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Wave Attenuation Due to Bottom Friction across the Southwest Indian Continental Shelf

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ABSTRACT

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The energy of any coastal zone is dependent on the wind generated waves in the offshore and their transformation in shallow water controlled by processes such as refraction, shoaling and bottom frictional attenuation. In examples described from the southwest coast of India, the loss of energy due to bottom frictional attenuation, though neglected sometimes, plays a major role in shaping the coastal wave climate. The study has been carried out for three selected locations with varying bottom slopes and sediment characteristics along this coast using a wave refraction model. Though there is significant difference between shelf sediment characteristics of the southern and other parts of the shelf, a friction factor of 0.02 seems to account well for the attenuation. The energy loss due to bottom frictional attenuation on the northern (gently sloped) coast is much greater than on the southern (steep) shelf. This predicted variation agrees with the observed distribution of wave energy as determined from wave measurements along this coast. The study underlines the importance of shelf slope in controlling spatial contrasts in bottom frictional attenuation and consequently the coastal energy regime.

ADDITIONAL INDEX WORDS: *Bottom friction, coastal engineering, Indian coast, wave energy, wave refraction.*

INTRODUCTION

Waves in deep water can propagate for enormous distances without appreciable attenuation. The coastal wave climate of any region is dependent on deep water waves and their complex transformation processes. When those waves enter shallower water encountering depths of the order of half their wave length, the bottom starts to influence their propagation in several ways. Due to the shoaling process, wave heights first decrease in the shallow waters and then increase once more. It is well-established that the reduction in phase velocity in shallow waters causes refraction in a process analogous to Snell's law in geometrical optics. The wave trains curve so that the crests become more or less parallel to the bathymetric contours and the wave height and consequently wave energy may increase or decrease depending on the convergence or divergence of the orthogonals. Both shoaling and refraction depend only on water depth and not on the type of bottom. Shoaling and refraction are linear processes in the sense that they do not depend on the height of the waves.

The next important influence of the bottom is the attenuation in wave energy by bed friction, which although commonly ignored, may play a major role in determining the coastal energy regime. There are several frictional mechanisms involved, essentially two factors, *viz.* slope of the shallow water profile and the nature of the bottom.

The purpose of this paper is to assess the role bottom friction plays in attenuation of wave energy in shallow waters of a coastline such as the southwest coast of India, which has varying shelf gradients and sediment characteristics. The study was prompted by the results of BABA *et al.* (1983a, b and 1985) who have reported a decreasing nearshore wave energy regime from south to north along this coast.

LOCATION

The study was conducted at three selected locations along the southwest coast of India *viz.* Trivandrum,

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Alleppey and Calicut (Figure 1). The three shelf profiles are indicated in Figure 2. While Trivandrum is characterized by steep inshore shelf gradient, Alleppey and Calicut are fronted by wide, flat inshore profiles. For Calicut the offshore slope beyond 30 m depth is exceptionally gentle. Trivandrum has a sandy inshore bottom, while Alleppey and Calicut have silty bottoms (Table 1). Whereas the Trivandrum coast has approximately NW-SE trends, the other two are more NNW-SSE oriented.

The wave climate along this coast shows considerable spatial variation. The southernmost part (Trivandrum) is a high-energy coast compared to Alleppey and Calicut (BABA *et al.*, 1983a, b and 1985). Significant wave heights for the fair season (November-April) and rough season (May-October) are reproduced in Figure 3 from BABA *et al.* (1985). During the rough season, for 50% of time, the significant wave heights exceed 2.0 m at Trivandrum, 0.9 m at Alleppey and 0.8 m at Calicut. During fair weather, wave heights exceed 1.0 m at Trivandrum, 0.6 m at Alleppey and 0.7 m at Calicut for 50% of time. The maximum wave heights reported during the period 1980-85 at Trivandrum, Alleppey and Calicut are respectively 6.0 m, 3.8 m and 3.3 m (BABA *et al.*, 1986).

