

Viscous Damping of Solitary Waves in the Mud Banks of Kerala, West Coast of India

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Analysis of wave damping in mud bank region following the process of transfer of wave energy to the interior of fluid column through the boundary layer and the energy loss computations owing to viscous shear beneath the solitary wave over a smooth horizontal surface are presented. It is shown that waves can almost or completely be dissipated over a mud bank of width about 3 - 4 km when the kinematic viscosity increases to $1 \text{ cm}^2 \cdot \text{sec}^{-1}$. Waves of higher amplitude are dissipated much faster than those of lower amplitude.

Importance of mud banks and the extraordinary calming effect they exert on surface waves have been well recognised. Several theories have also been proposed to explain this phenomenon of natural death of ocean waves¹. For example, assuming small amplitude wave theory, the wave damping within the soft muddy bottom has been explained with the help of few theoretical models²⁻⁴. In addition to the losses in energy, the incoming waves have been reported to suffer from changes in their form from sinusoidal to solitary like as they propagate over fluid muds⁵ along the coast of South America. It is thus reasonable to apply the theoretical rate of loss of wave energy owing to viscous shear beneath a solitary wave to the waves propagating over the mud banks.

In the present study an attempt has been made to examine wave damping within the mud bank, situated along certain localities off the coast of Kerala following the process of transfer of wave energy to the interior of the fluid column through the boundary layer and the energy loss computations on the basis of solitary waves in a viscous fluid.

Materials and Methods

Two areas, one sheltered by mud bank (Narakkal - Malipuram) and the other directly exposed to the incoming waves (Anthakaranazhi) were selected for this study along the barrier beaches of the central Kerala coast (Fig. 1). Maps showing wave energy distribution (Fig. 2) along this stretch of the coast was made using refraction diagrams⁶. Information on the characteristics of breakers along this area were obtained through field surveys made at 12 stations. The wave amplitude dissipation owing to viscous shear beneath the solitary wave over a smooth horizontal surface was computed, using the formula⁷

$$\frac{dH}{dx} = -0.334 \left[\frac{\nu}{\sqrt{gd \cdot d}} \right]^{1/2} \left[\frac{H}{d} \right]^{5/4}$$

where H is the wave height at depth d , x is the horizontal distance travelled by the wave, ν is the kinematic viscosity of the fluid column and g is the acceleration due to gravity.

Results and Discussion

The beaches at Narakkal and Malipuram were protected by mud banks during the southwest monsoon season. During the other seasons the near shore bottom was covered by loose mud deposits of varying thickness (1-2 m). A comparison of wave heights near the coast as computed from wave refraction diagrams with the observed breaker heights (Table 1) presented large anomalies along the beaches sheltered by the mud banks. At Anthakaranazhi where the shore was not protected by the mud bank, higher breakers were observed compared to those at Narakkal - Malipuram region. These heights were comparable to those obtained from refraction studies at the former locations (Fig. 2 and Table 1). But the environmental factors such as the nearshore bottom relief and/or the nature of sediments did not present any significant differences within this stretch⁸. Thus, it is clear that the extremely low breaker heights observed at Narakkal-Malipuram beaches are due to the effect of mud banks.

Before examining the implications of mud banks on waves in the coastal region, the following features have been identified that cause this seasonal and localized occurrence of mud banks:

(a) Under the influence of high wave activity during the southwest monsoon the clastic sediments occupying the shelf between 3 and 60 m isobaths are

