

Morphology & Grain-Size Characteristics of a Log-Spiral Beach at Nagwa (Diu), West Coast of India

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Sediment samples collected along 6 beach profiles of a log-spiral shaped beach and nearby dunes have been studied for particle size distribution in relation to wave refraction patterns. The results reveal that the foreshore sediments are in the coarse to fine sand grade (M_z : 0.84 to 2.96 ϕ), well to poorly sorted (0.45 to 1.73 ϕ) and positive to negatively skewed (0.25 to -0.54 sk_i) classes. Sediments at profile st 1 in E are coarser and poorly sorted while they are fine-grained and better sorted in W as well as along the curved section of the beach. Alongshore variations in grain-size characteristics of beach sediments which have been discussed in relation to beach topography, wave induced littoral flows and prevailing meteorological and oceanographic conditions indicate clearly the suitability of the area close to st 6 in the curved part of the bay for developmental activities related to coastal zone.

As part of a reconnaissance survey of Nagwa beach (Diu) and its nearshore environments and for information on shoreline stability and suitability of inshore waters for development of water sports, an overall assessment of (i) climatological wind and wave data, (ii) prevailing environmental setting and (iii) morphology and sediments of the beach has been made¹. This paper describes the present status of the log-spiral shaped coastline bordering Nagwa bay, in relation to various physical forces operating in this region, with special emphasis on sediment distribution.

Study Area

Regional setting—Diu Island (37 km²) lies off the southern coast of Saurashtra (Fig. 1). Nagwa bay lies on the southern side of this island. The island has limestone/sandstone cliffs (20 to 30 m high) on the sea side². The coast is generally rocky and provides a panoramic view with its undercut hanging cliffs and wave cut platforms. At places the rocky cliffs are cut by wave action, forming large blocks. Sandy beaches with a near log-spiral shape exist between rock promontories all along the coast which is oriented in a E-W direction. These beaches are backed by sand dunes with heights varying from 1 to 5 m at few locations (near sts 5 and 6, Fig. 1) and act as second line of defence. The beach at Nagwa Point has a crescent shape—an ubiquitous feature of the coastline. Such bays, normally, possess a definite orientation with respect to the predominant swells on sea side. Their shape reflects on the nature of stability of the beach since the swells change their orientation as they approach the shoreline in a direction almost normal to all the sections of the beach.

The shore (~7 km length) bordering Nagwa bay extends from Nagwa Point to Fort de Nagwa. This bay comprises a log-spiral section on the upcoast side in the vicinity of Nagwa Point on the west followed by 2 tangential sections, T₁ and T₂ (Fig. 1), each of ~1 km length, with a rocky platform at the middle and lower foreshore regions. The rest is occupied by cliffs mostly on the eastern side. The waves at this point of the shoreline experience diffraction on the western side of Nagwa Point and refraction along the tangential sections of the beach. This particular stretch of the beach—of which similar crescent or log-spiral shaped beaches including many bayside beaches abound along many coastal regions—has 3 main features which are, in general, not common to all. These are: (i) The concave part near the Nagwa Point has a channel (at C, Fig. 1) between the main land and the Nagwa Point; the slope here is gentle contrary to the expectation of a steep slope. (ii) The tangential part (T₂) has steeper slope compared to (i) above; this type of beaches generally have steeper slopes tapering down gradually to moderate slopes from the concave to the straightened terminal part. (iii) The central part of this beach provides a geomorphological departure from the rest (T₁ and T₂ and Nagwa Point). This is formed mainly of sandstone/limestone and is apparently devoid of sand except a thin veneer of sand here and there. The nearshore topography off Nagwa bay shows gentle slopes as compared to the open ocean beaches probably due to the curved shape of the bay; the bottom slopes between the shoreline and the 5 m isobath being of the order of 0.0065 on the western side and gradually increase to 0.0327 on the eastern side. The supply of sediments to this area is probably

