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Nearshore Processes along Tikkavanipalem Beach, Visakhapatnam, India

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ABSTRACT

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Directional wave data collected at 12 m water depth, at 1 km distance off Tikkavanipalem from December 1997 to November 1998, was used to estimate the longshore currents and longshore sediment transport rate considering the sea and swell waves separately using the CERC formula. Daily littoral environmental parameters were observed at 3 stations and longshore sediment transport rate was estimated using the Walton's equation. A comparative study was carried out on theoretical and measured longshore currents. The ratio of spectral energy at first and second spectral peaks show that the energy at second peak was more than fifty percent of the energy at first peak in 35% of the data collected. The longshore current speed computed based on Longuet-Higgin's equation was about 25% more than the measured and that based on Galvin's equation was about 22% more than measured. The difference between the gross sediment transport rate estimated based on the two method is around 6%. The sediment transport using Walton's equation shows that average annual gross transport was 0.371×10^6 m^3 and the average annual net transport (towards northeast) was 0.173×10^6 m^3.

ADDITIONAL INDEX WORDS: *Littoral drift, Indian coast, littoral environmental parameters, Longshore currents, Longshore sediment transport.*

INTRODUCTION

The objective of the study was to estimate longshore current and sediment transport from measured as well as from littoral environmental observations and to assess the longshore transport along the study area. Accurate estimates of wave height and wave direction at the breaker line are required in order to predict the longshore currents and sediment transport. Wave angle just before breaking is an important parameter in the nearshore zone. Proper understanding of the seasonal littoral transport trend is important for the efficient management and development of the coast.

Tikkavanipalem beach along east coast of India is 30 km south of Visakhapatnam Harbour in Andhra Pradesh (Figure 1). The beach is free from intertidal and mud flats or coral reefs. There are small creeks like Mutyalammapalem creek which discharges fresh water during monsoon periods. Rock outcrops exist in the nearshore region at 1 km distance southwest and 5 km northeast of this study region. The average orientation of the coast along this region is 72° with respect to north and is straight. The coastline consists of long sandy beaches with high dunes. The coastal region is comprised of small hillocks and plains. The plains are used for agricultural purpose. The cyclonic storms in this region generally occur in association with heavy rains and rough seas.

Oceanographic properties of the nearshore waters along this region are subjected to seasonal variability with the reversing southwest (June to September) and northeast monsoons (October to January). The tides in this region are semi-diurnal. As reported in Indian Tide Table for Visakhapatnam, the mean spring tidal range is 1.43 m and the neap tidal range is 0.54 m. The wind table for Visakhapatnam is compiled based on 30 years observations from 1931 to 1960 from the Climatic Tables shows that afternoon and evening winds are stronger than the forenoon winds. The mean forenoon wind speed varies between 3.7 and 9.3 km/hr and the mean afternoon and evening wind speed varies between 7.5 and 11.1 km/hr. The stronger winds observed during evenings and monsoon months, would influence the sea surface currents. From February to June, the winds are predominantly from S and SW and from July to September, it is from SW and W. From October to January the winds are predominantly from NE and E. The wave climate of this region is dominated by southwest monsoon, northeast monsoon and fair weather period (February to May).

The pattern of longshore sediment transport in this region has not yet been investigated in detail due to non availability of measured wave data and longshore currents. Earlier works were based on the visual observations and deep water ship observed wave data (Chandramohan *et al.* 1988; Sarma and Reddy, 1988; Sunder and Raju, 1997).

In the present study, to obtain directional wave data, a Datawell directional wave rider buoy was deployed at 12 m water depth, at 1 km distance off Tikkavanipalem (Figure 1) and data on significant wave height (H_S), zero crossing wave period (T_Z) and wave direction were recorded for 20 minutes duration, at every 3 hour intervals for a period of one year (from December 1997 to November 1998). Measured waves

