



MEASUREMENT OF WAVES, TIDES AND CURRENTS IN MANDOVI ESTUARY, GOA DURING THE MONSOON SEASON

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ABSTRACT

The channel across the Aguada sand bar at the mouth of the Mandovi river is navigable only during the fair weather season (October to May). During the monsoon period (June to August) the navigation across the sand bar is suspended for safety reasons. The high and steep waves breaking over the sand bar and their interaction with the large fresh water out-flow from the river make the navigation across the bar very difficult and hazardous. In order to develop an engineering solution to the problem, it became necessary to initiate data collection programme for understanding the physical processes leading to the formation of sand bar and the associated navigational problems. In this paper the measurements undertaken and the problems faced during the 1980 monsoon period are presented. Preliminary results of the analysis of data on waves, currents and tides are also included.

INTRODUCTION

The navigational channel across the Aguada sand bar at the mouth of the Mandovi river is of great economic importance to Goa. A large number of barges with capacity upto 1000 DWT carry iron and manganese ores during the fair weather season (September to May) through this channel to Mormugao harbour. During the same period, Bombay-Panjim passenger liner and a large number of fishing trawlers and country boats utilise this navigation channel. During the south-west monsoon, the Captain of Ports at Panjim closes the channel to vessel traffic. Some of the vessels however, take up a longer route passing through the Cumbarjua canal which links the Mandovi and Zuari rivers (Fig. 1). As the major contribution for the economic development of the region comes from the export of iron ore, there is a great need for improving the navigational conditions across the Aguada sand bar. In order to understand the physical processes taking place in this estuary and to develop some insight to the phenomenon of sand bar

formation, a measurement programme on waves, tides, currents and bathymetry was initiated during the 1980 monsoon. A number of problems were faced during the installation and operation of the instruments because of heavy vessel traffic during the pre-monsoon period and rough sea conditions in the monsoon period. The study will be further extended to understand the sediment transport, and related changes in the bathymetry at the Aguada bar channel and its vicinity.

Description of the Study Area:

The area where the Mandovi river enters the Arabian sea is in the form of a bay, known as the Aguada bay (Fig. 1). Sinquerim and Caranzalem bays form an integral part of this bay. The bay is about 3.25 km wide between the Cabo and Aguada headlands with an average depth of about 7 m. The surface area of the bay is about 11.5 million square metres. The Mandovi river narrows down to a width of about 700 m at Reis Magos wherein the maximum water depth is about 10 m in the bar channel and the average depth is about 4.5 m.

During the fair weather season (October to May) the flow is predominantly tidal in nature and the estuary is well mixed. With the onset of the south-west monsoon (June to September), the estuary becomes progressively stratified due to the increase in the fresh water flow from the Mandovi river into the Arabian sea (Murty, Das, Nair, Veerayya and Varadachari, 1976). The Aguada bar is a composite of two bars viz the Reis Magos bar and Aguada bar (Fig. 2). The navigation channel with about 10 m water depth runs between these two bars. The ends of the two bars adjacent to the channel are having nearly vertical banks upto 2-3 m below the mean sea level followed by less steep slopes (1 : 10) further below. In the fair weather season, at low tide levels, some portion of both of these bars are visible above the water surface (Fig. 3).

Measurement Programme and Associated Problems:

As a part of the detailed study it was decided to initiate the data collection programme during the 1980 monsoon itself. The wave rider buoy was installed at about 8 m water depth (location D in Fig. 2). Fig. 4 shows the wave rider buoy mooring system used at this location. For the description of the wave rider buoy reference may be made to the paper, "Wave measurements off the Bombay coast" by Nayak and Anand (1981) presented in this conference. Continuous data on waves were obtained from 2nd June to 4th July, 1980. On 5th July, the wave record was noticed to be completely erroneous. Careful investigation and trouble shooting tests revealed the fact that it was the effect of the failure of electronics inside the buoy itself. Hence, the wave rider buoy was retrieved and it was noticed that the accelerometer had gone out of order and could not be repaired. However, very useful wave data could be collected during the first part of the monsoon period. Fig. 5 shows the condition of the wave rider buoy recovered in July 1980 after operating it for about a month. The rubber fender was found missing and the external surface of the buoy was covered with marine growth and barnacles.