COMPUTATION OF FRICTIONAL ATTENUATION

Early attempts to determine the energy attenuation by bottom friction were initiated by KEULEGAN (1948) and by PUTNAM and JOHNSON (1949). BRETSCHNEIDER and REID (1954) derived the relevant equations. A computer programme was developed by DOBSON (1967), who calculated the refracted wave height based on the equation

$$H = K_r K_s H_0 \qquad (1)$$

where K_r and K_s are the refraction and shoaling coefficients respectively and H and H_0 are the refracted and deep-water wave height respectively. The scheme was subsequently modified by COLEMAN and WRIGHT (1971) for inclusion of bottom frictional attenuation

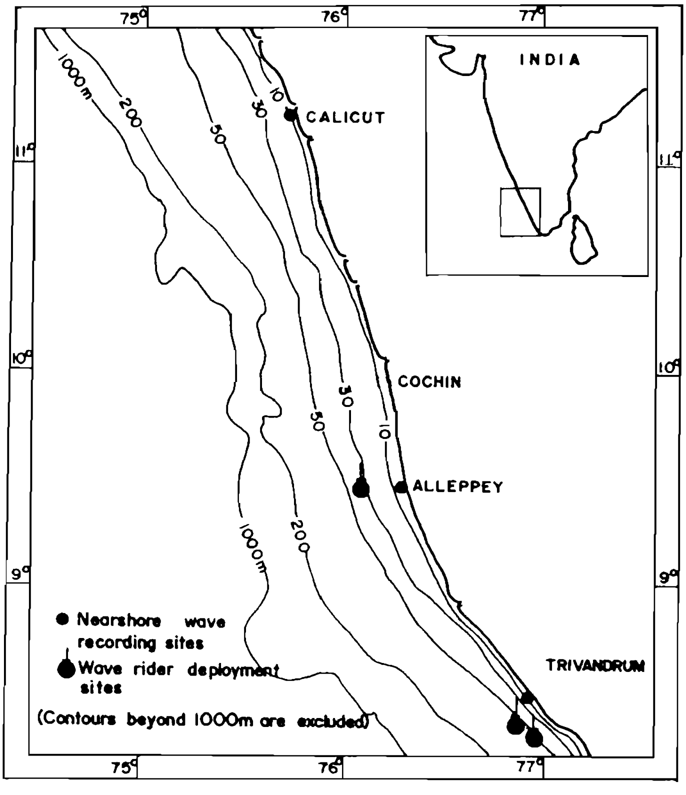

Figure 1. Location map with bathymetry and wave recording stations.

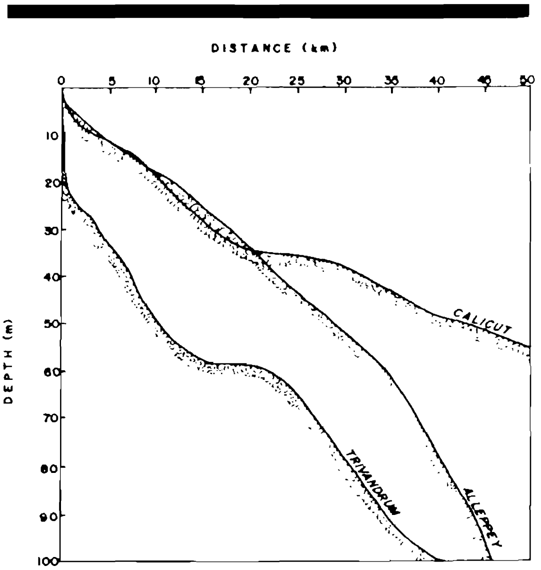

Figure 2. Innershelf profiles at different locations.

Table 1. *Average size characteristics of nearshore sediments at different locations (depth: 5-15 m)*

Location	Sediment Size (mm)	
	Median	D_{90}
Trivandrum	0.203	0.368
Alleppey	0.029	0.088
Calicut	0.025	0.109

using the equations of BRETSCHNEIDER and REID (1954). This computer programme is used for the present study but with some further modifications as in KURIAN and BABA (1986). The equations used are as follows:

$$H_j = H'_{j-1} / [(f \varnothing \Delta x H'_{j-1}) / (K_{sj} T^4)] + 1 \cdot 0 \qquad (2)$$

$$H'_{j-1} = H_{j-1} (K_{sj} / K_{sj-1}) (K_{rj} / K_{rj-1}) \qquad (3)$$

$$\varnothing - (\delta \pi^3 / 3 g^2) (K_{sj} / \sin h (2 \pi d / L))^3 \qquad (4)$$

