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AEOLIAN SAND TRANSPORT AND ITS EFFECTS ON THE STABILITY OF MIRAMAR-CARANZALEM BEACH

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ABSTRACT

Removal of sand by wind from the beach at Miramar-Caranzalem, Goa, has been found to effect its stability over a relatively longer time scale. This aeolian sand transport has been computed for this strip of the beach utilising the relation between the rate of sediment transport, the sediment and wind characteristics. The winds recorded at Panaji for the period 1969-1973 have been analysed and discussed for the directional transport of sand from the beachface. During fair weather months, the diurnal, inland, aeolian transport has been found to be nearly 180 m^3 per km. length of the beach subjected to 10 m/sec. winds lasting for periods of approximately 8 hrs. a day. The resulting transport and its effects on the stability of this beach has been discussed.

Key-words: Aeolian transport, sediment, beach, stability, Miramar-Caranzalem.

INTRODUCTION

Knowledge of directional transport of large quantities of sand from beaches is of prime importance to engineers and for those engaged in planning and design of coastal structures. This transport takes place due to different forces acting at different locations of the beaches and cause problems of supply and/or loss of sediments.

Winds transport sediments from the sub-aerial portions of the beach and help in building up sand dunes along the backshore. Alternatively, offshore winds transport the sediments to the beach. Large quantities of sand get transported under the influence of steady and strong on-shore winds along Miramar-Caranzalem beach (Fig.1) resulting in its deposition on the nearby road and dune field during the fair weather months. This phenomenon received very little attention of engineers or scientists as evidenced by the lack of information on any indepth studies of this vital aspect, barring a few remarks on such features observed earlier (Veerayya and Varadachari, 1975).

Several researchers (O'Brien and Rindlaub, 1936; Kawamura, 1951; Bagnold, 1954; Hsu, 1973; Svasek and Terwindt, 1974) have attempted this problem of aeolian sand transport from the beaches under field and laboratory conditions. Amongst these, Bagnold's (1954) approach is more sound and superior from the analysis point of view. In general three modes of sand transport by wind could be distinguished: viz. (i) suspension load, (ii) saltation (bouncing motion initiated by impact) and (iii) bed-load or surface creep, rolling across the surface.

Considering the large differences in density of the sand grains and air, Bagnold (1954) developed analytical formulae governing the wind shear velocity and size of the beach sediments based on theoretical and experimental tests.

Before attempting to examine the nature and magnitude of the primary and secondary forcing functions influencing such transport, the computations were made utilising largely the simplified relations between rate of transport of sand and the wind for different size grades of the beach sediments and are presented in this communication.

A part of the shore about 2 km. in length at Miramar-Caranzalem forms a bay-side beach and is situated on the left bank of the river Mandovi (Fig.1). The river mouth is flanked by two headlands – Aguada and Cabo Raj on the northern and southern sides respectively. These headlands

