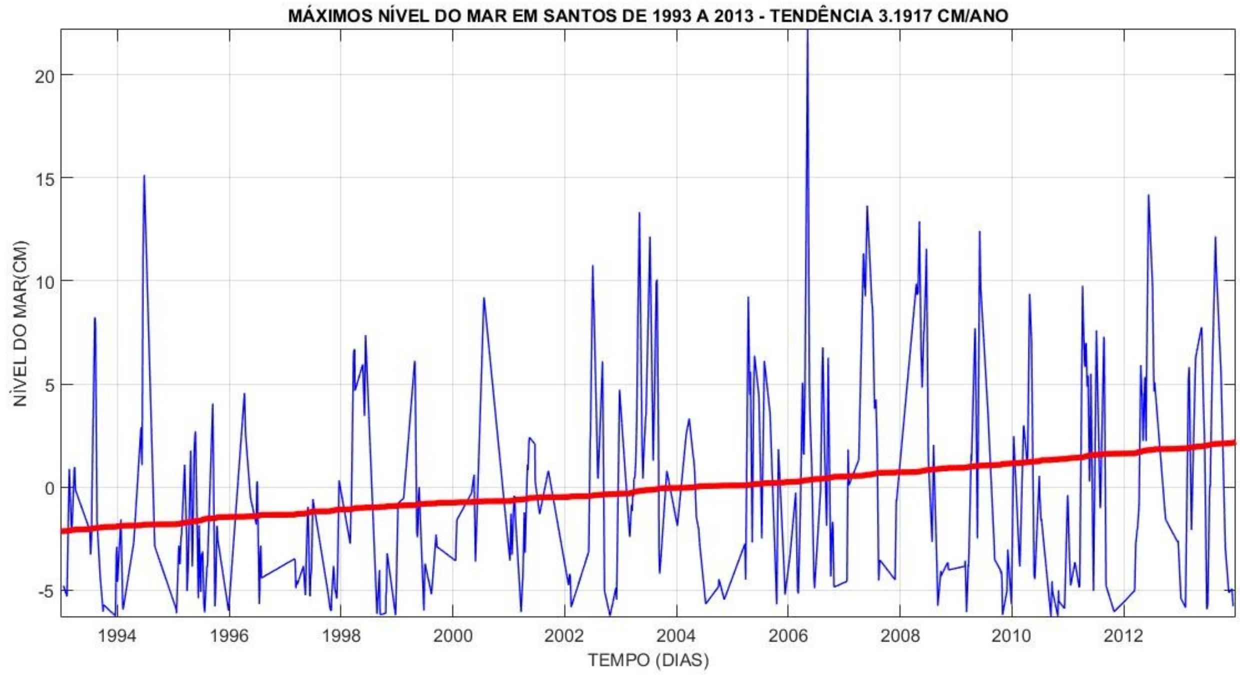


Figure 20 - Discrete Fourier transform of the series of sea level maximums, obtained from a tide gauge in Santos, from 1945 to 1990. Source: Produced by the author.

For the period from 1993 to 2014, we have the series of maxima shown in Figure 21, whose upward trend was 3.1917 cm / year.

Figure 21 – Series of sea level maximums (in cm) from 1993 to 2014, obtained through satellites, in the Santos region and trend (in cm / year).



Source: Produced by the author.

The series of maxima obtained by altimetric satellites was resampled for constant time intervals and subjected to analysis by the discrete Fourier transform, obtaining the result shown in Figure 22, with different intervals between 1.0 cm and 1.5 cm.

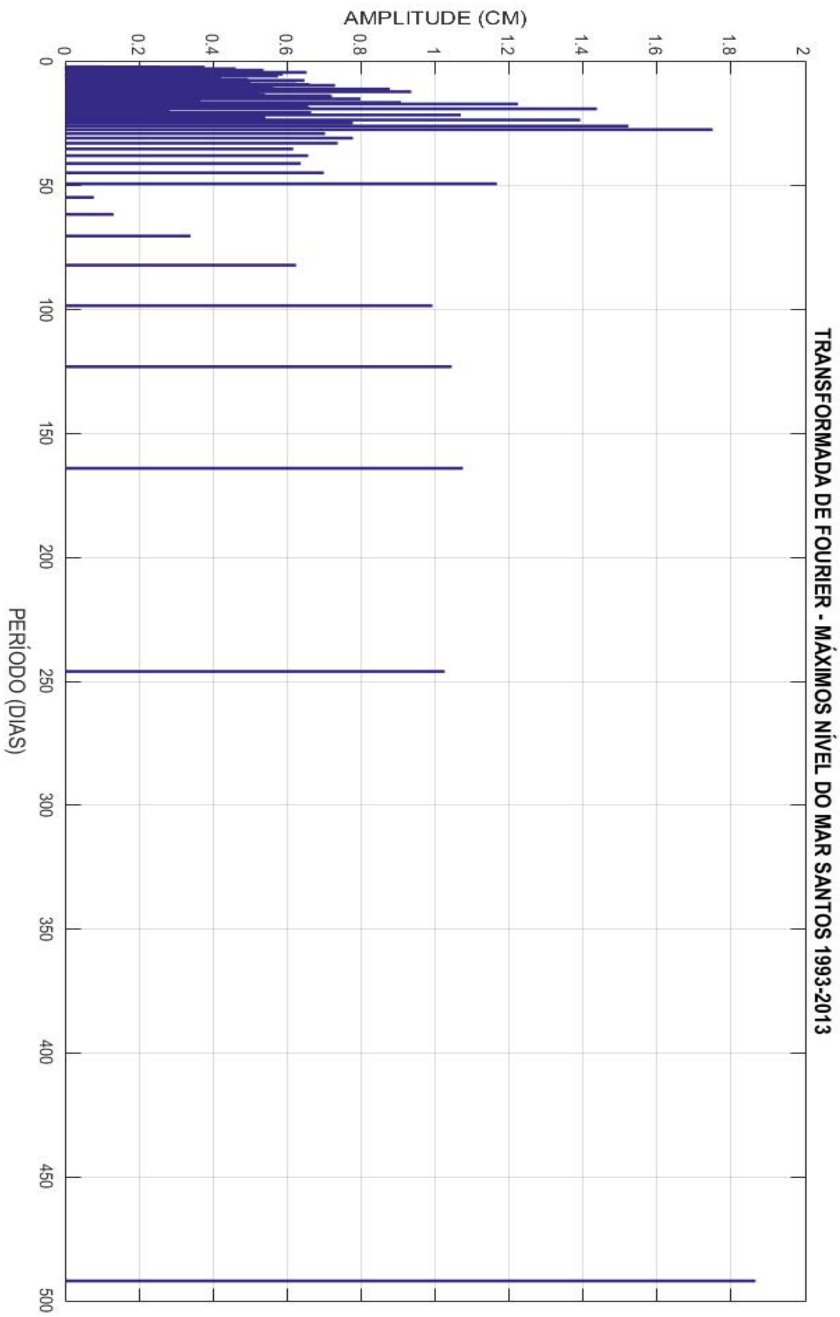


Figure 22 - Discrete Fourier transform of the series of sea level maximums, obtained from satellites in Santos, from 1993 to 2014.

Source: Produced by the author.

8. 2. Hydrodynamic modeling 2D and 3D

Using the Delft 3D software, we obtained values for sea level (in meters), current components (in meters per second) and current intensity (in meters per second) throughout the month of August 2016, at hourly intervals . Initially, these values come from 2D modeling, using only tidal forcing.

The 5 observation points were chosen according to the gradual distance from the Costa directed from Ponta da Praia, allowing the monitoring of the evolution of the model results (Figure 23).

Next, we performed 3D modeling, using meteorological data from the Climate Forecast System Reanalysis (CFSR), produced by the National Center for Atmospheric Research (NCAR), of the National Center for Environmental Prediction (NCEP). The NCEP updated the CFS to version 2 on March 30, 2011. Average sea level data and temperature and salinity profiles at the edges of the grid were specified from the results of the European global oceanic model of CMEMS - Copernicus Marine Environment Monitoring Service.

Next, we will show the results obtained through 3D modeling, starting with the sea level time series and currents, in the 5 observation points (Figures 24 to 28). From the series at the chosen observation points it was possible to choose the best periods of analysis of extreme positive and negative levels, in the simulated period.

Figure 23 – Observation points chosen in the grid, having the indexes of (row, column): (55, 73); (32, 56); (27, 44); (36, 27) e (50, 9).

Source: Produced by the author by the software Delft 3D and Matlab.

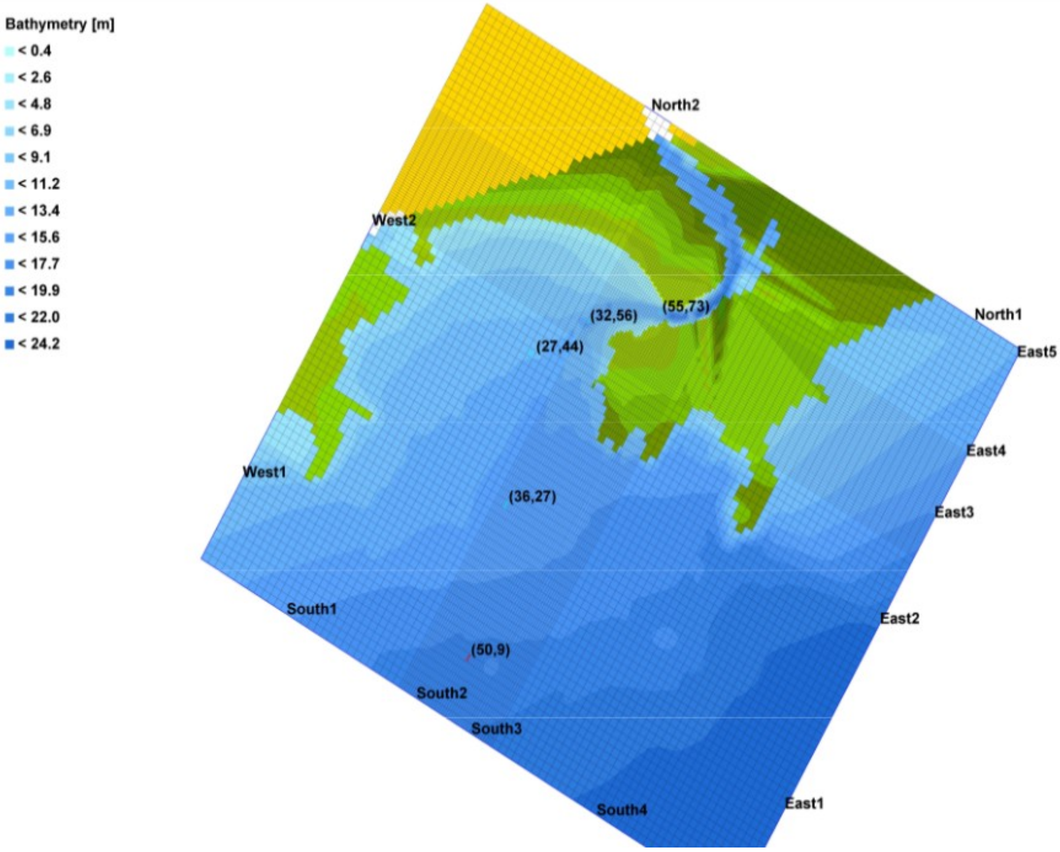
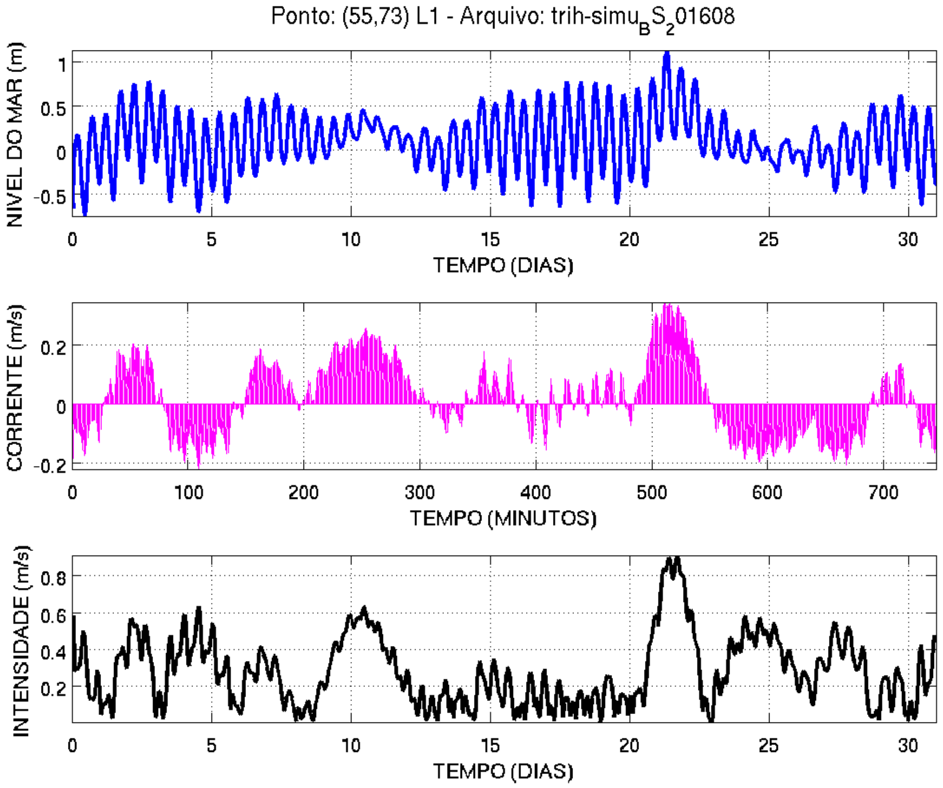
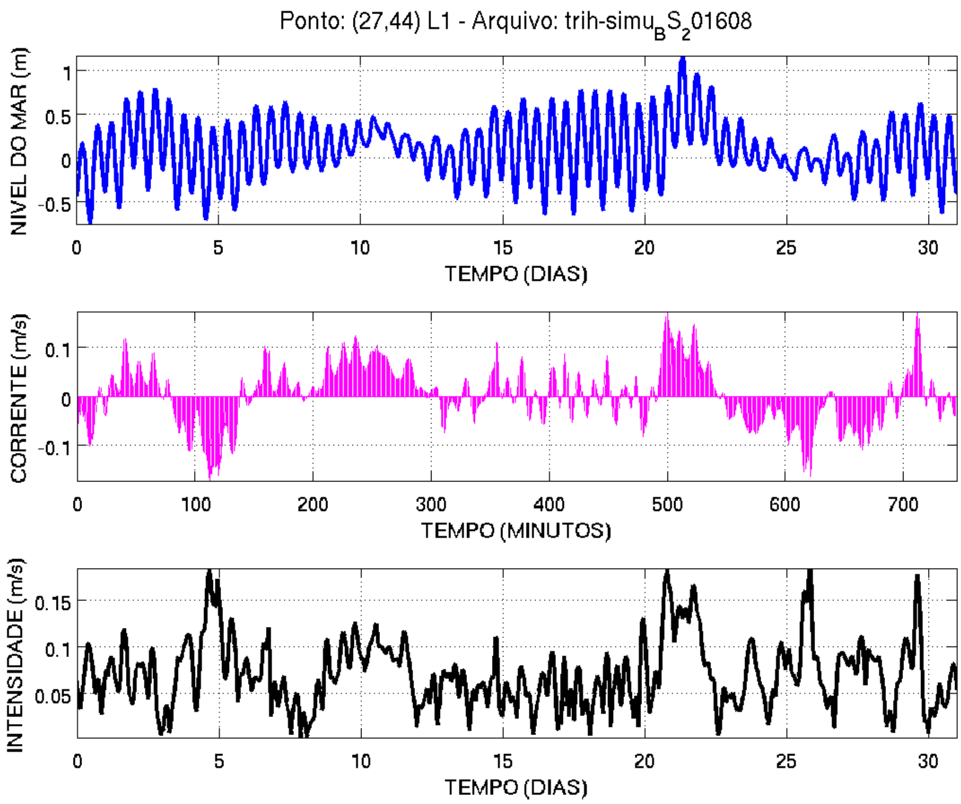


Figure 24 - Results of the sea level model (in meters), current vectors (in meters per second) and current intensity (in meters per second) at the observation point (55,73).



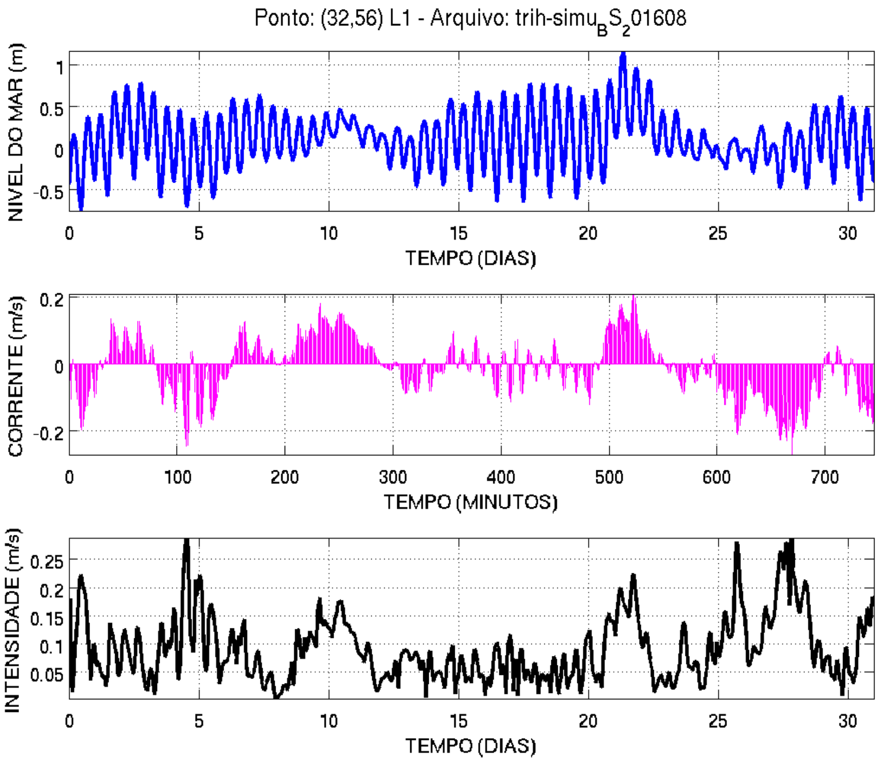
Source: Produced by the author by the software Delft 3D and Matlab.

Figure 25 - Results of the sea level model (in meters), current vectors (in meters per second) and current intensity (in meters per second) at the observation point (27,44).



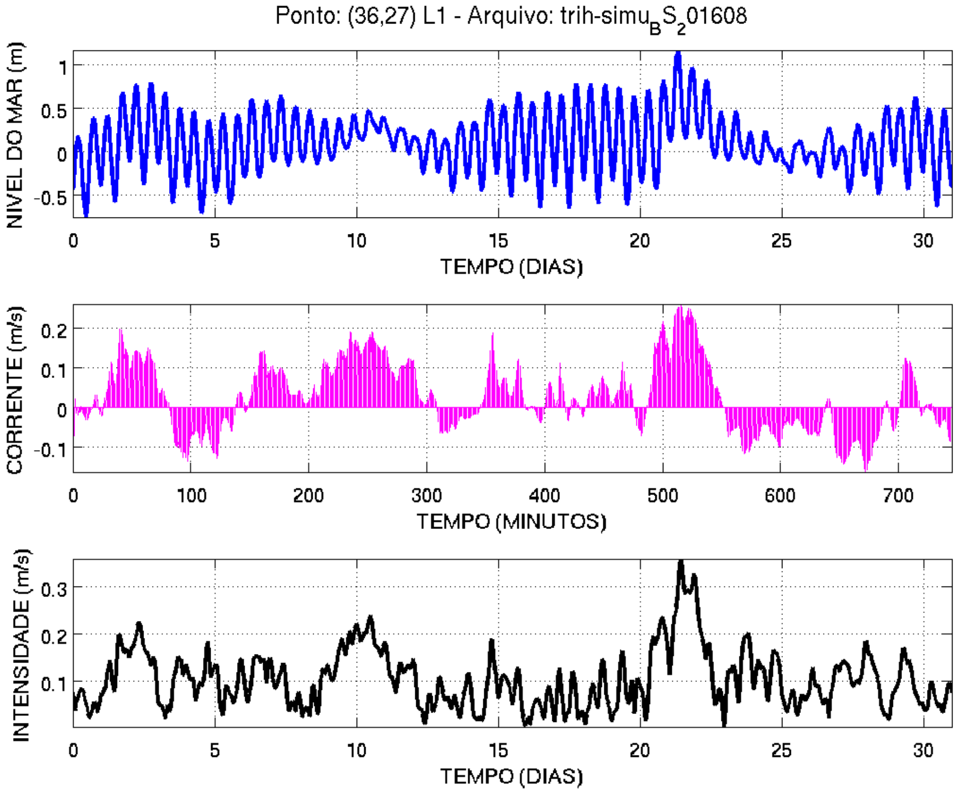
Source: Produced by the author by the software Delft 3D and Matlab.

Figure 26 - Results of the sea level model (in meters), current vectors (in meters per second) and current intensity (in meters per second) at the observation point (32,56).



