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Mudbanks of the Southwest Coast of India. I: Wave Characteristics

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ABSTRACT

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The dynamics of the unique mudbanks of the southwest coast of India is examined. *In situ* studies were conducted to understand the processes involved in mudbank formation, sustenance and dissipation. Long-term nearshore wave data show that the pre-mudbank wave intensity and its persistence have a direct bearing on the sustenance and dimensions of the mudbanks. Synchronous nearshore and offshore wave measurements indicate that wave energy is almost completely dissipated before it reaches the shoreline in the presence of the mudbank; the dissipation is only on the order of 25% or less in the absence of the mudbank. The role of bottom fluid mud in absorbing surface wave energy is recognized.

ADDITIONAL INDEX WORDS: *Energy dissipation, fluid mud, wave spectra.*

INTRODUCTION

Several reaches of coastal waters have soft muddy bottoms consisting primarily of silty-clays and clayey-silts. Field observations and theoretical studies show that waves are attenuated rapidly while propagating over a bottom blanketed by these fine-grained, cohesive sediments. In certain localities, the attenuation is so high that the waves are almost completely damped by the time they reach the shore. Such areas, known as mudbanks, occur along the southwest coast of India, northeastern coast of South America and other coasts. Most mudbanks occur adjacent to large rivers, which are the primary sources of the constituent sediment. In contrast to the mudbanks reported elsewhere, the ones at the southwest coast of India also appear in areas which are practically free from the influence of rivers. River dependent mudbanks have been studied more extensively compared to the latter.

Mudbanks along the southwest coast of India have been defined as patches of calm, turbid waters with a high load of suspended sediment, appearing close to the shore with a clayey substrate during the rough monsoon season (KURUP, 1977; CMFRI, 1984; MALLIK *et al.*, 1988; RAMACHANDRAN, 1989). Fifteen to twenty such mudbanks (Figure 1), with dimensions of 2–5 km alongshore and 1.5–4.0 km offshore, appear along this coast during the southwest monsoon season almost every year (KURUP, 1977; CMFRI, 1984).

Although severe storms normally do not occur regularly along this coast, high southwest monsoonal waves attack the coast for a short period of a week or two, during June–July. As a result, several locations of this coast are affected by severe erosion during this rough season. The mudbanks are formed during this period and wherever present, like submerged breakwaters, protect the beach behind them from further erosion. The socio-economic importance of these mudbanks is well known. These zones serve as fishing grounds, and the local fishermen use them as temporary harbors, since other regions are inaccessible due to the rough sea.

An early report on the mudbank is contained in BRISTOW (1938), which includes hypotheses on the source of mud and the formation and movement of mudbanks, all based on visual observations. More specialized investigations on various aspects of mudbanks have been carried out since the late fifties by, among others, RAMASASTRY and MYRLAND (1959); NAIR *et al.* (1966); VARMA and KURUP (1969); GOPINATHAN and QASIM (1974);

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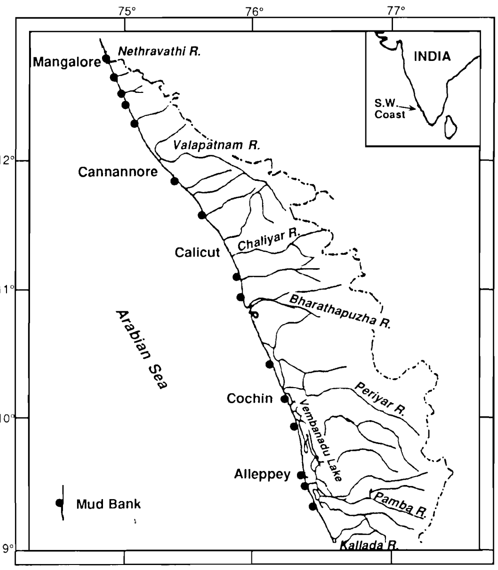

Figure 1. Locations of monsoonal mudbanks along the southwest coast of India.

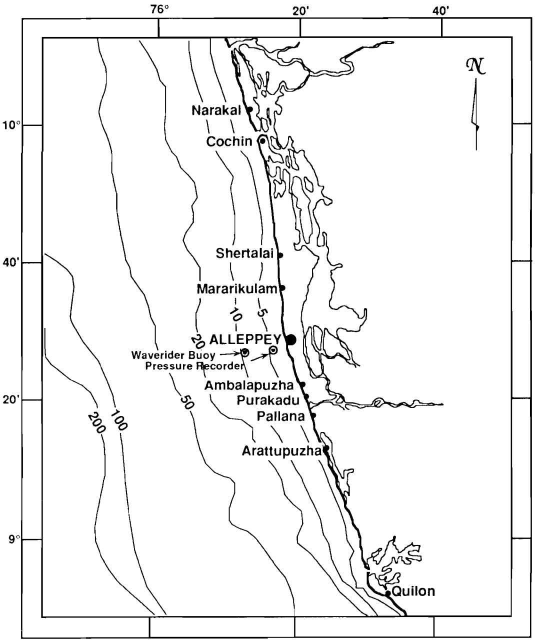

Figure 2. Area of study and locations of wave recording at Alleppey. Depths are in meters.