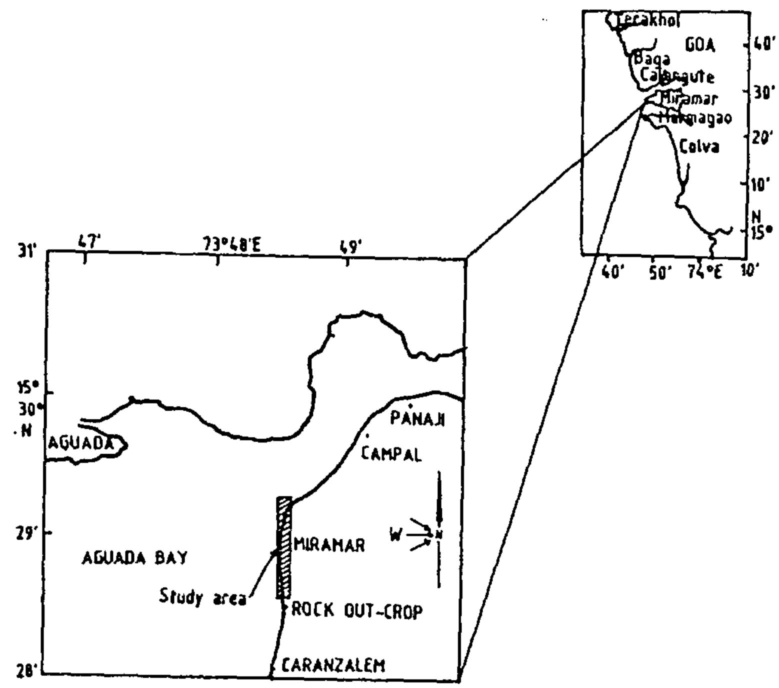

Fig.1. Map showing the region of study.

protect partially the beach from low swell waves of 5-7 sec. from W to NW during fair weather season and high wind waves with periods of 7-12 sec. from W to SW during monsoon (Reddy, 1970). The beach near Miramar has a foreshore width of 20-30 m with a slope of 10-5° whereas on the Caranzalem side it is very flat and relatively wider (~ 200 m). The beach on its northern end is backed by casuarina plantations and coconut groves and on its southern side by a sea wall. The beach is exposed to changes in water level due to tides which are of semidiurnal nature having a range of 2 m during spring tide.

The sediments of the foreshore at Miramar have mean grain size of medium to fine sand grade, moderately well to poorly sorted whereas those in Caranzalem side they are in fine sand grade, well to moderately well sorted (Fig.2). There is a general increase in the mean size from

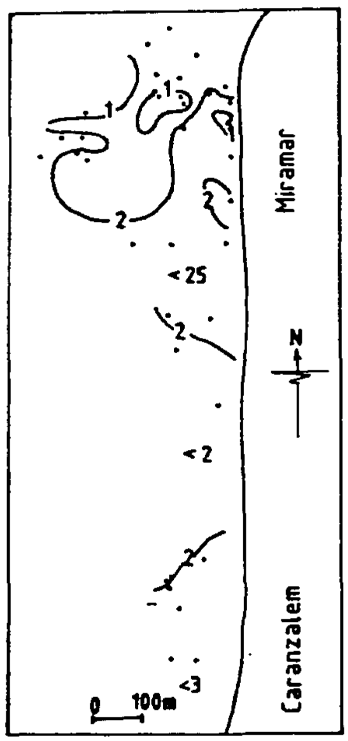

Fig.2. Mean grain size (Mz ϕ) distribution along the Miramar-Caranzalem beach (Source: Murty, C.S., Das, P.K., Nair, R.R., Veerayya, M. and V.V.R. Varadachari, 1976).

the upper to the lower foreshore and decrease southward from Miramar upto the rock outcrop where a slight increase is noticed and beyond this further southward it continues to decrease to the end of Caranzalem beach. The sands from the dunes adjacent to the beach have their medium diameter ranging from 2.8 ϕ to 3.0 ϕ and fall in the required sizes of the sediments for aeolian transportation (Folk, 1968).

MATERIAL AND METHODS

The sand transport on a natural beach depends largely on wind velocity (shear) prevailing near the coastline. In the coastal regions, one of the important features of the wind field is the presence of land and sea breeze circulation. To examine this, wind data recorded for about 5 years from 1969-1973 was collected from the meteorological observatory at Panaji. The data has been analysed to obtain the alongshore and onshore/offshore components for every month (Fig.3). In addition, the monthly mean directions of winds for the monsoon and the fair weather season during the course of the day and the mean directions averaged over five years have been computed and shown in Fig.4. From this data, the wind shear has been computed making use of the following relation (Zingg, 1952).

$$U = 6.13\ U_* \log \frac{Z}{Z'} + U'$$

where U is the wind velocity at a height Z above the sand surface, U_* is the wind shear and Z', U' are the coordinates of the focus given by empirical relations depending upon the grain size of the sediments considered. From this, the aeolian transport of sand has been computed using the relation (Bagnold, 1954),

$$q = c\left(\frac{d}{D}\right)^{0.5} \frac{\rho}{g} U_*^3$$

where q the total sand transport per unit width and unit time; d, the grain diameter; D, the average grain diameter of standard 2.0 ϕ (0.25 mm); ρ, the density of air; g the acceleration of gravity and c = (1.8) the Bagnold's constant for naturally graded sand.

