

Wave refraction studies off Agonda beach (Goa)

V Krishnakumar, M C Pathak & K L Kotnala
 National Institute of Oceanography, Dona Paula, Goa 403 004, India

Received 16 November 1990; revised 23 September 1991

Analysis of wave refraction and longshore current has been carried out for a narrow strip off the shores of Agonda. Zones with high wave energy and rip currents have been demarcated. It is found from the analysis that the southern part of the beach is hazardous for water sport activities.

Study of nearshore wave and current dynamics has an important role to play in solving coastal management problems and also in selection and development of beaches for recreational activities. Keeping this in view, a small stretch of beach at Agonda (15°02'N and 73°59'E) has been taken up for a feasibility study.

Agonda is a small sandy beach with clear waters for greater part of the year. Rocks (submerged at high water) are encountered in the beach zone and also in the nearshore of the southern part of the beach.

Materials and Methods

As the wave/current dynamics is primarily controlled by the bathymetry in the nearshore area, a detailed survey¹ has been carried out on the southern part of the beach (Fig. 1) up to 9 m water depth during October 1988. The survey has been limited to the southern part because lot of rock outcrops are encountered there.

Bathymetric data were collected using Atlas Deso-10 dual frequency (30 and 210 kHz) echosounder. Total area surveyed was >2000 m². Necessary corrections for the tide were made in the

bathymetric data. The accuracy in position fixing was ± 5 m and the error in depth-data was about 1%.

The water depths in the study area vary from 1 m in the inshore to 9 m nearshore at a distance of 650 m from the high water line and the area beyond 9 m depth have bottom contours almost parallel to the shore except for the southern part where they bulge slightly offshore. The beach is low and has a mild offshore gradient. The sea bed is covered with sand and broken shells in the nearshore region. Table 1 gives the bottom slopes off sts 6 and 7 from 3 directions WNW, W and WSW.

For wave refraction studies 8 stations were arbitrarily fixed (Fig. 1) approximately 400 m apart to assess the wave energy levels. A detailed wave refraction study was carried out for waves with 6 and 10 sec periods with approach-directions WNW, W and WSW, considering the climatological mean wave conditions prevailing along this coast². Bathymetric data collected by echosounding and also from hydrographic chart No. 215 (NHO, corrected up to 1983) were utilized for the study. Waves with unit heights in deep water were traced towards the shore to understand the effects of refraction, reduction/

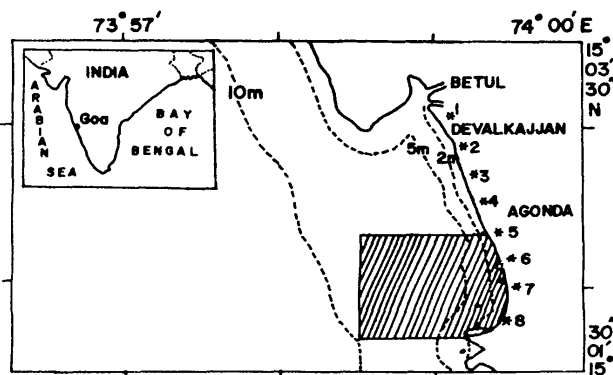


Fig. 1—Area of study showing station positions (striped area indicates bathymetric/echosounding survey)

Table 1—Bottom slopes off stations 6 and 7

	MTL—2 m	2-5 m
St 6		
WNW	0.0095	0.0126
W	0.0084	0.0138
WSW	0.0100	0.0133
St 7		
WNW	0.0104	0.0133
W	0.0101	0.0133
WSW	0.0096	0.0118

amplification in the wave heights, etc. on approaching the shore. For this purpose the numerical method of wave refraction³ was utilized and the computation was carried out using ND 520/570 computer. Wave height (h) was calculated along the ray paths using the relation $h = h_0 K_1 K_2$, where h_0 is the deep water wave height and K_1 and K_2 are refraction and shoaling coefficients respectively. A qualitative analysis of the alongshore currents and rip current arising from the asymmetric distribution of wave heights⁴ was also attempted. Probable longshore current directions deduced from wave height distribution and wave refraction diagrams are presented for waves of 6 and 10 sec periods for all 3 directions.