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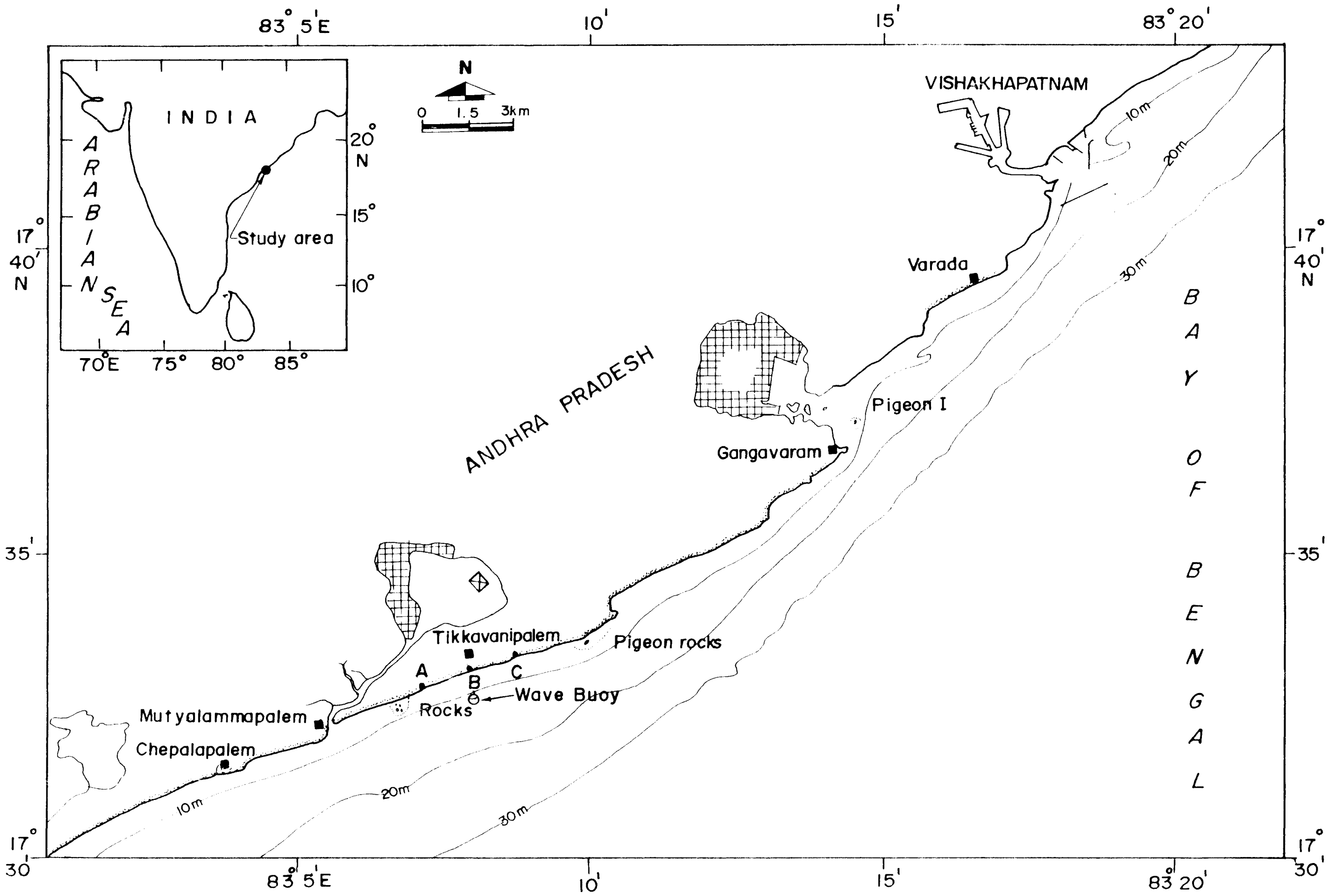

Figure 1. Study area.

were used to estimate the longshore currents and longshore sediment transport rate. Daily littoral environmental parameters (SCHNEIDER, 1981) were observed at Tikkavanipalem beach at 3 stations and the longshore sediment transport was estimated. A comparative study was carried out on theoretical and measured longshore currents.

METHODS AND ANALYSIS

Waves

Based on the measured wave data, significant wave height (H_s), zero crossing wave period (T_z) and first wave direction (with respect to north) corresponding to the peak of the spectrum (maximum spectral energy) and second wave direction corresponding to the secondary peak were estimated. This has become necessary because the wave spectra at this location is mainly double-peaked with contribution from seas and swells. The sea and swell waves were separated as follows. A cut frequency was determined between the two peak frequencies where the spectral energy was minimum and the wave spectrum was divided into two parts. Then the wave height, wave period and direction of the both wave fields, seas and swells were calculated for each record based on the spectral method. It is to be noted that in many cases the wave direction is considered as the direction corresponding to the maximum spectral energy (KUIK *et al.*, 1988).

Breaking Wave Characteristics

The wave height and direction of the sea and swell waves measured at 12 m water depth were reduced to wave breaking zone (SKOVGAARD *et al.*, 1975; WEISHAR and BYRNE, 1978). The wave shoaling coefficients were estimated using small amplitude wave theory. As the contours are straight and parallel, the wave directions measured at 12 m water depth were corrected to refraction effects using Snell's law and the breaker angles of sea and swell waves were calculated separately assuming no wave-wave interaction. Hence in the present study two breaker heights and breaker angles corresponding to the sea and swell waves were estimated.