RESULTS AND DISCUSSION

Wind field distribution: The analysis of winds indicate that the strength of the on-shore winds (Fig.3) on an average is more or less same (15 km/hr) during monsoon months, throughout the day, except in a few occasions. During fairweather season marked changes have been noticed from morning to evening. These winds blow during monsoon season with a mean speed of 15 km/hr. and occasionally exceed 20 km/hr. The offshore winds in the fair weather season blow gently, reaching a maximum of 9 km/hr. It is interesting to note that these winds blow always onshore in evening hours and offshore during morning hours indicating the existence of sea and land breeze associated with the diurnal wind circulation. It was also noted that the alongshore component of the winds is always northerly except in a few cases where it is southerly. From Fig.4 b, it could be seen that during monsoon months the land and sea breeze circulation is either merged with or masked by the monsoonal wind circulation. The strength and the direction of these onshore winds contributing to an inland transport of sand from beaches would, therefore, be more than that of the offshore winds.

Wind shear and sediment transport: It was observed from a 24 hr. record of wind that the speed associated with land and sea breeze varied from a low to a very high value during fair weather season. In general,

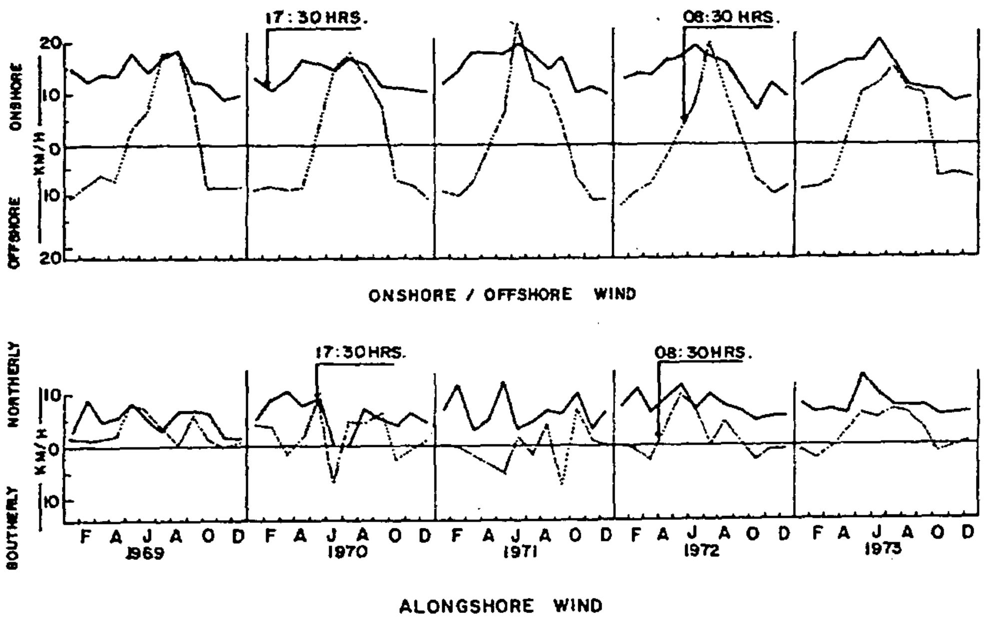

Fig.3. Onshore/offshore, alongshore components of the winds at Panaji (Source: Murty, C.S., 1977).