KURUP (1977); RAO *et al.* (1983); MURTY *et al.* (1984); SHENOI and MURTY (1986); MALLIK *et al.* (1988); RAMACHANDRAN and SAMSUDDIN (1991).

Even after several studies, the generation, sustenance, dissipation and localization of the mudbank have yet to be explained satisfactorily. Previous investigations on mudbanks covered the salient hydrographic features and some of the physical processes involved in the different stages of mudbank evolution (KURUP, 1977; CMFRI, 1984; MALLIK *et al.*, 1988; RAMACHANDRAN, 1989). Unfortunately, data gathered from such studies are insufficient to provide an explanation for wave energy dissipation over a cohesive bottom.

Wave transformation processes such as refraction, diffraction, reflection, shoaling, bottom friction, percolation, *etc.*, on a sandy bed are fairly well known. However, in the zones of occurrence of fine-grained mudbanks on the southwest coast of India, the mechanics of wave transformation is practically unknown except for a few theoretical and laboratory studies (REDDY and VARADACHARI, 1973; MCPHERSON and KURUP, 1981; SHENOI and MURTY, 1986, *etc.*). In this paper the wave characteristics under different bottom conditions, which appear to hold the key to the generation, sustenance and dissipation of mudbanks, are presented.

DATA COLLECTION AND ANALYSES

The present investigation essentially involved the collection and analyses of nearshore wave data for a period of four years, including synchronous recording of offshore and nearshore waves during mudbank and non-mudbank periods. The location selected for the present study is off Alleppey (Figure 2), where a mudbank is formed almost every year. A pier available here served as a platform for the measurement of directional waves and currents.

The recording of waves in the nearshore was made using a pressure-type wave and tide gage and a telemetering system. The direction of the nearshore waves was observed from the pier with the help of a Bruntun compass. Wave measurements 1.1 km offshore were made using a waverider buoy. Details of the measurement systems, recording and analyses are given in MATHEW (1992).

Synchronous wave data from outside and inside the mudbank off Alleppey, collected for the first time at the mudbanks of this coast, were studied for an understanding of the behavior of waves during their propagation over mudbanks and the process of wave energy dissipation. For compar-

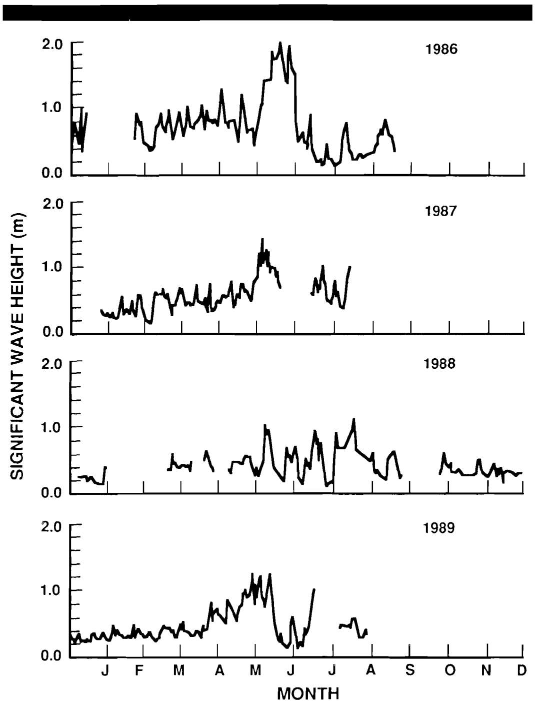

Figure 3. Daily variation of nearshore significant wave height for four years (1986–1989).

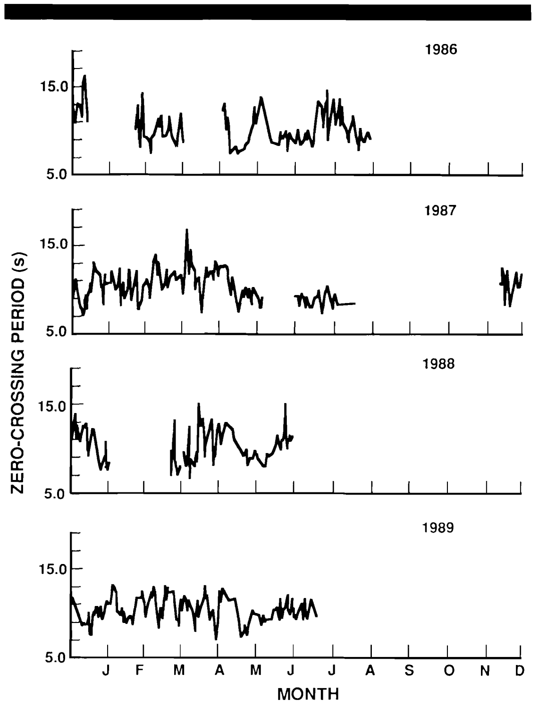

Figure 4. Daily variation of nearshore zero-crossing period for four years (1986–1989).

ison purposes, results of studies on wave transformation based on synchronous offshore and nearshore wave data at the same locations during the non-mudbank period are also presented.