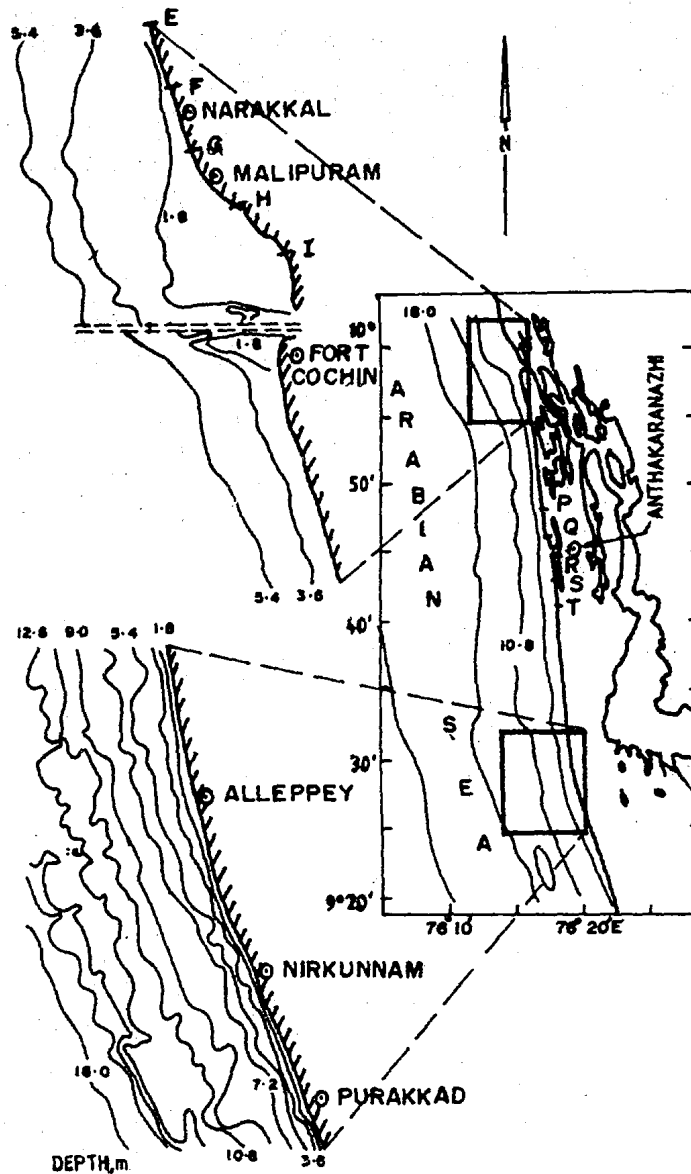


Fig. 1—Area of study (central Kerala coast) with station locations and bottom topography off Narakkal and Purakkad

likely to increase the sediment concentrations in the water column over which the waves are propagating. But this should lead to the existence of mud banks all along the coastline which is not the case.

(b) At the time of the southwest monsoon season enormous quantities of fresh water ladden with fine suspended sediments are added to the nearshore waters through the few outlets giving rise to increased concentrations of suspended sediments locally.

(c) The increase of the water level in the backwater system due to flooding as a result of increased land runoff following the rainfall and the decrease in sea level due to the process, viz. upwelling, wave set-down and baroclinic adjustment of the sea surface slope for a

southerly flow, will give rise to differences between the sea level and the water level in the backwater system. This apparent difference in the water levels would lead to an increase in the pressure head of the fresh water column which in turn develops a fresh water flow seaward through the coastal aquifer which may confine to selected tracks giving rise to ground water effluence much below the sea level. This is in contrast to its emergence in the vicinity of the low tide terrace of the main land beaches⁹. However, the onshore component of the strong winds should give rise to increased sea surface slopes along the shore. This has a counteracting action on the otherwise observed lowering of the sea level.

