CHAPTER 127

COASTAL STUDY OF ESPÍRITO SANTO/BRAZIL

by

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I - INTRODUCTION

The elimination of land transportation costs for raw materials and/or industrialized products has encouraged integration of industrial and port activities and, at many ports, facilities are being built for the installation of industrial complexes adjacent to the port areas.

This general trend has been clearly observed along the coast of the State of Espirito Santo, Brazil, north of Rio de Janeiro. Several new port terminals, associated with industrial plants, are under construction or were designed recently.

In fact, the State's port development began with its Commercial Port in Vitoria, located at the mouth of the Santa Maria river. The following terminals connected with industries were built at a later date:

a) Tubarão Maritime Terminal, which was brougth into operation in 1966, sited at the outer end of Espírito Santo Bay, 9 Km away from Vitória, for iron ore exports. This terminal belongs to the stateowned Companhia Vale do Rio Doce - CVRD. Iron ore exports reached more than 50 milion ton per year during the last three years.

b) Ubu Maritime Terminal, inaugurated in 1977 and sited in the south of the State, was designed for exporting pelletized iron ore produced by a plant sited in the port area. This plant receives its raw material (ore fines) through a pipeline approximately 400 Km long. These facilities belong to privately-owned SAMARCO Mineração S.A., and will have a total export capacity of 7 million tons of pellets per year when it reaches it final expansion phase.

c) Barra do Riacho Port, which should start operation in 1978, built by PORTOCEL (owned jointly by PORTOBRÁS, Aracruz Celulose and CVRD) is intended to export wood chips and pulp produced at industrial facilities adjacent to the port.

In addition to these terminals, there are plans to built other ports which will handle goods to be produced by industries now moving into Espírito Santo.

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The main already designed is Praia Mole Port, to be built just north of Tubarão in order to attend the steel mill of Companhia Siderúrgica de Tubarão - CST - being built in that area.

This terminal is planned mainly for export of steel products and for import of coal for steel production.

Several studies and surveys have been made for designing and constructing the above mentioned ports. These studies and surveys provide a rather reasonable sample of coastal conditions in Espirito Santo. This paper aims at analysing and consolidating the most pertinent Coastal Engineering data already collected, so as to serve as a possible guideline for future designers engaged in coastal studies in this area.

II - DESCRIPTION OF THE COAST AND ITS MAIN PORTS

The coast of the State of Espirito Santo, approximately 205 miles long (Fig. 1), may be divided into four well-defined areas:

a) For the first 84 miles, from the Lençõis Cape, at the extreme north, to the Doce River Mouth, the coast is almost entirely flat, low and sandy, covered with low vegetation, and uniformly shaped. The main feature in this area is the São Mateus river mouth, conspicuous for its long sand dunes.

b) For the next 46 miles, from the mouth of the Doce River to the Espírito Santo Bay, the coastal line rises against the background of the Aimorés mountains. The coast is again sandy, often interrupted by reddish cliffs and protected by occasional reefs that extend sometimes up to one mile into the sea.

c) The Espírito Santo Bay, approximately 2.5 miles long, is located between the Tubarão and Santa Luzia headlands. Here the Santa Maria River drains into the sea, its two main arms forming the Island of Espírito Santo, where the capital of the State is sited, with 300,000 inhabitants and forming the main commercial port of the area.

d) For the last 72 miles, from the Espírito Santo Bay to the Itabapoana River bar, the coastal aspect and shape are quite varied. The coastal plain becomes increasingly narrower in this area, as the Aimorés mountains reach closer and closer to the sea.

In these four areas some of the main specialized cargo terminals in Brazil are sited. Others are in design stage and shoud be built in the near future. A description of these ports is found below:

2.1 Existing Ports

2.1.1 Ubu Maritime Terminal

This maritime terminal, sited at the Ubu headland (Fig.2), was built for the export of 5 million tons of pelletized iron ore per year. The ore is mined in the State of Minas Gerais and is tranferred through a pipeline, in the form of slurry, down to the port facilities, where it is pelletized and stockpiled for shipment. The harbor will take in ships up to 250,000 DWT after expansion (Ref. 1).





The marine terminal is formed by an "L" - shaped stone breakwater, 1,250 m long, and a 313 m long reinforced concrete pier. Ships reach the pier through a dredged channel, 18 m deep, which becomes wider near the pier so as to form a turning basin.