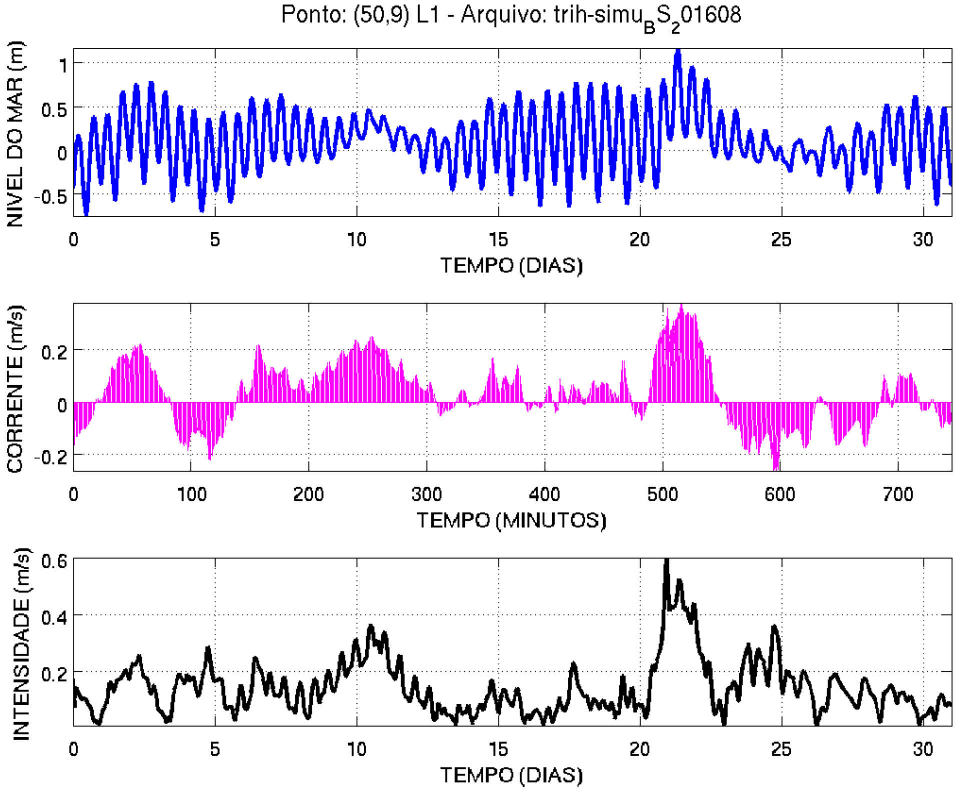
Source: Produced by the author by the software Delft 3D and Matlab.

Figure 27 - Results of the sea level model (in meters), current vectors (in meters per second) and current intensity (in meters per second) at the observation point (36,27).



Source: Produced by the author by the software Delft 3D and Matlab.

Figure 28 - Results of the sea level model (in meters), current vectors (in meters per second) and current intensity (in meters per second) at the observation pointo (50,9).



Source: Produced by the author by the software Delft 3D and Matlab.

Ponto	nm_max (m)	Nível do mar em relação ao fundo(m)
(55, 73)	0,73	10,73
(32, 56)	0,75	13,70
(36, 27)	0,73	15,72
(27, 44)	0,74	11,99
(50, 9)	0,73	19,41

Table 2 - Observation points, maximum levels and sea levels in relation to the bottom, in the period of interest. Source: Produced by the author, generated by Delft 3D software.

From the results of the Delft 3D hydrodynamic model processing, maximum mean sea level values were obtained in August 2016, for the 5 selected observation points (Table 2). Minimum sea levels were not analyzed, as they do not affect floods.

The biggest flood, in the Ponta da Praia region, occurred on August 21st at 18h -3GMT (21h + 0GMT). So, we chose this day to analyze the results of the model, using the Delft 3D Quickplot tool. On this day we can observe average sea levels above 0.70 meters (Table 2).

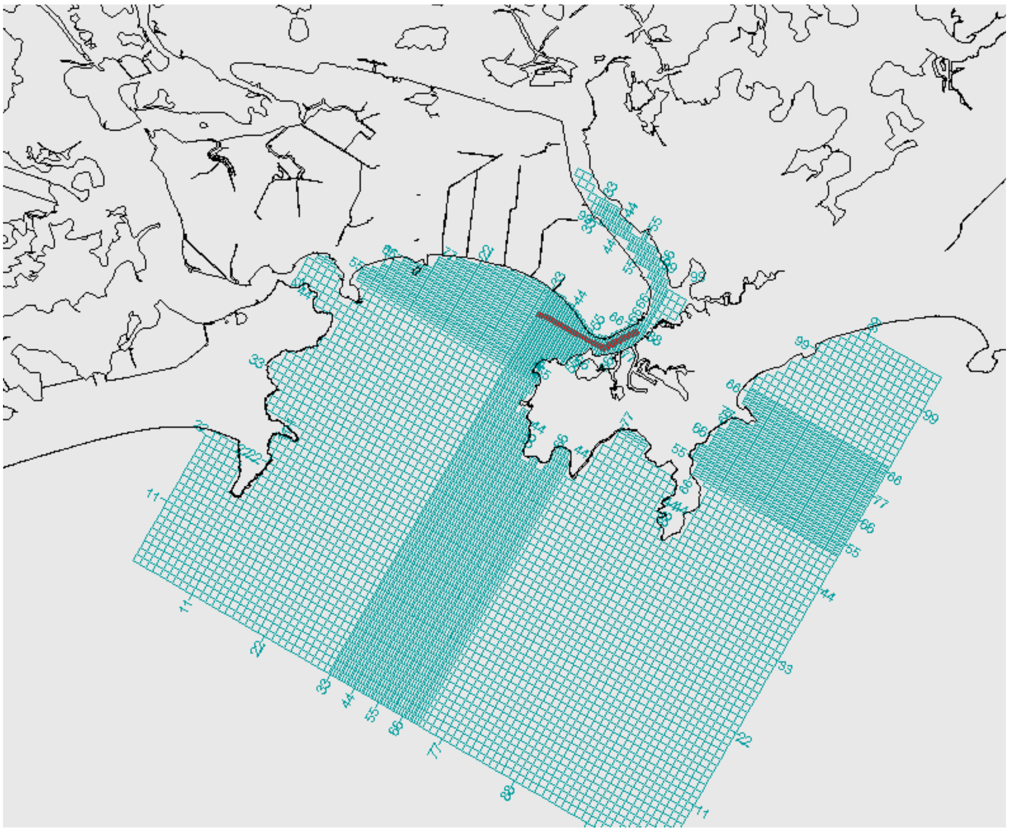
In addition to the 5 observation points, a continuous section of grid points near Ponta da Praia was selected for detailed analysis of the modeling results, located in Figure 29. In this section, the vertical profiles of properties calculated by the model were analyzed, through the Delft 3D Quickplot tool. There is a marked influence of the channel made artificially for the passage of boats to the port of Santos; as this area has periodic dredging, the results presented represent the situation found specifically on this day.

Figures 30 to 35 show the results of the model for the vertical profiles in the section delimited in Figure 29, for the variables: temperature, salinity, specific mass, magnitude of currents, hydrostatic pressure and turbulent energy. In these figures, the geographical positions are relative to the WGS 84 (World Geodesic System) datum.

Among the vertical profiles of variables calculated by the model in the region near Ponta de Praia, hydrostatic pressure (Figure 34) is of particular importance; values around

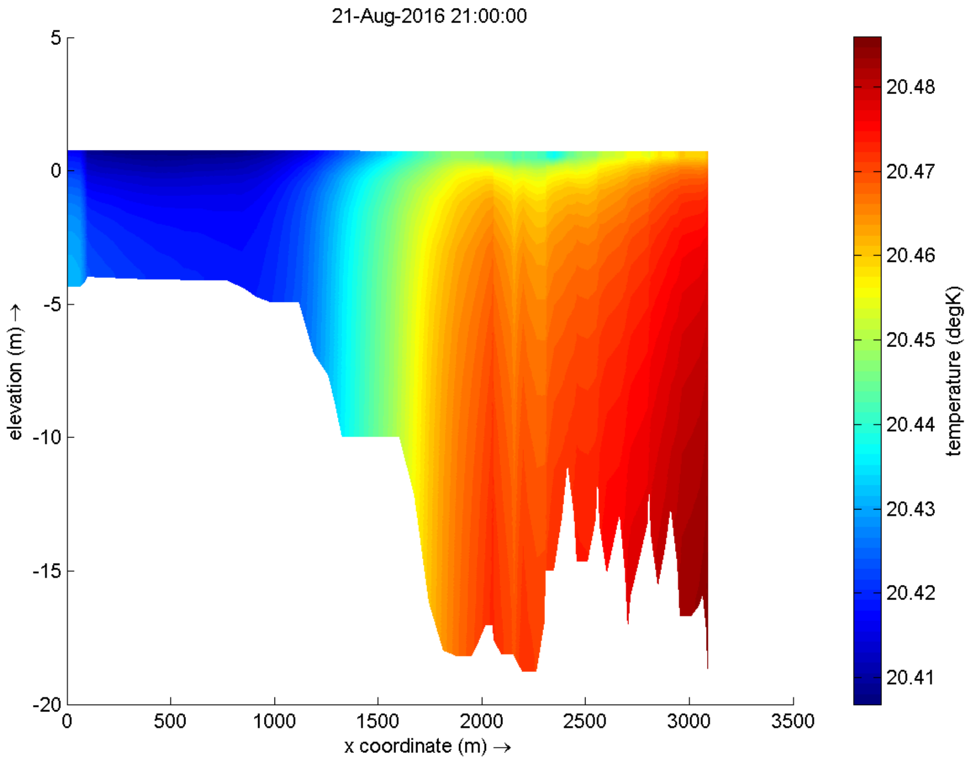
20000 kg / m / s^2, close to the surface, must be considered in the flood containment project.

Figure 29 - Section for data analysis in the region of interest of the grid.



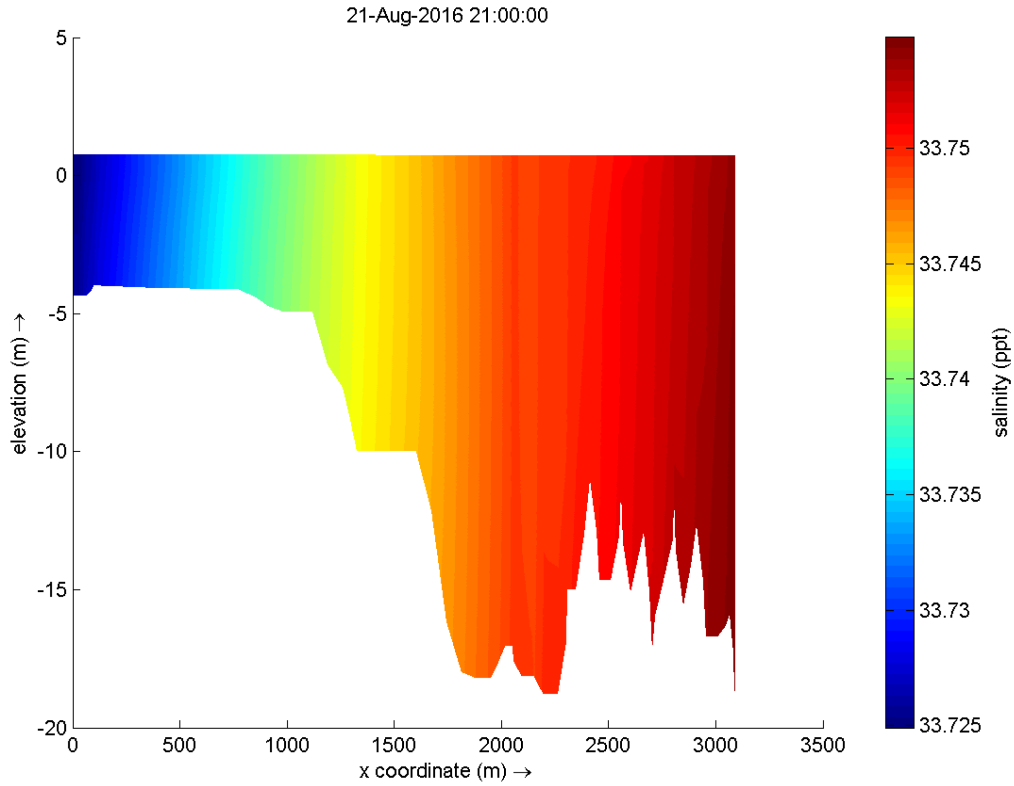
Source: Produced by the author by the software Delft 3D.

Figure 30 - Temperature results of the numerical model, in the vertical section near Ponta da Praia, on August 21, 2016 (9:00 pm + 0GMT, 6:00 pm -3GMT). Levels in meters, temperature in degrees Celsius.



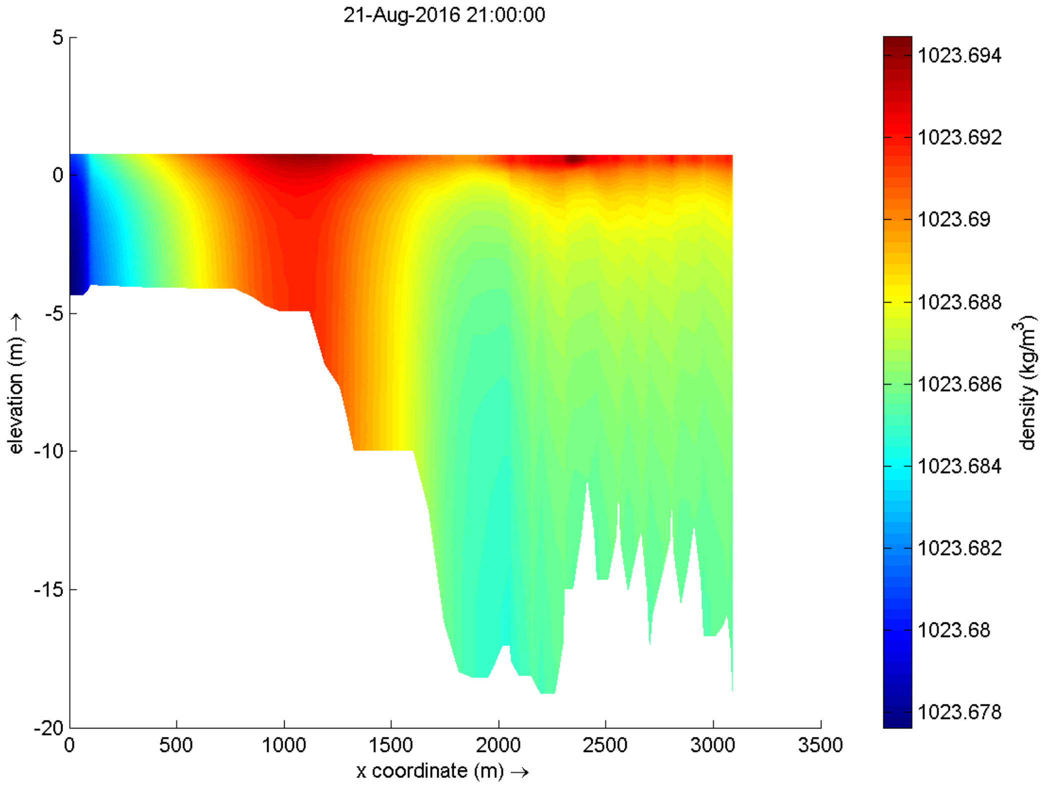
Source: Produced by the author by the software Delft 3D.

Figure 31 - Salinity results of the numerical model, in the vertical section near Ponta da Praia, on August 21, 2016 (9:00 pm + 0GMT, 6:00 pm -3GMT). Levels in meters, salinity in ppt.



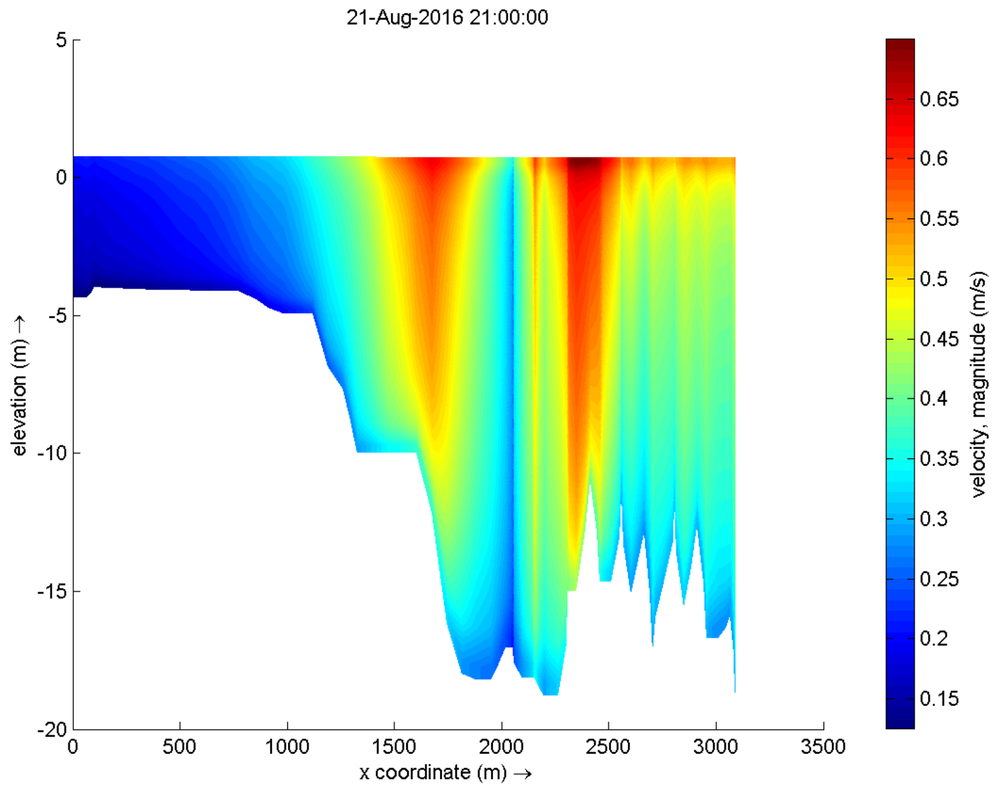
Source: Produced by the author by the software Delft 3D.

Figure 32 - Results of specific mass of the numerical model, in the vertical section near Ponta da Praia, on August 21, 2016 (9:00 pm + 0GMT, 18h -3GMT). Levels in meters, specific mass in kg / m3.



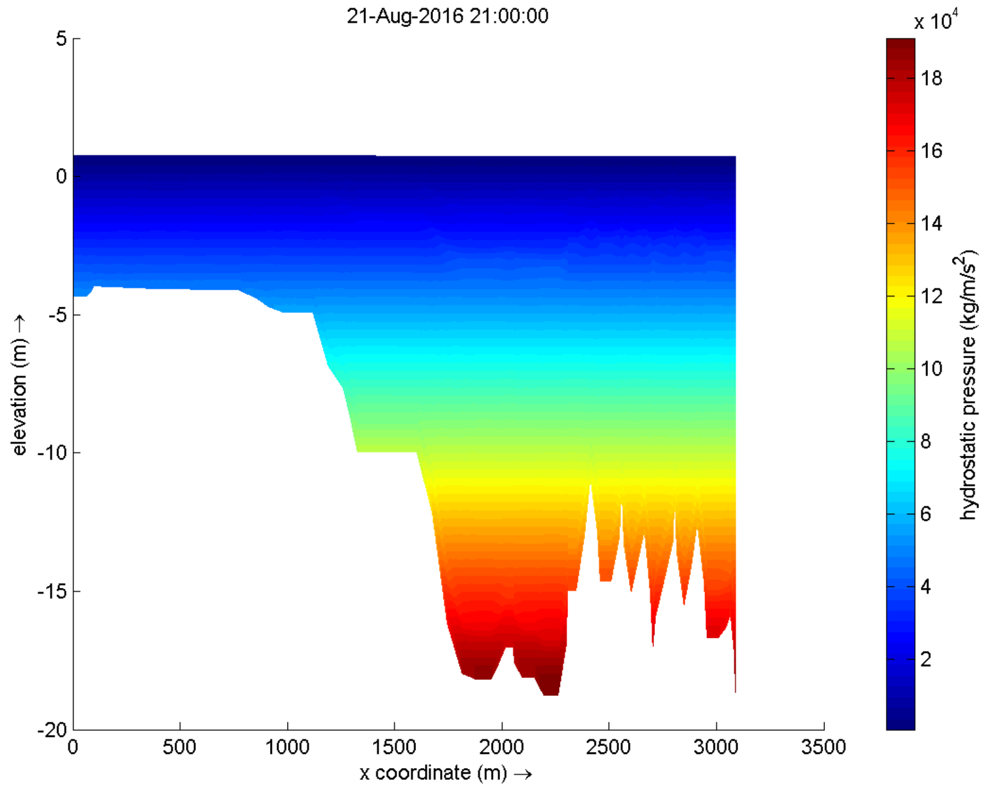
Source: Produced by the author by the software Delft 3D.

Figure 33 - Speed magnitude results of the numerical model, in the vertical section near Ponta da Praia, on August 21, 2016 (9:00 pm + 0GMT, 18h -3GMT). Levels in meters, magnitude in m / s.



