

Energy Attenuation of Sea Surface Waves through Generation of Interface Waves on Visco-elastic Bottom as in the Mud Banks, SW Coast of India

S.Minirani and P.G.Kurup¹

School of Marine Sciences, Cochin – 682 016

¹Amrita School of Arts and Sciences, Brahmastanam, Cochin – 682 024

E.mail ; kuruppg@yahoo.co.uk

ABSTRACT

The mud banks present picturesque instances of large- scale natural damping of sea surface waves. When waves propagate on the surface of a layer of inviscid fluid overlying a visco-elastic bottom fluid of greater density, surface wave energy is dissipated by the coupling between the surface waves and the waves generated at the interface. Using a dimensionally correct expression (Mac Pherson and Kurup, 1981) obtained from Gade's mathematical model (1958), the wave energy attenuation is calculated for different wave periods, water depths and fluid layer thickness. The predicted wave decays are comparable to those observed in the mud banks where the seabed is of soft viscous mud. The waves get almost completely attenuated over a distance of 5-10 wavelengths.

INTRODUCTION

The patches of calm, turbid water with high load of suspended sediment, appearing close to the shore in some places on the southwest coast of India during the monsoon season are known as the mud banks. The forming of mud banks is unique phenomenon influencing shoreline changes and socio-economic life of the fishermen community along this coast. They generally form on the alluvial stretches on the southwest coast of India. Acting as dampers to waves, the mud banks protect the adjoining beach from erosion and also help in trapping sediments from either side facilitating growth of the beach. They provide calm fishing grounds during the monsoon season, when the sea is otherwise rough and inaccessible to the rowing boats used by local fishermen. The mud banks contribute substantially to prawn, sardine, mackerel and sole fishery on this coast.

The mud banks form close to the shore and extend more or less in a semi-circular shape about 5-7 km into the sea. The alongshore stretch varies from 3 km to 6 km. From the shore the mud bank can be easily distinguished by the absence of waves while high swells occur outside the bank area. Separating the calm mud bank region from the rough surface of the monsoon sea is a transition zone in which the wave heights get attenuated rapidly. Calmness of surface and high turbidity of the water are the apparent features of the mud banks. During the monsoon months, when wind force reaches 7 Beaufort or more, the mud bank

regions remain calm. The water in the mud bank is laden with thick suspension of fine clay at the surface and highly viscous bottom sediments of unconsolidated ooze-like 'liquid mud' at the bottom. The suspended sediment load is of the order of 1000 to 1800 mg / l. The fine clay is characterized by soft, plastic touch, dark green color and an oily appearance.

The most remarkable feature of the mud banks is the large-scale damping surface waves in about 40-50 sq. km. of the bank area. The wave energy is absorbed in the peripheral zone that is about a kilometer wide. Attenuation of enormous amount of wave energy in a distance of 5-10 wave oscillations is a matter of great significance. Dalrymple & Liu (1978), Rosenthal (1978) and Hsiao and Shemdin (1980) suggested that it might be possible to extract energy from surface waves by a suitably prepared artificial sea bottom. This could be of advantage because it avoids the strong currents generated by conventional methods of coastal protection.

A review of the earlier studies on the mud banks is presented by Kurup (1969). It is generally accepted that the thixotropy of the mud in association with high wave activity in the regions of wave convergence (Varma & Kurup 1969; Kurup, 1972) is the causative factor for the formation of the mud banks. Regarding wave energy attenuation, the earlier authors generally accepted the view of viscous damping of waves by the turbid mud-laden waters. Kurup (1977), however, showed that viscosity increase due to contamination by suspended mud caused no appreciable damping of surface waves. He suggested that, during monsoon

season, when the mud banks are active, the seabed is soft and fluid-like. As water waves pass over this bed, waves are generated in the bed itself. Let us call them 'interface waves'. These interface wave propagations dissipate energy of the surface waves, resulting in amplitude decrease of the surface waves.