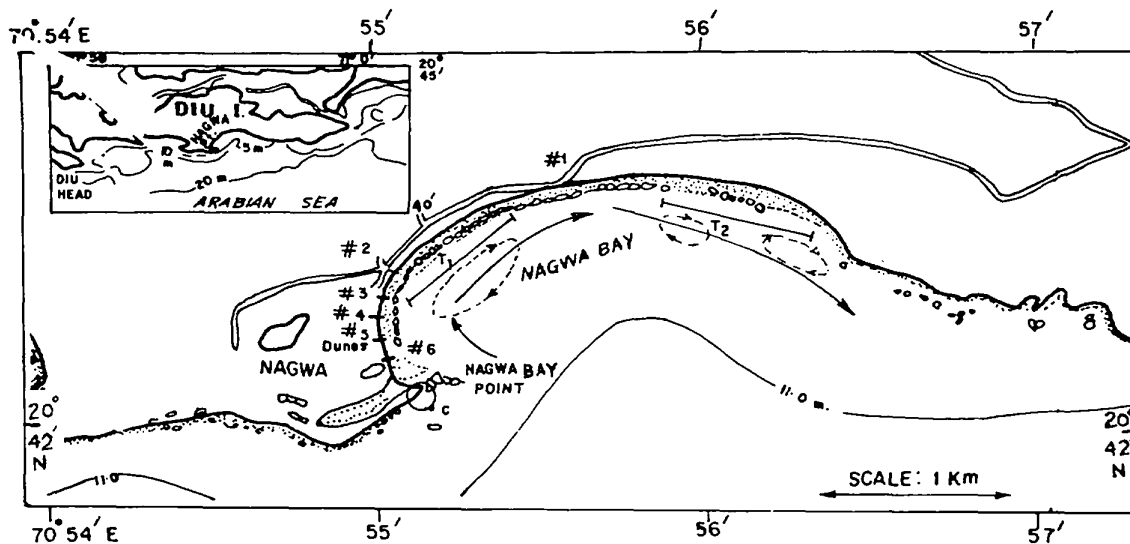


Fig. 1. Environmental setting at Nagwa bay and location of study area (#1, #2---, #6 beach profile stations. Long and thin arrows indicate probable littoral drift)

channeled through the existing runnel immediately W of the Nagwa Point and E of the cliff.

Environmental factors—Winds as recorded at Veraval (published in IDWR), a station close to Diu, have been examined for over 5 y. The data reveal that, in general, the average wind speeds are $\sim 3 \text{ m sec}^{-1}$ during morning hours and 5 m sec^{-1} during evening hours. Directional change of these winds could be seen clearly during the fair weather months and indicate the presence of land and sea breeze air circulation. During monsoon months, this feature appears to get masked by the strong and steady southwest to westerly winds. The prevailing deep water wave climate for different months³ shows that the wave periods range from 5 to 13 sec and the wave heights lie between 0.5 and 4.5 m during a year. During the SW monsoon months waves approach the coast from directions 210° to 300° while the waves from other directions (N to ENE) appear to be moving away from the coastline during non-monsoon months. The tides in this area ($\sim 1.75 \text{ m}$) fall within the micro-tidal range⁴. The currents associated with these differ in their magnitude and directional set as one moves from the coast to offshore area. In general, they are of the order of $70\text{--}80 \text{ cm sec}^{-1}$ in strength and set in NW-SE direction. These currents change their direction to W-E beyond almost 5 km away from the shore. The major surge amplitudes that can occur on the coasts around the Kathiawar Peninsula between Diu and Dwaraka are $\sim 1.5 \text{ m}$ and are almost half the tidal range in this area. The

frequency of storms here is high, but usually they are not intense^{5,6}.

Methods

Six reference stations were established on the extreme landward side of the beach backshore or dune and beach profiles were measured seaward from the reference stations (Fig. 1). Sediment samples were collected from the upper 4 cm of the backshore-foreshore regions along all profile transects. Observations on wind, periods, heights and directions of waves and breakers, and littoral currents were made at each profile transect. Methodology of beach profile measurements, sediment sampling and monitoring of relevant oceanographic and meteorological parameters followed is similar to that described earlier^{7,8}.