Results and Discussion

Index of wave refraction—Waves of 6 sec period: These waves approaching from WNW (Fig. 2) do not show appreciable refraction up to water depths of 10 m. Wave rays show divergence at sts 1-3 and 8 while convergence at sts 4 and 6. Fig. 2 also shows the refraction of waves for a nearnormal approach (W). Compared to waves from WNW these waves show very low degree of refraction not only in the deep water but also in the nearshore regions. There are zones of divergence at sts 2, 3 and 5 and concentration of energy (convergence of wave rays) at sts 4 and 6, but the extent of energy concentration is low compared to waves of oblique incidence. This can give rise to lower wave

heights (low energy levels) and one can expect the sequence of wave breaking—spilling to plunging to collapsing to surging class as the wave height decreases. The same order of breaking sequence can also be noted if wave height and beach slope are held constant and the wave period is increased or if height and period are held constant and the beach slope is increased⁵. This feature of breaking types have been reported and well documented all along the west coast of India during southwest monsoon season⁶.

Divergence is observed at sts 3-5, while convergence at sts 6 and 8 (Fig. 2) for 6 sec period waves approaching from WSW. In this case, compared to the waves from W, the degree of refraction is slightly higher.

Waves of 10 sec period: Waves from WNW with 10 sec periodicity undergo refraction and produce divergence at sts 1-3 and 8, and convergence at st 6 (Fig. 3). Thus high energy levels are expected near st 6, while comparatively low wave energy levels at all other stations. Fig. 3 also shows refracted wave rays approaching from W and WSW. Similar to waves of 6 sec period, the waves from W also distribute their energy almost evenly all along the coast except at northern and southern ends. Similarly, the waves from WSW discharge their energy like 6 sec period waves. In this case there are convergences at sts 6 and 8.

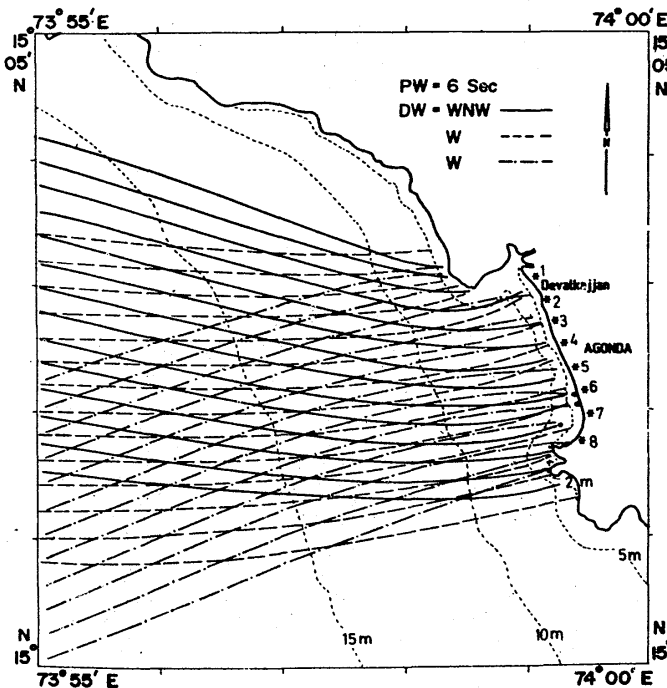


Fig. 2—Wave refraction diagram for 6 sec period waves approaching from WNW, W and WSW