2.1.2 Tubarão Maritime Terminal

The Tubarão Maritime Terminal sited north of the city of Vitória, is designed for a yearly throughput of 60 million tons of iron ore. An additional ore handling berth was built between 1972 and 1973 to handle 270,000 DWT vessels (Pier nº 2), with a 2-mile approach channel dredged to a depth of - 23 m (Ref. 2). Fig. 3 shows the terminal's layout after expansion, including the originally built Pier nº 1, which can handle ships up to 100,000 DWT, as well as the protecting rubble mound breakwater.

2.1.3 Barra do Riacho

A specialized port complex at Barra do Riacho is under construction for the export of cellulose produced by local existing and future plants.

In their initial stage, the facilities will comprise a 200 m long berth capable of handling blenched pulp vessels of up to 35,600 DWT. This has involved the construction of protecting wharves and a docking pier, as well as dredging the approach channel and turning basin, as shown in Fig. 4.

In addition to the cellulose, the port complex will handle the raw materials required by the local plants, in the form of liquid or solid bulks. The largest vessels expected to call at this part of the port will be 30,000 DWT oil tankers.

2.2 Port Projects

In addition to these ports already in operation, the coast of the State of Espirito Santo is being considered for future facilities, for which hydrographic data have been gathered along the coast from north of the Doce River mouth to Espirito Santo Bay. (Refs. 3,4 and 5).

2.2.1 Praia Mole

A basic layout for the port facilities being planned for Praia Mole has been arrived at, the harbor being artificially protected by a 7 km long rubble mound breakwater, at an estimated dredging volume of 20 million cubic meters (Fig. 5).

The approach channel to the Praia Mole port will be dredged to a - 19 m depth, which will permit handling vessels up to 120,000 DWT. In addition to the general cargo and coal handling berths, which will service the steel plant, other specialized terminals are being contemplated within the basin of the port.

III - ANALYSIS OF EXISTING DATA

This section presents the main conclusions of the studies performed along the coast of Espírito Santo.

3.1 Wind Conditions

In general, the Brazilian east coast is considered to be a meteorologically very calm area, unaffected by violent tropical storms.

For the Barra do Riacho (PORTOCEL) project, the Danish Hydraulic Institute (DHI) performed anemographic measurements throughout the year of 1974 (Ref. 6). Such measurements are representative of the entire region, from Vitória to Doce River, and are presented in the wind rose of Fig. 6. Measurements made at Barra do Riacho have shown a maximum wind speed of 22 m/s, but only 0.3% of all measurements were in excess of 15 m/s.

The predominant wind directions are from NE-E and from S-SW, with the northeasterly winds dominating in strength. During more than 2.5% of the year, these winds exceed 10 m/s.

Daily maximum wind speeds at Barra do Riacho for the year of 1974 have been compared with measurements made at Vitória for the years 1971-73 (Ref.6). There was good agreement between data, which are shown in Fig. 6.

3.2 Wave Climate

The currently available information on wave conditions along the Espírito Santo coast stems from the wave observation sources listed below (items a and b) as well as from wave measurements mentioned in items \overline{c} , d and e:

a) Ocean Wave Statistics, compiled from visual observations on ships by the National Physical Laboratory, London, covering a 9 year period. The Marsden Square areas that are of particular interest to this study are MS37 and MS40, set apart from each other by the 209 parallel, crossing slightly south of Barra de Santa Cruz. The Ubu, Tubarão and Praia Mole harbors belong to MS40, whereas Barra do Riacho and other planned harbors to be sited near mouth of Rio Doce River belong to MS37. Fig. 7 shows the deep-water roses for MS37 and MS40.

b) Atlas of Sea and Swell Charts-South Atlantic, compiled by the U.S.Navy Hydrografic Office also from visual observation in deep waters.

c) Measurements off Barra do Riacho, performed by DHI with the help of two wave recorders for a period of 15 months in 1973/74.

d) Wave measurements performed at Petrobras Oil Rigs Pl and P2, for a period of 8 months, during 1972/73.

e) Wave measurements made at the Tubarão Iron Ore Terminal for a period of 9 months, during 1971/72.

Table 1 below summarizes the data obtained from the various wave measurement cam paigns up to 1974.

Due to the short duration of the measurement work performed by the Petrobrás Pl and P3 Oil Rigs and Tubarão Terminal, these data were not used for engineering purpose.