Surf Zone Characteristics

Daily visual observation on breaking wave height, wave period and surf zone width were carried out at 3 stations (*i.e.*, A, B, C) along Tikkavanipalem beach during December 1997 to November 1998 (SCHNEIDER, 1981). The distance between the stations was 1500 m. The parameters were observed from the coast while standing close to waterline. Also magnitude and direction of the longshore currents were measured daily at these stations using Rhodamine-B dye in the surf zone approximately at 1/3rd of the surf zone width distance from the shoreline. The distance covered in 2 minutes was measured and the average longshore current was estimated.

Theoretical Longshore Currents

Two commonly used equations to estimate the longshore current are:

$$V_G = KgmT \sin 2\alpha_b \quad \text{(GALVIN, 1963) and} \qquad (1)$$

$$V_{LH} = 20.7m(gH_b)^{1/2}\sin 2\alpha_b \quad \text{(LONGUET-HIGGINS, 1970)} \qquad (2)$$

where, V_G and V_{LH} are the mean longshore current velocities in the surf zone in m/s, K is a dimensionless coefficient depending solely on the geometry of the breaking wave which is taken as 1 (GALVIN, 1987), g is acceleration due to gravity in m/s^2, m is the foreshore slope, T is the wave period in s, H_b is the breaking wave height in m and α_b is the breaker angle (angle between the breaking wave crest and the shoreline). The longshore currents were estimated for the sea and swell waves separately and the resultant was estimated as the vectorial sum of both.

Longshore Sediment Transport

The longshore sediment transport rate is usually estimated from an empirical equation relating the longshore energy flux in the breaker zone to the longshore transport rate (KOMAR and INMAN, 1970). CHANDRAMOHAN (1988) discussed the suitability of the Coastal Engineering Research Center (CERC) formula (SHORE PROTECTION MANUAL, 1984) for estimating the longshore sediment transport rate for the Indian coast. The computed breaker parameters of sea and swell waves based on the measured wave data were used for estimating the longshore sediment transport using CERC formula. The CERC formulation assumes all of the energy is associated with a single peak in the wave spectra. MILLER (1999) by comparison of the longshore sediment transport rate computed by energy flux method using the CERC formula based on spectral peak wave parameters at breaking and that measured found that predicted values compared reasonably well except when the sea and swell directions are different and suggested to include other terms to account for the directional distribution of energy within the wave spectrum alongwith other parameters. In the present case the wave spectrum were double peaked. Hence the wave characteristics of sea and swell waves were considered separately for estimating the longshore sediment transport rate.

The daily observed littoral environmental parameters were used to estimate the longshore sediment transport using Walton's equation (WALTON and BRUNO, 1989). Here the main parameters used were observed breaker height, surf zone width and the measured longshore current speed. The friction coefficient was taken as 0.01 and the theoretical dimensionless longshore current velocity was estimated as per LONGUET-HIGGINS (1970).

RESULTS AND DISCUSSION

Measured Waves

Based on the analysis of the wave records, it shows that the wave heights were relatively high during May to November. The highest significant wave height of 1.91 m observed in November 1998 before the passage of a cyclonic storm very close to the study region during the study period. The waves were separated into sea and swell components and the variation of significant wave height (Hs) is shown in Figure 2(A). The Hs of sea waves varied from 0.2 to 1.7 m with an average value of 0.7 m. The Hs of swell waves varied from 0.1 to 1.8 m with an average value of 0.6 m. The measured wave direction at 12 m water depth of the sea waves varied from 92° to 213° with an average value of 162° and that of the swell waves varied from 104° to 201° with an average value of 159° and is shown in Figure 2(B). The estimated breaker angle corresponding to the wave direction of sea and swells are shown in Figure 3(A). The breaker angle for the waves approaching the coast from southwesterly are considered as negative and that for waves approaching the coast from northeasterly are considered as positive. The average value of the breaker angle for the sea waves was −0.7° and that for the swells was 0.9°. The figure shows that breaking sea waves were mainly from southwesterly direction during March to October and the breaking swell waves were mainly from northeasterly. SUNDER and RAJU (1997), found that the breaker angle was highest during the southwest monsoon period and a maximum of 12°5′ was observed for the Visakhapatnam coast. The present study shows that the breaker angle of sea waves varied from +20° during the northeast monsoon period to −20° during the southwest monsoon period and that of swell waves varied from −10° to 16°. The ratio of spectral energy at first and second spectral peaks estimated shows that the energy at second peak is more than 50% of the energy at first peak in 35% of the data collected.