MATERIALS AND METHODS

Viscosity is the internal friction of fluids caused by the intermolecular cohesive forces. The coefficient of viscosity η , decreases rapidly with increasing temperature, but increases only slightly with increasing salinity. Instrumental measurement of viscosity of suspensions is difficult because of the movement of suspended particles due to settling and Brownian motions. Using attenuation of intensity of light, Kurup & Varadachari (1975) estimated variations in flocculated settlement of suspended mud of the mud banks under different salinity conditions. Williams (1968) described the variations of physical properties mud-water suspensions from theoretical considerations. Dahneke (1983) attempted to measure suspended particles using scattering of light. Einstein (1906) showed that if the colloidal particles are taken to be approximately spherical and are non-ionised, then for low concentrations the viscosity η^l of the suspension is related to the viscosity η of the liquid and the volume concentration C by the relation

$$\eta^l / \eta = 1 + 2.5C \quad (1)$$

The damping time for waves is given by

$$T = \lambda^2 / 8\rho\pi^2\nu \quad (2)$$

where T - damping time i.e., time required in seconds for the wave height to be reduced to $1/e$ of its original value, λ - wavelength in cm. (Lamp (1932). Using computed values of kinematic viscosity, Kurup (1977) showed that a 1 m wave takes about 1.2 hours to be damped to $1/e$ of its amplitude with a mud suspension concentration as high as 2000 mg/l. This shows that viscosity increase due to contamination by suspended mud in the water column has no appreciable effect on the decay of waves.

Gade (1958) developed a mathematical model explaining how waves could be damped by the absorption of wave energy in an inviscid fluid overlying a viscous fluid of greater density and bounded by a horizontal rigid plane. The energy loss per unit area and time is

$$P = -1/2 [\rho g (Ae^{-kix})^2 g H_0 R (\eta_2/\eta_1) \sin(\phi' - \phi)] \quad (3)$$

The total average wave energy per unit area is

$$E = 1/2 [\rho g (Ae^{-kix})^2] \quad (4)$$

The mean relative energy loss per unit area in unit time is

$$P/E = g H_0 R (a_2/a_1) \sin(\phi' - \phi) \quad (5)$$

where ρ - density, g - acceleration due to gravity, A - amplitude of surface wave at $x = 0$, H_0 - thickness of the upper layer under equilibrium conditions, R - magnitude of complex function, a_2, a_1 - amplitudes at