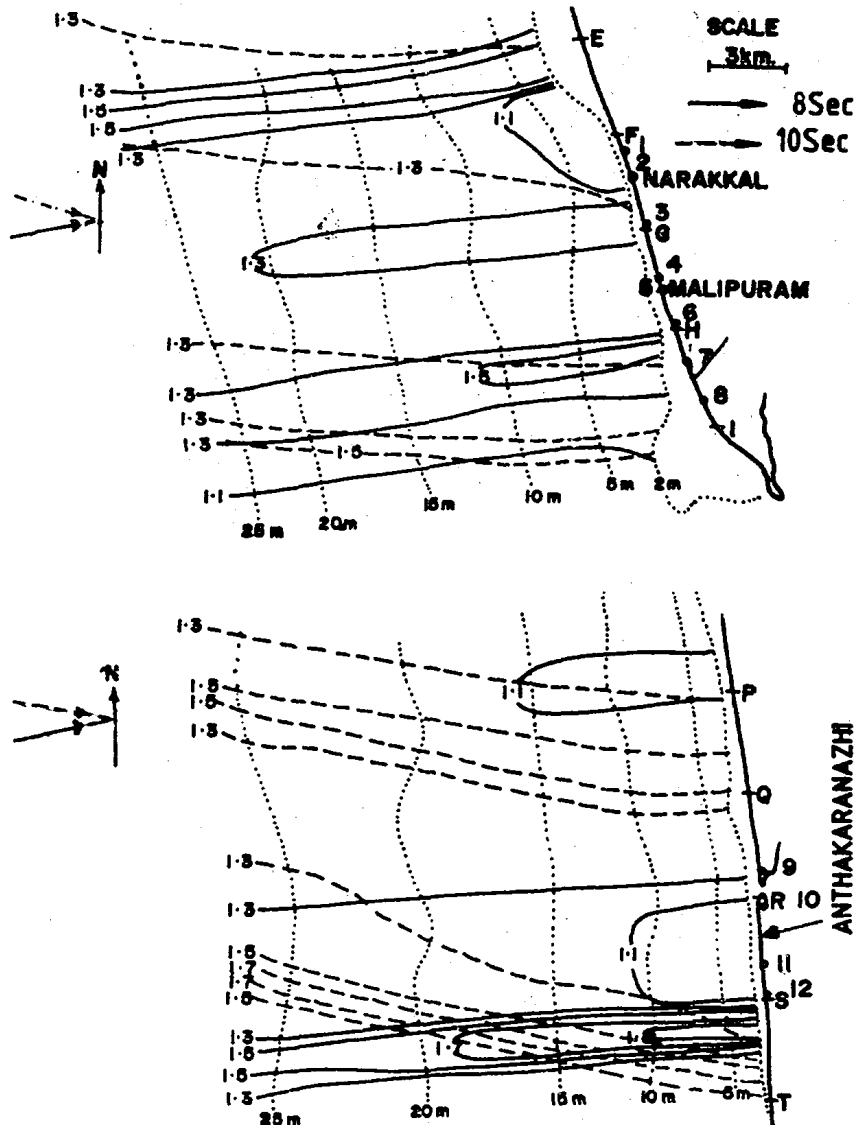


Fig. 2—Wave height distribution computed from wave refraction diagrams in the Narakkal - Malipuram and Anthakaranazhi regions for waves of 8 sec approaching from 260° TN and 10 sec waves approaching from 280° TN

Table 1—Observed Breaker Heights (m) in 1981

| Month | Narakkal | | | Malipuram | | | | | Anthakaranazhi | | | |
|-------|----------|------|------|-----------|------|------|------|------|----------------|-------|-------|-------|
| | St 1 | St 2 | St 3 | St 4 | St 5 | St 6 | St 7 | St 8 | St 9 | St 10 | St 11 | St 12 |
| Jan. | 0.20 | 0.20 | 0.20 | 0.15 | 0.12 | 0.12 | 0.10 | 0.10 | 0.50 | 0.40 | 0.55 | 0.55 |
| Feb. | 0.20 | 0.20 | 0.20 | 0.10 | 0.10 | 0.08 | 0.10 | 0.10 | 0.82 | 0.82 | 0.82 | 0.82 |
| March | 0.40 | 0.40 | 0.35 | 0.16 | 0.11 | 0.15 | 0.15 | 0.15 | 1.00 | 1.00 | 1.00 | 0.82 |
| April | 0.20 | 0.20 | 0.00 | 0.10 | 0.00 | 0.00 | 0.17 | 0.00 | 1.25 | 1.25 | 1.20 | 1.25 |
| May | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.10 | 0.10 | 1.50 | 1.50 | 1.50 | 1.50 |
| June | 0.18 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.18 | 2.00 | 2.10 | 2.25 | 2.20 |
| July | 0.20 | 0.20 | 0.20 | 0.00 | 0.00 | 0.00 | 0.11 | 0.15 | 2.25 | 2.35 | 2.25 | 2.25 |
| Aug. | 0.10 | 0.10 | 0.10 | 0.08 | 0.08 | 0.10 | 0.13 | 0.15 | 0.92 | 0.82 | 0.82 | 0.82 |
| Sept. | 0.18 | 0.20 | 0.22 | 0.20 | 0.20 | 0.10 | 0.15 | 0.15 | 1.75 | 1.60 | 1.75 | 1.75 |
| Oct. | 0.16 | 0.17 | 0.10 | 0.30 | 0.20 | 0.20 | 0.20 | 0.20 | 0.35 | 0.50 | 0.40 | 0.40 |
| Nov. | 0.35 | 0.35 | 0.40 | 0.25 | 0.15 | 0.15 | 0.12 | 0.10 | 1.00 | 1.00 | 1.00 | 1.00 |
| Dec. | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.08 | 1.25 | 1.25 | 1.00 | 1.10 |