Surf Zone Characteristics

The variation of zero crossing wave period (T_z) visually observed and computed for sea and swell waves from measured wave data are shown in Figure 3(B). The average zero crossing wave period of the sea waves was around 4 s and that of swells was around 12 s. The average value of the visually observed wave period was also 12 s. The figure shows that the difference between observed wave period and that of the swell component are less. Also it shows that in the visual observation there is a possibility of neglecting the sea waves.

The width of the surf zone was more (>30 m) during April to November and it was relatively narrow (<30 m) during rest of the year (Figure 3(C)). The average surf zone width was 38 m with a standard deviation of 11.4 m, indicating a broad distribution. The daily variation of breaking significant wave height (H_b) estimated and observed at 3 stations A, B and C are shown in Figure 4. The computed breaker height of the sea waves varied from 0.3 to 2.1 m with an average

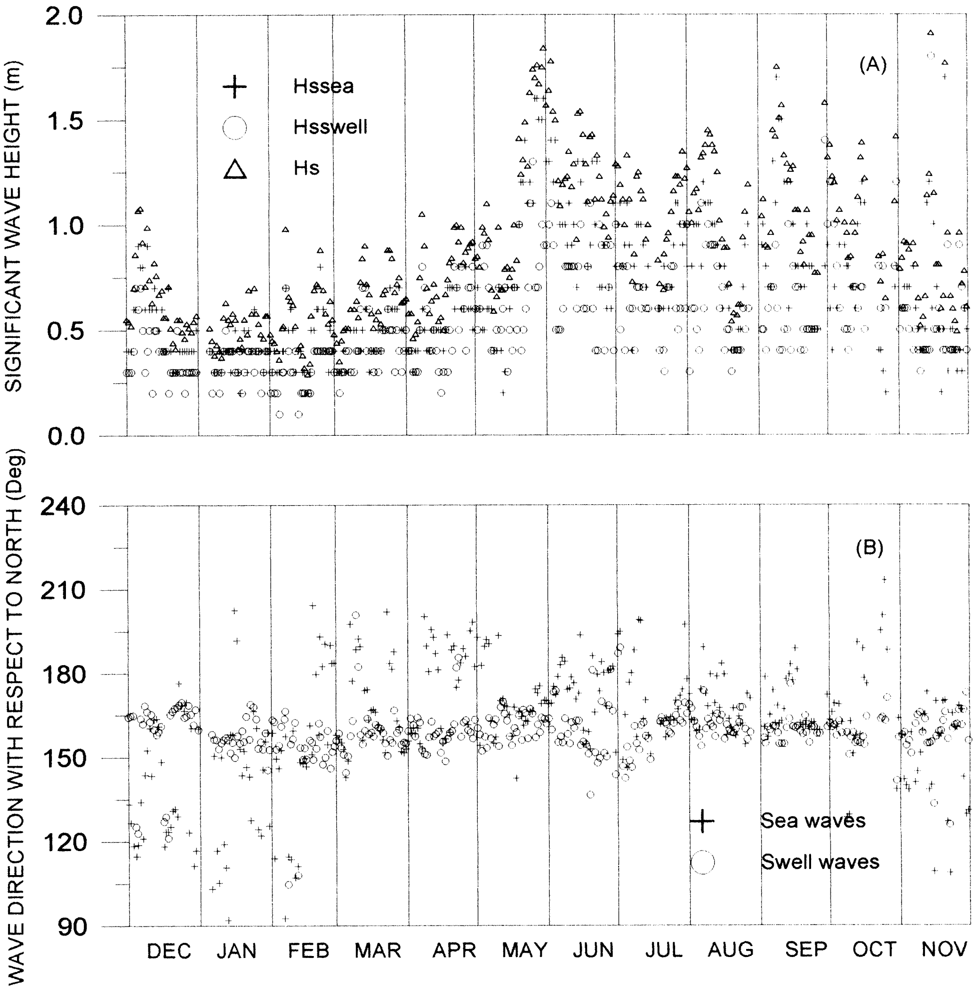

Figure 2. Variation of (A) measured significant wave height and (B) wave direction of sea and swell waves.

value of 0.8 m and that of the swell waves varied from 0.3 to 2.3 m with an average value of 1 m. The observed breaker height varied from 0.2 to 2 m with an average value of 0.9 m. The data shows that the visually observed wave height was the combination of sea and swell waves and was 70% of the computed data with a correlation coefficient of around 0.7.