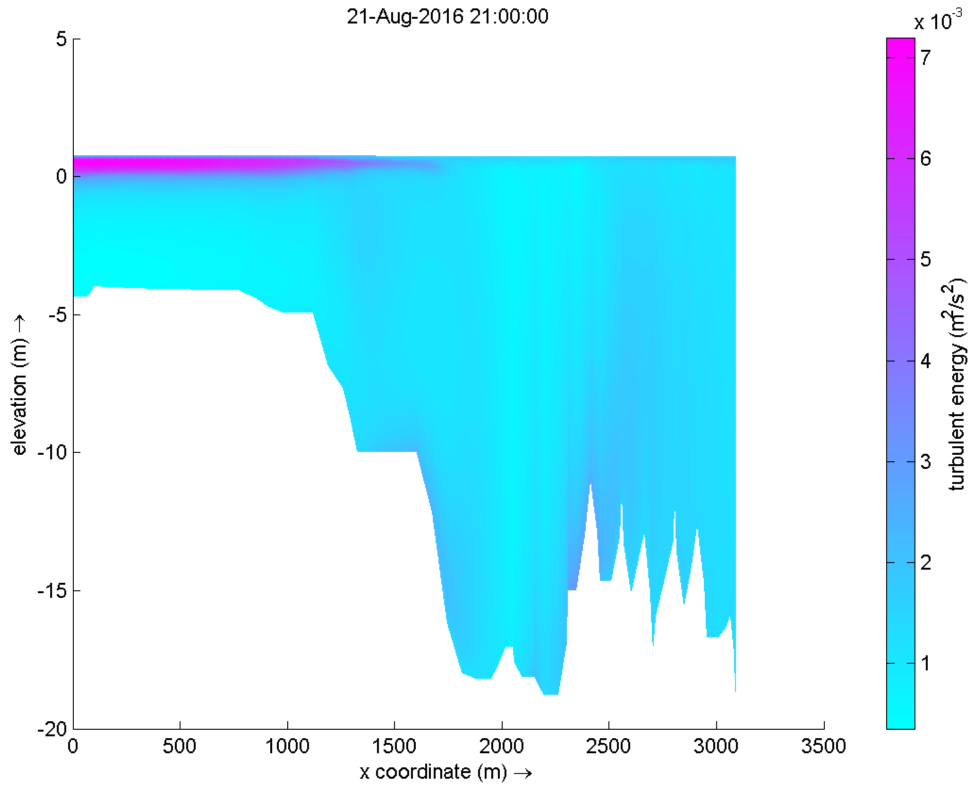
Source: Produced by the author by the software Delft 3D.

Figure 34 - Results of hydrostatic pressure of the numerical model, in the vertical section near Ponta da Praia, on August 21, 2016 (9:00 pm + 0GMT, 6:00 pm -3GMT). Levels in meters, hydrostatic pressure in kg/m/s².



Source: Produced by the author by the software Delft 3D.

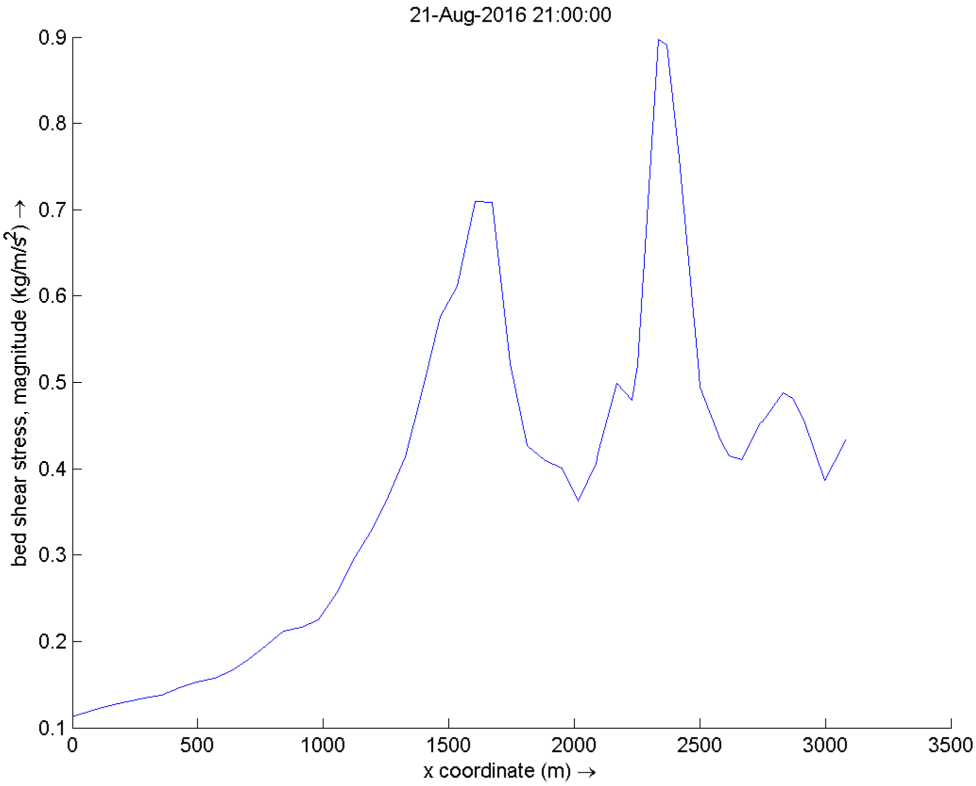
Figure 35 - Results of turbulent energy of the numerical model, in the vertical section near Ponta da Praia, on August 21, 2016 (9:00 pm + 0GMT, 6:00 pm -3GMT). Levels in meters, turbulent energy in m^2/s^2.



Source: Produced by the author by the software Delft 3D.

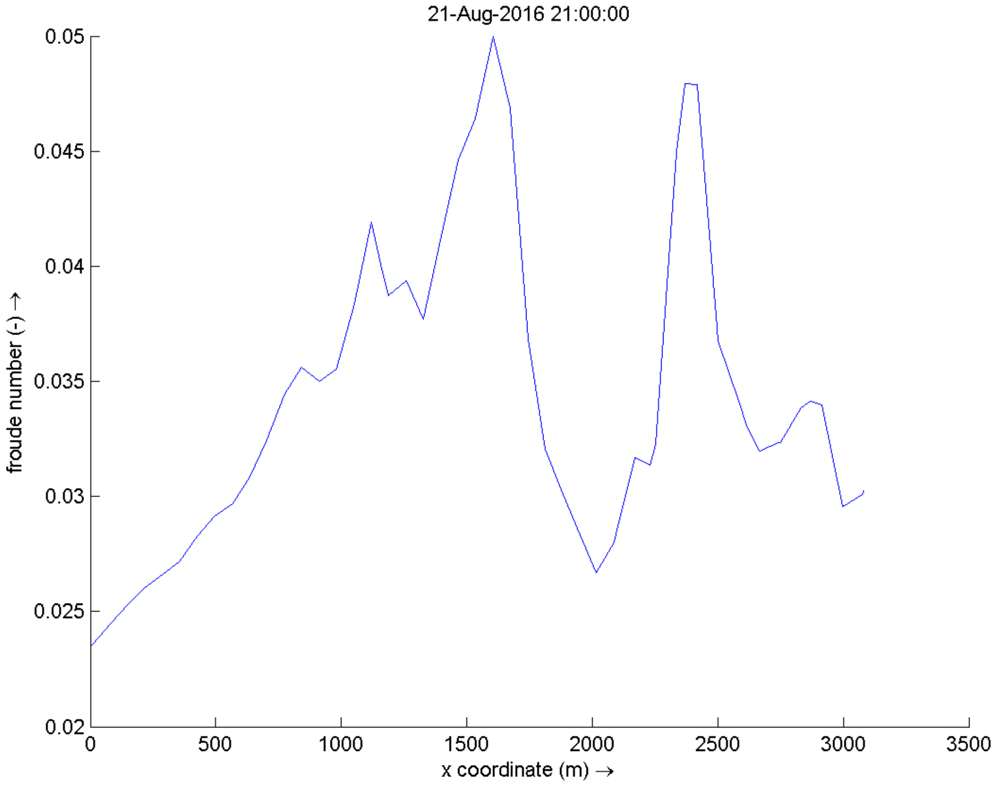
Next, values are presented along the section near Ponta da Praia, referring to the shear stress at the bottom and Froude number for the surface (indicating the places of greatest turbulence), in Figures 36 and 37.

Figure 36 - Shear stress results at the bottom of the numerical model, in the vertical section near Ponta da Praia, on August 21, 2016 (9:00 pm + 0GMT, 6:00 pm -3GMT). Levels in meters, tension in kg/m/s^2.



Source: Produced by the author by the software Delft 3D.

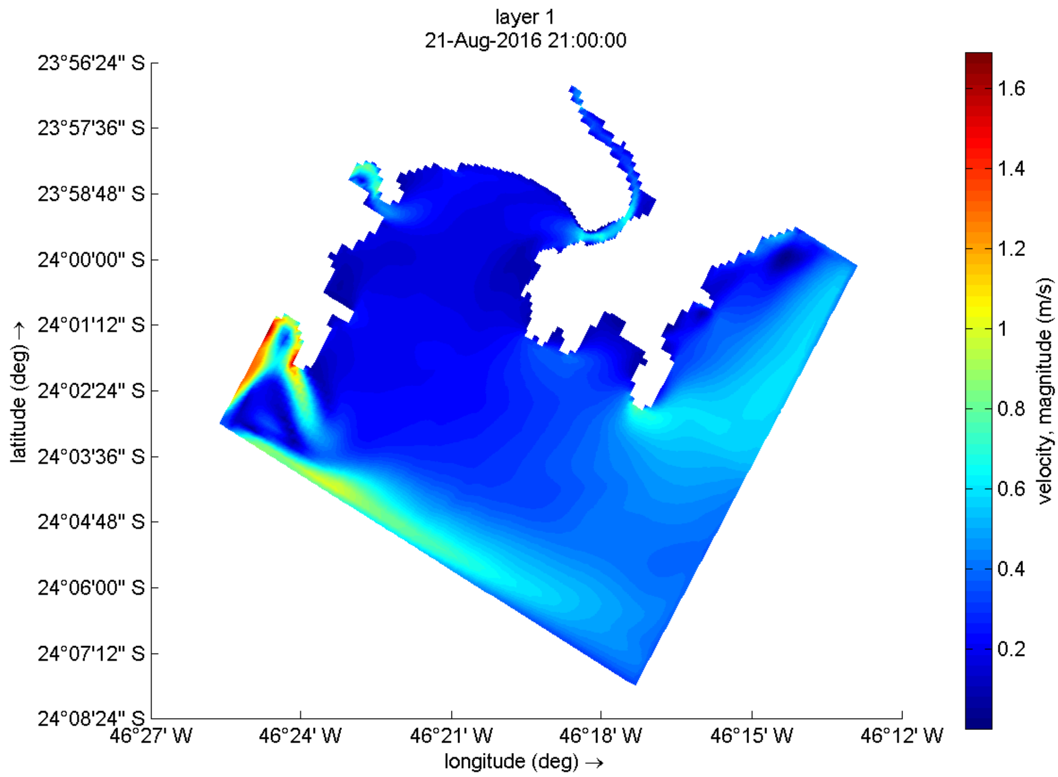
Figure 37 - Results of Froude's number on the surface of the numerical model, in the vertical section near Ponta da Praia, on August 21, 2016 (9:00 pm + 0GMT, 6:00 pm -3GMT). Levels in meters.



Source: Produced by the author by the software Delft 3D.

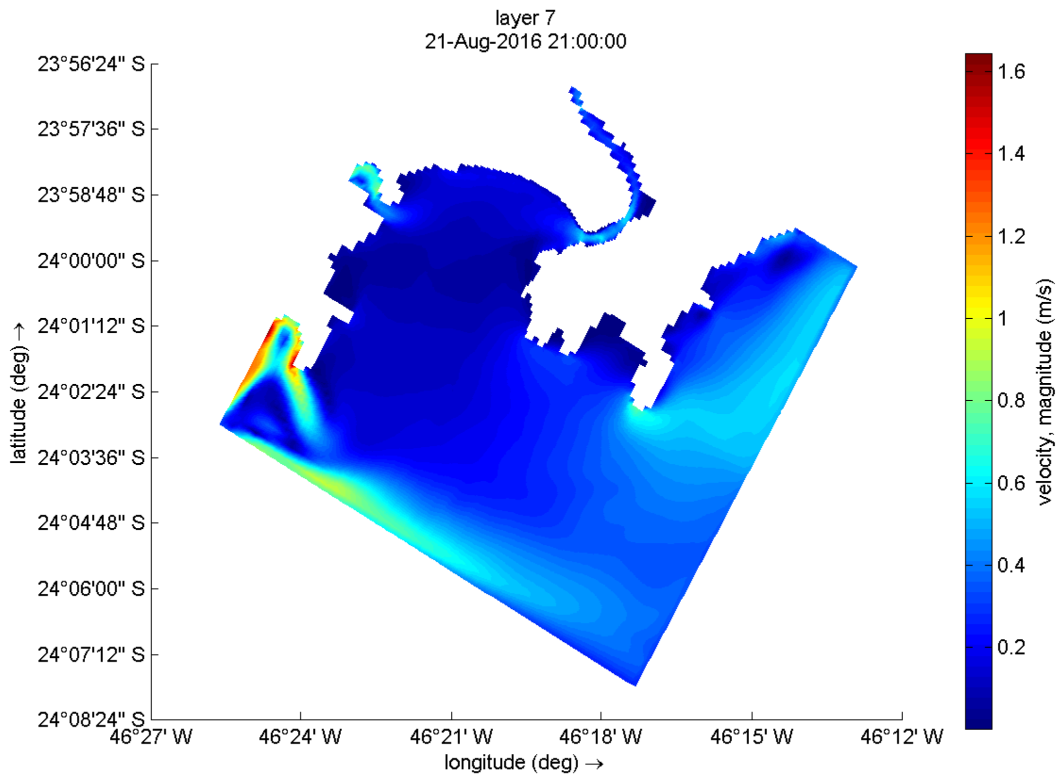
Next we will see the results obtained in the 3D model, in magnitude of those resulting from speed, in view of a division in 15 sigma layers, for the 21st of August 2016 (9:00 pm + 0GMT, 18h -3GMT). The results refer to the first layer (the closest to the surface), the seventh sigma layer (intermediate layer) and the fifteenth layer (closest to the bottom), in Figures 38 to 40.

Figure 38 - Results of current intensities of the numerical model, for the 21st of August 2016 (21h + 0GMT, 18h -3GMT), in the first layer. Intensity in m/s.



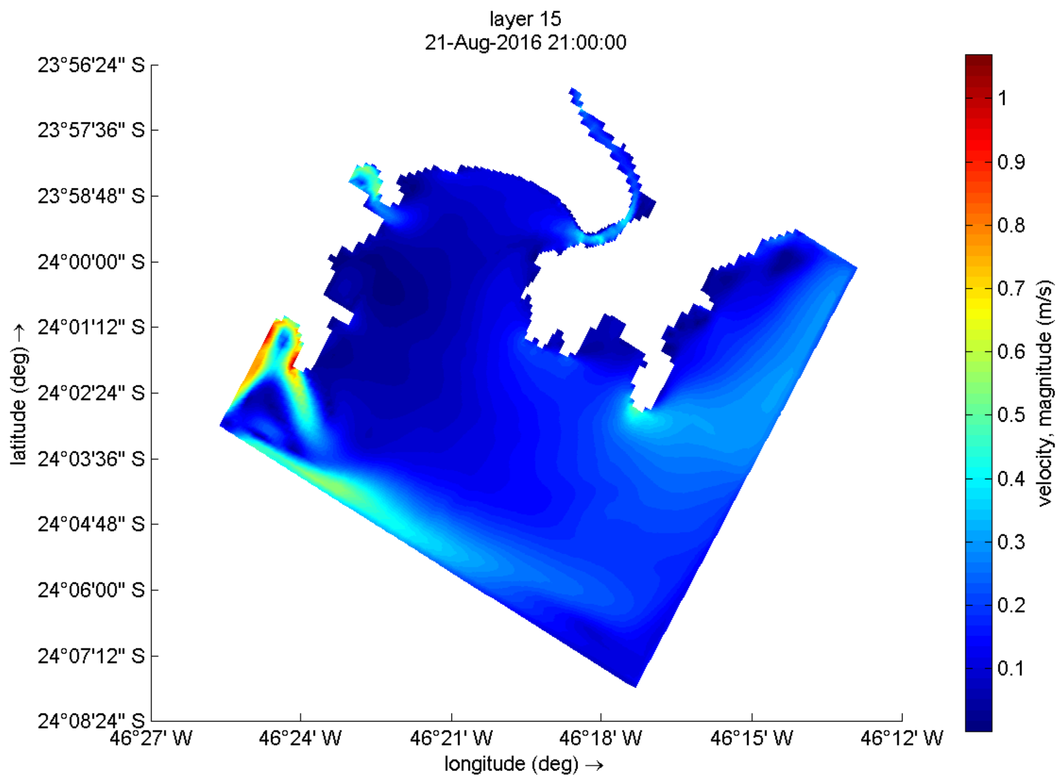
Source: Produced by the author by the software Delft 3D.

Figure 39 - Results of current intensities of the numerical model, for the 21st of August 2016 (21h + 0GMT, 18h -3GMT), in the intermediate layer. Intensity in m/s.



Source: Produced by the author by the software Delft 3D.

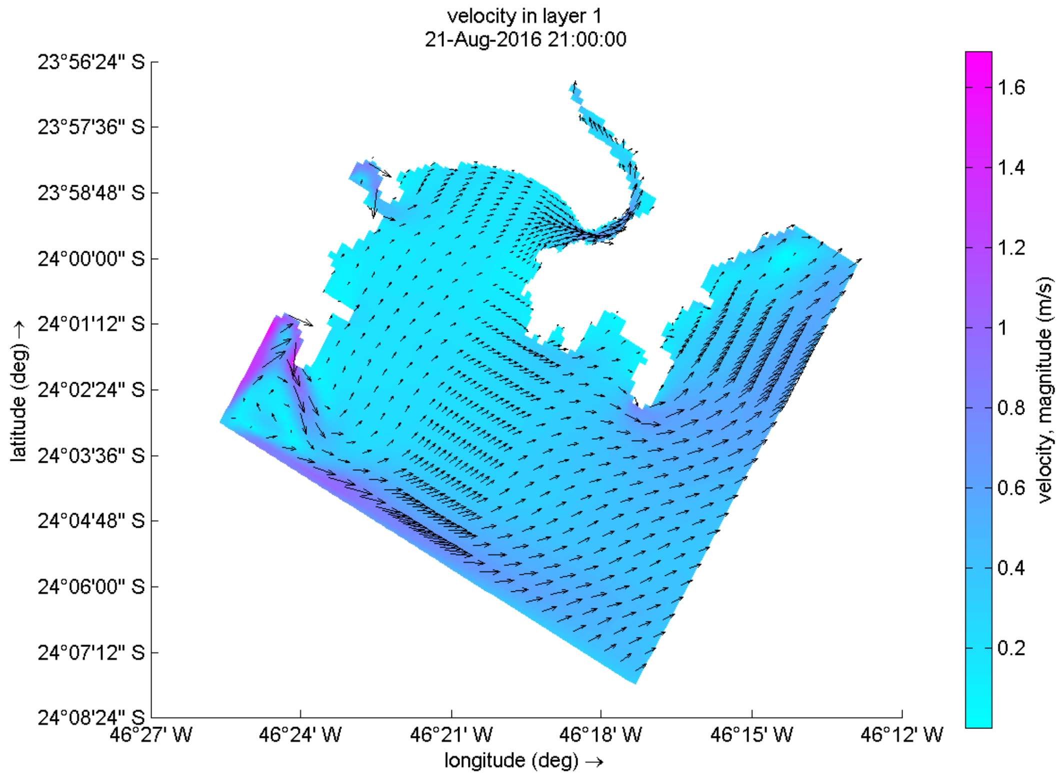
Figure 40 - Results of current intensities of the numerical model, for the 21st of August 2016 (21h + 0GMT, 18h -3GMT), in the bottom layer. Intensity in m/s.



Source: Produced by the author by the software Delft 3D.

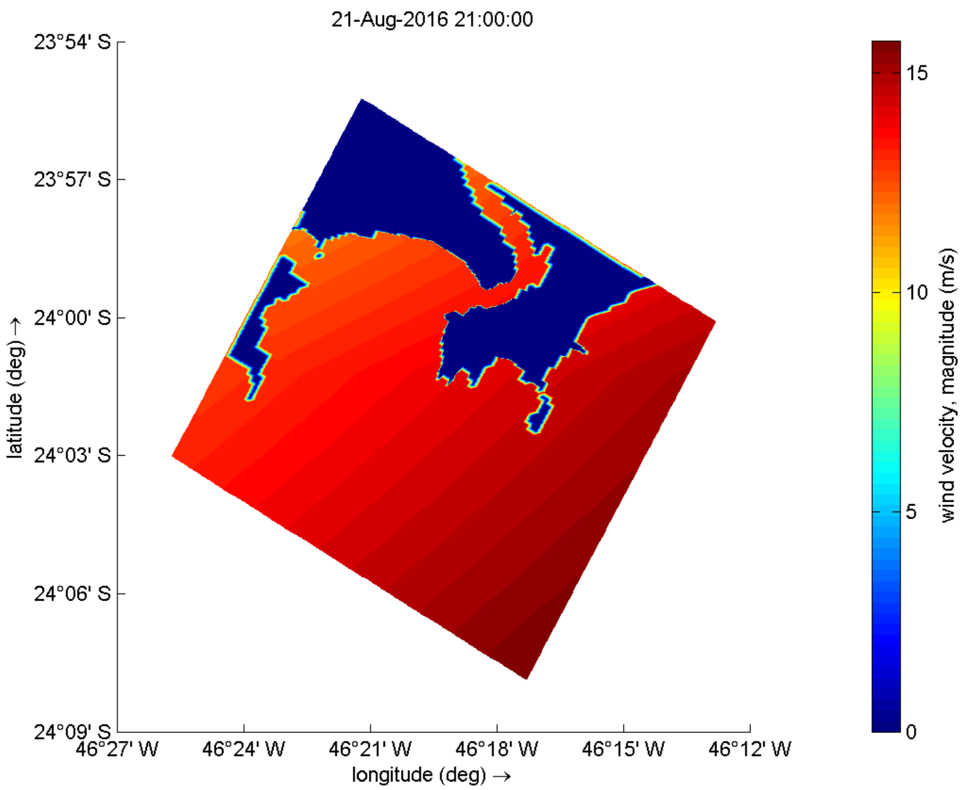
The following are the vector distributions of currents and wind intensity at the time of interest, August 21, 2016 (9:00 pm + 0GMT, 6:00 pm -3GMT), across the grid, in Figures 41 and 42.