LONG-TERM WAVE CLIMATE OFF ALLEPPEY

Daily (1200 hr) nearshore significant wave heights (H_s) measured intermittently during the 1986 to 1989 period are presented in Figure 3. The wave intensity was comparatively lower during the October–April period. In this region the waves become intensified by about the end of May and high waves persist for a week or two. This is followed by the formation of a mudbank in most years. Except for the monsoon period (May–September), the measured H_s values were less than 0.75 m for most of the time, and there was no significant inter-annual (seasonal) variation. The H_s values ranged from 0.05 m to 2 m for the study period. This range is consistent with values for an earlier five-year period reported by HAMEED (1988), who observed a maximum significant wave height of 3 m for this coast. It is interesting to note that both the highest and the lowest values of H_s occurred during the rough monsoon period. The lowest value is due to the presence of the mudbank.

Daily (1200 hr) zero-crossing period (T_z) for 1986 to 1989 is given in Figure 4. The T_z values are observed to range between 10 sec and 18 sec for the non-monsoon period (October–April), and 7 sec and 10 sec for the monsoon period (May–September). The predominant periods during monsoon were 8 sec and 9 sec. There was no significant year-to-year variation except for the peaks of the pre-monsoon swell.

The nearshore wave directions ranged from 235° to 280° N. The dominant wave directions during monsoon ranged from 240° to 265° N, indicating that the wave crests became more or less parallel to the coast during this season, the normal to the shoreline being 260° N. A comparison with the deep water wave directions reported in the Indian Daily Weather Reports revealed that the waves in this area reach the nearshore after undergoing considerable refraction (MATHEW, 1992).

Examples of typical non-mudbank monsoonal nearshore wave spectra are shown in Figure 5. Almost all the spectra are single-peaked and the energy is confined to the 0.05–0.2 Hz frequency range. There is no significant variation in the shape of the individual spectra both in terms of the size and number of peaks. During the non-monsoon period, the wave spectra generally had very low energy. At the onset of monsoon the energy increased and soon attained its maximum value.

WAVE TRANSFORMATION WITHOUT MUDBANK

Wave transformation features were studied by comparing the synchronous offshore and nearshore wave heights and spectra. The offshore wave recording was done just outside the zone of occurrence of the mudbank (Figure 2). The time of propagation of waves from the offshore station to the nearshore is not accounted in this comparison, given the comparative stationary character of the waves and the relatively short distance between the nearshore and offshore recording stations. A plot of the nearshore significant wave height against the corresponding offshore wave height is given in Figure 6. It is observed that there is some attenuation of wave height in most cases. The line of best fit is

$$H_s(\text{nearshore}) = 0.94H_s(\text{offshore}) - 0.09 \quad (1)$$

which is applicable for H_s(offshore) > 0.5 m. Attenuation of wave height ranges from nearly zero to 30%, which is well within the range reported by KURIAN (1987), who observed attenuations of up to 50% for deep water waves propagating over a distance of 18 km in the relatively shallow waters of this coast. Nearshore and corresponding offshore wave spectra for the non-mudbank period are compared in Figure 7. The energy losses are observed to be in the range of 0–40% except in a few cases, where a slight increase in energy is observed, which is attributed to directional influences of wave propagation. In most of the cases the energy loss is less than 25%. The peak frequencies are found to approximately coincide in most cases, indicating the retention of the major portion of the energy density in the vicinity of the same peak frequency even after transformation. A detailed study of the wave height and spectral transformation along this coast was conducted by KURIAN (1987) and KURIAN and BABA (1987). They suggested that bottom friction is likely to be the principal factor causing the dissipation of wave energy for this coast under non-mudbank conditions.

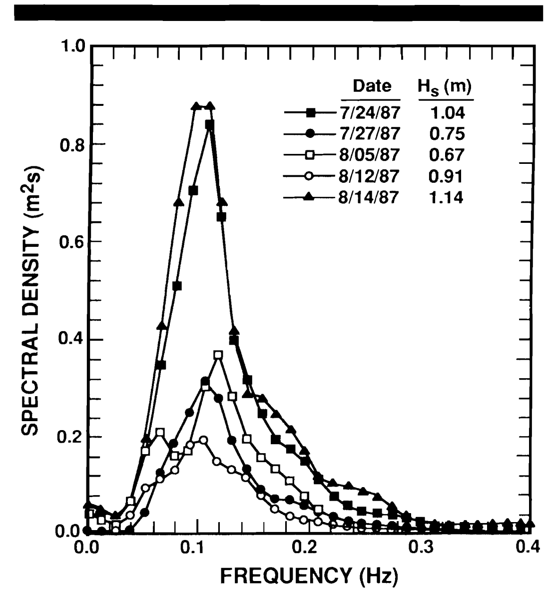

Figure 5. Typical non-mudbank monsoonal wave spectra.