Longshore Currents

The daily variation of longshore current estimated based on Longuet-Higgins equation (V_{LH}) and Galvin's equation (V_G) with the measured current at 3 stations are shown in Figure 5. It shows that the average longshore current speed was 0.3 m/s at all stations and it was predominantly towards northeast during February to September and towards southwest during October to January. Strong longshore currents (>0.5 m/s) were observed in June, July and September. Longshore current was relatively weaker (<0.5 m/s) during rest of the year.

The comparison of the measured and computed longshore current speed shows that longshore current estimated based on Galvin was 22% more than the measured one and that based on Longuet-Higgin's was 25% more than the measured one. The average correlation coefficient between measured and computed was around 0.52. BROCCHINI (1997) found that the maximum mean longshore velocity in the surf zone and at the breaking point computed based on their proposed model compare favourably with that estimated based on Longuet-Higgin's with about 15% discrepancy in magnitude.

Based on the 5 year average of the monthly averaged longshore currents, SUNDER and RAJU (1997) found the longshore current at Visakhapatnam was towards north during February to September with a maximum speed of 1 m/s and towards south during November and December with a maximum speed of 0.5 m/s. Based on visually observed breaker parameters and measured longshore currents for an year at Visakhapatnam, CHANDRAMOHAN and NARASIMHA RAO (1984) found that longshore currents estimated using Longuet-Higgins equation was slightly lower and Galvin's equation was higher than the measured currents.