Particle size distribution of sediment samples was determined using standard method of sieving⁹. Grain-size parameters, viz. mean grain size, standard deviation and skewness of sediments were calculated using the formulae of Folk and Ward¹⁰.

Results and Discussion

Beach morphology—Beach profiles (Fig. 2) show that the width of the exposed beach foreshore varies between 35 and 60 m, the widest and moderately flat beach being present between sts 3 and 5 near Nagwa Point while the beach is narrow and relatively steep all along the E-W trending strip between sts 1 and 2 covering tangential sections T_1 and T_2 reflecting the

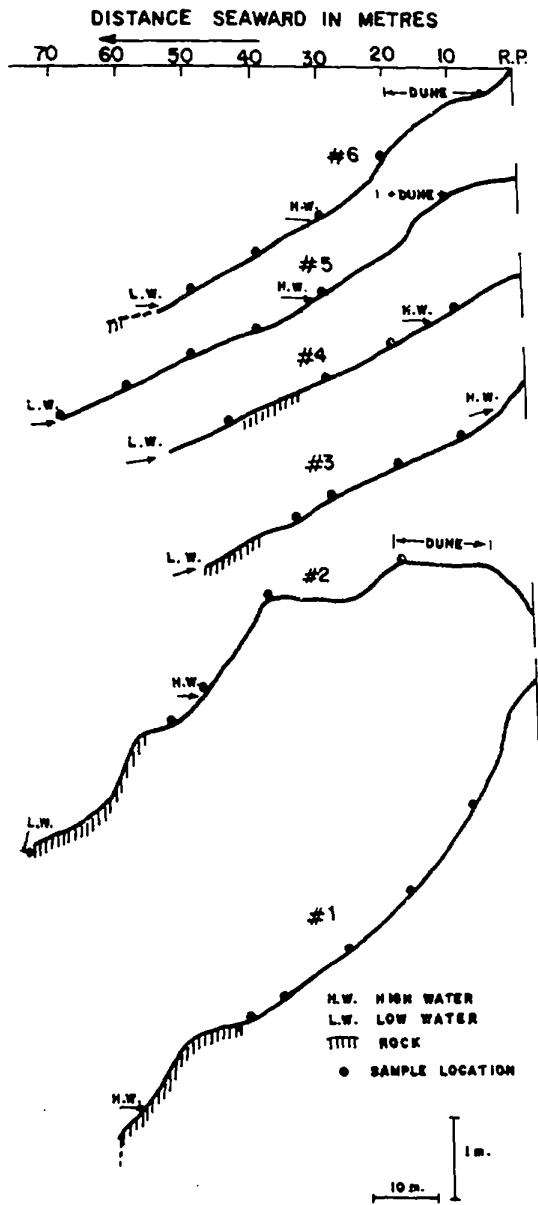


Fig. 2--Beach profiles (see Fig. 1 for locations of profile stations)

moderate and high energy environments respectively prevailing in the area. The profile at sts 5 and 6 is backed by dunes. Profile at st 2 is characterised by a prominent berm. A conspicuous feature is the occurrence of convex shaped rock platform (sandstone) at middle and lower foreshore parallel to the shore along the beach between sts 1 and 4. The rock platform which forms a distinct morphologic feature is

about 20 m wide at st 1 in E, narrows to <5 m at st 4 and becomes gradually less distinct and gets covered by sands south of st 4. The seaward side of the rock platform is remarkably steep which restricts the run-up on the beach face.