WAVE CHARACTERISTICS ASSOCIATED WITH MUDBANK

The nearshore significant wave height (H_s) during various stages of mudbank evolution for different years is presented in Figure 8. In 1987 no

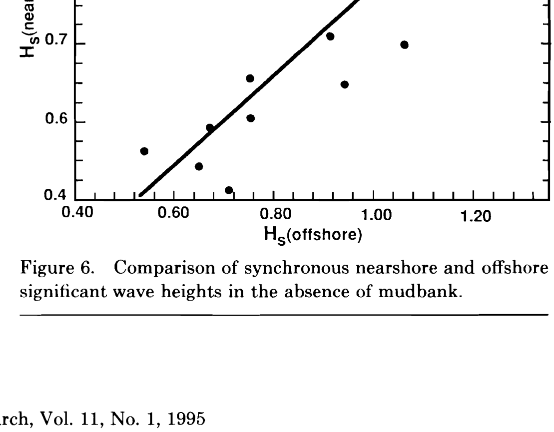

Figure 6. Comparison of synchronous nearshore and offshore significant wave heights in the absence of mudbank.

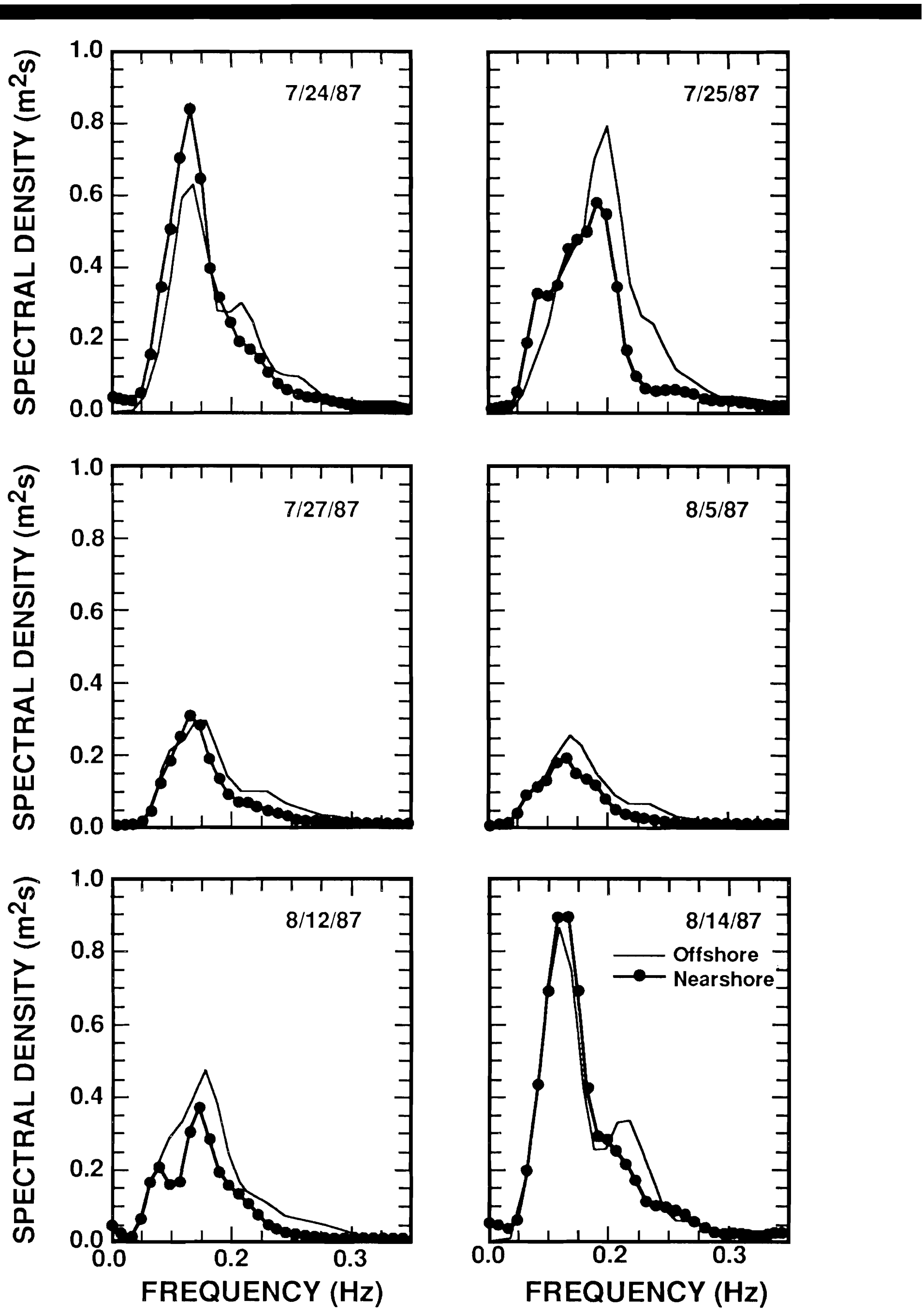

Figure 7. Comparison of synchronous nearshore and offshore wave spectra in the absence of mudbank.