An Aanderaa current meter was installed near the Verem jetty (location A in Fig. 2) on 28th May 1980 to measure bottom currents. The

mooring system consisted of a 400 kg. reinforced concrete block in which a stainless steel pipe of 50 mm dia was embedded (Fig. 6). The current meter was securely fixed with the marker buoys (painted red and yellow) as indicated in Fig. 6. Unfortunately, the mooring lines of the marker buoys got entangled with the rudder of an ore carrying barge in the night of the day of installation. The current meter with its mooring system was carried away along with the barge upto a distance of about 8 km upstream of the river. The spindle of the current meter was badly bent and the rotor was lost. The current meter, fortunately, was not damaged.

The monsoon had already set in and the installation of current meters at locations B and C and reinstallation at A (Fig. 2) could be undertaken only on 11th June, 1980. The type of mooring arrangement was the same as shown in Fig. 6. The current meters were fixed to measure currents at about 1 m above the sea bed. Due to the onset of the monsoon and non-availability of a suitable boat with derrick facility, it was not possible to install a current meter for measuring surface currents as originally proposed. The marker buoys attached to the current meter at location B (Fig. 2) were lost or removed by the local fishermen. Because of this, there was a considerable delay in the recovery of this instrument. As a result, the data from this location could not be analysed and presented in this paper.

When the current meter installed at position C (Fig. 2) was retrieved immediately after the monsoon, the magnetic tape in it was observed to contain only 6 hours' data. The cause of this malfunctioning of the instrument could not be found. For tide level measurements, a tide gauge developed by the Institute was installed near the Verem jetty (location A in Fig. 2).

Wave Data Analysis and Results:

The wave records were analysed using Tucker's method and the wave parameters like significant wave height H_s , zero crossing period T_z , maximum wave height H_{max} , period associated with the maximum wave height T_{max} and the spectral width parameter ϵ are determined as explained in the conference paper, "Wave measurements off the

Bombay coast" (Nayak and Anand, 1981).

Fig. 8 and 9 present the variation of daily highest significant wave height H_s and the daily highest maximum wave height H_{max} for the recording period, 2nd June to 4th July 1980. The highest significant wave heights H_s ranged from 1.5 m to 2.75 m. The maximum wave heights H_{max} were found to fluctuate between 2.5 m and 3.5 m. The highest maximum wave height occurred on 24th June 1980 and it was 4.45 m.

Joint distribution of H_s and T_z is presented in Fig. 10. As expected, the figure indicates that the monsoonal waves are high and steep with wave steepnesses ranging from 1/15 to 1/50. Majority of the waves have the zero crossing periods ranging from 7.5 to 9.5 secs.

In Figs. 11 (a) to (d), frequency distribution diagrams of H_s , H_{max} , T_z and ϵ are presented. They give the percentage of occurrence of each of these wave parameters in different class intervals.

Fig. 12 shows the cumulative distribution of the daily highest significant wave height H_s and the daily highest maximum wave height H_{max} for the period of measurement. It can be seen that the significant wave height exceeded 1 m for 98% of the time, 1.5 m for 80% of the time, and 2 m for 22% of the time. Similarly H_{max} values exceeded 2 m for 90% of the time, 3 m for 15% of the time and 3.5 m for 2% of the time.

Description of the Aanderaa Current Meter:

The Aanderaa recording current meter is a self contained compact instrument. This can be pre-set to record temperature, conductivity, pressure, current speed and direction at a given interval of time on a 6.35 mm magnetic tape. A Savonius type rotor and a magnetic compass sense the current speed and direction respectively. Temperature is sensed by a thermister and conductivity by an inductive type sensor. The accuracies of measurements of the current meter are as follows: $\pm 5^\circ$ for current direction, $\pm 0.15^\circ\text{C}$ for temperature, $\pm 0.1\%$ for conductivity and depths. The threshold speed

of the rotor is 2 cm/sec. A recording interval of 20 minute was chosen for the present study.