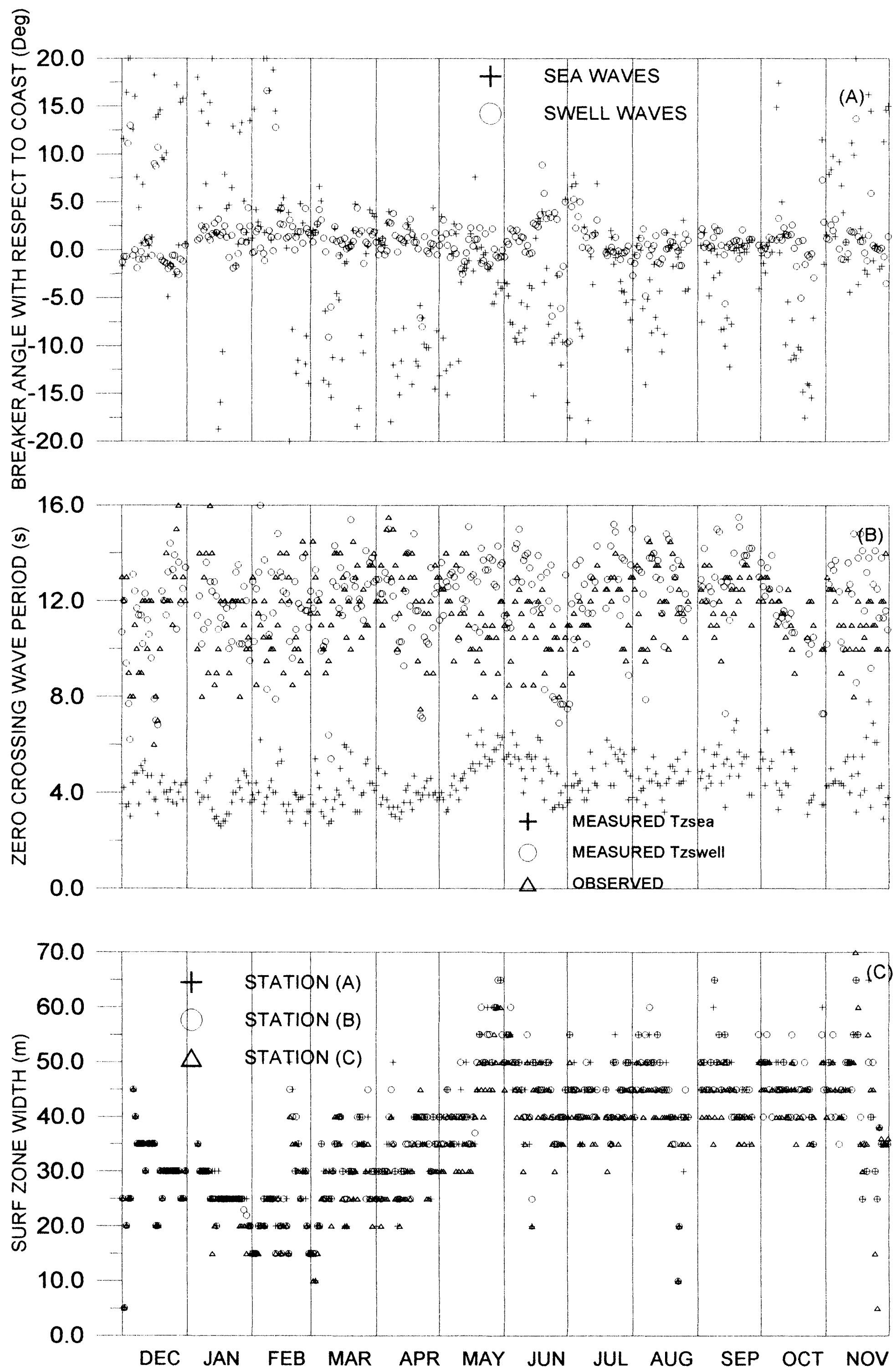

Figure 3. Variation of (A) breaker angle of sea and swell waves (B) observed and measured zero crossing period of sea and swell waves (C) surf zone width.

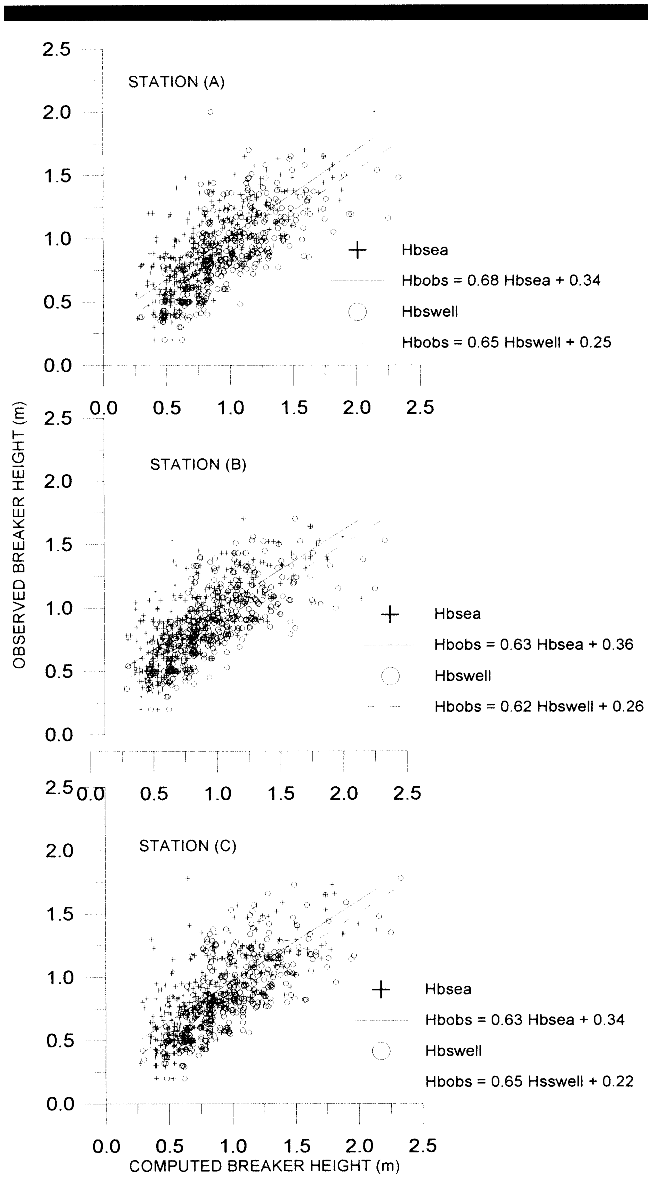

Figure 4. Comparison of observed and computed significant breaker wave height for 3 stations.