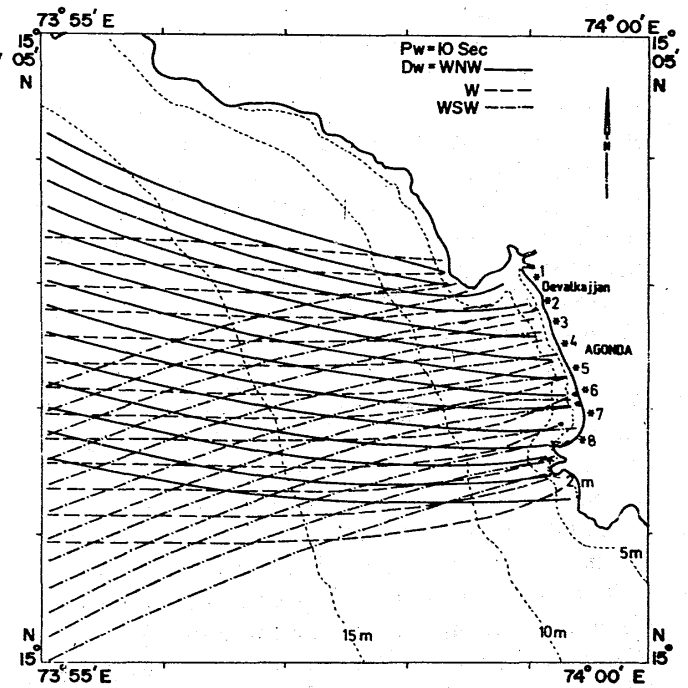


Fig. 3—Wave refraction diagram for 10 sec period waves approaching from WNW, W and WSW

In general, the pattern of refraction is nearly identical from the point of approach direction or from their periodicities except for the differences in energy levels.

Wave height distribution—High level of wave energy discharges (wave ray convergences) which in turn produce comparatively high waves are less throughout the stretch. As no abnormal energy distributions are noted for any waves along this stretch, the wave height distribution also is quite normal. Maximum amplification factor is of the order of 1.5 near st 6 for 10 sec period waves from WNW and WSW. Wherever there are convergences of wave rays wave height amplification is in the order of 1 to 1.5. For the waves from W, as it is near normal approach and the wave energy is distributed almost evenly, comparatively low amplifications in wave heights are observed all along the coast for waves of 6 and 10 sec periods. In general, comparatively low wave heights are expected along this stretch except at northern and southern ends where there are rock outcrops. Irrespective of direction and period, wave orthogonals converge near st 6 showing the possibility of formation of high waves.

Longshore and rip currents—Non-uniform distribution of wave heights resulting from varying wave energy levels along the coast gives rise to currents parallel and normal to the coast. Wherever there is a zone of divergence with convergences on either side, comparatively low wave heights occur which in turn give rise to longshore currents directed towards the divergence zone. This piling up of water from either side may cause the water to flow into the sea, to keep equilibrium, in the form of rip currents. The probable flow directions along this coast for 6 and 10 sec period waves from WNW, W and WSW, which are deduced from wave refraction diagrams and wave height distribution are presented in Fig. 4.

Waves with 6 sec period from all 3 directions show the existence of a quasi-permanent zone of rip current (shown by arrows pointing towards the sea in Fig. 4) near st 8. A boulder surfaces near the zone of rip current. Rip currents are also noted at sts 2 and 5 for waves from WNW and W and near st 3 for WSW waves. For 10 sec period waves rip currents occur near sts 2 and 7 for waves from WNW, near st 8 for waves from W and near sts 1, 6 and 7 for waves from WSW.

The general nearshore flow in this area does not show a steady trend considering either period or direction of the wave. Because of the rocks near st 6, a high wave-energy zone may be permanently present there producing flows to either side where comparatively low wave heights occur. At the southern

tip, again the rocky cliff may drive a flow towards north. These two are almost permanent 'feeder currents' for the quasi-permanent rip current encountered near st 8. As these nearshore currents are strongly dependent on the bottom topography of the area, the existing nearshore flow pattern also is highly vulnerable to the existing bathymetric features (Fig. 4). The ridges and channels in the nearshore bathymetry would be the places where high magnitudes of onshore and offshore flows respectively can occur⁷⁻⁹.