The depth below the sea level where the ground water effluence takes place could be obtained using the formula¹⁰.

$$Z = \frac{\rho_f}{\rho_s - \rho_f} \cdot h,$$

where ρ_f is the density of the freshwater, ρ_s is the density of seawater and h is the head of fresh water above sea level. Considering $\rho_f = 1 \text{ g.cm}^{-3}$, $\rho_s = 1.02 \text{ g.cm}^{-3}$ and h is the water level increase in the backwater system—10 to 15 cm (which is most likely due to the freshwater discharge through various rivers associated with an average rainfall of 240 cm during the southwest monsoon season¹¹). For this h , the depth below the sea level (Z) where the ground water effluence takes place could be about 5 - 8 m. As a result of this effluence the prevailing loose silty - clays or claye - silts would lose their plasticity. During this period these sediments have been reported to contain more than 72% moisture¹². These sediments are, therefore, likely to (amenable to) get dislodged from the bottom only to be brought into suspension by the high monsoonal waves breaking within this zone. This, in turn, would increase the viscosity of the water column. It is probably during this phase that the mud banks would form. During the calm weather the decrease in the wave intensities and further lowering of the water level in the backwater system in addition to the readjustment in the sea surface slopes help in settling of these suspended sediments.

From the shoreline dynamics point of view the following possible mechanism for wave energy dissipation is suggested. It is known that the periodic motion of the fluid produces in the first place boundary layers at both bottom and free surface. These oscillatory boundary layers have thickness of only a few millimetres under normal conditions. The distribution of mass transport associated with these waves are strongly influenced by the viscous boundary layers¹³. Thus the high viscosity of the media and the fluid mud bottom as the one prevailing at Narakkal - Malipuram mud bank area may be to enlarge the boundary layer thickness (δ) which is generally expressed as,

$$\delta = 5 \left(\frac{2\nu}{\omega} \right)^{1/2}$$

where ν is kinematic viscosity and $\omega = 2\pi/T$, the radian frequency. The boundary layer thickness for various viscosities and wave periods are presented in Table 2. With the increase of ν in the range of 1 - 10 $\text{cm}^2.\text{sec}^{-1}$ for a wave of 10 sec period, the boundary layer thickness increases to 28 cm from 9 cm. However,

Table 2—Boundary Layer Thickness (δ , cm) for Different Viscosities (ν) and Wave Periods (P_w)

| P_w (sec) → | 6 | 8 | 10 | 12 | 14 |
|---|--------|--------|--------|--------|--------|
| ν ($\text{cm}^2.\text{sec}^{-1}$) | | | | | |
| 0.001 | 0.22 | 0.25 | 0.28 | 0.31 | 0.33 |
| 0.01 | 0.67 | 0.60 | 0.90 | 0.98 | 1.06 |
| 0.1 | 2.19 | 2.52 | 2.82 | 3.09 | 3.34 |
| 1 | 6.91 | 7.98 | 8.92 | 9.77 | 10.56 |
| 10 | 21.85 | 25.23 | 28.21 | 30.90 | 33.38 |
| 100 | 69.10 | 79.79 | 89.21 | 97.72 | 105.56 |
| 450 | 146.59 | 169.26 | 189.23 | 207.30 | 223.91 |