Variation in grain size parameters—Table 1 shows that the sediments of the foreshore are in the coarse to fine sand grade (M_z 0.84 to 2.96 ϕ), mostly well to moderately sorted (0.45 to 0.88 ϕ), and positive to very

Table 1— Grain-Size Parameters of Nagwa Beach and Dune Sands

| Sample No. | Distance from Ref. pt. in m (seaward) | Location | Grain-size parameters | | |
|--------------|---------------------------------------|----------------|---------------------------------|----------------------------------|----------------|
| | | | Mean grain size (M_z, ϕ) | Standard dev. (σ, ϕ) | Skewness (ski) |
| Profile st 1 | | | | | |
| 1 | 10 | UF | 1.33 | 0.6983 | 0.2115 |
| 2 | 20 | | 1.13 | 0.7438 | 0.2006 |
| 3 | 30 | MF | 1.30 | 0.8841 | 0.2528 |
| 4 | 40 | | 0.84 | 1.1656 | 0.1052 |
| 5 | 45 | LF | 0.93 | 1.2466 | 0.0874 |
| Profile st 2 | | | | | |
| 6 | 20 | Dune | 1.91 | 0.6230 | -0.0676 |
| 7 | 40 | UF | 2.26 | 0.7053 | -0.4864 |
| 8 | 50 | MF | 2.07 | 0.5300 | 0.0097 |
| 9 | 55 | LF | 1.94 | 0.5088 | 0.1274 |
| Profile st 3 | | | | | |
| 10 | 10 | UF | 2.65 | 0.4725 | -0.1696 |
| 11 | 20 | MF | 2.58 | 0.5704 | -0.2063 |
| 12 | 30 | | 2.43 | 0.7257 | -0.2842 |
| 13 | 35 | LF | 2.42 | 0.7334 | -0.3132 |
| Profile st 4 | | | | | |
| 14 | 10 | UF | 2.76 | 0.4487 | -0.0251 |
| 15 | 20 | MF | 2.74 | 0.4674 | -0.0104 |
| 16 | 30 | | 2.87 | 0.5528 | -0.1524 |
| 17 | 40 | LF | 2.85 | 0.6056 | -0.1843 |
| Profile st 5 | | | | | |
| 18 | 30 | UF | 2.73 | 0.5136 | -0.0999 |
| 19 | 40 | | 2.87 | 0.6385 | -0.2988 |
| 20 | 50 | MF | 2.75 | 0.7916 | -0.5091 |
| 21 | 60 | | 1.39 | 1.7332 | -0.0860 |
| 22 | 70 | LF | 1.22 | 1.3974 | 0.2796 |
| Profile st 6 | | | | | |
| 23 | 20 | UF | 2.96 | 0.4960 | -0.2717 |
| 24 | 30 | | 2.75 | 0.6885 | -0.1457 |
| 25 | 40 | MF | 2.64 | 1.1780 | -0.5367 |
| 26 | 50 | LF | 2.27 | 1.4103 | -0.4630 |
| Dune | | | | | |
| 27 | | Windward | 2.01 | 0.6314 | -0.1219 |
| 28 | | Top | 2.30 | 0.5868 | -0.2578 |
| 29 | | Leeward top | 2.37 | 0.4656 | -0.1251 |
| 30 | | Leeward middle | 2.09 | 0.5927 | -0.0980 |
| 31 | | Leeward base | 2.55 | 0.3688 | -0.1388 |

UF = Upper foreshore; MF = Middle foreshore; LF = Lower foreshore.

negatively skewed classes (0.25 to -0.54 ϕ). Coarser grain size, poorly sorted and positively skewed sediments occur at the lower foreshore or near the low-water line. The dune sands, in general, are in the fine-sand class, well to moderately sorted and symmetrical to negatively skewed.

Table 1 also shows that the sediments at st 1 in E are relatively coarse, less well sorted and positively skewed whereas those between sts 3 and 6 in W are fine-grained, better sorted and negatively skewed. The data further show a decrease in mean-grain size, improvement in sorting of foreshore sediments from E to W along tangential sections and thence towards S up to st 4 along the curved section of the beach. Contrastingly, the results show decrease in grain-size and improvement in sorting from S to N between sts 6 and 4 along this curved section near Nagwa Point, the region of finest grain size being located around st 4.