TABLE I

WAVE CONDITIONS OBSERVED AT VARIOUS LOCATIONS ON THE COAST OF THE ESPÍRITO SANTO STATE

| LOCATION | Maritime Terminal of Tubarão (CVRD) | Petrobrás Oil Rigs Pl and P3 | Barra do Riacho Port | |
|--|--|--|---|--|
| OBSERVATION SITE | Seaward of Tubarão's breakwater | Off Doce River mouth | South of Riacho River mouth,off the Southern reef. | |
| WATER DEPTH OF INSTRUMENT | 9.0 m . | P1: 22.0 m P3: 53.0 m | 16.0 m | |
| PERIOD OF MEASUREMENTS | June 1971 to April 1972 | October 1972 to May 1973 | September 1973 to December 1974 | |
| TYPE OF WAVE RECORDER | Pressure wave recorder (Hydro Products O.E.C. type WR 421) | Ultrasonic recorder (Neyrpic) | Waverider System(Datawell) and Pressure Wave recorder (OSPOS) | |
| RECORDING PROGRAM | 15 min.of continous re- cords, at 12 hours intervals | 15 min. of continous re- cords, at 12 hours intervals | 20 min.of con- tinous records each 3 hours (Datawell)and 15 min.each 3 hours (OSPOS) | |
| AVERAGE WAVE PERIOD (TZ) | 10 sec. | Between 7 and 8 sec. | 8 sec. | |
| HIGHEST OBSERVED SIGNI- FICANT WAVE HEIGHT(^H Smáx.) | 4.25 m | 2.7 m | 2.2 m | |
| MONTHS OF HIGHEST OBSER- VED WAVES | June and September | March and May | June, July and September | |
| MONTHS OF LOWEST OBSERVED WAVES | January and March | October and February | February,March and April | |
| HIGHEST WAVE | S and SF | NF and S | S – S F | |
| MOST FREQUENT HAVE DIRECTIONS | S and SE | E-NE and E | E and NE | |
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The data obtained from wave recorders at Barra do Riacho are of good quality, and they supersede the ones originating from visual observations, which can be used only for comparison or on a preliminary basis.

DHI conclusions based on comparisons with the measured wave data are that wave heights calculated on the basis of deep water (observed) data will result in considerably higher waves, but with a direction distribution very similar to that obtained off Barra do Riacho during 1973/74.

Wave measurements made off Barra do Riacho by DHI in 1974 are shown in Fig. 6. Waves have been recorded by a Datawell Waverider together with an Ospos recorder. The Waverider was programmed to record a 20-minute time series every three hours, whereas the Ospos records were for 15 minutes every three hours. Observations of wave directions were performed by the local operator.

During the time interval covered by the observations the highest significant wave height was Hs = 2.2 m, corresponding to a maximum wave height of Hmax = 3.4 m, at a depth of water of 16 m. The highest waves were measured in June, early July and September. Waves did not exceed Hs = 1.5 m from January through May, as well as during the greater part of July and October. The season with lowest waves was February to April. Mean wave periods between 5s and 15s were measured. The average mean period is 8s.

Along the Espirito Santo coast, from the Ubu Terminal up to the mouth of the Doce River the highest waves occur from S-SE, but most frequently wave directions are between E and NE. For the highest waves, the wave period varies between 8 and 12 s.

3.3 Water Levels and Currents

The water level variation caused by tide and storm surges has been reproduced by the Ospos wave recorder during the measurements performed by DHI. The discrete values of the water level obtained at Barra do Riacho were compared with the water level at the tide recorder at Vitoria/Tubarão. The result was that the water level measured by the Ospos recorder at Barra do Riacho follows the tidal prediction for Vitoria and Tubarão closely. From the predictions, the maximum yearly tidal range is found to be 1.8 m. In addition to the astronomical tide, the water level may be affected by rises resulting from storm surges.

On the grounds of DHI float tracking at Barra do Riacho (Ref. 6), it is estimated that a current velocity of 0.25 m/s will on the average be exceeded with a total duration of 75 days per year, and that a velocity of 0.6 m/s will be exceeded 24 hours per year.

3.4 Soil Characteristics

In the area between Tubarão and Barra do Riacho, the subsoil material is of a complex nature. In general, there occurs a predominantly sandy surface layer of average compactness. Underlying it, there is a stiff clayey layer of varying thickness, below which the soil again becomes sandy, though more compact than at the surface.