Figure 41 - Current vector results of the numerical model, for the 21st of August 2016 (21h + 0GMT, 18h -3GMT), in the surface layer. Intensity in m/s.



Source: Produced by the author by the software Delft 3D.

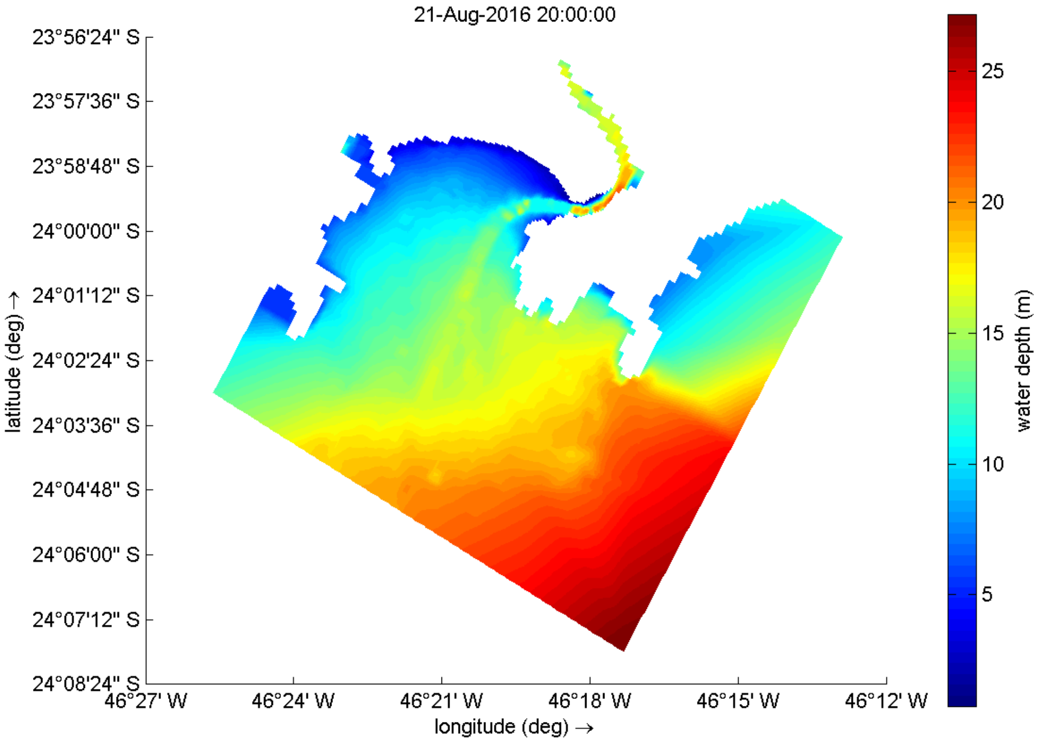
Figure 42 – Wind intensity data on the surface of the CFS, for the 21st of August 2016 (9:00 pm + 0GMT, 18h -3GMT). Intensity in m/s.



Source: Produced by the author by the software Delft 3D.

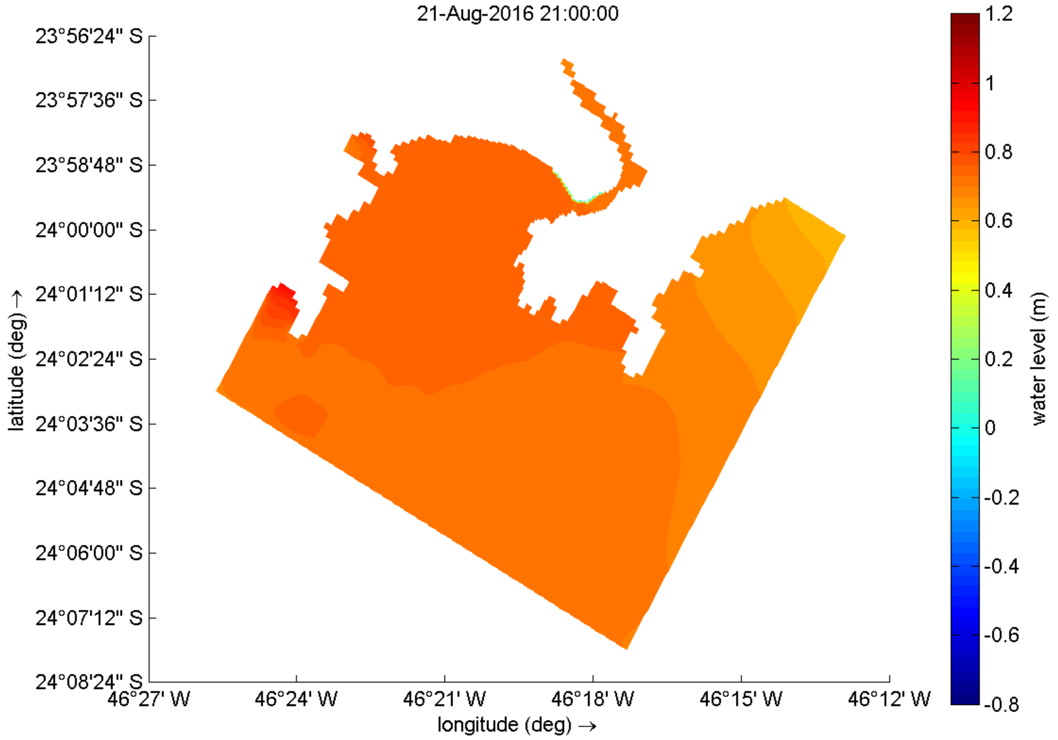
Next, the instantaneous bathymetry distributions on August 21, 2016 (8 pm + 0 GMT, 5 pm -3 GMT) and the sea level oscillations in relation to the average, on the day of the flood and the day after, when the higher levels, causing extreme flooding, with values of 0.8m on 08/21/2016 at 6pm, and approximately 1.2m at 5am and 6am on 08/22/2016 (-3GMT), in the Ponta region da Praia (Figures 43 to 46).

Figure 43 – Batimetry (in meters), in 21 de august 2016 (20h +0GMT, 17h -3GMT).



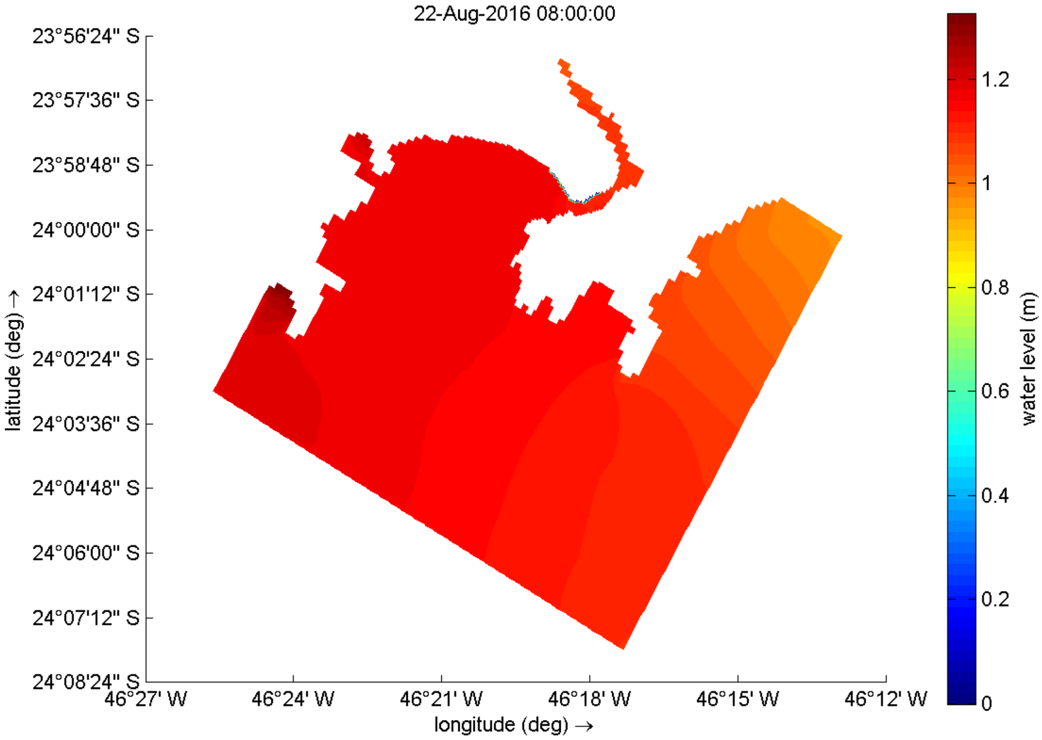
Source: Produced by the author by the software de cited maps, GlobalMapper, RFGRID and Delft 3D.

Figure 44 – Variation of sea level in relation to the average, on 21/08/2016 at 21h + 0GMT, 18h -3GMT), in meters.



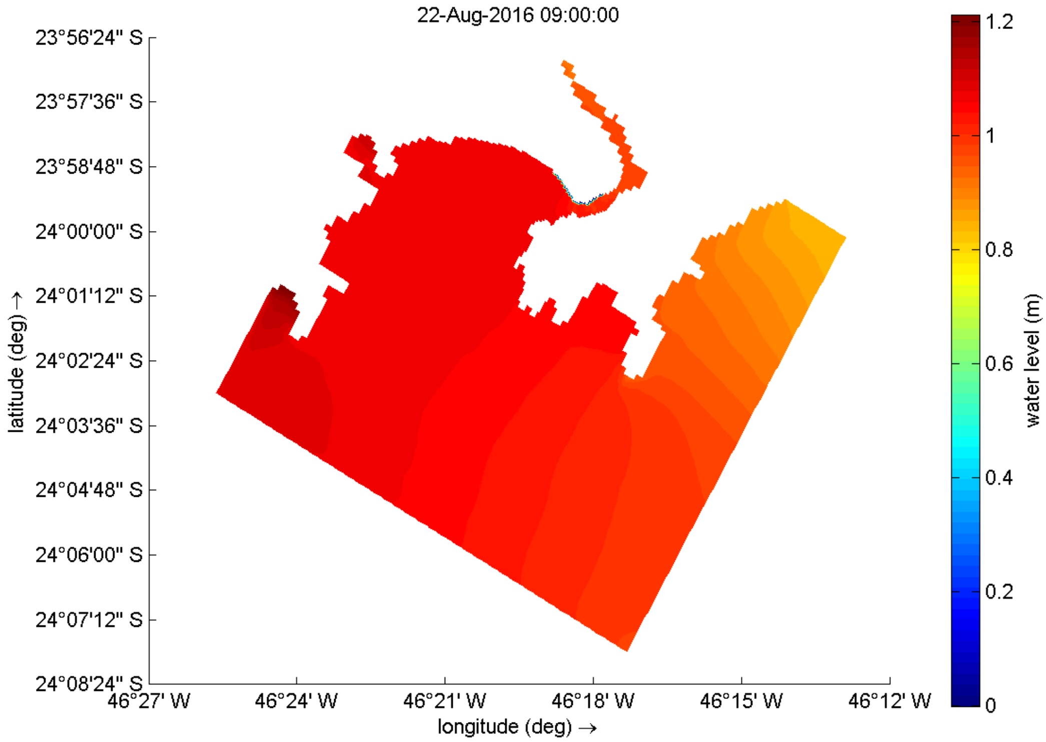
Source: Produced by the author by the software Delft 3D.

Figure 45 – Variation of sea level in relation to the average, on 08/22/2016 at 08h + 0GMT, 05h -3GMT), in meters.



Source: Produced by the author by the software Delft 3D.

Figure 46 - Variation of sea level in relation to the average, on 08/22/2016 at 09h + 0GMT, 06h -3GMT), in meters.



Source: Produced by the author by the software Delft 3D.

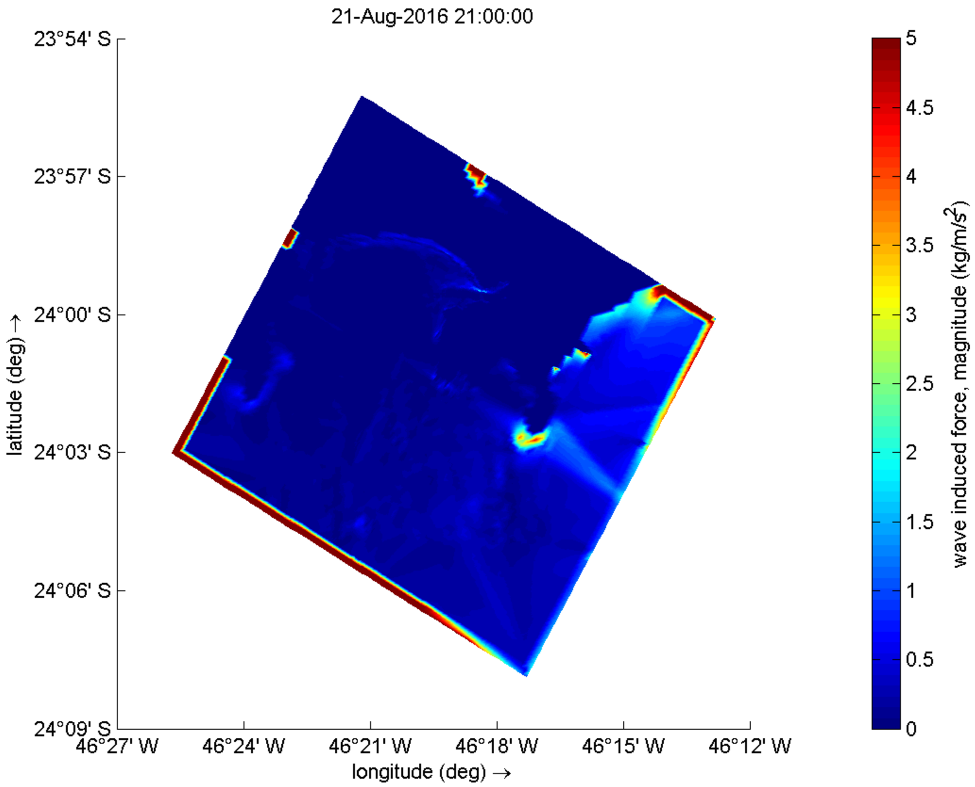
Next, we will see the results obtained by the wave module, to analyze the significant amplitudes to be considered in the design of flood containment projects.

The Wave provides several results, however to propose the solution to a constructive we will emphasize the wave induced force (wave induced force, N / m²), energy transport (W / m), significant wave height (m), dissipation of energy (N / ms) and current speed (m / s) - see Figures 47 to 51.

We will use the extreme data of the day when the maximum rise in the average sea level mentioned above was recorded. It should be noted that more intense positive extremes can occur, if a longer period is considered; and, in case of real implementation of the project, a longer period of years should be considered for obtaining extreme data.

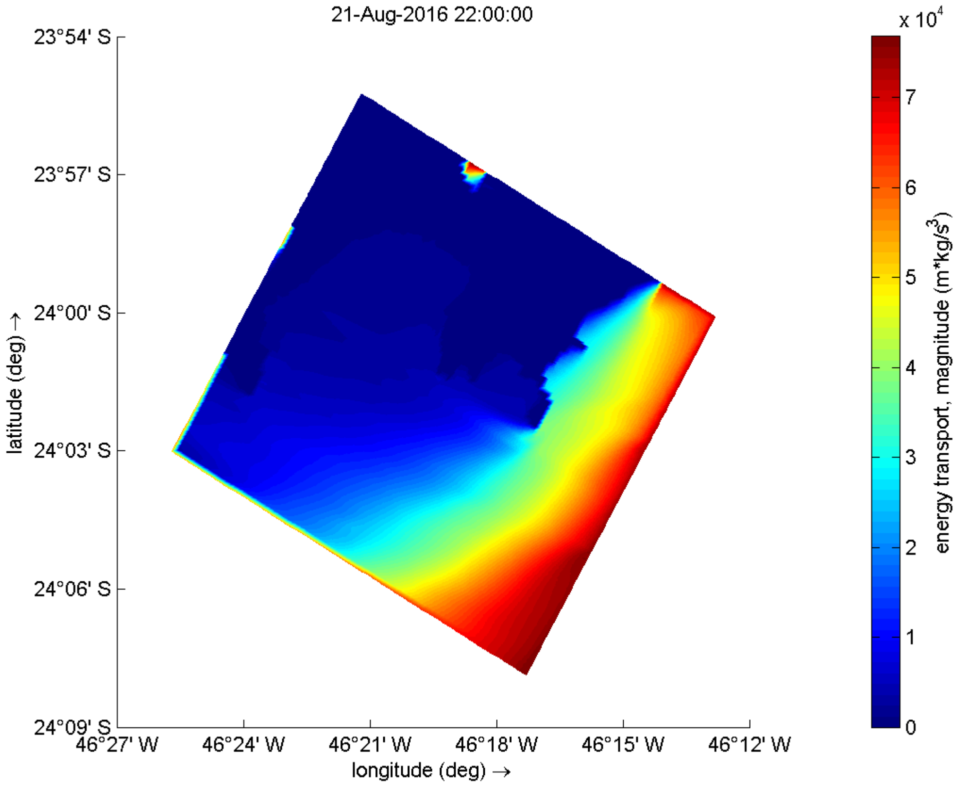
Therefore, according to the height of the waves, the moment referring to August 21, 2016 (22h + 0GMT, 19h -3GMT) was selected. It can be seen, through the results obtained, that the waves in the outermost part of the grid reached up to 4.5m of significant height, but close to the region where it is intended to build the flood containment structure, in Ponta da Praia, maximum values of approximately 1.5m were obtained.

Figure 47 - Results of the numerical model for the induced force of surface waves (in N / m²), for August 21, 2016 (21h +0GMT, 18h -3GMT).



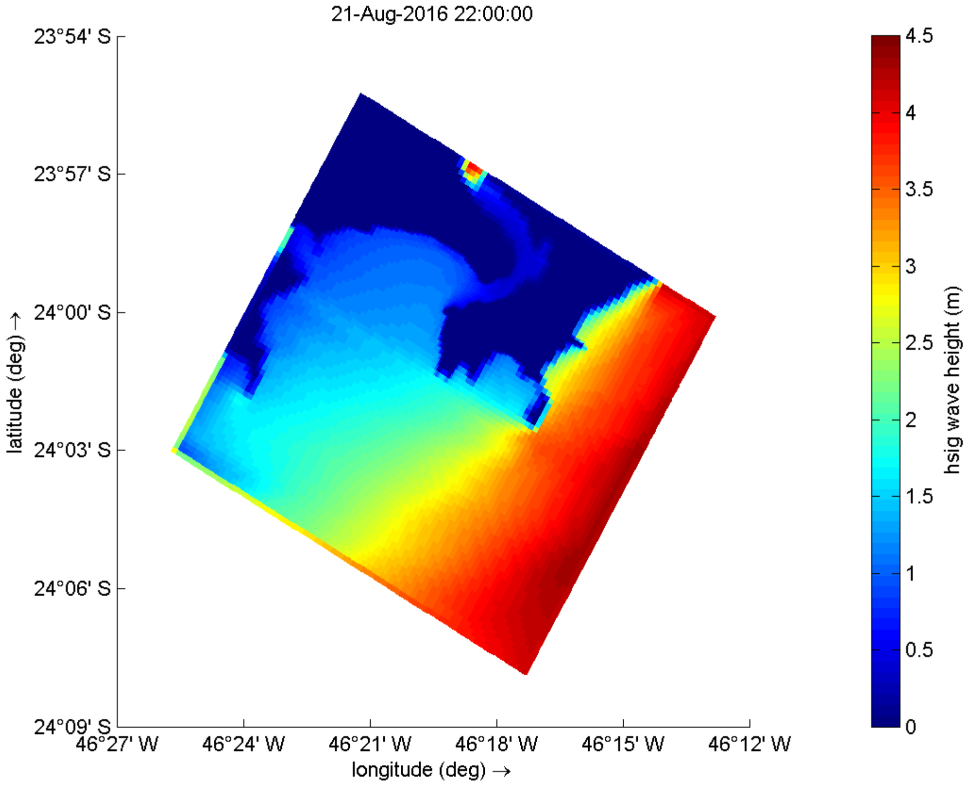
Source: Produced by the author by the software Delft 3D.

Figure 48 - Results of the numerical model for the transport of wave energy (in m*kg/s³), for August 21, 2016 (22h +0GMT, 19h -3GMT).