The massive rock outcrop in the offshore reaches of st 8 makes the waves collapse through breaking or may cause caustics. After breaking, the energy released here favours the formation of secondary wavelets proceeding further to dissipate the energy by way of multiple breaking. The zones of rip currents may exhibit migratory tendency (up and down the beachface) and so is the divergence/convergence zone

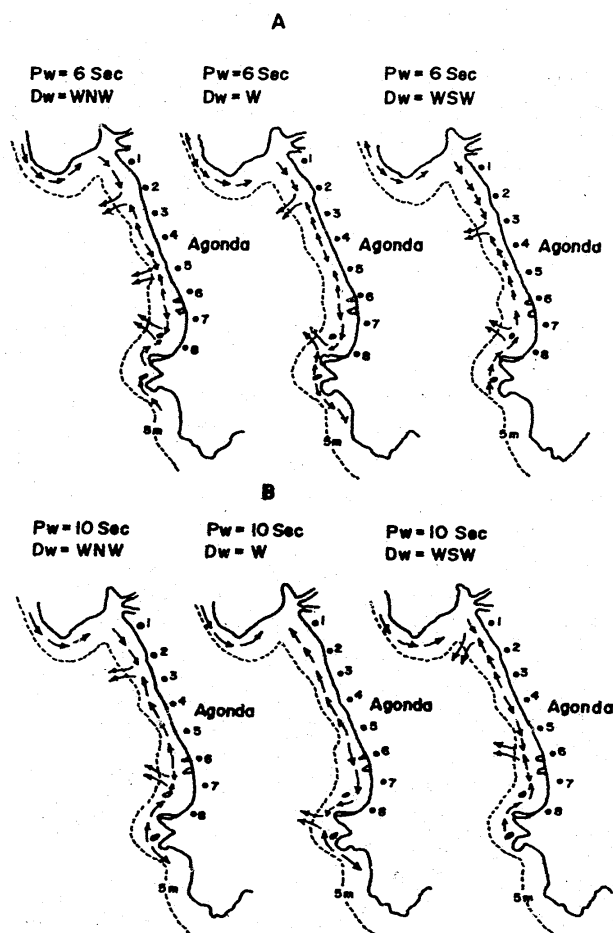


Fig. 4—Probable longshore current directions for waves approaching from WNW, W and WSW for (A) 6 sec, (B) 10 sec period waves (rip currents are shown by arrows pointing towards the sea)

of wave energy, with the change in the water level due to tides. For a quantitative analysis of alongshore and rip currents, model studies of nearshore circulation^{7,9} and more field observations are necessary.

The factors mentioned above suggest that flood tide will be more suitable for water sports in this area and swimming, etc. should not be encouraged near sts 7 and 8 as there are quasi-permanent rip current zones. During rough weather the intensity of these currents coupled with increased levels of suspended loads may attain dangerous levels.

Acknowledgement

The authors are thankful to Dr B N Desai, Director, for facilities provided. The help given by Drs R Sengupta and C S Murty and other colleagues during the study is gratefully acknowledged. M/s Sima Hotels and Resorts Ltd provided the necessary baseline facilities at the site and funding for the investigation.

References

- 1 Anonymous, *Survey of the neashore regions off Agonda beach to judge suitability for water sports*, Proj Report (National Institute of Oceanography, Goa, India), 1989, pp. 15.
- 2 Anonymous, *Wave (swell) atlas for Arabian Sea and Bay of Bengal* (National Institute of Oceanography, Goa, India), 1982, pp. 175.
- 3 Mahadevan R, *Numerical calculation of wave refraction*, Tech Rep No 2/83 (National Institute of Oceanography, Goa, India), 1983, pp. 28.
- 4 Longuet-Higgins M S, in *Waves on beaches and resulting sediment transport*, edited by R E Meyer, (Academic Press, London), 1972, 203.
- 5 Galvin CJ, in *Waves on beaches and resulting sediment transport*, edited by R E Meyer, (Academic Press, London), 1972, 413.
- 6 Murty C S, Veerayya M & Varadachari V V R, *Indian J Mar Sci*, 11 (1982) 35.
- 7 Krishnakumar V, *Nearshore circulation at some selected places of the coast of Goa*, M.Sc. thesis, Bombay University, 1987.
- 8 Krishnakumar V, Murty C S, Shenoi S C & Heblekar A K, *Indian J Mar Sci*, 18 (1989) 184.
- 9 Krishnakumar V, Murty C S & Heblekar A K, *Proc Indian Acad Sci (Earth Planet Sci)*, 98 (1989) 265.