$$K_f = H_j / (K_{rj} K_{sj} H_o) \qquad (5)$$

$$E - \delta g H^2 / 8 \qquad (6)$$

where H_j = wave height after frictional attenuation at point j; H_{j-1} = wave height after frictional attenuation at the preceding point j−1 (on the orthogonal) distant Δx from point j; f = bottom friction factor; K_f = friction coefficient; δ = density of water; g = acceleration due to gravity; d = water depth; L = wave length; T = wave period; and Δx = some small distance seaward of location j. The applicability of this programme for simulation of refracted waves have been verified by BRYANT (1979), KURIAN *et al.* (1985) and KURIAN and BABA (1986).

The value of friction coefficient, K_f at any point will reflect the total amount of energy expended

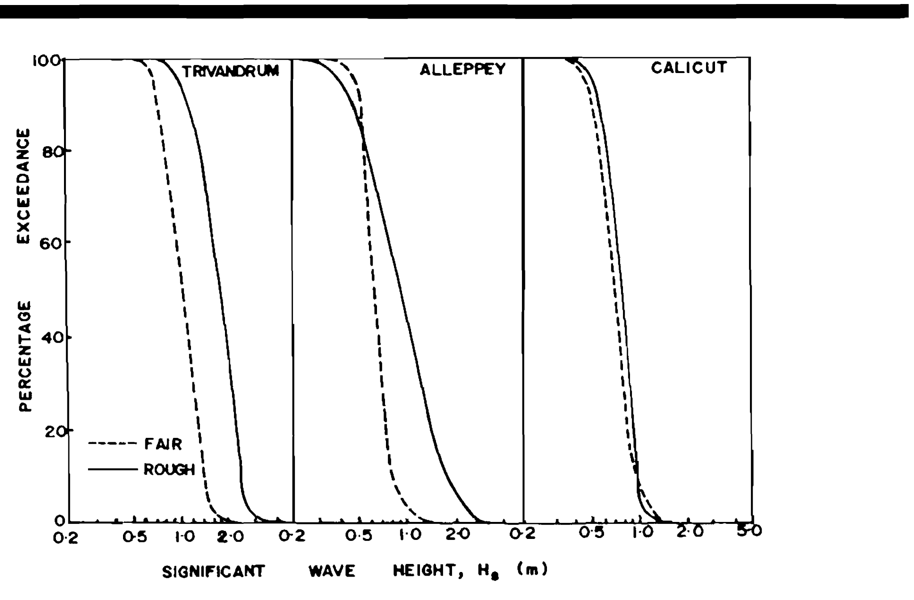

Figure 3. Percentage exceedance diagram for waves at different locations (after BABA *et al.*, 1985).

during the propagation of the wave front from deep water up to that point.

The value of K_f have been used to determine the percentage loss of energy due to bottom friction at nearshore points along different locations of this coast.

Determination of Friction Factor

The friction factor f has been given considerable attention in laboratory and theoretical studies in recent years. More recent laboratory studies have indicated a dependence of friction factor on the Reynolds number and bottom roughness height. JONSSON (1966) and KAMPHUIS (1975) produced and refined a friction factor diagram which could be used to find f, if the Reynolds number at the sea floor, R_e, and the relative roughness height, A / k_s are known. The Reynolds number is related to the bottom velocity under the wave by

$$R_e = U_b A / \nu \qquad (7)$$

where U_b = maximum horizontal water particle bottom velocity; A = horizontal displacement amplitude of water particles; and ν = kinematic viscosity of sea water.

RESULTS AND DISCUSSION

The friction-factor diagram was applied for the study locations for the different ranges of wave characteristics and sediment size. It was found that the friction factor was less than 0.005 for Alleppey and Calicut and around 0.007 for Trivandrum for the different wave characteristics off these locations.