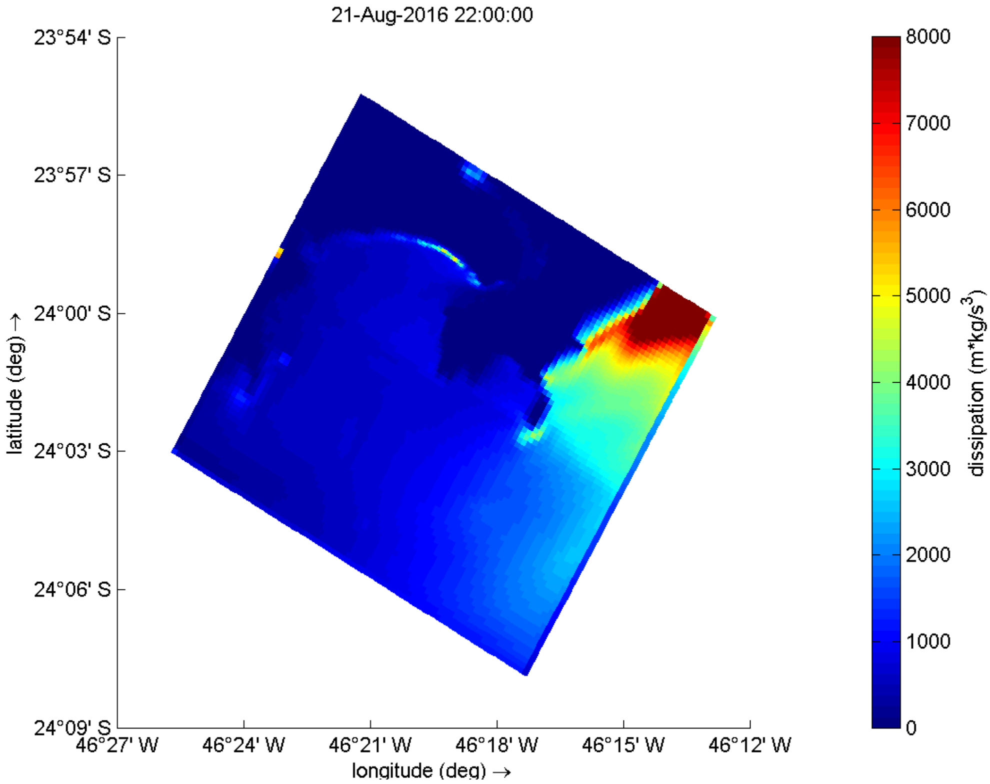
Source: Produced by the author by the software Delft 3D.

Figure 49 - Results of the numerical model for the significant height of the waves (in m), for the 21st of August 2016 (22h +0GMT, 19h -3GMT).



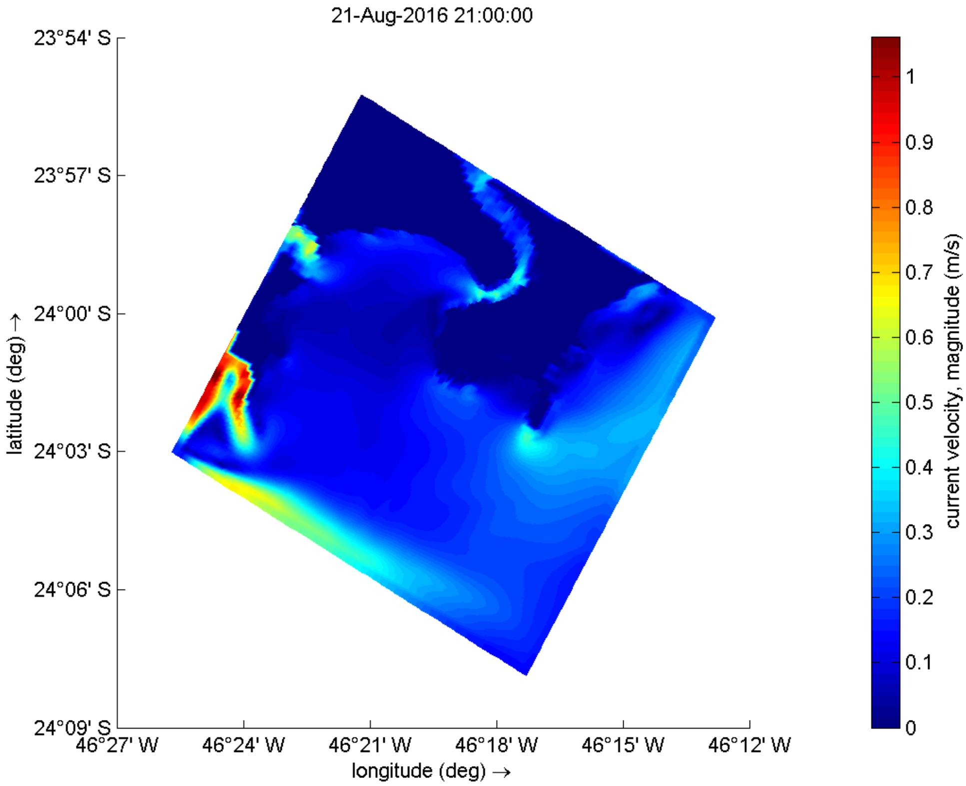
Source: Produced by the author by the software Delft 3D.

Figure 50 - Results of the numerical model for the dissipation of wave energy (in m*kg/s³), for August 21, 2016 (22h +0GMT, 19h -3GMT).



Source: Produced by the author by the software Delft 3D.

Figure 51 - Results of the numerical model for the magnitude of the currents (in m / s), for August 21, 2016 (22h +0GMT, 19h -3GMT).



Source: Produced by the author by the software Delft 3D.

8.3. Statistical analysis

According to Cheng, Burau and Gartner (1991) apud BATISTA (2016) i it is recommended that a numerical model be validated, by comparing its results with observations or results from other models, so that it can be used as a research tool. hydrodynamic processes. The validation helps to indicate possible errors in the model, so that it can be improved, in order to increase the reliability in its ability to reproduce the events of interest.

Next, we will compare the model data produced by Delft3D with the model data HYCOM[x]. Considering that the grid we adopt covers a small area, there is only one point of comparison for HYCOM present in the grid of the Delft3D model.

The results validation process is based on statistical methods, such as linear correlation, absolute mean error and parameter *Skill* of Willmott (1981)[xi]. Below, all the parameters used in the comparison of the results of the two models are detailed, whose time series of results are denoted as Obs (for HYCOM) and Mod (for Delft), with time index i, with i ranging from 1 to n. These series have average Modmed and Obsmed values, and the range of the phenomenon corresponds to the difference between the minimum and maximum Obs values.

The Relative Mean Absolute Error (RMAE) method is defined through Equation (11):

$$\text{RMAE}=\frac{\sum_{i=1}^{n}\left(\text{Obs}_{(i)}-\text{Mod}_{(i)}\right)}{\sum_{i=1}^{n}\left(\text{Obs}_{(i)}\right)} \qquad (11)$$

The RMAE that indicates greater proximity to the compared data if it corresponds to zero, so that the quality of the modeling results is classified according to the values in the table below (WALSTRA et al., 2001[xii]).

RMAE	**Classification**
RMAE<0,20	Excelent
0,20<RMAE<0,40	Good
0,40<RMAE<0,70	Reasonable
0,70<RMAE<1	Bad
RMAE>1	Terrible

Tabel 3 – Classification of the quality of the results of a model, according to the values of RMAE Source: WALSTRA et al., 2001 apud YANG 2016[xiii]

There is also the Absolute Mean Statistic Error (AMSE) method, which is calculated according to the equation (12). Acoording to WILLMOTT (1982)[xiv] AMSE has the same unit as the studied variable, its ideal value being null.

$$\text{AMSE}=\frac{1}{n}\sum_{\text{i}=1}^{n}\left(\text{Obs}_{(i)}-\text{Mod}_{(i)}\right) \qquad (12)$$

We also have the square root parameter of the mean square error (Root Mean Square Error - RMSE), which is defined according to equation (13). The RMSE has the same unit as the studied variable, and its ideal value corresponds to zero.

$$\text{RMSE}=\sqrt{\frac{1}{n}\sum_{\text{i}=1}^{n}\left(\text{Obs}_{(i)}-\text{Mod}_{(i)}\right)^2} \qquad (13)$$

There is also the Skill coefficient, which can be calculated according to equation (14), and its ideal value corresponds to 1 (HESS & BOSLEY, 1991 *apud* YANG 2016[xv]).

$$\text{Skill}=1-\frac{\text{RMSE}}{\text{Range}} \qquad (14)$$

The Index of Agreement (IOA) method is defined according to equation (15), with an ideal value equal to 1.

$$\text{IOA}=1-\left[\frac{\sum_{\text{i}=1}^{n}\left(\text{Obs}_{(i)}-\text{Mod}_{(i)}\right)^2}{\sum_{\text{i}=1}^{n}\left(\left(\text{Mod}_{(i)}-\mathit{ModMed}_{(i)}\right)+\left(\text{Obs}_{(i)}-\mathit{ObsMed}(i)\right)\right)^2}\right] \qquad (15)$$

Pearson's correlation coefficient is calculated after obtaining the covariance (equation 16) between the compared series and their standard deviations (denoted by σ). This correlation coefficient is calculated according to equation (17), with 1 being its ideal value.

$$\text{Cov}\left(\text{Mod}_{(i)},\text{Obs}_{(i)}\right)=\frac{1}{n}\sum_{\text{i}=1}^{n-1}\left[\left(\text{Mod}_{(i)}-\mathit{ModMed}_{(i)}\right)\left(\text{Obs}_{(i)}-\mathit{ObsMed}_{(i)}\right)\right] \qquad (16)$$

$$\text{Pearson}=\frac{\text{Cov}\left(\text{Mod}_{(i)},\text{Obs}_{(i)}\right)}{\sigma_{\text{Mod}(i)},\sigma_{\text{Obs}(i)}} \tag{17}$$

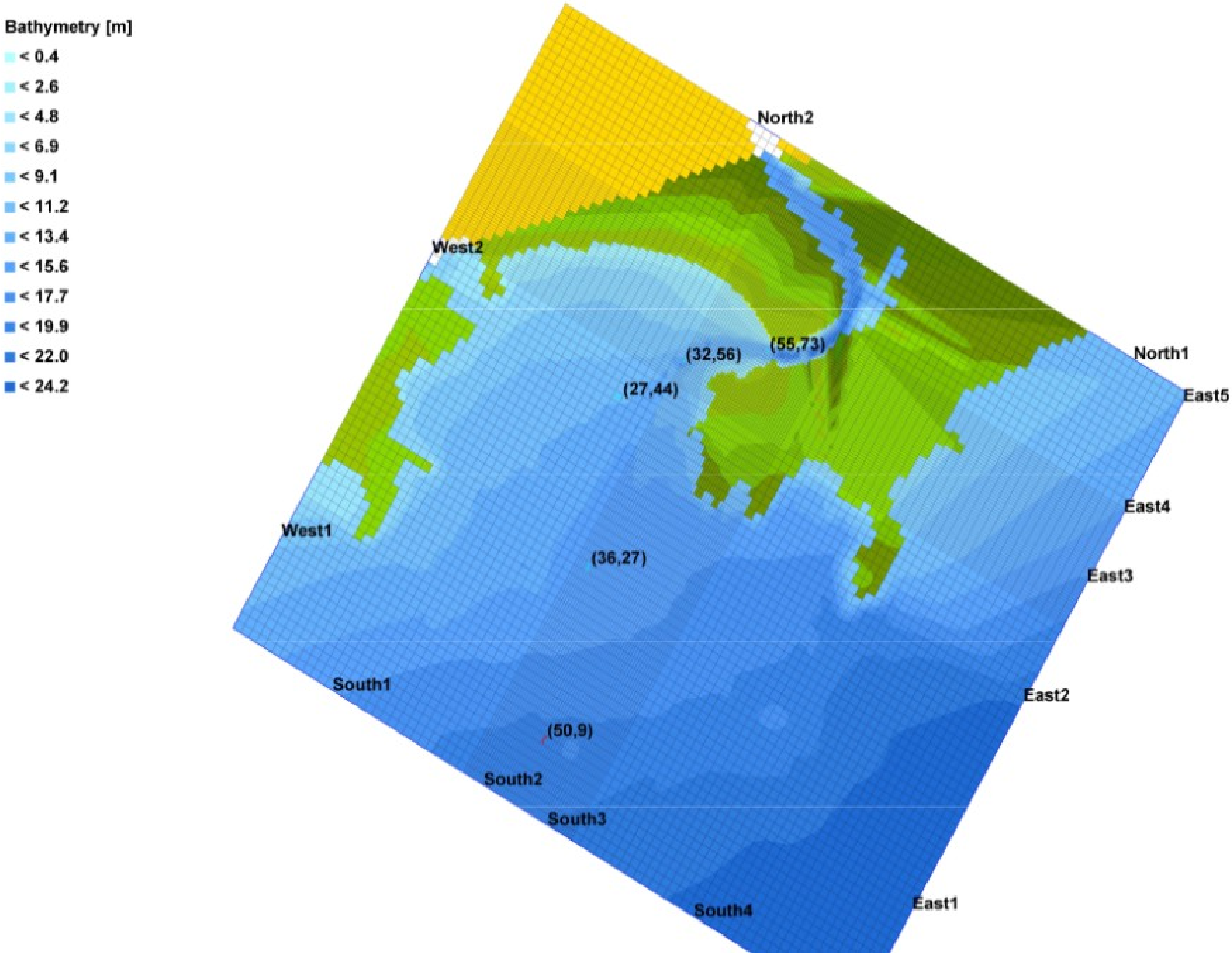
Finally, the coefficient R^2 is defined according to equation (18) and has an ideal value corresponding to 1.

$$R^2=1-\frac{\sum_{i=1}^{n}\left(\text{Obs}_{(i)}-\text{Mod}_{(i)}\right)^2}{\sum_{i=1}^{n}\left(\text{Obs}_{(i)}-ObsMed_{\text{Obs}(i)}\right)^2} \tag{18}$$

Expressions (11) to (18) were written in MATLAB language, for the HYCOM (Obs) and Delft3D (Mod) series, these referring to point (50.9), which corresponds to the only point of HYCOM present in in the grid of the present study (see position in Figure 52).

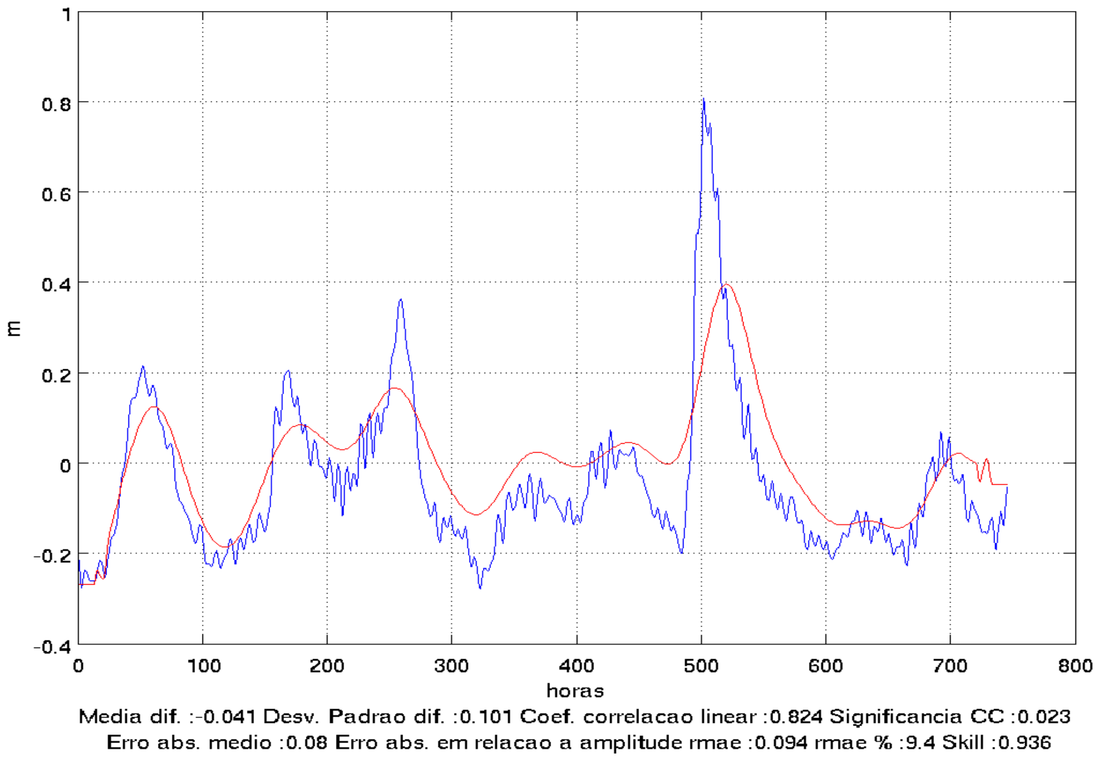
Figures 53 to 59 show the time series of HYCOM and Delft, and Table 4 provides the comparative parameters for the variables of sea level, temperature and EW and NS components of currents (on the surface).

Figure 52 – Point (50,9), in common of HYCOM and Delft3D, for comparison of model results.



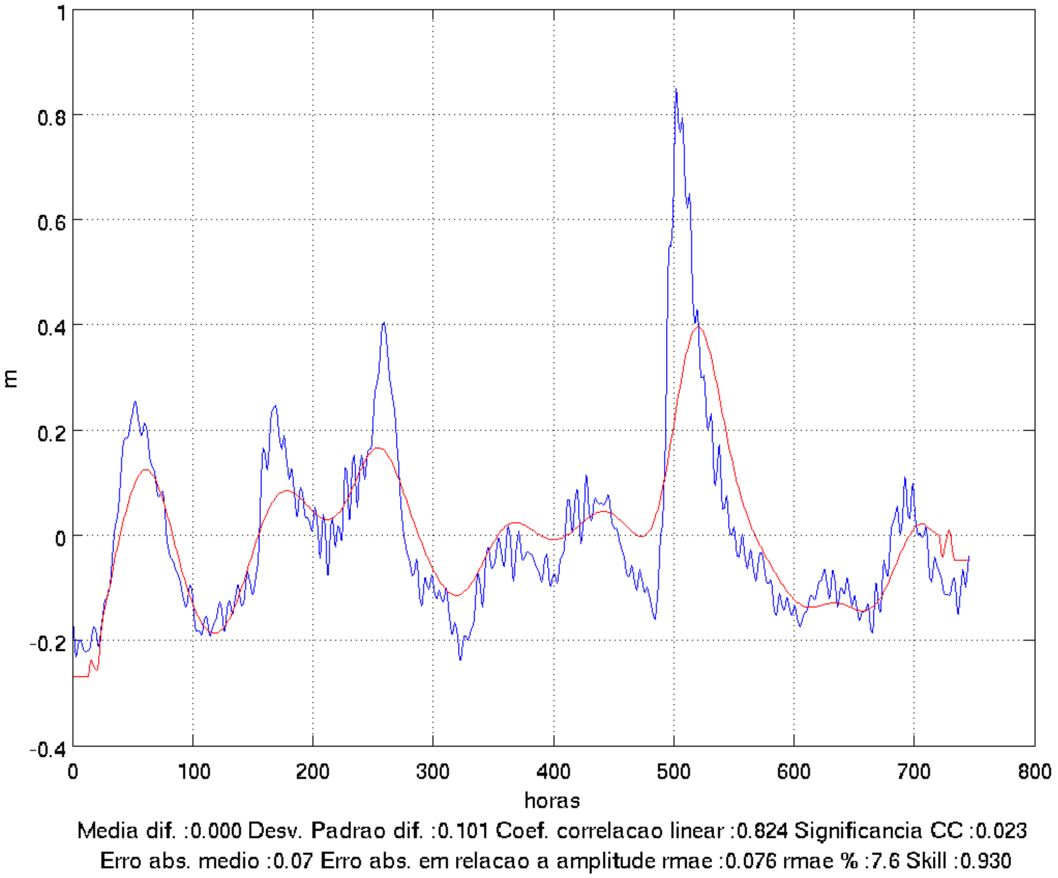
Source: Produced by the author from software Matlab and Delft3D.

Figure 53 – Comparison of the results of total sea level elevation of the point (50.9) in meters, produced by HYCOM (red) and Delft3D (blue); the sub-legend contains the comparative statistical parameters.



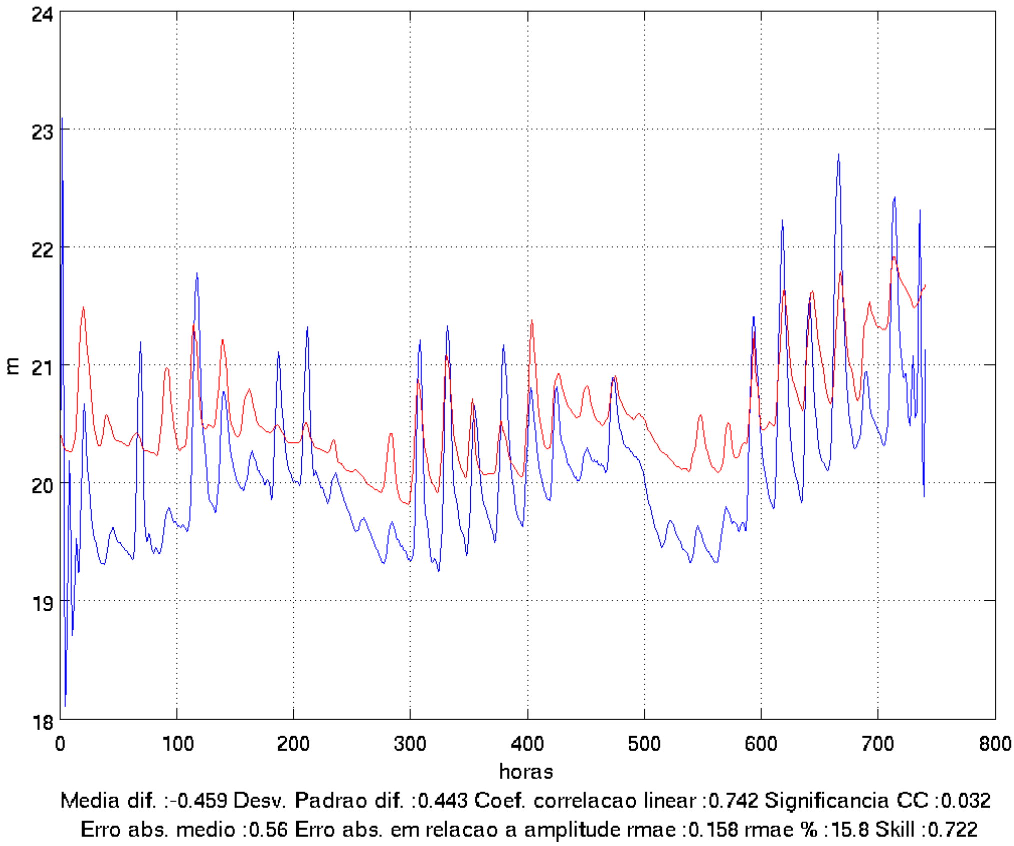
Source: Produced by the author from software Matlab and Delft3D.