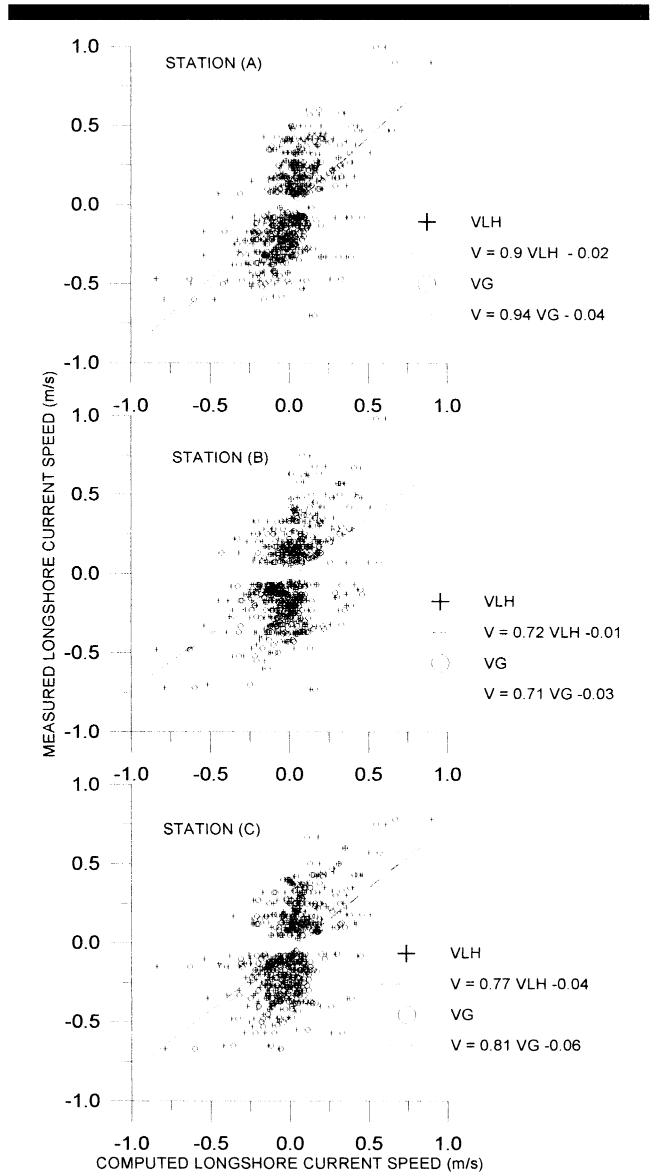

Figure 5. Comparison of longshore current velocity computed based on Longuet-Higgins and based on Galvin with measured for 3 stations.

Longshore Sediment Transport

The average coastal orientation of this coast is N72°E (*i.e.,* 72° clockwise to North). The 3-hourly measured wave characteristics reduced to breaker zone were used and the estimated monthly transport is presented in Table 1. Sediment transport estimated based on sea and swell waves and the resultant are shown in the Table. It shows the annual longshore sediment transport was 0.188×10^6 m^3 in the northeasterly direction (April to October) and 0.163×10^6 m^3 in the southwesterly direction (November to March). The annual net sediment transport was 0.025×10^6 m^3 in the northeasterly direction and annual gross sediment transport was 0.351×10^6 m^3.

Even though the CERC formula works well without considering the size of the sand (NIELSEN, 1992), a weak grain size dependence was confirmed by KAMPHUIUS (1990) who based on dimensional analysis related sediment transport with root mean square value of breaker height, beach slope at break point, deep water wave length corresponding to the peak wave period and median size of sediment. BRUUN (1997) found large variations in grain size of beach materials (sand to gravel and cobble stones) may cause deviating results in estimation of longshore sediment transport rate and if grain sizes are limited to fine and medium sand (0.15 to 0.4 mm) the difference will be small.

In the present study median size (d_{50}) of the beach sediment shows that the entire study region mainly consists of very fine to fine sand. The average median size was around

Table 1. *Estimated longshore sediment transport rate in m^3 based on measured wave data.*

Month	Based on sea waves			Based on swell waves			Resultant		
	NE	SW	Net*	NE	SW	Net*	NE	SW	Net*
Dec 97	247	31697	31450	4453	7447	2994	1067	35512	34445
Jan 98	1080	18236	17156	547	5134	4587	458	22201	21743
Feb 98	8709	11937	3228	204	6787	6582	5885	15695	9810
Mar 98	11785	2808	−8977	945	9876	8931	8081	8035	−46
Apr 98	17842	263	−17579	5837	9800	3962	18335	4719	−13616
May 98	41122	2377	−38744	8964	14417	5453	42653	9361	−33292
Jun 98	67914	2027	−65887	8645	22081	13435	65358	12906	−52452
Jul 98	43220	2301	−40919	12355	15449	3093	50345	12519	−37825
Aug 98	34469	916	−33554	8051	6167	−1884	37377	1939	−35438
Sep 98	28322	8818	−19504	6533	12395	5862	29526	15885	−13641
Oct 98	28985	11499	−17486	5935	21418	15483	30922	28919	−2003
Nov 98	3805	42525	38720	2313	60272	57959	4715	101394	96679
Annual net transport		-0.152095×10^6			0.126459×10^6			-0.025636×10^6	
Annual gross transport		0.333204×10^6			0.130228×10^6			0.350990×10^6	

* (−) northeasterly transport (NE), (+) southwesterly transport (SW)

0.35 mm during the high wave activity *i.e.*, in June, November and December. It was less than 0.25 mm during the remaining period. This observation is similar to the conclusion made by BRUUN (1954) that the particle size is large in coasts subjected to severe wave action and small on weak wave action.