values as high as 450 $\text{cm}^2.\text{sec}^{-1}$ —equivalent to a thick sugar syrup—have been reported by Keen¹⁴ for these mud banks. In addition, the thin vertical streaks obtained in the echograms from mud bank area due to muds in suspension¹⁵, show the possible existence of such high viscosities. Thus one can safely assume kinematic viscosities of the order of 1 $\text{cm}^2.\text{sec}^{-1}$ for the water column when the mud banks are reported to be active. For this kinematic viscosity, the increased thickness of the boundary layers would help transfer of wave energy to the interior of the fluid column. From the moment of starting the waves, the second order vorticity developed at the surface will get transported into the fluid by viscous diffusion¹⁶ and there it gets dissipated through internal friction rapidly. This energy transported into the fluid may keep the mud in suspension and in turn will enhance the viscosities. As such this mechanism appears to be a feed back causing rapid decay of waves and maintains the mud bank active during the southwest monsoon season.

Now considering the solitary waves, the rate of loss of energy due to increased viscosities for Narakkal - Malipuram mud bank (with an average water depth of 3 m) shows that a wave having a height of 1.5 m at the outer periphery of the mud bank loses 50% of its total energy over a distance of about 1.5 km and nearly 100% over a distance of about 4 km, for $\nu = 1 \text{ cm}^2.\text{sec}^{-1}$ (Fig. 3A). This indicates that kinematic viscosities in the range 0.1 - 1.0 $\text{cm}^2.\text{sec}^{-1}$ within the boundary layer could significantly attenuate the waves as they propagate through the mud banks.

The decrease in wave height with the increase of viscosity for different wave heights at the outer periphery of the mud bank are shown in Fig. 3B and C. When $\nu < 0.01 \text{ cm}^2.\text{sec}^{-1}$ there is hardly any reduction in the wave height. But when ν increases to 0.1 $\text{cm}^2.\text{sec}^{-1}$ the decrease in wave height is considerable and the rate of change increases abruptly with further increase in ν to 1 $\text{cm}^2.\text{sec}^{-1}$. When $\nu = 0.8 \text{ cm}^2.\text{sec}^{-1}$ the wave height is about 15 cm irrespective of the initial wave height (Fig. 3B). This indicates that for a mud