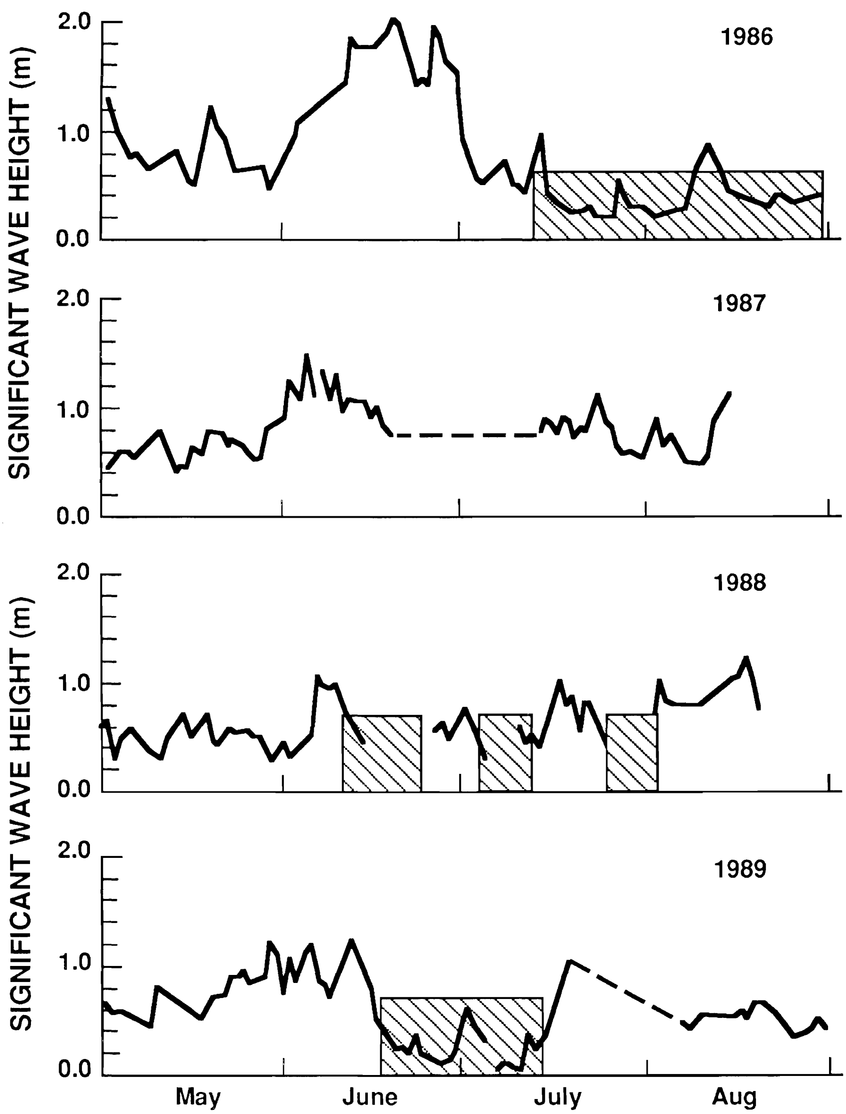

Figure 8. Daily nearshore significant wave height during the monsoon period. Hatched areas indicate durations of mudbank occurrence.

mudbank was formed at the study location but appeared at the adjacent coast. During other years, the mudbank occurred after an increase in the wave height. Furthermore, the duration of mudbank sustenance is seen to be related to the wave height during the pre-mudbank period and its persistence. It can be seen that the mudbank was sustained longer during 1986 when the pre-mudbank waves were relatively more intense (H_{smax} = 2 m) and persistent. Mudbank sustenance was the least during 1988, when the pre-mudbank waves were also least intense and persistent. Intermittent occurrence and disappearance of the mudbank was observed during 1988.

Occasional spurts in the wave activity during mudbank sustenance were also observed, which was related to the occurrence of high swell in deep water. This phenomenon has been noticed by oth-