Figure 54 – Comparison of the results of total filtered sea level rise (in meters, with elimination of high frequency noise), produced by HYCOM (red) and Delft3D (blue); the sub-legend contains the comparative statistical parameters.



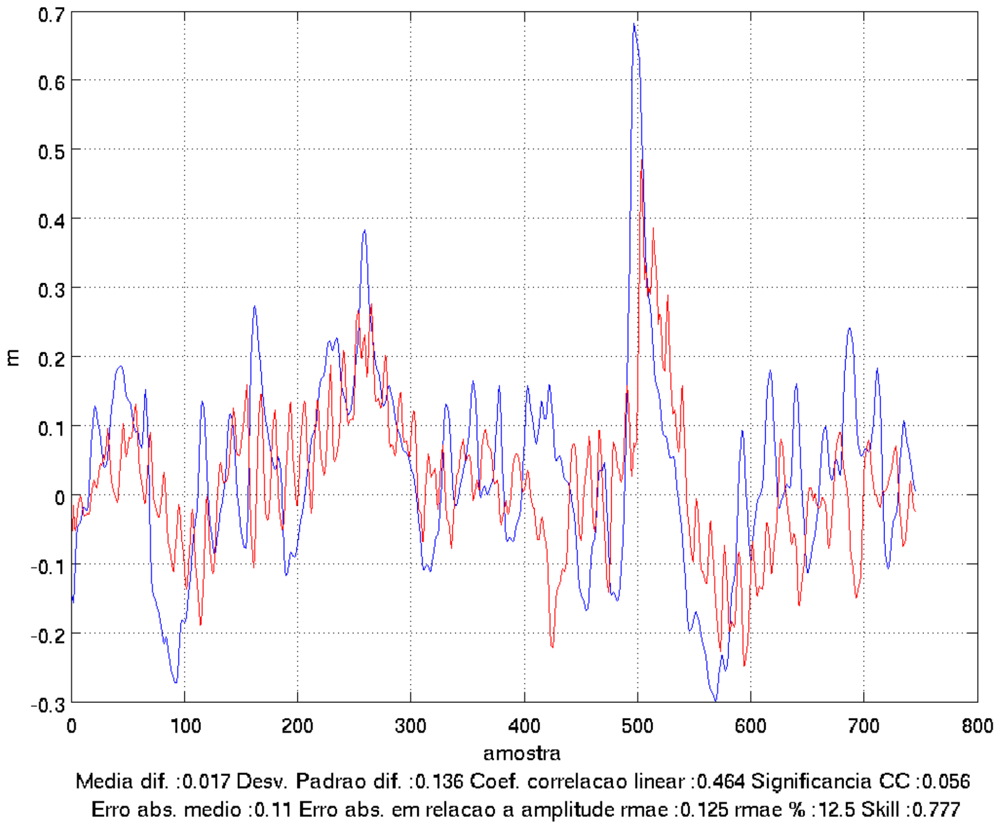
Source: Produced by the author from software Matlab and Delft3D.

Figure 55 – Comparação dos resultados de temperatura na superfície (em ºC), produzidos pelo HYCOM (vermelho) e Delft3D (azul); na sublegenda, se encontram os parâmetros estatísticos comparativos.



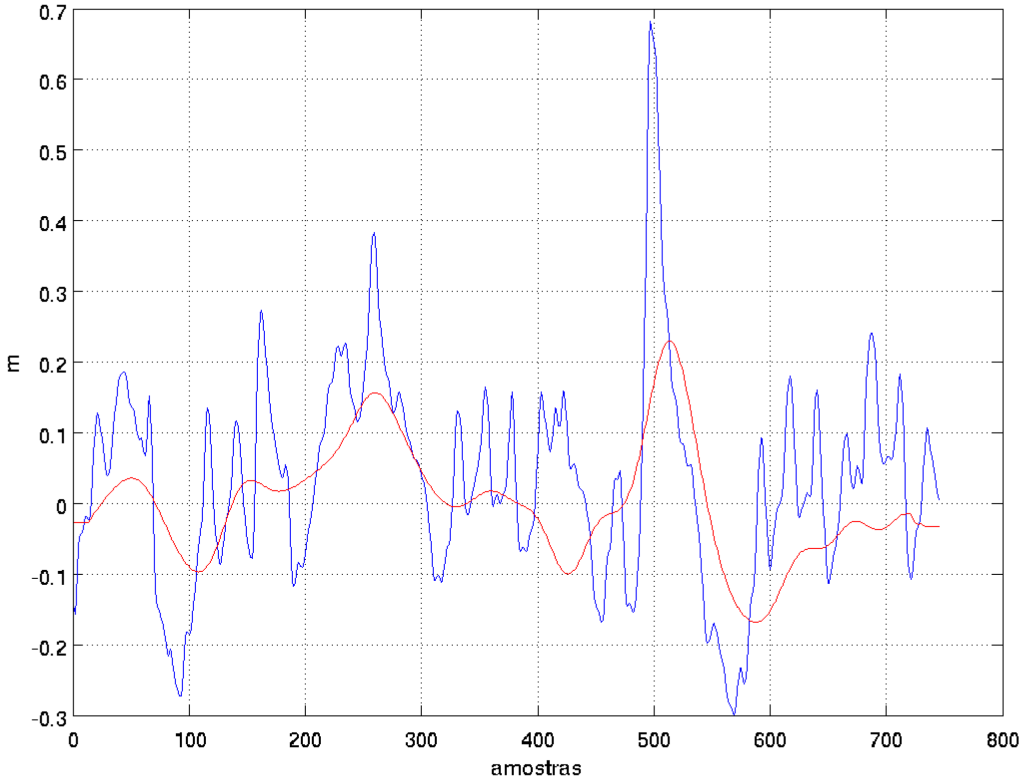
Source: Produced by the author from software Matlab and Delft3D.

Figure 56 – Comparison of the results of EW component of surface current (in m / s), produced by HYCOM (red) and Delft3D (blue); the sub-legend contains the comparative statistical parameters.



Source: Produced by the author from software Matlab and Delft3D.

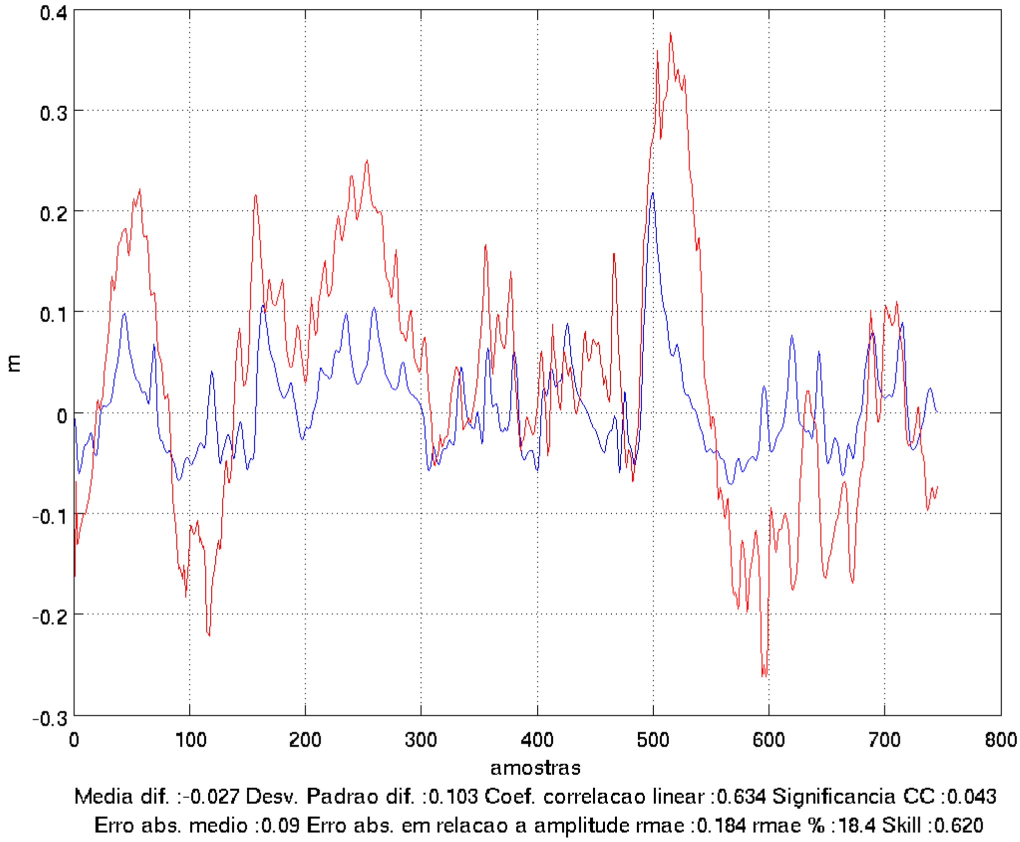
Figure 57 – Comparison of the results of EW component of surface current (in m / s, with elimination of high frequency noise), produced by HYCOM (red) and Delft3D (blue); the sub-legend contains the comparative statistical parameters.



Media dif. :0.035 Desv. Padrao dif. :0.122 Coef. correlacao linear :0.571 Significancia CC :0.048
Erro abs. medio :0.10 Erro abs. em relacao a amplitude rmae :0.145 rmae % :14.5 Skill :0.809

Source: Produced by the author from software Matlab and Delft3D.

Figure 58 – Comparison of the results of NS component of surface current (in m / s), produced by HYCOM (red) and Delft3D (blue); the sub-legend contains the comparative statistical parameters.



Source: Produced by the author from software Matlab and Delft3D.

Figure 59 – Comparison of the results of NS component of surface current (in m / s), produced by HYCOM (red) and Delft3D (blue); the sub-legend contains the comparative statistical parameters.

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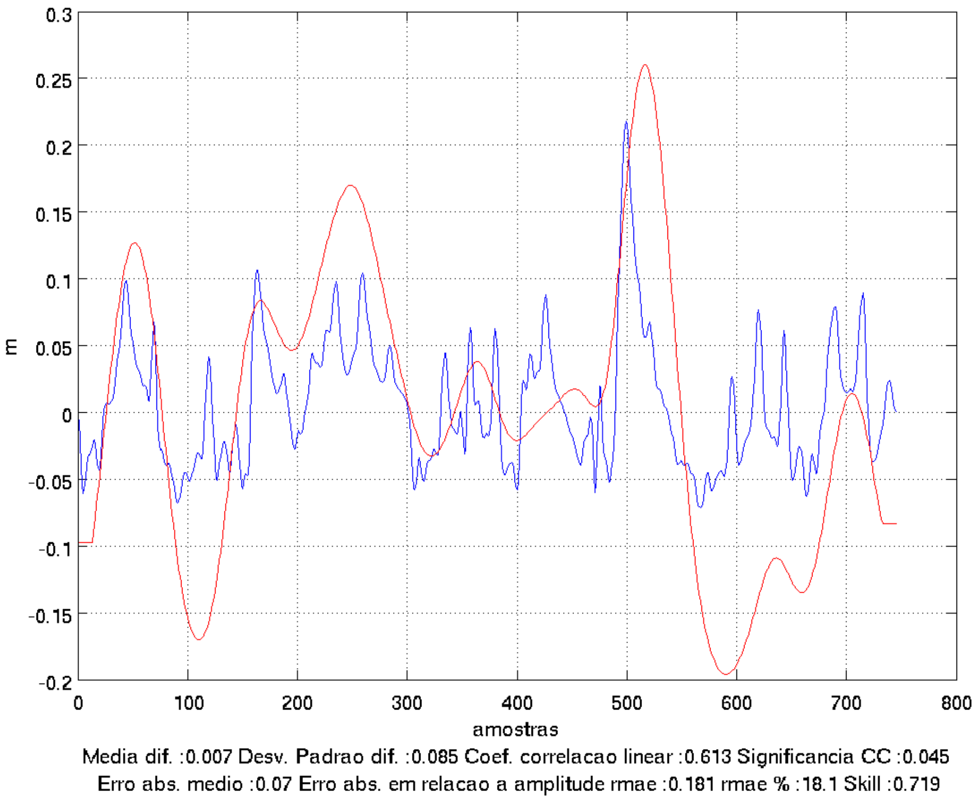


Source: Produced by the author from software Matlab and Delft3D.

Ponto (50,9)	Média	Desvio padrão	CC	SIG	MAE	RMAE	RMAE PERC	SKILL
Sea Surface Height	0,001	0,100	0,824	0,023	0,066	0,076	7,600	0,930
Temp.	0,459	0,442	0,742	0,032	0,559	0,157	15,784	0,721
U(filtr.)	0,035	0,121	0,571	0,048	0,100	0,145	14,519	0,809
V(filtr.)	0,007	0,085	0,613	0,045	0,067	0,181	18,118	0,719

Tabel 4 – Comparative statistical parameters of the results of the HYCOM and Delft3D models, according to equations (11) to (18), for the series of total sea level, temperature and EW and NS current components.

8.4. The Hydraulic Structure

8.4.1. Containment structure

According to NEVES et al (2012) i, considering that the foundation on which the structure will be laid is stable, that is, not considering the ruin due to geotechnical aspects, the ruin modes of a structure are reduced to the possible ones sliding and tipping movements. We take into account the static balance of the system to analyze the stability of sliding and tipping, assuming that the action on the structure is constant. Thus, several simplifying hypotheses are considered:

• The maximum instantaneous forces acting on the structure are constant over time;

• The structure-foundation system is considered rigid until the previous moment in which the ruin occurs by sliding or falling, that is, there is no accumulation of damage, but only instant ruin.

Usually, this method is applied considering as the most serious case the one where the structure is infinite (considering the effect of the contours of the negligible structure), and the incidence is normal to the structure.

In the case of the Ponta da Praia region, waves may break in the structure in case of floods, so the use of this method does not consider the waves breaking, it only proposes the best physical configuration for cases where the surf occurs. However, in case of application of the project, the surf should be studied in particular.

The forces on a vertical or mixed structure are considered to have a hydrostatic component that acts on both sides of the structure and its base, and a hydrodynamic component, resulting from the action of the wave, which acts only on the base and the mud of the structure, that is, it is considered that the sum of the hydrodynamic component is negligible, if there is no overtopping. In the specific case of Ponta da Praia, we do not have surface hydrodynamics at Sotamar, but the slope of the sidewalk, whose subpressures must be considered.

Once the horizontal and underpressure forces are calculated, sliding safety coefficients, C SD, and tipping, C SV, are established, which relate favorable and unfavorable efforts to the stability of the structure. For the system to be considered stable, the coefficients must always be greater than 1, and values between 1.2 and 1.4 are usually considered.

$$C_{SD} = \frac{\mu\left(\text{Peso} - \text{Subpressões}\right)}{\Sigma\left(\text{ForçasHorizontais}\right)} \quad (19)$$

$$C_{SD} = \frac{M_{\text{Peso}}}{M_{\text{ForçasHorizontais}} + \text{M}_{\text{Subpressões}}} \quad (20)$$

The μ coefficient is the friction coefficient between the structure and the base. Nagai (1973) apud NEVES et al (2012) i, based on results of the physical model and experience from a prototype for mixed breakwaters, suggests values of μ between 0.65 and 0.70 in the event of block displacement of the mantle in storms during the first years of the work, increasing to values between 0.7 and 0.9 if the displacement occurs more than two years after the end of the construction of the work and between 0.80 and 0.90 in the case of no there will be displacement of mantle blocks in the early years of the work. The same author also suggests the value of 0.60 as a value to be used in a project, considering safety. In the CSV calculation, M represents the moment associated with each of the forces and the weight represents the total weight emerged.

The balance of forces that was presented is valid for agitation with normal incidence to the structure, where the forces are in phase along the entire structure.

In static equilibrium, forces are also considered to be constant over time.

Dynamic balance, on the other hand, takes into account the succession of responses to the actions that the structure suffers. This response can be elastic (balancing oscillatory movements) or plastic (permanent sliding and tipping movements). The succession of responses leads to the degradation of the system and the progressive ruin of the structure, which can lead to its total ruin in the long run.

To address the dynamic balance of the system, there are different approaches, each with its simplifications. According to NEVES et al (2012) ii, to obtain the forces in vertical and mixed breakwaters, the method most used in design is based on empirical or semi-empirical formulas. Its main disadvantage is that the direct application of these formulas is limited to structures with simple geometries, specific agitation conditions and levels for which they were developed. Another limitation is the fact that all methods consider the structure as infinite and impermeable, not considering possible effects that can modify the characteristics of the agitation that affects the structure. Because they are based on reduced model tests, they can also be affected by errors due to scale effects.

Still according to the work of NEVES et al (2012) iii, the following criteria should be taken into account when designing maritime containment structures, in order to optimize the project and ensure that the structure safely and economically meets the requirements of project:

The value of the maximum elevation reached by the design wave (η max) is the main variable to be taken into account in the design, since from it it is possible to calculate the maximum pressure for the average sea level of reference. Thus, its value must be obtained through the application of numerical models that allow to know correctly the distribution of energy in front of the structure, as we did previously.

The maximum horizontal hydrodynamic pressure, Pmax, can be calculated based on the maximum elevation reached by the design wave (η max), using the expression:;

The hydrodynamic underpressure added to the structure is not always zero, it depends on the energy transmitted through the porous mantles. When calculating subpressures based on laboratory tests, it should be checked whether the result is affected by scale effects, due to incorrect reproduction of the characteristics of the foundation mantle, specifically its porosity. The correction of the size of the material of the mantles, in order to avoid scale effects, may allow to avoid errors in the calculation of subpressures.

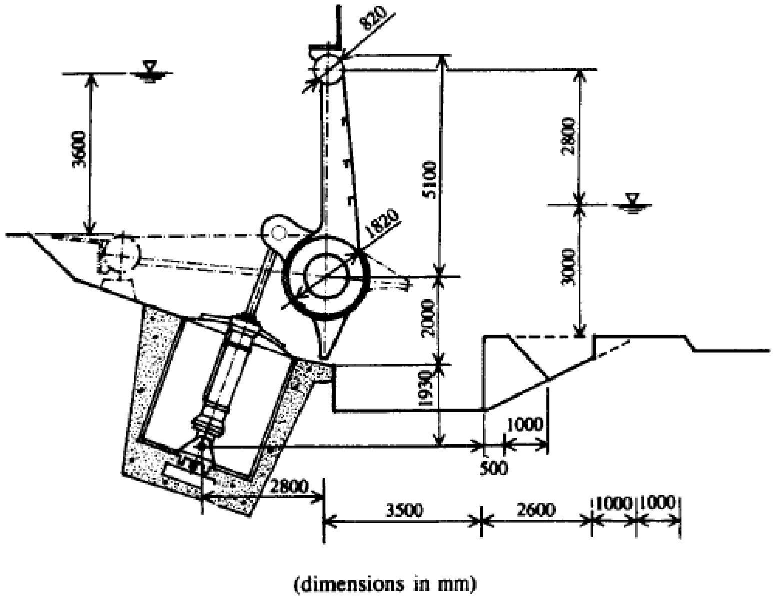
Ruin modes should be checked for combinations of horizontal and vertical forces, the effect of which is the most unfavorable.

The present work does not aim to make a structural analysis of a containment structure, but to analyze the data of the requests present in the region of interest and propose a constructive solution with low environmental impact.

Thus, there are several types of containment structures and different ways of dimensioning them. However, for our case, we recommend the use of a mobile metallic structure with pneumatic drive. There are also several methods for calculating the necessary resistance, however, we will show in this work the balance of forces, as an initial step for the application of some structure in the place, with the use of the appropriate safety coefficients, as indicated in the Brazilian Norms of Actions and Safety in Structures (NBR 8681/2004) and Forces due to Wind in Buildings (NBR 6123/1988).

O modelo de estrutura mais próximo ao que pensamos para as necessidades do local estudado seria uma adaptação do modelo de Cabelka and Gabriel *apud* NOVAK(2007)[xvi].

Figure 60 – Rotating gate type Cabelka (Cabelka e Gabriel, 1985).



Source: NOVAK(2007).

However, in view of the different requests, the design values would be different. In addition, bearing in mind that the structure can receive waves in the breaking phase, the curved formation at the edges of the containment structure is indicated, to minimize the breaking effect, as indicated in the attached figure (ANNEX 1)

Several gates in this format must be installed throughout the region where floods occur, with a neoprene sealing system between them. The activation of the pneumatic system can be done manually or automatically, depending on the preference of the agent that puts these containment structures in execution.