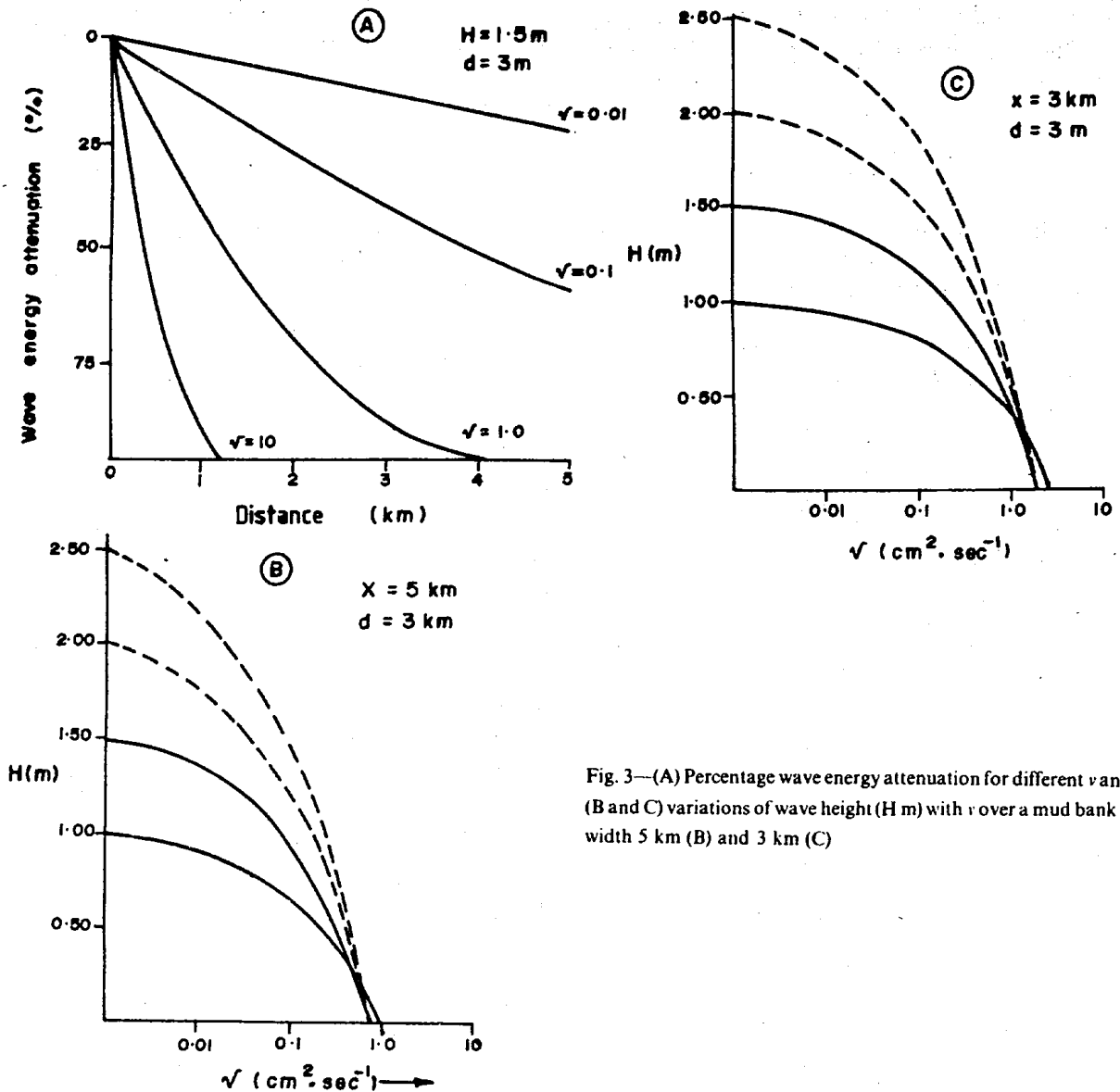


Fig. 3—(A) Percentage wave energy attenuation for different ν and (B and C) variations of wave height (H m) with ν over a mud bank of width 5 km (B) and 3 km (C)

bank having a width of 5 km and average depth of 3 m whatever may be the wave height at the periphery, wave height near the shore will be constant ($\sim 15\text{ cm}$) when $\nu = 0.8\text{ cm}^2 \cdot \text{sec}^{-1}$. The above value of kinematic viscosity may be considered as critical value for a mud bank of the above descriptions. This critical value increases with the decrease in the width of the mud bank. For example $\nu = 1.4\text{ cm}^2 \cdot \text{sec}^{-1}$ is required to reduce all the waves to 25 cm over a distance of 3 km (Fig. 3C). Thus, over a mud bank, for a given ν and water depth d , the higher waves will dissipate much faster than the waves having lower wave heights.

The wave dissipation as discussed above will be valid fully if the bottom is smooth and horizontal. The soft muddy bottom may be treated as physically and hydraulically smooth. This is similar to the conditions reported off the coast of Surinam⁵. But the bottom

slope differs from zero and the water depth does not remain constant over the mud bank probably due to loose nature of these sediments along this coast. Thus additional energy must be dissipated by higher near bottom viscosities in the boundary layer or by other mechanisms.