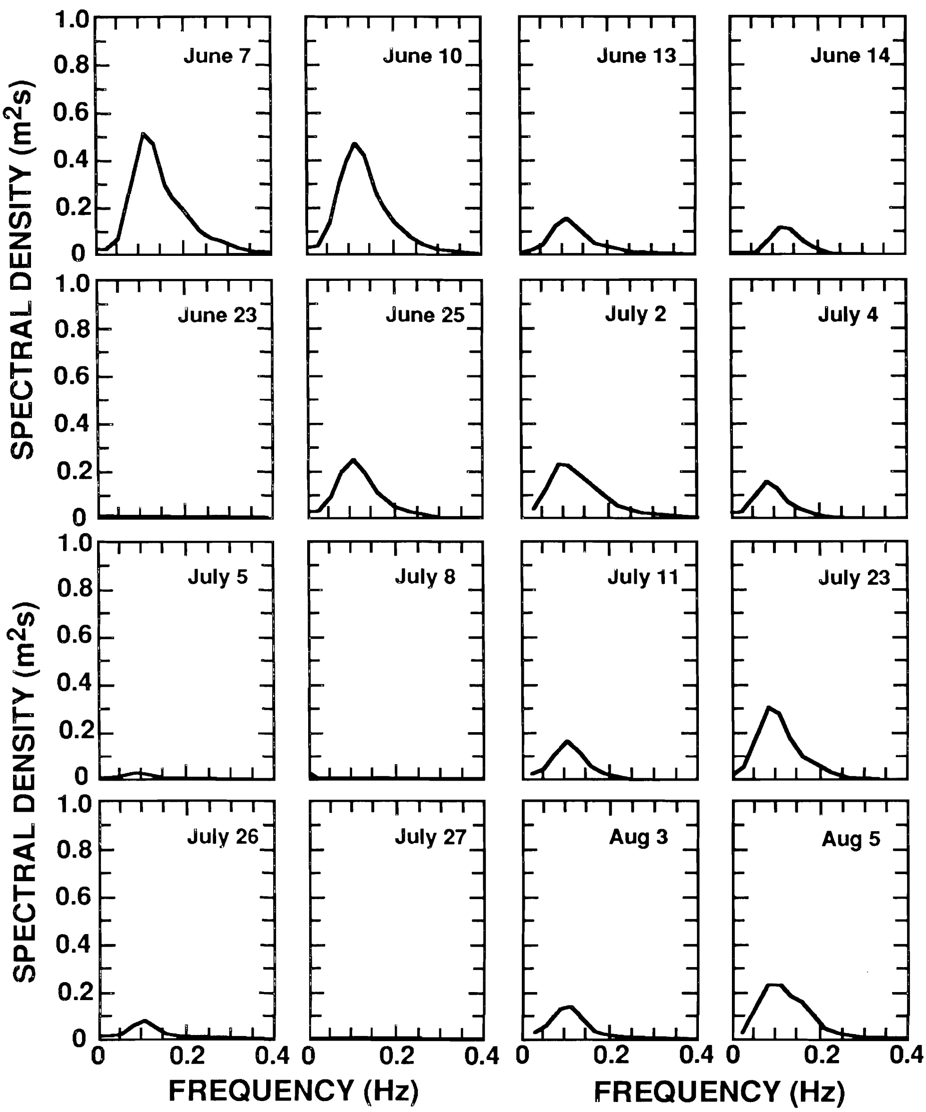

Figure 9. Transformation of nearshore wave spectra during pre-mudbank, mudbank and post-mudbank conditions in 1988.

er researchers, as well, at this and other locations along the southwest coast of India (KURIAN, 1988; HAMEED, 1988).

No significant changes were observed in the wave period during the occurrence of the mudbank compared to the pre-mudbank condition (Figure 4). Also, since the waves were very small, dominant directions were not discernible.

Examples of time-varying wave spectra associated with the pre-mudbank, mudbank and post-mudbank periods of 1988 and 1989 are given in Figures 9 and 10. In the pre-mudbank stage, a rapid decay towards the low frequencies and a moderate decay towards the high frequencies are observed. The spectrum becomes narrow just before mudbank formation and loses energy gradually during the formative stage until it is fully developed, when the energy content of the spectrum is the least.