Tide Measurements:

A tide level recorder developed by the Institute was installed near Verem jetty (position A in Fig. 2) to record tide levels. Fig. 7 shows the metal mounting used for installing the tide gauge. A strain gauge pressure transducer senses the hydrostatic pressure due to the water column above it. The output of the sensor after proper filtering is recorded on a strip chart recorder installed in a building located on the bank of the river. The signal from the sensor was transmitted to the recorder through a 5 core underwater cable.

The tides were predominantly semi diurnal. The tide levels recorded at the Verem jetty were compared with those observed at and predicted for the Mormugao harbour as shown in Fig. 13. Based on only a preliminary analysis, the high tide levels at Aguada bar channel is found to occur about 30 minutes after the occurrence of high tide levels at Mormugao harbour. Detailed analysis will be carried out to establish proper relationship between tides at Mormugao harbour and the Mandovi estuary.

Currents at Aguada Bar Channel:

Currents were found to be dominated by tides causing flood currents flowing into the river and ebb currents flowing out of the river into the sea. Only for two days (11th and 12th June 1980), the current speed and directions were plotted with time as shown in Fig. 14. The maximum current measured at about 1 m above the bottom was 0.8 m/sec. A general time lag of about 4 hours was observed between maximum currents and the high or low tide levels as indicated in Figs. 13 and 14. Analysis of the remaining data and collection of more data may lead to very useful relationships for evaluating the sediment transport conditions and stability of the Aguada bar channel.

CONCLUSIONS

Based on the preliminary observations made during June/July 1980, the following conclusions

are drawn:

1. The daily highest significant wave heights H_s and the daily maximum wave heights, H_{max} varied from 1.5 m to 2.5 m and 2.5 m to 3.5 m respectively. The highest significant wave height and maximum wave height were 2.75 m and 4.45 m respectively. The wave steepness varied between 1/15 and 1/50 as expected of the monsoon waves. The zero-crossing periods ranged from 8.5 to 10.5 secs.
2. The tides are predominantly semi diurnal. The high tide at Mandovi estuary has a time lag of about 30 minutes with respect to the high tides at Mormugao harbour.
3. Currents in Aguada bar channel are predominantly tidal in character. The current directions are mainly parallel to the alignment of the channel with flood currents flowing into the river and ebb currents flowing into the sea. A general time lag of about 4 hours was observed between the occurrence of maximum currents and the high or low tide levels.
4. A more detailed data collection programme should be undertaken to understand the physical processes at the Aguada bar channel. Data on waves, currents, tides, winds, bathymetry, river flow etc. should be collected during the monsoon and non-monsoon seasons and properly analysed to evaluate the stability of the Aguada bar channel and related navigational problems.

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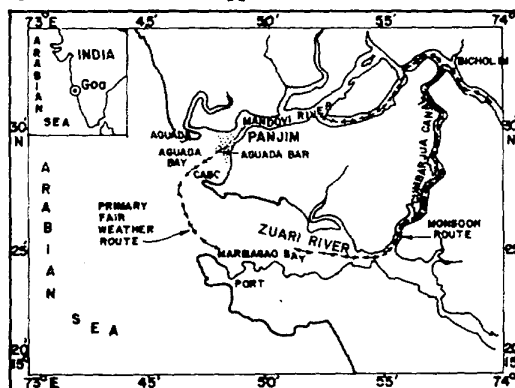