The theoretical models suggested by Gade² and MacPherson⁴ explains the possibility of exceptionally high rates of attenuation where the waves propagate over a soft viscous bed. If the bottom is purely elastic there is zero decay when waves propagate over it¹⁷. A two layer model developed by Dalrymple and Liu¹⁸ indicates extremely higher rates of wave attenuation when the thickness of the lower layer approaches to that of the internal boundary layer. A model similar to Gade's² developed by MacPherson and Kurup⁴ involves the generation of progressive oscillations in

the soft fluid like sea bed and as a result the waves are damped through viscous dissipation with the sea bed. Tubman and Suhayda¹⁹ have shown that an oscillating bottom can dissipate energy at a rate at least an order of magnitude greater than that resulting from bottom friction alone. But it is not known whether fluid mud over the mud banks oscillate vertically while maintaining its cohesive structure.

Varma and Kurup²⁰ explained the disappearance of mud banks as due to the flocculated settlement of mud during the postmonsoon season when the salinity of the water column increases. This settlement of mud floccules will certainly provide a soft muddy bottom during the non-monsoon periods also. If this is the case there must be considerable wave damping as observed during southwest monsoon season in these areas, if the wave energy can dissipate over the soft muddy bottom alone. But the fact is that in these areas the wave heights observed during the non-monsoon periods are comparatively higher than that during southwest monsoon season (Table 1). Results show that wave damping could only be due to the internal friction resulting from the extraordinarily high kinematic viscosities of muddy coastal waters. However, more field observations are needed to examine in detail the implications of mud banks on waves. Specifically, it would be helpful to make direct measurements of waves, flows and viscosity of the fluid at few locations within and in the vicinity of the mud banks atleast over few tidal cycles. Such a set of observations would help to assess the role of waves in suspending and transporting the fluid muds.

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References

- 1 Bristow R C, *History of mud banks*, Vol 1 (Cochin Govt Press, Ernakulam) 1938, 174pp.
- 2 Gade H G, *J Mar Res*, **16** (1958) 61.
- 3 MacPherson H, *J Fluid Mech*, **97** part 4 (1980) 721.
- 4 MacPherson H & Kurup P G, *Indian J Mar Sci*, **10** (1981) 154.
- 5 Wells J T, *Shallow-water waves and fluid-mud dynamics, Coast of Surinam, South America*, Ph D, thesis, Louisiana State University, 1977.
- 6 Shenoi S S C & Prasannakumar S, *Indian J Mar Sci*, **11** (1982) 201.
- 7 Dean R G & Eagleson P S, in *Estuary and coastline hydrodynamics*, edited by A T Ippen (Mc Graw Hill Book Co, New York) 1966, 93.
- 8 Shenoi S S C, *Studies on the littoral processes in relation to stability of beaches around cochin*, Ph D thesis, University of Cochin, 1984.
- 9 Murty C S, *Studies on the physical aspects of shoreline dynamics at some selected places along the west coast of India*, Ph D thesis, University of Kerala, 1977.
- 10 Hubbert M K, *J Geol*, **47** (1940) 785.
- 11 Ananthkrishnan R, Parthasarathy B & Pathan J M, in *Contributions to marine sciences*, edited by G S Sharma, A Mohandas & A Antony (Prof Kurian's Shashtyabdhapoorthi felicitation committee) 1979, 60.
- 12 Kurup P G, *Bull Dept Mar Sci Univ Cochin*, **8** (1977) 1.
- 13 Longuet-Higgins M S, *Phil Trans R Soc Lond*, **A245** (1953) 535.
- 14 Keen B A, in *Report of the special committee on the movement of mud banks*, edited by C G Ducaine (Cochin Govt, Press, Ernakulam) 1938, 48.
- 15 Gopinathan C K & Qasim S Z, *Indian J Mar Sci*, **3** (1974) 105.
- 16 Longuet-Higgins M S, *J Fluid Mech*, **8** part 2 (1960) 293.
- 17 Mallard W W & Dalrymple R A, *Proc Offshore Tech Conf*, 2895 (1977) 141.
- 18 Dalrymple R A & Liu L-F P, *J Phy Oceanogr*, **8** (1978) 1121.
- 19 Tubman M W & Suhayda J N, *Proc 15th Conf Coast Engg*, **2** (1976) 1163.
- 20 Varma P U & Kurup P G, *Curr Sci*, **38** (1969) 559.