No significant shift in the peak frequency is

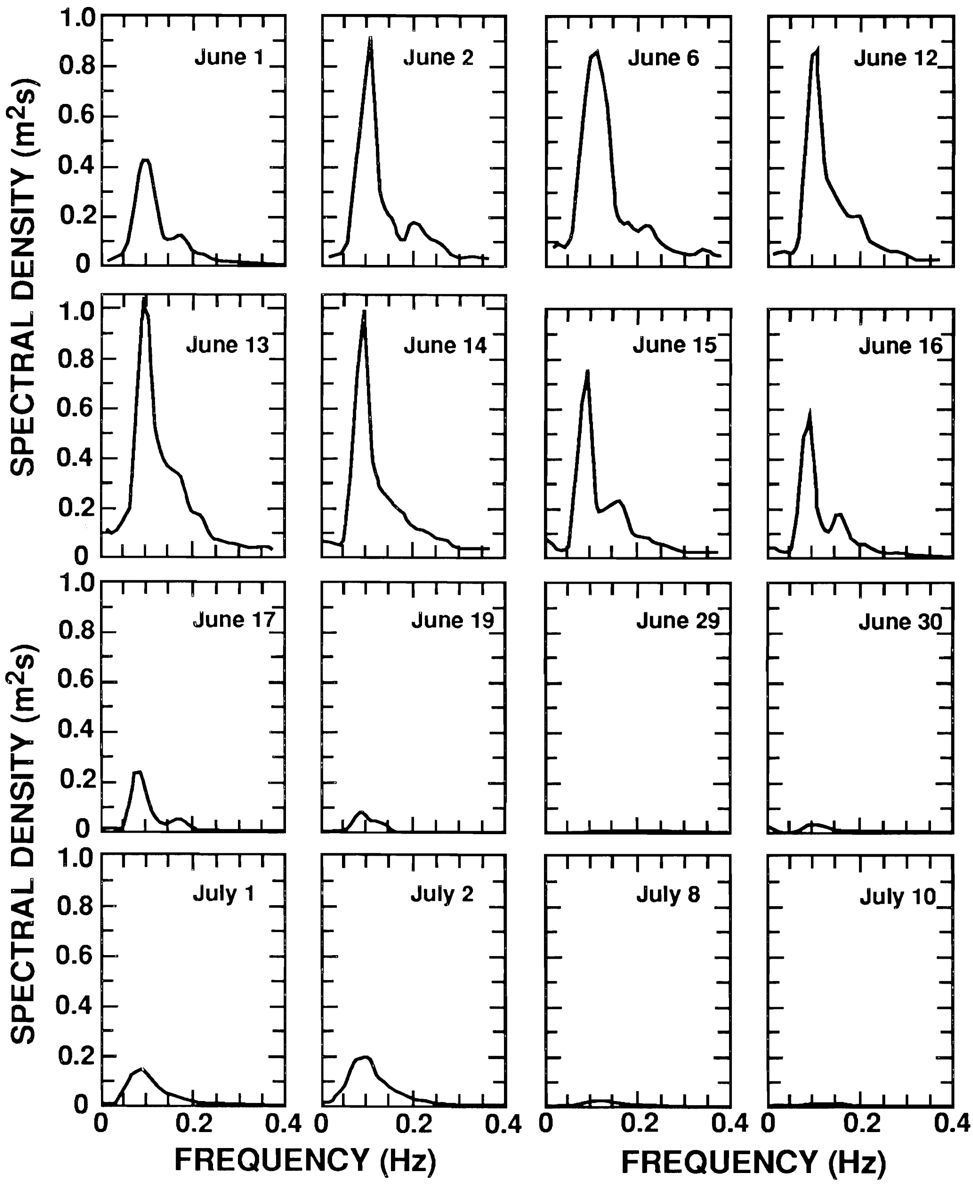

Figure 10. Transformation of nearshore wave spectra during pre-mudbank and mudbank conditions in 1989 (the mudbank dissipated on 20th July due to high wave activity, which damaged the wave recorder, hence no spectra could be obtained to show the dissipation stage).

noticed in any of the spectra during the development as well as the decay stages. The spectral peaks are mostly observed at frequencies in the 0.09–0.10 Hz (periods 10–11 sec) range before mudbank formation, shifting to 0.11–0.13 Hz (periods 8–9 sec) upon the formation of the mudbank. Occasional lower values ($<$ 0.06 Hz) are also observed during the mudbank period. The peak spectral density reaches a maximum of 0.77 m^2 sec just before mudbank formation, and reaches the lowest value of 0.01 m^2 sec when the mudbank is fully developed. Occasionally a secondary peak,

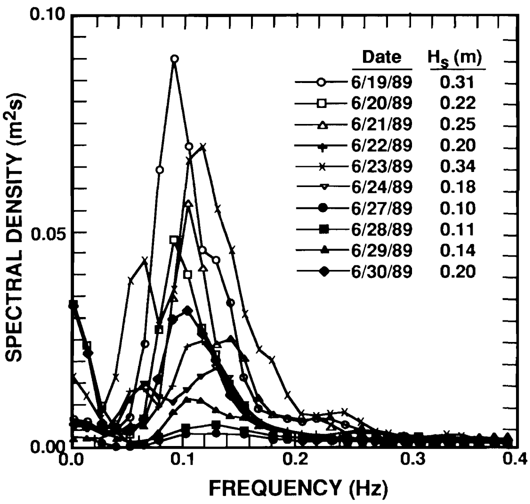

Figure 11. 1989 mudbank wave spectra (with an amplified density scale).

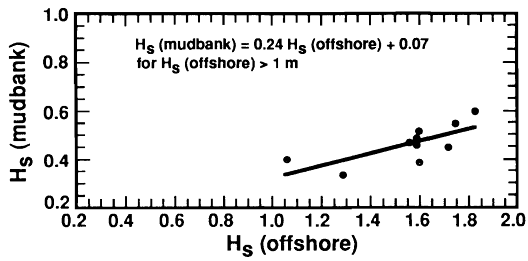

Figure 12. Comparison of synchronous mudbank and offshore significant wave heights.

though not prominent on the high frequency side, is observed in the mudbank spectra (Figure 11). This indicates the presence of sea waves in the mudbank area.

While a gradual decrease in the wave energy is observed in the formative stages of the mudbank, a rapid increase in energy is observed in the dissipative stage. The spectral characteristics during the dissipative stage are similar to those in the formative stage.

WAVE TRANSFORMATION OVER MUDBANK

The characteristics of wave transformation during the formative and dissipative stages of the mudbank were studied by comparing the wave parameters obtained from the offshore recording station outside the mudbank and the nearshore station within the mudbank.

A comparison of the significant wave height inside the mudbank area, against the corresponding wave height outside the mudbank (Figure 12), shows a drastic decrease occurring within a distance of just 1.1 km of wave propagation to the nearshore. It must be recognized that the data correspond to a period of intense wave activity in the offshore. The line of best fit for the data is

$$H_s(\text{mudbank}) = 0.24H_s(\text{offshore}) + 0.09 \quad (2)$$

which is valid for H_s(offshore) > 1 m. It was observed that in the developing and dissipating stages of the mudbank the wave height was attenuated by about 75–85% by the time it reached the nearshore recording station and almost 100% before it reached the shoreline. Thus, in a fully developed mudbank almost complete dissipation of wave height occurred within a distance of just a few wavelengths over the mudbank zone.

The most conspicuous aspect of transformation of the wave spectrum in the presence of mudbank is its high rate of energy reduction. Figure 13 shows examples of wave spectra inside and outside the mudbank. An 80–90% reduction in spectral energy is observed. The peak frequencies, however, are found to approximately coincide in a majority of the cases, as in the case of the non-mudbank condition.