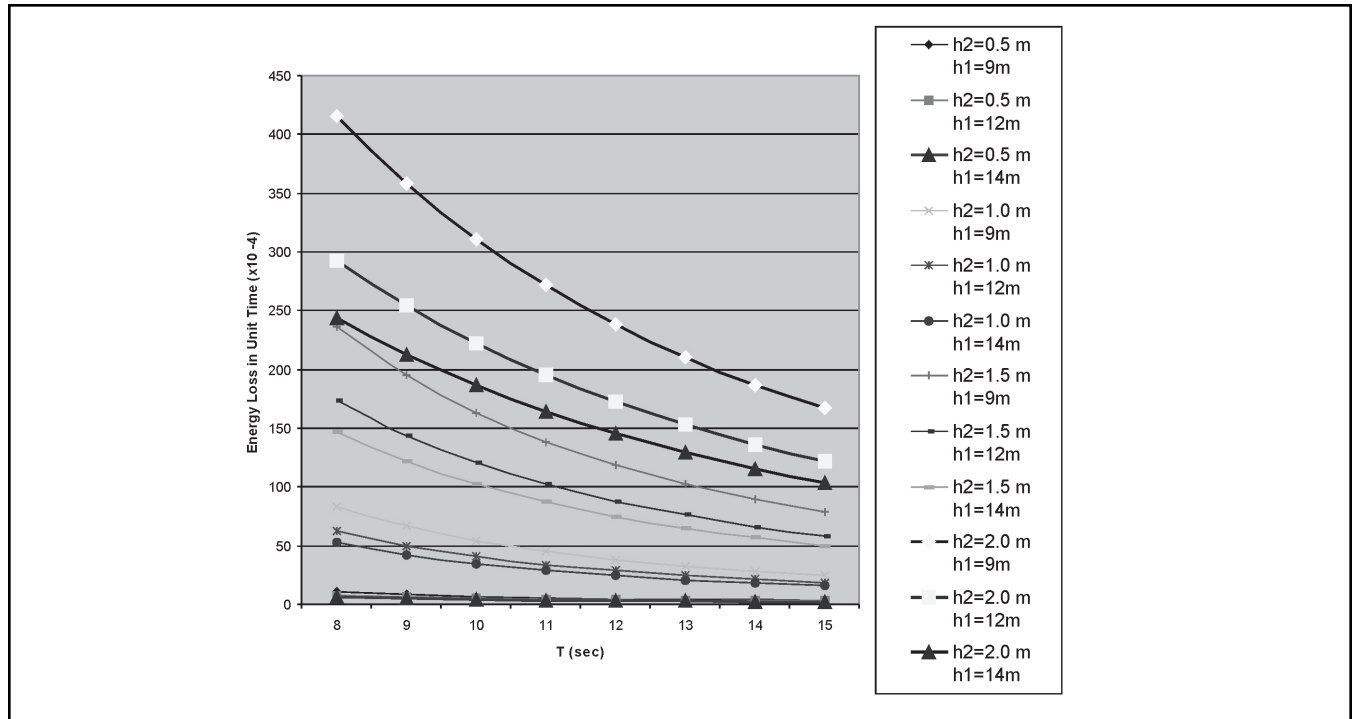


Figure 1. Energy Attenuation for Different Fluid Thickness

surface and interface layers respectively, ϕ' - angle, argument of $(k/\sigma)^2$, ϕ - angle, argument of C . We know that the dimensionless parameter gH_0R is likely to be found in the vicinity of unity, though always less. Also, ϕ is small compared to ϕ' ; the latter is always negative, making the ratio P/E positive.

On the basis of small amplitude wave theory, Mac Pherson (1980) described the coupled interaction between the bed, which responds to both elasticity and viscosity, and an overlying layer of inviscid fluid. The average rate of energy dissipation is

$$P = 1/2 \rho_1 g (a_2 e^{-Dx})^2 \sigma \text{Im} \{ \sigma^2 [g m \cosh m h_1 - \sigma^2 \sinh m h_1] / [g m (g m \cosh m h_1 - \sigma^2 \sinh m h_1)] \} \quad (6)$$

The local energy per unit area, E , is given by

$$E = 1/2 \rho_1 g (a_1 e^{-Dx})^2 + 1/2 (\rho_2 - \rho_1) g (a_2 e^{-Dx})^2 \quad (7)$$

where G - shear modulus of elasticity, g - acceleration due to gravity, ρ_1, ρ_2 - density of the upper and lower layer respectively, h_1 : thickness of lower layer, σ : radian frequency, m : complex wave number, D : decay parameter. The relative energy dissipation per unit time is given by the ratio P/E .

Mac Pherson and Kurup (1981) obtained dimensionally correct expression for P/E by modifying Gade's equation as

$$P/E = 2kD g h_1 / \sigma \quad (8)$$

They used dispersion relation given by Gade:

$$m g (h_1)^{1/2} / \sigma = \{ h_1 / h_2 + \Gamma - [(h_1 / h_2 - \Gamma)^2 - 4v \Gamma h_1 / h_2]^{1/2} / 2v \Gamma \}^{1/2} \quad (9)$$

where $v = 1 - (\rho_1 / \rho_2)$, $\Gamma = 1 - (\tanh [1-i] (\sigma h_2^2 / 2v)^{1/2} / (1-i) (\sigma h_2^2 / 2v)^{1/2})$; ρ_1, ρ_2 - densities of water and seabed respectively. In the limiting case of negligible viscosity, i.e. as $\gamma \rightarrow 0$, then $\Gamma \rightarrow 0$, and the dispersion relation reduces to that for the oscillation of two inviscid layers of fluids of different densities as given by Defant (1961). For given values of h_1 / h_2 , ρ_1 / ρ_2 and $(\sigma h_2^2 / 2v)^{1/2}$, we can evaluate $m(g h_1)^{1/2} / \sigma$; the real part of which is the dimensionless wave number, $k(g h_1)^{1/2} / \sigma$, and the imaginary part is the dimensionless decay parameter, $D(g h_1)^{1/2} / \sigma$.