Coarse-grained sediments at sts 1 and 2 along the tangential sections are believed to have been derived from erosion of cliffs on E and partly from the rock platform at the foreshore by wave action and wave scour and subsequently get transported in the direction of predominant longshore currents. The beach between sts 1 and 2 characterised by fairly steep slope and more exposed to wave action could be very moderately reflective. Here the nearshore bottom is fairly steep (0.0327). Field observations indicated that the breaker activity was quite intense along the tangential sections of the bay characterised by 1.5 to 2m high plunging breakers. The intense breaker activity close to the beach face just at the seaward edge of the rock platform and the steep beach foreshore would give rise to strong swash-backwash. But the presence of a convex shaped rock platform at the middle and lower foreshore acts apparently as a barrier to the free movement of swash and thus reduces its speed. Similarly, the backwash speed is inhibited at the shoreward edge of the rock platform giving rise to less well sorted sediments, particularly at the lower foreshore. Positive skewness, an uncommon feature, exhibited by the foreshore sediments at st 1 could be due to the presence of coarse grained sediments as predominant mode with fines as tail in the grain size distribution.

The alongshore variation in grain size distribution mentioned earlier has been studied in relation to the probable directions of littoral currents inferred from the wave refraction patterns and the observed littoral flows. For the former purpose, the directions of wave approach have been chosen after an examination of exposure of the shoreline for different deep water wave conditions and wave refraction diagrams^{11,12} have been constructed for waves of periods 6, 8 and 10 sec

approaching from 210° and 225° following the computer programme of Mahadevan¹³. The results indicated that deepwater waves approaching the coast from 210° and 225° TN with 6, 8 and 10 sec periods show, in general, relatively higher wave heights on either sides of the Nagwa bay when compared to the central part of the bay (Figs 3 and 4). However, the refraction coefficient shows very low wave heights a little E of st 1 whose location shifts further E when the direction of deep water wave approach changes from 210° to 225° TN. The littoral flow patterns derived from the values of direction function reveal that for waves of 6, 8 and 10 sec periods approaching from 210° and 225° TN the flows in general, are directed towards W along the tangential sections and towards E on either sides of Nagwa Point giving rise to converging flows within the bay, the point of convergence shifts either side depending on wave period and direction (Figs 3 and 4). Therefore, the westerly flows might have helped in the transport of finer component of material to the west leading to the decrease in grain size along the tangential sections of Nagwa beach. Similarly, sediments must have been transported towards the east through the runnel between the Nagwa Point and the mainland and to a large extent deposited in the bay. The littoral current observations made during field studies show that the flows are directed towards W between sts 1 and 2; N at sts 5 and 6 near Nagwa Point while the flow is southerly at st 3 and weak onshore/offshore flows at st 4. This suggests the occurrence of a zone of converging current pattern between sts 3 and 5. The opposing alongshore currents find their way as rip currents. The alongshore flow and the seaward flowing rip currents in conjunction with onshore flows form circulation cells. This kind of circulation pattern within the breaker zone might have helped in transport of fine-grained sediments towards st 4 leaving behind coarse-grained sediments at sts 3 and 5. But the presence of promontory at Nagwa Point would complicate the flow pattern especially when the waves approach the shore from 240° - 270° TN. These waves may get diffracted near the promontory and diffracted wave energy may give rise to complicated cellular circulation of smaller sizes. The flows near sts 2 to 6 would be influenced to maximum extent by these diffracted waves compared to other portions of the bay. Thus the flow pattern due to refracted and diffracted waves near Nagwa Point, the local surfzone irregularities and also the marked variation in beach slopes might have aided in further dispersal of sediments along the beach giving rise to the observed grain size variations. The area particularly close to st 6 provides the required environment for developmental activities connected to coastal zone management.