Fig. 1 Location Map of Mandovi Estuary

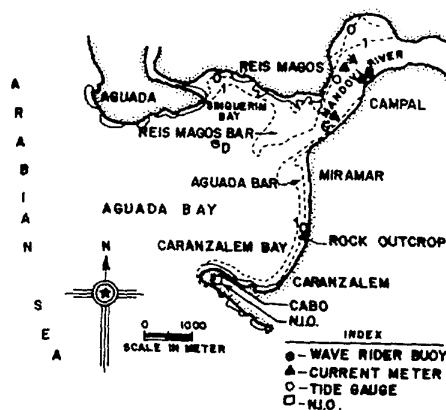


Fig. 2 Map Showing the Study Area

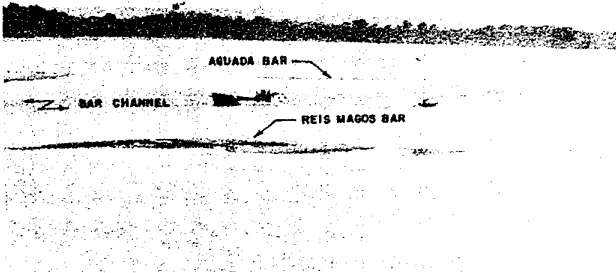


Fig. 3 Sand Bars Exposed at Low Tide Level in Mandovi Estuary, Goa

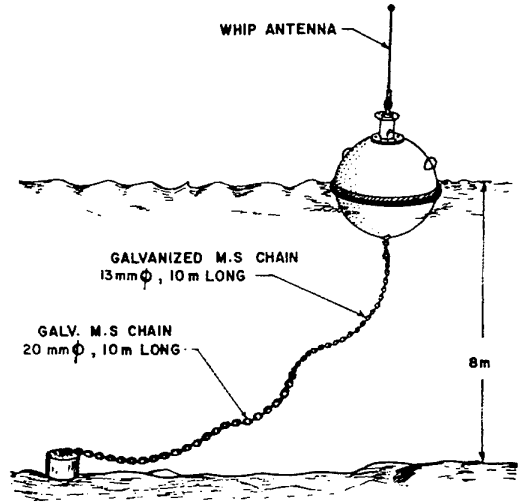


Fig. 4 Mooring Arrangement for Wave Rider Buoy



Fig. 5 Wave Rider Buoy after One Month's Operation in Aguada Bay

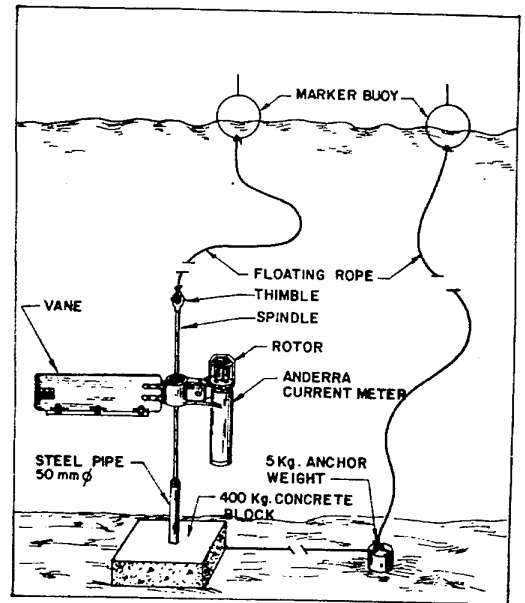


Fig. 6 Current Meter Mooring Arrangement

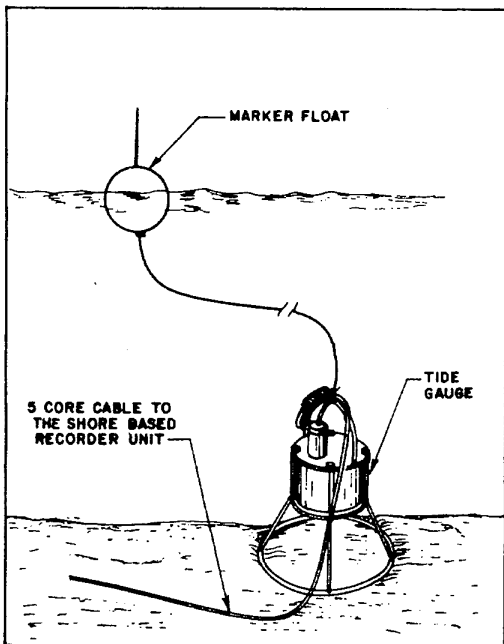


Fig. 7 Bottom Mounting for the Tide Gauge

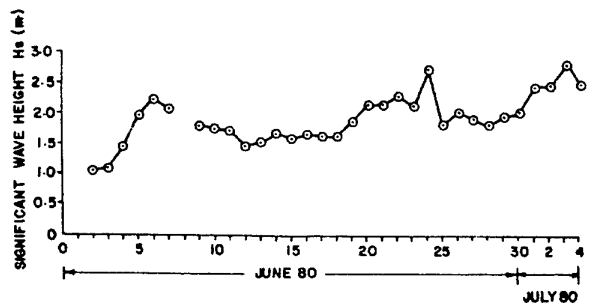