RESULTS AND DISCUSSION

P/E is evaluated for different water depths and fluid layer thickness. Kinematic viscosity n and the ratio of fluid densities ρ_1 / ρ_2 are kept constant. Experimentally determined dynamic viscosity was used to obtain kinematic viscosity as 11,400 cm²/s. The relative energy loss per unit time, P/E is calculated for eight periods (8 - 15 sec), for three water depths ($h_1 = 9, 12$ and 14 m) and for four fluid layer thickness ($h_2 = 0.5, 1.0, 1.5$ and 2.0 m). Fig. 1 shows variation of relative energy loss in unit time with period for different values of h_1 and h_2 . For all the three water depths considered, the energy loss decreases with increasing wave periods. The rate of this decrease itself

decreases with increase in wave period resulting in almost constant values at higher wave periods. When the fluid layer thickness is 0.5m (Fig. 1), P/E decreases with increase in water depth. For wave periods between 8 and 15 seconds, P/E varies between 1.07×10^{-3} and 2.41×10^{-4} for the water depths considered.

When the fluid layer thickness is increased to 1m also, P/E shows the same trend of variation with period, indicating decrease with increasing periods. The increase in water depth leads to decrease in energy attenuation. P/E varies between 8.33×10^{-3} and 1.58×10^{-3} for wave periods between 8 and 15 seconds, for the three water depths considered.

The same trend of variation of relative energy loss with period is observed when the fluid layer thickness is 1.5m and 2m. The curves indicate decrease in energy attenuation with increasing periods and decrease with increasing water depths. For the wave periods 8-15 seconds, for the three water depths considered, the values of relative energy loss per unit time vary between 2.36×10^{-2} and 5.01×10^{-3} , for fluid layer thickness 1.5m and, between 4.14×10^{-2} and 1.03×10^{-2} for fluid layer thickness 2m.

For waves of period ranging between 8-15 seconds, and for fluid layer thickness between 0.5m and 2.0m, the relative energy loss per unit time varies between 0.041567 and 0.000241, for the three water depths considered. For all the four fluid layer thickness considered namely, 0.5m, 1.0m, 1.5m, 2.0m, it is seen the curves indicate an exponential decrease in relative energy loss per unit time with increasing period. There is a sharp decrease with decreasing fluid layer thickness, amounting to 0.03 for 2.0m, 0.019 for 1.5m, 0.006 for 1.0m and 0.0008 for 0.5m of fluid layer thickness. The maximum relative energy loss per unit time nonlinearly decreases with decreasing fluid layer thickness. The relative energy loss per unit time shows linear decrease with decreasing fluid layer thickness.

The increase in relative energy loss per unit time between water depths 9m and 14m is higher for lower periods and decreases with increase in period. This influence is found to decrease considerably with decreasing thickness of the fluid layer.

CONCLUSIONS

The study demonstrates the acceptability of the Mac Pherson and Kurup model to explain wave energy attenuation in the mud bank regions where the bottom is of viscous fluid mud. All the three parameters namely, water depth, fluid layer thickness and wave period, influence the rate of wave energy attenuation. Wave energy attenuation decreases with increasing water depth; increases with increasing

bottom fluid thickness and decreases with increasing wave periods. The relative importance of the role of each of these parameters is yet to be ascertained. The two-layer model does not take into account the variations of kinematic viscosity within the fluid bottom. However, the present model successfully explains the localized formation and the disappearance of mud banks. The rates of wave attenuation are comparable to those observed in the mud banks. The waves can almost completely be attenuated over a distance of a few wavelengths. The results are relevant wherever the seabed, in its response to water waves, is visco-elastic.