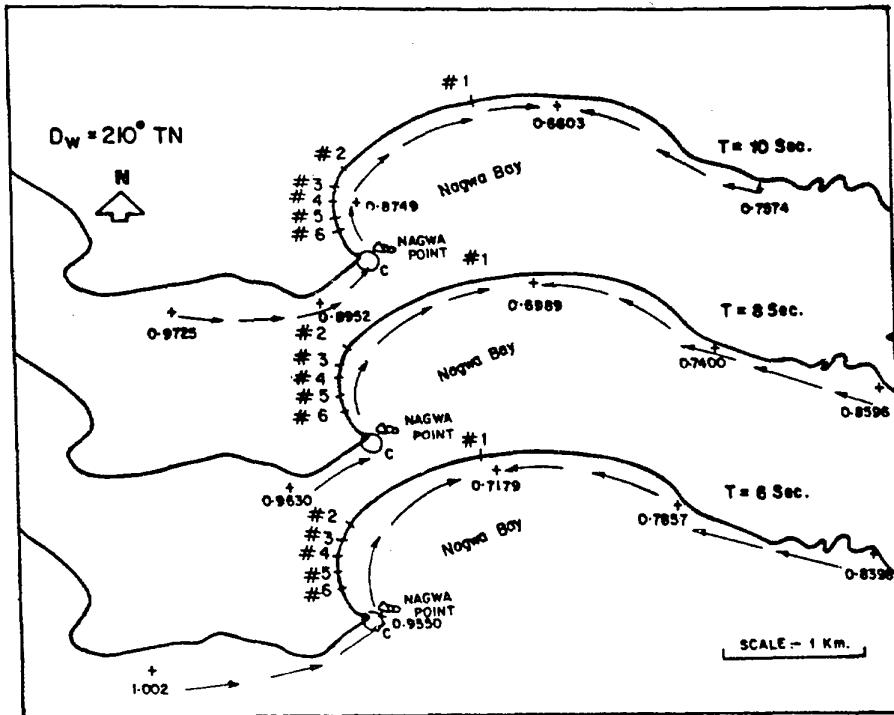


Fig. 3—Wave induced littoral flows along Nagwa beach for waves approaching from 210° TN (\rightarrow probable direction of littoral flow). The values of refraction coefficient are marked at +)

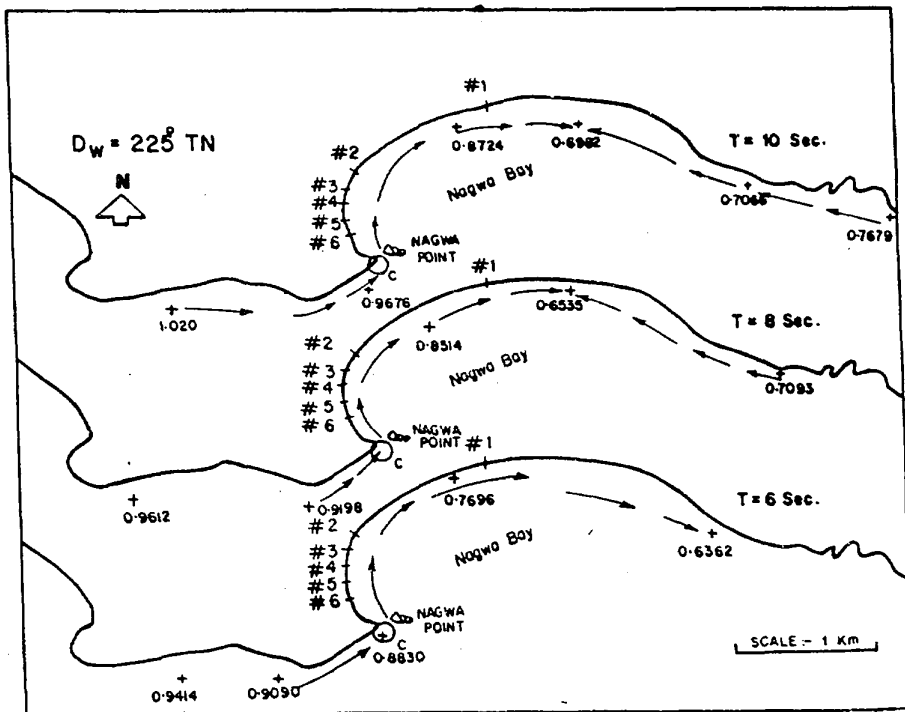


Fig. 4—Wave induced littoral flows along Nagwa beach for waves approaching from 225° TN (\rightarrow probable direction of littoral flow). The values of refraction coefficient are marked at +)

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