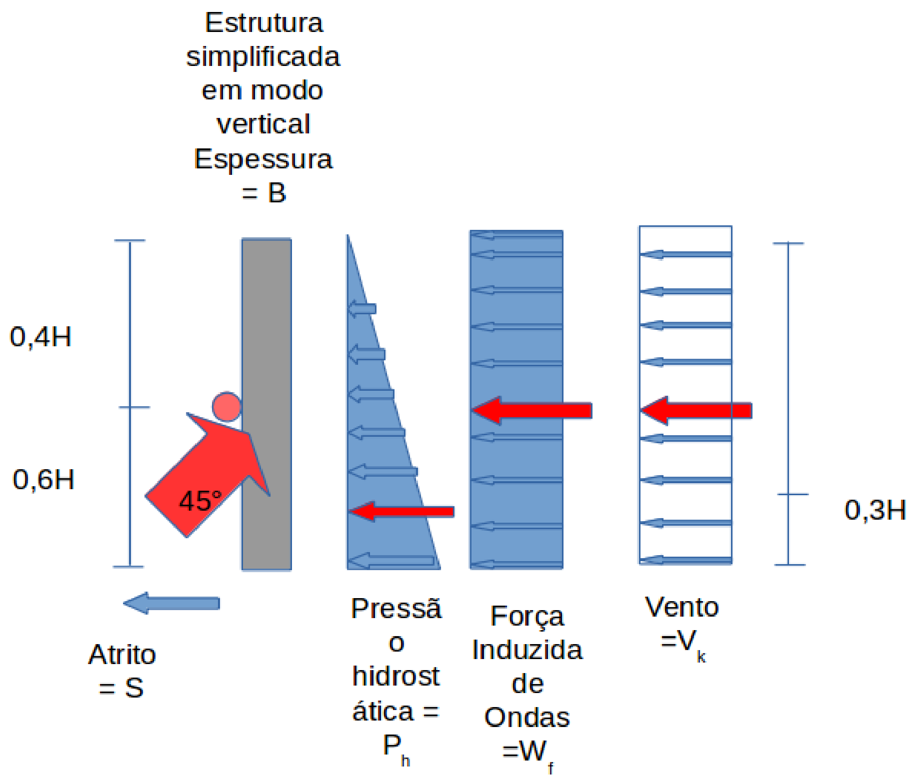
We will not stick to the calculations of the pneumatic mechanics of operation of this type of structure, but to the overall resistance for which it must be dimensioned, simplifying it for simple balance of forces. Stressing that, for the real application of a structure of this size, detailed structural analysis studies must be carried out.

In principle, it is indicated the use of high mechanical resistance and low alloy steel, made for the manufacture of thick sheets for structural use and resistance to atmospheric corrosion, according to NBR 5008, or to ASTM Norms, the steel of class A588, which it is resistant to a maximum of 345MPa in fy and 485MPa in fu. For application in the project, the weighting coefficients of the resistances used for steel, in the verification of flow or instabilities and in the verification of rupture, must be used in accordance with ABNT NBR 8800, NBR 5008, or ASTM Standards.

We will consider the soil composed of sand, thus having $\varphi = 30°$ for the sand and specific gravity of the sand $\gamma_{areia}=17kN/m^3$, sand cohesion $c=0$ e $\gamma_{aço}=77kN/m^3$.

For the analysis of the forces present in the structure, we will consider the structure in a containment position, as indicated in the previous figures, vertically, which would be the worst case in the flood situation. For simplification of calculations, we will consider the fully vertical profile of the structure.

Figure 61 - Simplified representation of forces present in the containment structure system.



Source: Autor

Sd being the requests made on the structural element and Rd the resistances provided by the structure, so that a structure is resistant to its demands we have to:

$$S_d < R_d \quad (21)$$

Checks for resistance to tipping, sliding and rupture must be carried out for the confinement box of the pneumatic piston that activates the metallic structure. For this purpose, one can consider some premises used in the Rankine method or the Mohr-Coulomb method, but, as previously mentioned, this work does not aim to analyze the resistance of the soil massifs in the region and, for the implementation of the project, it must detailed geological study should be carried out.

For the calculation of the force generated by the hydrostatic pressure, we will consider the maximum hydrostatic pressure found in the model for the region of interest on the day of maximum sea level rise. In our case, this pressure was approximately 60000 N / m² in the application region. We will find the force resulting from the hydrostatic pressure on the structure by multiplying Ph found by the H considered previously and by ½, since the hydrostatic pressure distribution profile is triangular:

$$F_{Ph} = ½.P_{h.}H \qquad (22)$$

As indicated by NEVES et al (2012), we will use as H the highest value between significant wave height (HD), or maximum mean sea level (η_{max}). As we observed in the model results, maximum HD values in the Ponta da Praia region, on days of maximum elevation, up to 2m, and maximum sea levels (η_{max}) of 1.5m. So we can use the value H = 2.0m.

We also have the presence of the induced force of waves. Through the model we found a maximum value of 2.5 N / m², considering the same H, and for each meter unit of the structure.

$$F_{Wf} = W_f.H.1 \qquad (23)$$

For the calculation of wind we will use the principles of NBR of Forces due to Wind in Buildings (NBR 6123/1988). The wind speed obtained through the numerical model, from the data of the global meteorological model CFS, has maximum values, in the place of interest and on the day of maximum elevation, of V_0 = 15m / s. We will consider the total wind speed as:

$$V_k=V_0.S_1.S_2.S_3 \qquad (24)$$

Since V0 is the speed found in the model, S_1 is the topographic factor, S_2 is the terrain roughness factor and S_3 is the statistical factor. According to the standard, for flat terrain, S_1 = 1.0. S_2 is divided into 5 categories according to the terrain, with sea being category I, also divided into 3 classes A, B and C in height of the building. Because it is less than 5m, our containment fits into category A. Thus, according to the table, the S_2 coefficient for our case is 1.06 (See Figure 62).

Figure 62 – Tabel of NBR 6123/1988 (Forces due to Wind in Buildings) for the coefficient S_2.

Tabela 2 - Fator S_2

z (m)	Categoria I			Categoria II			Categoria III			Categoria IV			Categoria V		
	Classe			Classe			Classe			Classe			Classe		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
≤ 5	1,06	1,04	1,01	0,94	0,92	0,89	0,88	0,86	0,82	0,79	0,76	0,73	0,74	0,72	0,67
10	1,10	1,09	1,06	1,00	0,98	0,95	0,94	0,92	0,88	0,86	0,83	0,80	0,74	0,72	0,67
15	1,13	1,12	1,09	1,04	1,02	0,99	0,98	0,96	0,93	0,90	0,88	0,84	0,79	0,76	0,72
20	1,15	1,14	1,12	1,06	1,04	1,02	1,01	0,99	0,96	0,93	0,91	0,88	0,82	0,80	0,76
30	1,17	1,17	1,15	1,10	1,08	1,06	1,05	1,03	1,00	0,98	0,96	0,93	0,87	0,85	0,82
40	1,20	1,19	1,17	1,13	1,11	1,09	1,08	1,06	1,04	1,01	0,99	0,96	0,91	0,89	0,86
50	1,21	1,21	1,19	1,15	1,13	1,12	1,10	1,09	1,06	1,04	1,02	0,99	0,94	0,93	0,89
60	1,22	1,22	1,21	1,16	1,15	1,14	1,12	1,11	1,09	1,07	1,04	1,02	0,97	0,95	0,92
80	1,25	1,24	1,23	1,19	1,18	1,17	1,16	1,14	1,12	1,10	1,08	1,06	1,01	1,00	0,97
100	1,26	1,26	1,25	1,22	1,21	1,20	1,18	1,17	1,15	1,13	1,11	1,09	1,05	1,03	1,01
120	1,28	1,28	1,27	1,24	1,23	1,22	1,20	1,20	1,18	1,16	1,14	1,12	1,07	1,06	1,04
140	1,29	1,29	1,28	1,25	1,24	1,24	1,22	1,22	1,20	1,18	1,16	1,14	1,10	1,09	1,07
160	1,30	1,30	1,29	1,27	1,26	1,25	1,24	1,23	1,22	1,20	1,18	1,16	1,12	1,11	1,10
180	1,31	1,31	1,31	1,28	1,27	1,27	1,26	1,25	1,23	1,22	1,20	1,18	1,14	1,14	1,12
200	1,32	1,32	1,32	1,29	1,28	1,28	1,27	1,26	1,25	1,23	1,21	1,20	1,16	1,16	1,14
250	1,34	1,34	1,33	1,31	1,31	1,31	1,30	1,29	1,28	1,27	1,25	1,23	1,20	1,20	1,18
300	-	-	-	1,34	1,33	1,33	1,32	1,32	1,31	1,29	1,27	1,26	1,23	1,23	1,22
350	-	-	-	-	-	-	1,34	1,34	1,33	1,32	1,30	1,29	1,26	1,26	1,26
400	-	-	-	-	-	-	-	-	-	1,34	1,32	1,32	1,29	1,29	1,29
420	-	-	-	-	-	-	-	-	-	1,35	1,35	1,33	1,30	1,30	1,30
450	-	-	-	-	-	-	-	-	-	-	-	-	1,32	1,32	1,32
500	-	-	-	-	-	-	-	-	-	-	-	-	1,34	1,34	1,34

Source: NBR 6123/1988

S_3 é dividido em 5 categorias, de acordo com o grau de segurança requerido e a vida útil do elemento construtivo. Consideraremos o coeficiente S_3=1,1, já que a obra é de suma importância para a proteção contra as intempéries citadas.

Figure 63 – Tabel of NBR 6123/1988 (Forces due to Wind in Buildings) for the coefficient S_3.

Tabela 3 - Valores mínimos do fator estatístico S_3

Grupo	Descrição	S_3
1	Edificações cuja ruína total ou parcial pode afetar a segurança ou possibilidade de socorro a pessoas após uma tempestade destrutiva (hospitais, quartéis de bombeiros e de forças de segurança, centrais de comunicação, etc.)	1,10
2	Edificações para hotéis e residências. Edificações para comércio e indústria com alto fator de ocupação	1,00
3	Edificações e instalações industriais com baixo fator de ocupação (depósitos, silos, construções rurais, etc.)	0,95
4	Vedações (telhas, vidros, painéis de vedação, etc.)	0,88
5	Edificações temporárias. Estruturas dos grupos 1 a 3 durante a construção	0,83

Source: NBR 6123/1988

We know that the wind drag force is calculated using the formula in the standard:

$$F_a = C_a.q.A_e \quad (25)$$

Being $q=0,613V_k^2$; Ca = 1,35; for a unitary area of influence of the wind on the structure we have:

$$F_a = 1,35.0,613.V_k^2 \quad (26)$$

$$F_a = 0,827.V_k^2 \quad (27)$$

The frictional force can be obtained through the results of the numerical model (in our case, maximum 0,9N/m²); applying the definition of resistance to deformation, called viscous resistance, one must consider the shear for a unit of contact area of the structure with the ground, being:

$$\sigma_{atrito}=F/A \quad (28)$$

$$F_{atrito}=\sigma_{atrito}.A \quad (29)$$

The “A” area depends on the thickness of the plate to be adopted in the design of the containment structure.

We will consider vertical water underpressures as the thickness of the structure profile multiplied by the area of the underpressure profile triangle.

Sub = ½.B.$\gamma_{água}$ (30)

The weight of the structure must be calculated by multiplying the specific mass of the steel present by the area of its section for each 1m of structure, being

P= $\gamma_{aço}$.Área (31)

According to NBR8681 / 2003, we can consider the following actions in the structure:

Permanent load - Structure weight

Overload - hydrostatic pressure and wave force

Suction Wind

Overpressure wind

We can analyze the combinations of forces that result from the intended use for the building:

NORMAL COMBINATIONS

$$S_d=\sum_{j=1}^{m}\gamma_{gi}F_{Gi,k}+\gamma_{q1}F_{Q1,k}+\sum_{j=2}^{n}\gamma_{qj}\psi_{0j}F_{Qj,k} \quad (32)$$

The combinations of special forces that result from the performance of variable actions of a special nature or intensity, usually transient or of construction, that result from the performance already during the construction phase:

SPECIAL OR CONSTRUCTION COMBINATIONS

$$S_d=\sum_{j=1}^{m}\gamma_{gi}F_{Gi}+\gamma_{q1}F_{Q1}+\sum_{j=2}^{n}\gamma_{qj}\psi_{0j,ef}F_{Qj} \quad (33)$$

And the combinations that result from the performance of exceptional actions, which can cause catastrophic effects:

EXCEPTIONAL COMBINATIONS

$$S_d=\sum_{j=1}^{m}\left(\gamma_{gi}F_{Gi,k}+\gamma_{q1}F_{Q,exc}\right)+\sum_{j=2}^{n}\gamma_{qj}\psi_{0j,ef}F_{Qj,k} \quad (34)$$

According to the standard, we need to use the weighting coefficients according to the table:

Figure 64 - Weighting coefficients γ_g.

Combinações	**Ações permanentes** (γ_g) [a c]					
	Diretas					Indiretas
	Peso próprio de estruturas metálicas	Peso próprio de estruturas pré-moldadas	Peso próprio de estruturas moldadas no local e de elementos construtivos industrializados e empuxos permanentes	Peso próprio de elementos construtivos industrializados com adições *in loco*	Peso próprio de elementos construtivos em geral e equipamentos	
Normais	1,25 (1,00)	1,30 (1,00)	1,35 (1,00)	1,40 (1,00)	1,50 (1,00)	1,20 (0)
Especiais ou de construção	1,15 (1,00)	1,20 (1,00)	1,25 (1,00)	1,30 (1,00)	1,40 (1,00)	1,20 (0)
Excepcionais	1,10 (1,00)	1,15 (1,00)	1,15 (1,00)	1,20 (1,00)	1,30 (1,00)	0 (0)

Source: NBR8681/2003.

Figure 65– Weighting coefficients γ_q

	Ações variáveis (γ_q) [a d]			
	Efeito da temperatura [b]	Ação do vento	Ações truncadas [e]	Demais ações variáveis, incluindo as decorrentes do uso e ocupação
Normais	1,20	1,40	1,20	1,50
Especiais ou de construção	1,00	1,20	1,10	1,30
Excepcionais	1,00	1,00	1,00	1,00

[a] Os valores entre parênteses correspondem aos coeficientes para as ações permanentes favoráveis à segurança; ações variáveis e excepcionais favoráveis à segurança não devem ser incluídas nas combinações.

[b] O efeito de temperatura citado não inclui o gerado por equipamentos, o qual deve ser considerado ação decorrente do uso e ocupação da edificação.

[c] Nas combinações Normais, as ações permanentes diretas que não são favoráveis à segurança podem, opcionalmente, ser consideradas todas agrupadas, com coeficiente de ponderação igual a 1,35 quando as ações variáveis decorrentes do uso e ocupação forem superiores a 5 kN/m^2, ou 1,40 quando isso não ocorrer. Nas combinações especiais ou de construção, os coeficientes de ponderação são respectivamente 1,25 e 1,30, e nas combinações excepcionais, 1,15 e 1,20.

[d] Nas combinações Normais, se as ações permanentes diretas que não são favoráveis à segurança forem agrupadas, as ações variáveis que não são favoráveis à segurança podem, opcionalmente, ser consideradas também todas agrupadas, com coeficiente de ponderação igual a 1,50 quando as ações variáveis decorrentes do uso e ocupação forem superiores a 5 kN/m^2, ou 1,40 quando isso não ocorrer (mesmo nesse caso, o efeito da temperatura pode ser considerado isoladamente, com o seu próprio coeficiente de ponderação). Nas combinações especiais ou de construção, os coeficientes de ponderação são respectivamente 1,30 e 1,20, e nas combinações excepcionais, sempre 1,00.

[e] Ações truncadas são consideradas ações variáveis cuja distribuição de máximos é truncada por um dispositivo físico, de modo que o valor dessa ação não possa superar o limite correspondente. O coeficiente de ponderação mostrado nesta Tabela se aplica a este valor-limite.

Source: NBR8681/2003.

Figure 66 – Weighting coefficients γ_q

Ações		γ_{f2} [a]		
		ψ_0	ψ_1	ψ_2 [d]
Ações variáveis causadas pelo uso e ocupação	Locais em que não há predominância de pesos e de equipamentos que permanecem fixos por longos períodos de tempo, nem de elevadas concentrações de pessoas [b]	0,5	0,4	0,3
	Locais em que há predominância de pesos e de equipamentos que permanecem fixos por longos períodos de tempo, ou de elevadas concentrações de pessoas [c]	0,7	0,6	0,4
	Bibliotecas, arquivos, depósitos, oficinas e garagens e sobrecargas em coberturas	0,8	0,7	0,6
Vento	Pressão dinâmica do vento nas estruturas em geral	0,6	0,3	0
Temperatura	Variações uniformes de temperatura em relação à média anual local	0,6	0,5	0,3
Cargas móveis e seus efeitos dinâmicos	Passarelas de pedestres	0,6	0,4	0,3
	Pilares e outros elementos ou subestruturas que suportam vigas de rolamento de pontes rolantes	0,7	0,6	0,4

[a] Ver alínea c) de 6.5.3.
[b] Edificações residenciais de acesso restrito.
[c] Edificações comerciais, de escritórios e de acesso público.
[d] Para combinações excepcionais onde a ação principal for sismo, admite-se adotar para ψ_2 o valor zero.

Source: NBR8681/2003.

According to SILVA(2012)[xvii], the post-critical transversal displacements of a plate, under efforts in its plane, respect the Germain-Lagrange equation:

$$\frac{\partial^4 w}{\partial x^4}+2\frac{\partial^4 w}{\partial x^2 \partial y^2}+\frac{\partial^4 w}{\partial y^4}=\frac{12\left(1-\upsilon^2\right)}{E*B^3}\left(-n_x\frac{\partial^2 w}{\partial x^2}-2\frac{n_{xy}*\partial^2 w}{\partial x \partial y}+\frac{\partial^2 w}{\partial y^2}\right) \quad (35)$$

being:

w - displacement perpendicular to the plate plane at the x and y coordinate point

ν - Poisson's ratio

E - Modulus of elasticity of steel

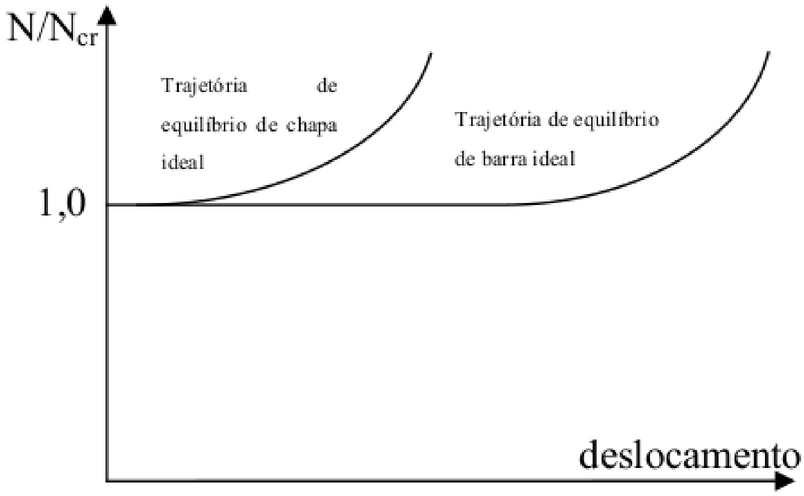
B - Plate thickness

n - force per unit length on the plate plane

A sheet subjected only to longitudinal forces and simply supported on two sides will behave in terms of instability like an axially compressed bar. However, if there are supports at one or two other ends, the behavior will be different, as the fibers parallel to one direction will restrict the deformation of the perpendicular fibers, increasing the critical force. In our case, it depends on how the project will be made possible on the sidewalk, and thus, according to the support provided, the behavior of the plate buckling can be analyzed.

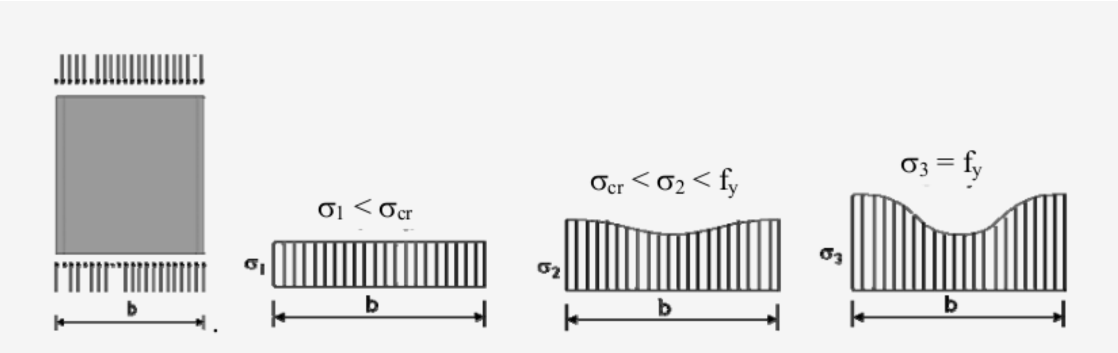
According to the same author, for subcritical tensions, the distribution is uniform. For increasing stresses, upon reaching the critical stress, the stress distribution is no longer uniform, and the ultimate limit state is reached when reaching the yield strength.

Figure 67 - Balance path of ideal structural elements**.**



Fonte: SILVA (2012).

Figure 68 - Stress distribution on a plate.



Source: SILVA (2012).