REFERENCES

- Dahneke, B.E., 1983. Measurement of suspended particles by quasi-elastic light scattering, John Wiley & Sons, New York, p.138.
- Dalrymple, R.A. & Liu, P.L.-F., 1978. Waves over soft muds: A two-layer fluid model, J. Phy. Oceanogr., 8, 1121-1131.
- Defant, A., 1961. Physical Oceanography, Vol. 1, Pergamon Press, New York, 729 pp.
- Einstein, A., 1906. *Eine neue bestimmung der molekuldimensionen bern* (A new determination of molecular dimensions) *Buchdruckerei K.J. Wyss*, Ph. D. Dissertation, Zurich University, 183 pp., also in *Annalen der Physik*, 19, 289.
- Gade, H.G., 1958. Effects of a non-rigid impermeable bottom on plane surface waves in shallow water, J. mar. Res., 16, 61-82.
- Gade, H.G., 1959. Notes on the effect of elasticity of bottom sediments to the energy dissipation of surface waves in shallow water, *Archiv For Mathematic og Naturvidenskab*, 55, 1-12.
- Hsiao, S.V. & Shemdin, O. H., 1980. Interaction of ocean waves with a soft bottom, J. Phy. Oceanogr., 10, 605-610.
- Kurup, P.G., 1969. Present status of knowledge on the physical aspects of mud banks along Kerala coast, Mahasagar- Bull. Natn. Inst. Oceanogr., 2, 25-31.
- Kurup, P.G., 1972. Littoral currents in relation to the mud bank formations along the coast of Kerala, Mahasagar-Bull. Natn. Inst. Oceanogr., 5, 158-162.
- Kurup, P. G., 1977. Studies on the physical aspects of the mud banks along the Kerala coast with special reference to Purakad mud bank, Bull. Dept. Mar. Sci., 8, 1-72.
- Kurup, P.G. & Varadachari, V.V.R., 1975. Flocculation of mud in the mud bank at Purakad, Kerala coast, Indian J. Mar. Sci., 4, 21-23.
- Lamp, H., 1932. Hydrodynamics, 6th ed., Cambridge University Press, 764pp.
- Mac Pherson, H., 1980. The attenuation of water waves over a non-rigid bed, J. Fluid Mech., 97, 721-742.
- Mac Pherson, H. & Kurup, P.G., 1981. Wave damping at the Kerala mud banks, Ind. J. Mar. Sci., 10, 154-160.
- Rosenthal, W., 1978. Energy exchange between surface waves and motion of sediments, J. Geophy.Res., 83, 1980-1982.
- Varma P.U. & Kurup, P. G., 1969. Formation of the Chakara (mud bank) on the Kerala coast, Curr. Sci., 38, 559-560.
- Williams, J., 1968. A mathematical model for description of turbid water in terms of suspended particle size and concentration, Chesapeake Bay Inst. Tech. Rep.38, 29 pp.

(Accepted 2007 May 16. Received 2007 May 14; in original form 2006 June15)



S. Minirani obtained her Masters Degree in Oceanography from Cochin University of Science and Technology in 1999 and pursued research in Coastal Oceanography at the School of Marine Sciences. Subsequently, she joined the Regional Centre of the National Institute of Oceanography at Cochin as Research Fellow. In 2006 she obtained Masters Degree in Mathematics also from the Calicut University. Presently she is working as a Lecturer in Mathematics in the Engineering College under Don Bosco Institute of Technology, Kurla, Mumbai.



Prof. Parameswar G. Kurup, Director (Research and Development), Amrita Vishwa Vidyapeetham University has recently been awarded the prestigious Emeritus Fellowship by University Grants Commission of India. He has authored nearly one hundred research papers in Oceanography and Ocean Engineering, carried out a large number of major research programs and guided twelve scientists in their doctoral research. His special interests are in wave- bottom interaction and marine pollution in which he has carried out leading investigations. Dr. Kurup is Life Fellow of the Institution of Engineers (India) and the Indian Geophysical Union.