Computations of nearshore wave parameters and energy were carried out using deep-water wave characteristics (Table 2) and friction factors as obtained above at Trivandrum and Alleppey. No computations could be made for Calicut since there were no recorded deep-water wave data for this location. Comparisons with measured nearshore wave data showed that the computed values were overestimated indicating that the friction factors used were insufficient to accommodate the frictional attenuation. It has to be noted that WRIGHT (1976), BRYANT (1979) and BRETSCHNEIDER and REID (1954) have used higher values of friction factors for their computations. Keeping the above in view, the computations were repeated with f = 0.02, 0.015 and 0.01. The values obtained with f = 0.02 for Trivandrum and Alleppey compared well with the measured values and the results are shown in Figure 4. KURIAN *et al.* (1985) also got good results at Alleppey with f = 0.02. The results indicate that a friction factor of f = 0.02 will sufficiently accommodate the frictional attenuation at different locations along this coast.

Table 2. *Deep water and nearshore wave characteristics*

Parameter	Deepwater	Nearshore
Significant wave height (m)	0.89- 2.72	0.85- 2.94
Period (s) (zero-crossing)	5.0 8.2	6.8 - 11.4
Direction (°N)	185 -300	200 -275

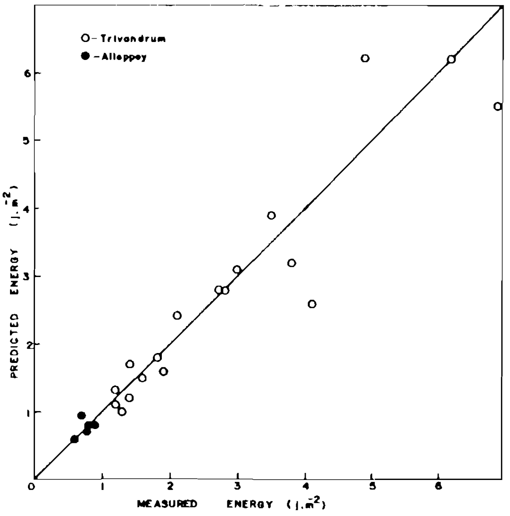

Figure 4. Plot of computed wave energy against measured energy.

From the present results it appears that the friction factor, as derived from the friction factor diagram, may not represent the true picture of the bottom. Bottom roughness alone cannot be taken as the criteria for determining f, since the soft bottom may deform in response to the wave, increasing the viscous dissipation. The high value of f even for soft bottom such as that of Alleppey and Calicut may be due to the latter effect.

Frictional Attenuation of Wave Energy along the Coast

The total loss of energy due to bottom friction during the propagation of a wave train is the cumulative effect of the shelf gradient, bottom roughness and the wave parameters in which the latter two determine the frictional factor. The percentage attenuation in terms of deep-water wave energy for different wave heights and periods are computed at each location and presented in Table 3. For the purpose of comparison between different locations, the deep-water wave direction is taken to be the normal to the coastline at each location.

Table 3. *Frictional attenuation of energy in terms of deep water wave energy at different locations*

		Percentage of frictional attenuation due to waves* of					
	Friction	Height (m)	1			2		
Location	factor	Period (sec)	6	9	12	6	9	12
Trivandrum	0.02		2	3	7	2	6	13
Alleppey	0.02		32	47	57	51	67	76
Calicut	0.02		47	68	82	67	84	93

*Wave direction normal to the coastline at each location

The attenuation is the least for the Trivandrum coast, and it increases towards the north reaching a maximum at Calicut. For the Alleppey and Calicut coasts, the energy loss due to bottom friction is quite high, especially for waves of higher period and higher amplitude. The loss is as much as 93% of the deep-water wave energy for waves of height 2 m and period 12 sec at Calicut. It is also significant to note that though Alleppey and Calicut have more or less the same type of bottom, and the difference in slopes of the innershelf is not great, the difference in loss, even for low periods, is quite significant.

The results show that even for the same deep-water wave conditions (directions being normal to the coastline at each location), there will be a significant decrease of wave energy towards the north. The pattern of frictional dissipation of wave energy as observed above explains very well the spatial variation of wave intensity along this coast (Figure 3) as reported by earlier researchers (BABA *et al.*, 1983a, b and 1985). The coastal energy regime of Trivandrum is quite comparable to that of the New South Wales Coast, where also very little frictional dissipation is reported by WRIGHT (1976) and BRYANT (1979). The higher rates of frictional loss found at Alleppey and Calicut are comparable with the high values reported by WRIGHT (1976) for the flatter shelves of the U.S. Atlantic Coast.