The dimensioning of the plates can be done by three methods: method of effective widths, direct method of determining the resistant forces and method of effective section. The effective width method has been used for many years and is still in ABNT NBR 14762: 2010. The method of direct determination of resistive stresses uses the actual stress distribution and can only be applied computationally. The effective section method is an application of the method of direct determination of the resistive stresses to some sections of cold-formed profiles most commonly found. Thus, for the project application, a detailed study of the buckling, bending, compression and torsion resistances of the structural elements must be made. However, as already mentioned, it is not part of the scope of this work to do the structural analysis of the plates.

Request scenarios

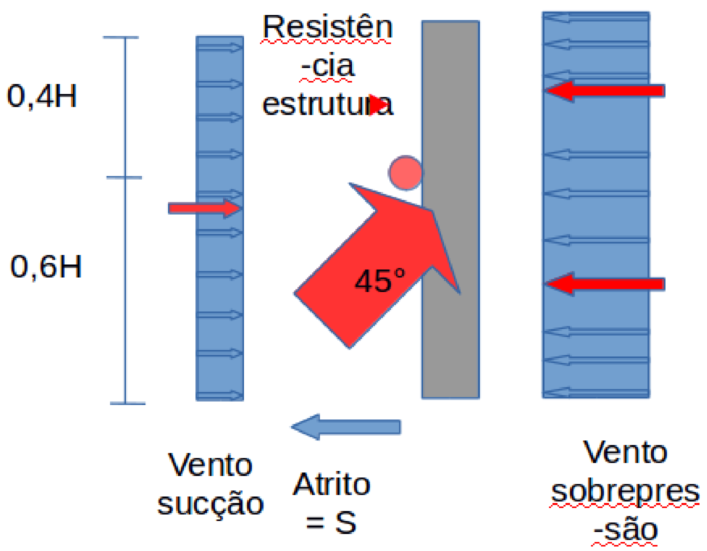
In order to carry out the resistance checks of the structure, we can think of 3 main scenarios, the first scenario C1, when the structure is in a flood position, in case of imminent flood, but there is still no flood, so it is forced only by the strength of the winds.

The second scenario C2, when the structure is in a flood position, in case of a flood in transition, there is flooding in part of the structure, so it is forced by the force of the winds in the non-flooded part and by the hydrostatic pressure together with the wave force in the flooded part.

The third scenario C3, when the structure is in a flood position, in case of a complete flood, in which there is total flooding, then it is forced by the hydrostatic pressure together with the wave forcing in the flooded part.

Scenario C1

Figure 69 – Simplified representation of forces present in the containment structure system in the scenario 1.



Fonte: Autor.

We will consider positive directions of the vectors from right to left, downward and clockwise. Considering that the SOIL SUPPRESSION force on the structure must be considered when calculating the piston box strength. And also using the weighting coefficients mentioned previously by the standard, we will have:

NORMAL COMBINATIONS

VERTICAL

Positive Sense

$$S_d = 1{,}0 \, . \, P \quad (36)$$

P = structure's own weight in N

Negative Sense

$$S_d = 1{,}0 \, . \, \text{sen}\, 45° \, . \, F_{\text{pistão}} \quad (37)$$

$F_{pistão}$ = Resistant piston force in N per meter of structure.

HORIZONTAL

Positive Sense

$$S_d = 1{,}25\,\mathrm{P} + 1{,}5\,.\,\mathrm{S} + 1{,}4\,.\,0{,}6\,.\,F_{\text{vento}-\text{sobrepressão}} \quad (38)$$

S = Frictional force in N

$F_{\text{vento-sobrepressão}}$ = Overpressure wind force in N for each meter of structure.

Negative Sense

$$S_d = 1{,}0\,.\cos 45°\,.\,F_{\text{pistão}} + 1{,}4\,.\,F_{\text{vento}-\text{sucção}} \quad (39)$$

$F_{\text{vento-sucção}}$ = Suction wind force in N for each meter of structure..

TUMBLE

It should be noted that the suggested structure has a point of application of force resistant to stresses present at the height of 0.6H of the structure and at 45 ° from the vertical, overcoming moment and forces applied to the structure, then:

M_{Ts}= F_a.(-0,08H²+0,18H²)+S.0,6H (40)

It should be remembered that the overpressure wind was considered, considering that, according to the model, the most critical case of winds to the structure (Figure 42)

Considering that the resistance to tipping will be due to the resistance of the weight of the structure itself, we will have:

M_{Tr}= P.(-0,6H+0,4H) (41)

M_{tr}= Resistant tipping moment in N.m

Considering the safety factor of FS≥1,5

FS=M_{Tr}/M_{Ts}≥1,5 (42)

$$\mathrm{FS} = \frac{\gamma_{\text{aço}}\,.\,B\,.\left(-0{,}6\,\mathrm{H} + 0{,}4\,H\right)}{F_{\text{vento}-\text{sobrepressão}}\,.\left(-0{,}08\,H^2 + 0{,}18\,H^2\right) + \mathrm{S}\,.\,0{,}6\,H} \quad (43)$$

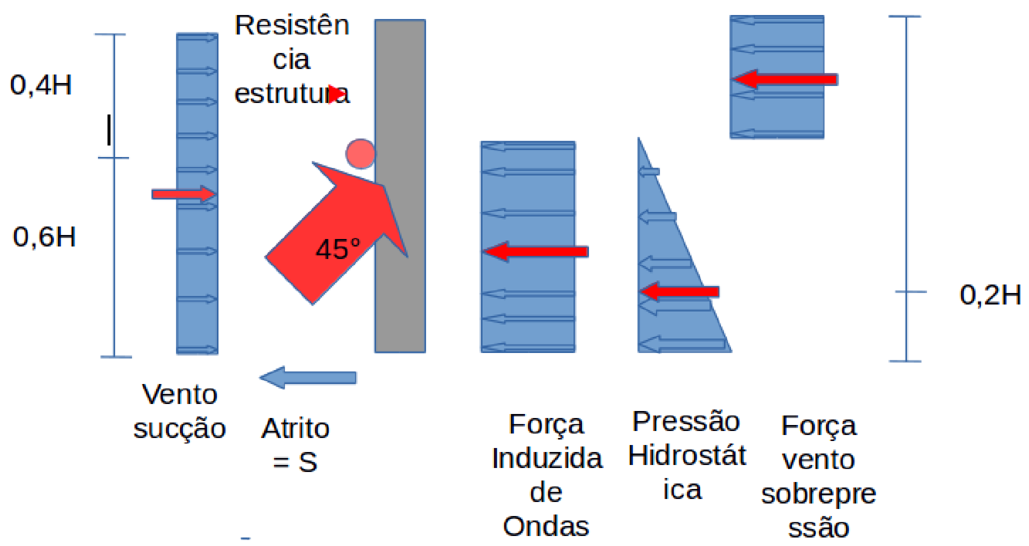
M_{ts}= Requesting tipping moment in N.m

$F_{vento\text{-}sobrepressão}$= Drag force of the overpressure wind for every meter of N-shaped structure.

S = Frictional force in N.

Scenario C2

Figure 70 – Simplified representation of forces present in the containment structure system in the scenario 2.



Fonte: Autor.

We will consider positive directions of the vectors from right to left, downward and clockwise. Considering that the SOIL SUPPRESSION force on the structure must be considered when calculating the piston box strength. And also using the weighting coefficients mentioned previously by the standard, we will have:

<u>SPECIAL OR CONSTRUCTION COMBINATIONS</u>

<u>VERTICAL</u>

<u>Positive Sense</u>

$$S_d = 1{,}0 \, . \, P \tag{44}$$

<u>Negative Sense</u>

$$S_d = 1{,}0 \, . \, \text{sen}\, 45° \, . \, F_{\text{pistão}} \tag{45}$$

The force that must withstand impact v

<u>HORIZONTAL</u>

<u>Positive Sense</u>

$$S_d = 1{,}15\,\mathrm{P} + 1{,}3\,.\,\mathrm{S} + 1{,}3\,.\,F_{\mathrm{wf}} + 1{,}3\,.\,F_{\mathrm{Ph}} + 1{,}2\,.\,0{,}6\,.\,F_{\mathrm{vento-sobrepressao}} \quad (46)$$

F_{wf} = Induced wave force for each meter of structure (in N for each meter of structure).

F_{ph} = Force produced by the hydrostatic pressure exerted in the area of the structure (in N for each meter of structure).

Negative Sense

$$S_d = 1{,}0\,.\cos 45°\,.\,F_{\mathrm{pistão}} + 1{,}4\,.\,F_{\mathrm{vento-sucção}} \quad (47)$$

TUMBLE

It should be noted that the suggested structure has a point of application of force resistant to stresses present at the height of 0.6H of the structure and at 45 ° from the vertical, overcoming moment and forces applied to the structure, then:

M_{Ts}= $-0{,}08H^2F_{sobrepressao}+W_{f.}0{,}18H^2+0{,}06P_h.H^2.+S.0{,}6H$ (48)

It should be remembered that the overpressure wind was considered, considering that, according to the model, the most critical case of winds to the structure (Figure 45)

Considering that the resistance to tipping will be due to the resistance of the weight of the structure itself, we will have:

M_{Tr}= $(P+F_{sucção})(-0{,}08H^2+0{,}18H^2)$ (49)

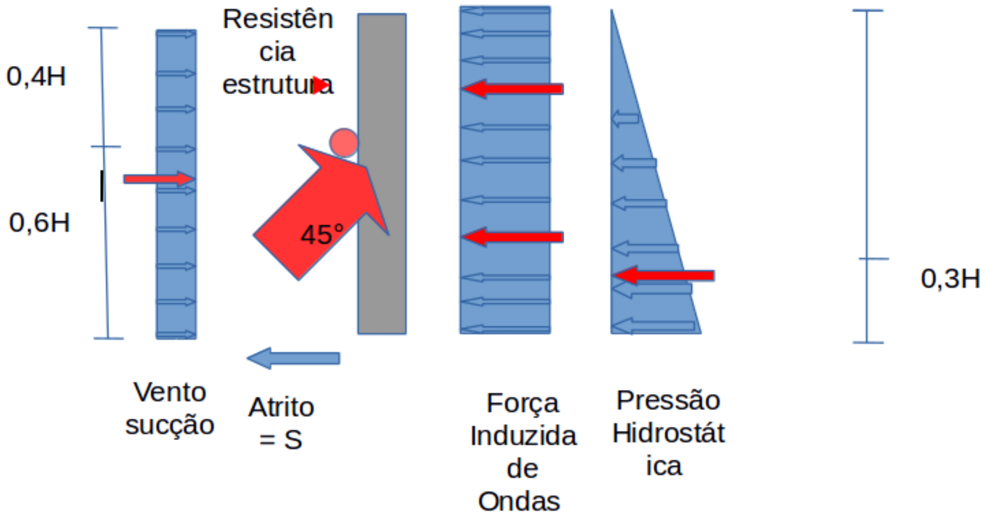
Considering the safety factor of FS≥1,5

$FS=M_{Tr}/M_{Ts}\geq 1{,}5$ (50)

$$\mathrm{FS} = \frac{0{,}1\,H\left(\mathrm{P}+\mathrm{F}_{\mathrm{sucção}}\right)}{0{,}16\,H\,.\left(F_{\mathrm{sobrepressao}}+\mathrm{W}_f+\mathrm{P}_h\right).+0{,}6\,.\,S} \quad (51)$$

Scenario C3

Figure 71 – Simplified representation of forces present in the containment structure system in the scenario 3.



Source: Autor.

We will consider positive directions of the vectors from right to left, downward and clockwise. Considering that the SOIL SUPPRESSION force on the structure must be considered when calculating the piston box strength. And also using the weighting coefficients mentioned previously by the standard, we will have:

<u>EXCEPTIONAL COMBINATIONS</u>

<u>VERTICAL</u>

<u>Positive sense</u>

$$S_d = 1{,}0 \,.\, P \quad (52)$$

<u>Negative sense</u>

$$S_d = 1{,}0 \,.\, \text{sen}\, 45° \,.\, F_{\text{pistão}} \quad (53)$$

The force have to resist the impact v

<u>HORIZONTAL</u>

<u>Positive sense</u>

$$S_d = 1{,}0\,\text{P} + 1{,}0 \,.\, \text{S} + 1{,}0 \,.\, w_F + 1{,}0 \,.\, P_h \quad (54)$$

<u>Negative sense</u>

$$S_d = 1{,}0 \, . \cos 45° \, . \, F_{\text{pistão}} + 1{,}0 \, . \, F_{\text{vento}-\text{sucção}} \quad (55)$$

TUMBLE

It should be noted that the suggested structure has a point of application of force resistant to stresses present at the height of 0.6H of the structure and at 45 ° from the vertical, overcoming moment and forces applied to the structure, so:

$$M_{Ts} = W_{f.}(0{,}18H^2 - 0{,}08H^2) + P_h(0{,}15H^2) + S.0{,}6H \quad (56)$$

It should be remembered that the overpressure wind was considered, considering that, according to the model, the most critical case of winds to the structure (Figure 45)

Considering that the resistance to tipping will be due to the resistance of the weight of the structure itself, we will have:

$$M_{Tr} = (P + F_{\text{sucção}})(-0{,}08H^2 + 0{,}18H^2) \quad (57)$$

Considering the safety factor of FS≥1,5

$$FS = M_{Tr}/M_{Ts} \geq 1{,}5 \quad (58)$$

$$FS = \frac{0{,}1\,H\left(P + F_{\text{sucção}}\right)}{0{,}1\,HF_{wf} + 0{,}15\,HF_{Ph} + 0{,}6\,S} \quad (59)$$

In the case of our work, for each meter of containment plate we find the Force caused by the hydrostatic pressure:

F_{ph} = 60kN

Force induced waves at every meter of:

F_{wf} = 5kN

Wind drag force on flood day:

F_a=0,253 kN

The force of underpressures, frictional force and the proper weight of the structure are dependent on the thickness of the plate used, which must be obtained through structural analysis, which is not in the scope of this work.

As previously mentioned, this work does not aim at the structural analysis of the practical application of the structure, therefore detailed calculations must be carried out with the structural modeling, in order to define a minimum thickness that will resist these requests.

This work shows a calculation demonstration for the conditions found on the dates consistent with the oceanic numerical simulations. It should be noted that, in case this new concept of maritime containment is adopted, computer simulations should be carried out for longer periods, in the order of one or two decades.

9. Discussion of results

Despite flaws in the data series and lack of homogeneity in obtaining them, the information obtained to date allows us to conclude that there is an increase in sea level in the Santos region, mainly since the 1950s.

In the studied month of August 2016, we observed that, in the Ponta da Praia region, the average sea level reached 0.7 meters above the historical average level. However, when additionally considering the tidal effects, the highs reached 1.8 meters above the average level, in a significant number of days in the last years analyzed. This shows us an alarming scenario for the Ponta da Praia region, and perhaps for other regions of Santos that are not part of the scope of our work.

Although we cannot say that this scenario of rising sea levels is purely cyclical or that it has been aggravated by global warming because we need more data, we know that this scenario is aggravated by atmospheric pollution, urbanization and soil sealing, present in the region. Thus, an ideal solution for the region of Ponta da Praia in the long term would be to vacate the region in view of the fact that this region is floodable and in the near term the flood scenario tends to worsen. Thus, with the eviction, there would be space for the local fauna and flora to reoccupy that region, with specific environmental studies it could return to a scenario similar to the original ecosystem. This would be the ideal solution for almost all those affected by the current flood situation: population, fauna, flora. However, from an immediate economic point of view, it would have a high impact on the region's real estate market and local commerce, since they would have to adapt to the new conditions.

Consequently, it is necessary to develop good quality sea level forecasting systems, including both tides and weather effects.

In view of political and economic interests, the possibility of adopting the ideal solution for unemployment is low. Thus, the immediate temporary solution for flood containment in extreme events and protection of the population that still resides or that visits the site would be the implementation of flood containment systems in the most critical areas, as proposed in the present work.

The results obtained were very close to the real data and have been compatible with the research being developed in the region for other purposes.

The cost of the containment structure will not be insignificant, especially considering that in the implementation it is decided to cover the entire extension of the Ponta da Praia region. However, is an investment in terms of protecting the population, infrastructure and the local economy, being fully feasible for a city hall the size of the city of Santos.

9.1. Environmental scenario discussion

As stated earlier, an ideal solution for the Ponta da Praia region in the long term would be to vacate the region, given that this region is floodable and the flooding scenario tends to worsen in the near term. With due care in specific environmental studies for this rehabilitation phase. However, from an immediate socioeconomic and political point of view, it would have a high impact on the region's real estate market and local commerce, since they would have to adapt to the new conditions.

It should be noted that for the implementation case, a detailed Environmental Impact Study should be carried out with specific studies carried out by qualified professionals from each impact sector, such as biologists, geologists, geographers and environmental engineers.

Thus, let us observe superficially, from an environmental point of view, what the implications of the implementation of flood containment systems in the most critical areas would be, as proposed in the present work on a temporary basis.

According to SANCHEZ (2008) i, the potential that a specific work or human action that causes environmental changes is linked to two factors:

The requests that will be imposed on the environment by the action or project, represented by the emission of pollutants, suppression or addition of elements to the environment.

The degree of vulnerability of the environment, the inverse of resilience, which in turn will depend on the state of conservation of the environment and the demands already imposed on it, whose effects have accumulated, in addition to the importance of the environment or the ecosystem.

Thus, we can assume the following discussion table regarding the environment of the study area in question:

Element	Magnitude	Probability	Duration	Distributive aspects	Reversibility and potential for adaptation	Description
Terrestrial Vegetation	Strong	High	Long-term temporary	Punctual	Reversible impact	The terrestrial vegetation of the study

						area is not native and was cultivated after the construction of the boardwalk
Mangrove	Weak	Low	Long-term temporary	Regional	Specific assessment required	The environmental analysis of the impact on the mangrove must be carried out by a professional in the area before any conclusion regarding the implementation.
Ichthyofaun	Weak	Low	Long-term temporary	Regional	Specific assessment required	It is close to the natural habitat of several species that even serve as food for birds, in addition to being of great importance for the Góes riverside

						population, in the city next door. However, the environmental analysis of the impact on the ichthyofauna must be performed by a professional in the area before any conclusion regarding the implementation.
Aquatic birdlife	Fraca	Average	Long-term temporary	Local	Specific assessment required	Migration route
Terrestrial birdlife	Weak	Average	Long-term temporary	Local	Specific assessment required	Several native and non-native species present
Leisure and Tourism	High	High	Long-term temporary	Regional	Positive Impacto	The current use occurs in mass and the study area has particular attractions that contribute to the

						increase in tourist activities. There is potential for development, and the implementation of containment works can favor the local economy.
Archeology	Weak	Low	Long-term temporary	Local	Specific assessment required	Relatively rare sites, however, a very important element for local history, for the history of the country and the world, in view of the characteristics of the formation of the city of Santos and the ancestral populations. But the work will not prevent large-scale archaeological work.

Tabel 5 – Main impacts of the containment work. Source: Produced by the author, based on SANCHEZ (2008)[xviii]

10. Conclusions

The study of the behavior of tides and tidal currents in the region is important, but it is not enough. The study of the behavior of the sea level, currents and waves under the influence of meteorological systems, were of paramount importance for the simulations, so that it is possible to propose adequate containment structures. Hydrodynamic 3D simulations, which took into account extreme meteorological factors, for the reproduction of the most critical conditions possible, in addition to critical scenarios of astronomical tides, were of great importance for the dimensioning of the proposed environmental solution.

This study showed the tendency of sea level rise in the region of Ponta da Praia Santos, from the observation of the data of tide gauges and satellite altimetry. It is encouraged to use this information in other works that aim to further investigate the causes of this elevation.

Through this work it was noticed that for coastal simulations Delft 3D proved to be more accurate than HYCOM. It was also noticed that using Delft 3D as a simulation model and HYCOM as a comparison model we obtained very close results.

From the results of the simulations in the period of 2 years (January 2016 to December 2017), we have the initial orders of magnitude from the critical events analyzed in this period, for the proposed containment work. They are the force caused by the hydrostatic pressure of Fph = 60kN, the force induced by waves at each meter of structure Fwf = 5kN, the wind drag force on the day of the flood Fa = 0.253 kN and the significant wave height to be considered in favor of safety and savings H = 2m (for this specific flood scenario). The force of underpressures, the force of friction and the proper weight of the structure are dependent on the thickness of the plate used, which must be obtained through structural analysis, which is not part of the objective of this work. Therefore, detailed structural modeling calculations must be performed to define a minimum thickness that can withstand the stresses described above.

This work demonstrates the calculation for the conditions found in the oceanic numerical simulations, for the period considered. If this concept of maritime containment is adopted, similar simulations should be carried out, for much longer periods, between one and two decades.

The cost of the containment structure will not be insignificant, it will mainly depend on the extent of extension to be adopted in the Ponta da Praia region, which will depend on the flood conditions (extent) found at the time of implementation studies. However, is an investment in terms of protecting the population, infrastructure and the local economy, being fully feasible for a city hall the size of the city of Santos.

In addition, according to the Coastal Engineering Manual (US Army, 2002) i, there are no absolute rules, nor absolute solutions, for the problem of coastal erosion, given the dynamics and diverse character of each coastline. No single set of regulations or philosophy for land use management is appropriate for all possible coastal situations or scenarios. The diversity of the coasts requires consideration of a variety of solutions when addressing problems in each specific area. Thus, for this constructive solution to be applied, it must be accompanied by several professionals, including modeling the behavior of soil massifs.

The ideal solution from the point of view of safety of the local population regarding the rise in sea level and from the point of view of the environment for the flooding region would be unemployment. However, considering the socioeconomic and political factors involved and the alarming situation of rising sea levels, also considering the possible impacts, the application of this constructive solution is indicated in the short term.

11. References

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