Fig. 8 Plot of H_s Versus Time in Days

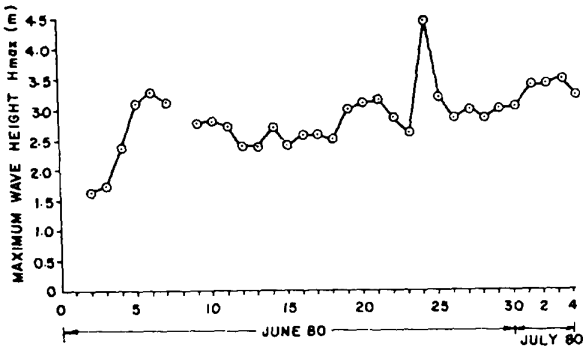


Fig. 9 Plot of H_{max} Versus Time in Days

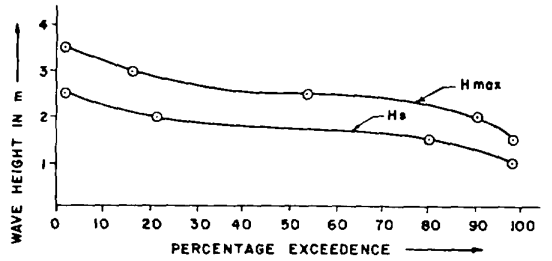


Fig. 12 Cumulative Distribution of H_s and H_{max}

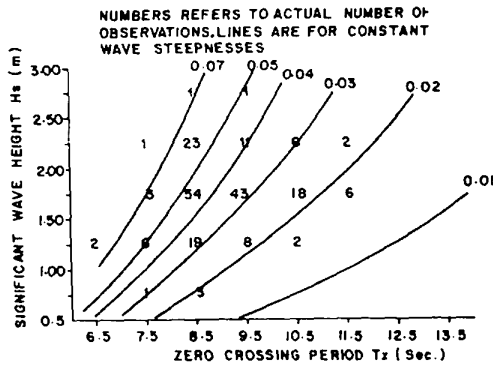


Fig. 10 Plot of H_s Versus T_z

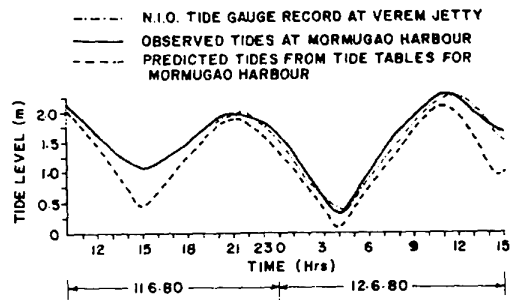


Fig. 13 Comparison of the Predicted and Observed Tide Levels.

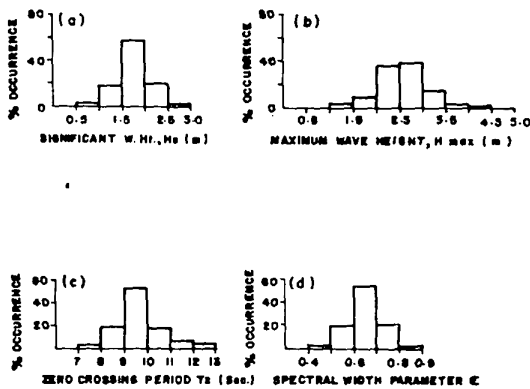


Fig. 11 Distributions of H_s , H_{max} , T_z and E

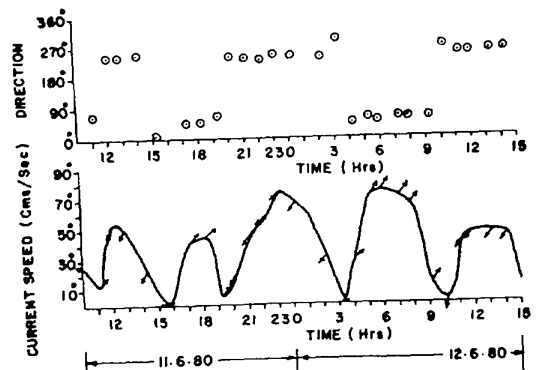


Fig. 14 Current Speed and Direction Versus Time