The extent of frictional dissipation determines the morphodynamics of the beaches. As the frictional dissipation is very low for the Trivandrum coast the complete energy is expended in a very narrow zone increasing the severity of waves on beaches, especially during storm periods. The beaches of Alleppey and Calicut on the other hand have lower input energy, as a major part of the energy is lost by frictional attenuation over a wide nearshore zone.

CONCLUSIONS

Studies on the wave climate along the southwest coast of India have shown that the wave intensity is maximum at the southern part and decreases towards the northern sections. A wave refraction programme incorporating bottom frictional attenuation used a friction factor of 0.02 which was found to be applicable irrespective of the differences in the shelf sediment characteristics. It is concluded that the friction factors based on bottom roughness alone do not account for the frictional dissipation over different shelf bottoms. The study shows that frictional attenuation increases towards north. It reaches a maximum of 93% deep water-wave energy at Calicut, in the case of a deep-water wave of height 2 m and period 12 sec. The frictional attenuation accounts very well for the variation in the observed wave intensity at the different locations. The study shows how important the bottom friction is in bringing about pronounced spatial contrasts in the coastal energy regime.

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□ RESUMEN □

La energia que llega a la costa depende del oleaje generado en el océano y de su transformación por profundidades reducidas por refracción, asomeramiento, fricción por fondo, etc. Se pone ejemplos del efecto de la atenuación de la energia por fricción en algunas playas de Suroeste de la India, y que se corresponden con tres playas de pendiente y sedimentos diferentes. Se ha considerado en todos los casos un coeficiente de fricción de 0,02. La disipación en la costa Norte con pendientes suaves es mayor que en la costa Sur donde la plataforma tiene fuerte pendiente. Esta presicción se corresponde con los resultados medidos a lo largo de la costa.--*Miguel A. Losada, Universidad de Cantabria, Santander, Spain*

□ ZUSAMMENFASSUNG □

Die Energie jeder Küstenzone ist von ablandige winderschaffene Wellen und seine Umwandlung in seichten Wasser, durch solche Prozesse wie Strahlenbrechung und Reibungsverdünnung auf dem Meeresboden, abhängig. Beispiele von südwestlichen Indien zeigen, dass der Energieverlust durch Reibungsverdünnung auf dem Boden ist auf der Formation des Küstenwellenklimas des Gebiets sehr wichtig, obwohl er oft vernachlässigt ist. Diese Forschung wurde für drei Örte entlang dre südwestlichen Küste mit verschiedenen Bodenneigen und Sedimentmerkmale durchgeführt; ein Strahlenbrechungsmodell wurde benutzt. Es gibt einer grosse Unterschied zwischen der südlichen Sedimentmerkmale der Sandbank und der anderen Sandbankmerkmale, obwohl einer Reibungsfaktor von 0.02 die Verdünnung zu erklären scheint. Der Energieverlust von der Reibungsverdünnung des Bodens ist stärker im Gebiet der nördlichen (mit sanften Neigen) Küste als der der südlichen (mit tiefen Neigen) Küste. Dieser vorhergesagtete Unterschied übereinstimmt mit der beachteten Verteilung der Wellenenergie, die von Wellenmessungen entlang der Küste bestimmt wurden. Diese Forschung betont der Bedeutung der Neige zur Beherrschung des Raumgegensatzes der Reibungsverdünnung auf dem Meeresboden und daher der allgemeine Küstenenergie.--*Stephen A. Murdock, CERF, Charlottesville, Virginia, USA*

□ RÉSUMÉ □

Les pertes d'énergie dues à l'atténuation par friction sur le fond jouent un rôle majeur dans le régime de la houle aux trois localités étudiées de la côte SW de l'Indie, qui présentent des pentes et des sédiments variés. Cette étude utilise un modèle de réfraction de la houle. Un facteur de friction de 0,02 rend compte de l'ordre de grandeur de l'atténuation. Au Nord, où la plateforme continentale est en pente douce, la perte d'énergie est plus importante qu'au Sud, escarpé. Ce qui confirme la variation prédite par la distribution de la houle observée. Cette étude souligne l'importance de la pente de la plateforme continentale comme facteur de l'atténuation par friction de la houle.--*Catherine Bressolier, EPHE, Montrouge, France*