Sandstone reefs (limonitic "cangas") are commonly found in most of the Espírito Santo coastline. Reefs or "cangas" outcrop in certain areas, which makes dredging work difficult and reduces equipment productivity - a problem which occurred with major or lesser intensity while dredging at Tubarão, Ubu and Barra do Riacho was in process.

The analysis of bottom sediment samples indicates that the median diameter (D_{50}) of sandy material is of the order of 0.2 to 0.3 mm at Praia Mole, and it ranges between 0.4 and 0.6 mm at Barra do Riacho. Along the beach stretch south of the mouth of the Doce River (Fig. 8), the median diameter of sand varies from 0.15 to 0.6 mm when in water depths up to 10 m and from 0.15 to 0.9 mm at depths between 10 and 15 m.

3.5 Coastal Processes

The beach slopes which form the eastward boundary of the Espírito Santo coastal plain vary accordingly with the size of the sand material.

Both north and south of the Doce River mouth, these slopes are between 99 and 129, but they may exceptionally be as steep as 159. North of the Doce River, where finer sand is found, beach slopes may be as flat as 59.

The large area of alluvial material which extends from Barra do Riacho, in the south, to Conceicão da Barra, in the north, makes up a huge delta deposit formed by sediments brought down to the sea over geological times by the rivers in the area, particularly the Doce River (Ref. 7). Waves, tidal currents and wind action have shaped the seaward side of this delta to bring about the coastline configuration as it is today.

The Doce River delta formation process my be summarized as follows:

- The finer materials (silt and clay) are carried in suspension in the directions determined by currents. Waves stir up all sediments wich may have been deposited in the sedimentary platform, where depths are small. Thus, the part of the delta formed by silt and clay has a tendency to migrate northwards along the coast, causing depths to decrease in this area as the submerged slopes gradually becomes less steep. This trend is confirmed by the shape of the alluvial fan of the river which expands little towards the south (see Fig. 8), while it becomes longer and wider towards the north, as indicated by bathymetric readings in the area. The result is an evident spread of the deltaic front towards the north.

- Coarser material (sand) is moved mainly by waves, being carried and deposited at each point in accordance with the local wave regime. Any sandy material not retained at the mouth, but flushed out to sea beyond the river bar, tends to be caught in areas relatively close to the mouth; there occurs a natural sorting of diameters, the less coarse material advancing further than the others.

The sand accumulates initially in the shallower zones of the alluvial fan itself. Waves are the determining factor for sand movement, due to the small depths and the gentle slope of the sedimentary platform which results in a wide surf zone.

The Doce River mouth constitutes an inflection point in the Espirito Santo coastline. South of it, the coastline heads SW, which gives it a smaller inclination with regard to the highest waves from SE and more protection against waves from NE. This coastal configuration has significant implications for sand movement along the coast.

Between Tubarão and Barra do Riacho the coastline is formed by a sucession of pocket beaches between reef headlands. From Barra do Riacho to the south of the Doce River mouth, sand is moved either north ot south, depending on the wave climate, but the net direction of the littoral drift is southward.

In the case of sand movement towards the north, sand is carried along the coast in this direction as long as waves from S and SE prevail; however, they will always tend to show an annual net movement towards the south, since this is the direction of the resulting littoral drift.

South of the Doce River mouth, the southward component of the littoral drift decrease as one moves down along the coast. It is estimated that, midway between Regência and Barra do Riaçho (Ref. 5), the maximum annual littoral drift is about $500,000 \text{ m}^3/\text{year}$ while the net annual littoral drift is $150,000 \text{ m}^3/\text{year}$, both southwards according to C.E.R.C.'s formula (Ref. 8) and Ocean Wave Statistics' deep water data. As one moves further south along the coast, the southward littoral drift decreases as the northward one increases; in the vicinity of Barra do Riacho, they practically cancel each other.

It has been gathered from examination of hydrographic charts, deep water wave data and aerial photographs, that the dominant direction of littoral drift north of the Doce River is northward. Typical signs of this are the shapes of bars, of beach stretches where natural sandstone spurs occur, and of tombolos formed in the lee side of the reefs.

A more accurate description or quantification of the littoral drift north of the Doce River can only be made after detailed knowledge of wave characteristics in the area has been obtained through wave measurement records and observation of directions for at least one whole year.