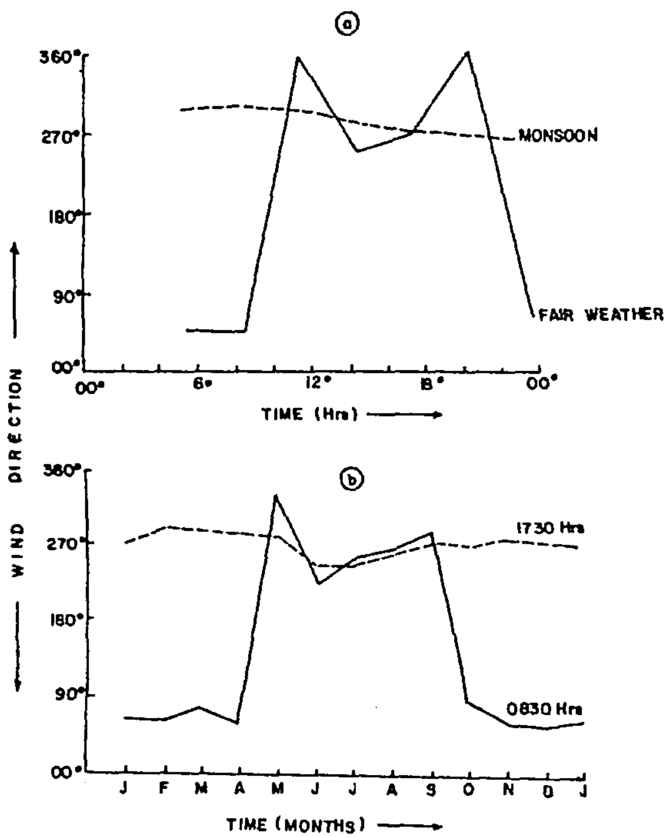

Fig.4. Mean direction of winds at Panaji. (a) In a day, and (b) over five years. (Source: Murty, C.S., 1977).

Table I — Computation of wind shear (cm/sec) with different wind speeds (cm/sec) and grain sizes (ϕ & mm).

	Wind Speed (cm/sec)				
Grain size	400	600	800	1000	1200
1.396 (0.38)	3.39	14.65	25.91	37.17	48.44
1.737 (0.30)	7.16	18.04	28.92	39.79	50.67
2.000 (0.25)	9.35	19.95	30.54	41.14	51.73
2.474 (0.18)	12.13	22.27	32.41	42.55	52.70
3.000 (0.125)	13.91	23.56	33.22	42.87	52.52

these winds blow with considerable magnitude for about 3 hrs. from SW; 3 hrs. from W and 2 hrs. from NW with respect to the orientation of the Miramar-Caranzalem shore line. The winds from other directions do not significantly contribute to inland transport of sediment. The wind shear was computed for different wind speeds (4-12 m/sec.) assuming that the measurements made hold good for winds at a height of 3 m above the beach sand surface and with U' and Z' specified (U'=20 d and Z'=10 d where d, grain diameter expressed in mm). Sands with grain sizes from 1.396 ϕ (0.38 mm) to 3.0 ϕ (0.125 mm) were considered in computing these values, since the shear values change with grain size. It is interesting (Table I) to note that the shear increases with wind except in the case of very strong winds blowing over the beach surface comprising very fine sands. This is because of the fact that the fine particles require higher threshold velocity to dislodge them (Kiyoshi and Shen, 1960).

In the present calculations 1 km. stretch of the beach near Miramar was considered. The perpendicular projections exposed to the concerned directions of winds from SW, W and NW were estimated to be 825, 775 and 262.5 m respectively. The diurnal aeolian inland sand transport computed for this stretch for each of the directions mentioned above along with their persistence is shown in Tables II-IV. The total sediment transport expressed in metric tons/cubic metres is presented in Table V. It is observed from these values (Table V) that the sand transport increases with wind speed. Further, the sand transport decreases with decrease in the grain size of the sediments at very high wind speeds. This anomalous transport

Table II — Sediment transport (metric tons) due to south-westerly winds

	Wind speed (cm/sec)				
Grain size (ϕ & mm)	400	600	800	1000	1200
1.396 (0.38)	0.1	7.7	42.8	126.4	279.7
1.737 (0.30)	0.8	12.8	52.8	137.7	284.4
2.000 (0.25)	1.6	15.8	56.9	139.0	276.5
2.474 (0.18)	3.0	18.7	57.7	130.6	248.0
3.000 (0.125)	3.8	18.5	51.7	111.2	204.0

Table III — Sediment transport (metric tons) due to westerly winds.