WAVE ENERGY DISSIPATION OVER MUDBANK

As noted earlier, dissipation of energy of up to 30% due to bottom friction had been observed during the non-mudbank period. However during the presence of the mudbank, near-complete energy dissipation was observed within a short distance of wave propagation over the mudbank. As evidenced from observations (Mathew, 1992), this dissipation is due to the presence of a near-bed fluid mud layer, rather than the effect of bottom friction or other mechanisms which normally dissipate wave energy in shallow waters with a sandy bottom.

The maximum rate of energy dissipation occurred at the seaward peripheral zone of the mudbank. Continued wave activity hindered the settling of fluid mud in the peripheral zone, helping the maintenance of the greater thickness (~2 m) of fluid mud there in comparison with the nearshore. At the same time, a relatively stress free condition prevailing inside the mudbank due to

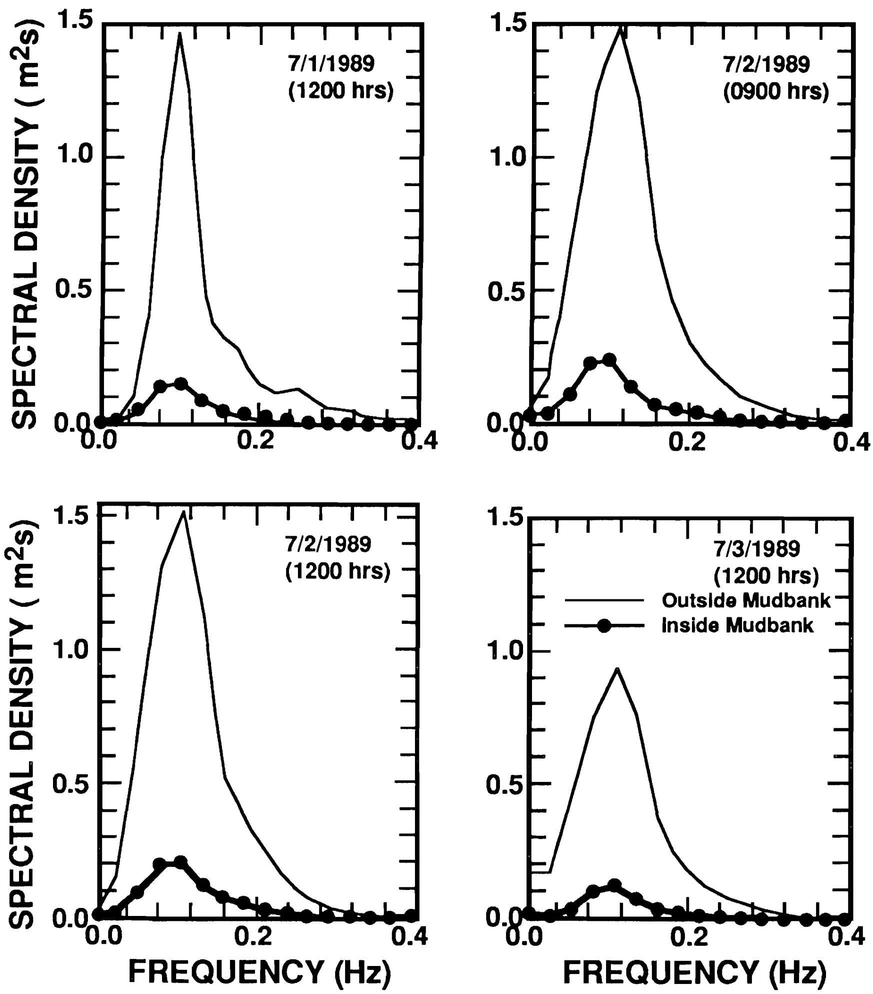

Figure 13. Comparison of synchronous mudbank and offshore wave spectra (inside and outside the mudbank, respectively).

energy dissipation together with the absence of strong currents allowed particle settling in this zone and a reduction in the thickness of the fluid mud layer there.

Wave forcing induces an oscillatory movement of the fluid mud. For example, vertical oscillations of bottom mud in the Mississippi Delta were measured by TUBMAN and SUHAYDA (1976). It is surmised that viscous dissipation associated with this oscillation may be the main factor controlling surface wave attenuation, even though mud oscillations were not measured in the present case. Measurements also indicated that the viscosity of the upper water column was negligible at all stages of mudbank evolution (MATHEW, 1992). Hence, earlier hypotheses suggesting the dissipation of wave energy due to an increase in the viscosity of the upper water column as the principal factor is difficult to accept.

CONCLUSIONS

Analyses of the nearshore wave data show that pre-mudbank wave intensity and its persistence have a direct bearing on the sustenance of the mudbank. The most important characteristic of the mudbank is its ability to attenuate surface waves. Low wave heights in the nearshore zone during the rough season in comparison with those during fair season are due to the high rate of dissipation of wave energy. This observation demonstrates the control of bottom sediment on surface waves during their propagation. It was observed that most of the wave energy dissipation took place in the seaward peripheral zone of the mudbank. Based on this observation, it is surmised that wave-induced oscillation of fluid mud causes the observed wave energy dissipation.

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