3.6 Breakwater Survey

Table 2 shows conditions for rubble mound breakwater designs for the artificial harbors along the Espírito Santo coast (Ubu, Tubarão and Barra do Riacho) and for the Praia Mole Harbor Project.

In June, 1978, CVRD performed a survey of the breakwater at the Tubarão Maritime Terminal, comprising the four cross-sections shown in Figs. 9 and 10.

| TABLE 2 | |
|---------|--|

| CTERISTICS | KD K Crest W Elevation Depth (m) (m) (m) | 3,5 5-8 +10,0 10,0 | 3,5 8-12 +7,0 14,0 | 3,5 6-8 +6,5 14,0 | 4,0 9-12 +9,5 15,0 | 4,0 9-12 +7,0 16,0 | 3,3 2,5-7 +6,7 10,0 | 3,3 2,5-7 +6,7 7,0 |
|-----------------------|---|-------------------------------|-------------------------------|--------------------------------------|---|---|--|--|
| BREAKWATER C CHARI | 3REAKWATER C CHARA ard γ_r rees) $(t/m^3$ | 25 2,67 | 25 2,67 | 25 2,6 | 5 2,7 | 5 2,7 | 5 2,64 | 5 2,64 |
| WATER Level | HHWS Seaw HHWS Coto (m) (deg | +1,80 1. | +1,80 1. | +1,80 1. | +1,80 1. | +1,80 1. | +1,80 1. | +1,80 1. |
| SNDITIONS | T (s) | 8-14 | 8-14 | 6-12 | 7-12 | 7-12 | 8-12 | 8-12 |
| WAVE (| H s (m) | 4,2 | 4,2 | 4,0 | s , 0 | 5 , 0 | 3,0 | 3,0 |
| | | Ubu Breakwater Section A-A | Ubu Breakwater Section B-B | Tubarão Breakwater Section A-A | Praia Mole Project South Breakwater Section A-A | Praia Mole Project North Breakwater Section B-B | Barra do Riacho South Breakwater Section B-B | Barra do Riacho North Breakwater Section C-C |

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The Tubarão breakwater extends in a straight line in the NE-SW direction, and provides protection for iron ore piers 1 and 2, in addition to the oil berth located at its lee side. It is directly exposed to wave action from the SE direction.

The survey shows an irregular cross-section. A certain amount of settlement of the breakwater crest was observed, probable due to loss of core material. The slope towards the sea is more regular from the shore end to the oil berth; from then on, it shows a decline of 1:1 at certain points above sea level which means that the armour stones were displaced by wave action and/or as a result of soil settlement. Below sea level the seaward slope has shown a flattening trend with time. No maintenance work has been done on the breakwater since it was built in 1963/64.

IV - CONCLUSIONS AND RECOMMENDATIONS

The port designs developed for the Espirito Santo coast have been based on different criteria. Due to the fact that wave climate measurements were made only for the harbor at Barra do Riacho, the various breakwaters were calculated with different design wave heights.

4.1 A comprehensive knowledge of wave characteristics is the basic requirement for Coastal Engineering designs. For the Espírito Santo coast, such characteristics will have to be determined by installing wave recorders at least at three points along the coastline: one north of the Doce River mouth, a second, south of the Doce River mouth, between Tubarão and Barra do Riacho (an OSPOS recorder is already being operated by INPH/PORTOBRÁS at Barra do Riacho); and a third, south of the Espírito Santo Bay, possibly near the Ubu Maritime Terminal. From the analysis of the data thus obtained, the distribution, of wave periods, wave heights at given depths, wave directions, as well as wave frequency and direction spectra can be obtained for each of these areas.

4.2 Additional studies are required to provide a better insight of coastal processes. In order to determine current direction and speed, it will be necessary to operate current meters for at least one year at certain points along the coast, preferably at those points where wave recording is carried out. To help quantify the littoral drift, the velocity of longshore currents may be measured and bottom sampling may be carried out at certain sites, from the shore to a depth of about 20 m, together with the analysis of such samples for determining mechanical and mineralogical analysis of the materials carried by the Doce river, and to compare them with the heavy minerals found along the shoreline.

4.3 Systematic yearly surveys are also recommended for the cross-sections of the various breakwaters recently built on the Espírito Santo Coast, in order to evaluate the damage experienced in time.

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