Grain size (ϕ & mm)	Wind speed (cm/sec) 400	600	800	1000	1200
1.396 (0.38)	0.1	7.3	40.2	118.8	262.7
1.737 (0.30)	0.7	12.1	49.7	129.4	267.0
2.000 (0.25)	1.5	14.9	53.4	130.6	259.7
2.474 (0.18)	2.8	17.6	54.2	122.7	233.0
3.000 (0.125)	3.6	17.4	48.6	104.5	191.7

Table IV — Sediment transport (metric tons) due to north-westerly winds.

Grain size (ϕ & mm)	Wind speed (cm/sec) 400	600	800	1000	1200
1.396 (0.38)	0.02	1.6	9.1	26.8	59.3
1.737 (0.30)	0.2	2.7	11.2	29.2	60.3
2.000 (0.25)	0.3	3.4	12.1	29.5	58.6
2.474 (0.18)	0.6	3.9	12.2	27.7	52.6
3.000 (0.125)	0.8	3.9	11.0	23.6	43.2

Table V — Total sediment transport (metric tons/cubic metres)

Grain size (ϕ & mm)	Wind speed (cm/sec) 400	600	800	1000	1200
1.396 (0.38)	0.2	16.6	92.2	272.0	601.7
	(0.1)	(10.4)	(57.6)	(170.0)	(376.0)
1.737 (0.30)	1.7	27.6	113.7	296.3	611.8
	(1.1)	(17.2)	(71.1)	(185.2)	(382.4)
2.000 (0.25)	3.5	34.1	122.4	299.1	594.8
	(2.2)	(21.3)	(76.5)	(186.9)	(371.8)
2.474 (0.18)	6.5	40.2	124.2	281.0	533.7
	(4.1)	(25.2)	(77.6)	(175.6)	(333.6)
3.000 (0.125)	8.2	39.7	111.3	239.2	438.9
	(4.1)	(25.2)	(69.6)	(149.5)	(274.4)

values given in parenthesis are in cubic metres

may be due to the fact that the fine sands require higher wind speed to initiate saltation. These transports are considered to be valid under certain assumptions: (i) smooth surface along and across the beach, (ii) steady and uniform wind field, and (iii) the mean diameter (D_{50}) is representative of the beach sediments. In these calculations no attempts were made to check the rate of transport when the sand exhibits moist conditions particularly at the berm crest as investigated by Belly (1962). Veerayya

(1978) through field studies indicated that the strength of the predominant prevailing onshore winds leading to inland transport in this area are of the order of 10 m/sec. Under these conditions, the computed transport of sand (Table V) to the tune of 180 m^3 should be adequate to result in sand loss to the beach. This material, removed and transported from the exposed parts of the upper foreshore and partly from the berm crest on to the back shore and dune fields might affect the stability of the beach on a long term basis. The large tidal range and the low water table at the shore (Murty, 1977) however, favour transport of the sediments of the beach besides the strong wind and insolation. Further, the wider the beach larger would be the quantity of sediment transported, thus leading to the build up of the adjacent dunes. A part of this material may be replaced due to the strong offshore winds, but in this area, the strength of these winds associated with land breeze do not exceed 5 knots and hence the transport is negligible. Beach stability studies (Murty, 1977) have indicated that the beaches are more or less stable on an annual basis. So, to encounter this, there must be a feed back mechanism to replace the losses of sediment at least to some extent. During this monsoon months, the heavy and succeeding runoff partly help in transporting these deposits from the roadstead and dune field sand which finally reach the nearshore areas only to be transported once again on to the beach by the action of waves. The detailed investigations to understand the exact mechanism of replacement and net loses from the beach has to be examined for better understanding of the problem.

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