The total longshore sediment transport rate in the surf zone was measured by WANG and KRAUS (1999) at a temporary groin installed at Indian Rocks Beach, west central Florida and concluded that constant K appearing in the CERC formula is not a constant and other factors may enter, such as breaker type, turbulence intensity and threshold for sediment transport. WANG *et al.* (1998) measured the total sediment transport rates by the streamer traps and short-term impoundment along the low-wave energy coasts and found that the rates measured are lower than that predicted by the various empirical formula. Using the root mean square wave height in the CERC formula, the empirical constant value was found to be 0.08 instead of 0.78 recommended in the Shore Protection Manual. In the present study K was taken as 0.39.

The average longshore current measured in the surf zone was used to estimate the sediment transport using Walton's equation and is presented in Tables 2 to 4 for stations A to C. At station A, it was found that the annual longshore sediment transport was 0.291×10^6 m^3 in the northeasterly direction (February to September) and 0.114×10^6 m^3 in the southwesterly direction (October to January). The annual net sediment transport was 0.177×10^6 m^3 in the northeasterly direction and annual gross sediment transport was 0.405×10^6 m^3. At station B, it was found that the annual longshore sediment transport was 0.252×10^6 m^3 in the northeasterly direction (February to August and October) and 0.101×10^6 m^3 in the southwesterly direction (September, November to January). The annual net sediment transport was 0.151×10^6 m^3 in the northeasterly direction and annual gross sediment transport was 0.353×10^6 m^3. At station C, it was found that the annual longshore sediment transport was 0.273×10^6 m^3 in the northeasterly direction (January to October) and 0.081×10^6 m^3 in the southwesterly direction (November to December). The annual net sediment transport was 0.192×10^6 m^3 in northeasterly direction and annual gross sediment transport was 0.354×10^6 m^3.

The distance between the stations are 1500 m. The net sediment transport estimated shows that the net movement is

Table 2. *Estimated longshore sediment transport rate in m^3 at station A.*

Month	Northeasterly	Southwesterly	Monthly Net
December 1997	0	32689	32689
January 1998	6747	9951	3204
February 1998	9886	7298	−2588
March 1998	16447	4052	−12396
April 1998	28999	3974	−25025
May 1998	49134	10594	−38540
June 1998	65184	5615	−59569
July 1998	89339	7439	−81900
August 1998	52169	4964	−47205
September 1998	44973	20765	−24208
October 1998	25463	29951	4488
November 1998	4106	77383	73277

Annual net sediment transport = -0.177×10^6 m^3
Annual gross sediment transport = 0.405×10^6 m^3

Table 3. *Estimated longshore sediment transport rate in m^3 at station B.*

Month	Northeasterly	Southwesterly	Monthly Net
December 1997	390	33346	32956
January 1998	4284	10686	6402
February 1998	9112	8160	−952
March 1998	15134	5076	−10058
April 1998	26791	1576	−25214
May 1998	46491	15152	−31339
June 1998	58053	13326	−44726
July 1998	91874	2025	−89849
August 1998	51381	1981	−49400
September 1998	26975	32219	5244
October 1998	24778	23967	−811
November 1998	7715	63698	55983

Annual net sediment transport = -0.151×10^6 m^3
Annual gross sediment transport = 0.353×10^6 m^3
The negative sign indicates northeasterly sediment transport

Table 4. *Estimated longshore sediment transport rate in m^3 at station C.*

Month	Northeasterly	Southwesterly	Monthly Net
December 1997	216	29557	29341
January 1998	6465	6435	−30
February 1998	11254	6819	−4435
March 1998	19440	5100	−14340
April 1998	26431	2589	−23842
May 1998	52696	7671	−45026
June 1998	56225	10672	−45552
July 1998	50796	6286	−44510
August 1998	48552	2390	−46163
September 1998	51425	3736	−47689
October 1998	24922	22850	−2072
November 1998	8872	60462	51591

Annual net sediment transport = -0.192×10^6 m^3
Annual gross sediment transport = 0.354×10^6 m^3
The negative sign indicates northeasterly sediment transport

towards northeast. At station A, the net sediment transport is 0.177×10^6 m^3 and at B it is 0.151×10^6 m^3. Hence from A to B there is a loss of 26,000 m^3 material in the littoral transport system. The beach profile studies carried out up to 1 m below the low tide level (NIO, 1999) shows that at station A, there is a net deposition of 11.1 m^3/m width of the beach in an annual cycle, which shows that part of the sediments in the littoral transport system gets deposited at A. From station B to C there is an increase of 41,000 m^3 in the net transport rate. The beach profile study shows that at station B and C, a net erosion of 15.22 and 38.35 m^3/m width of the beach were found in the annual cycle. Hence the increase in the transport rate is due to the erosion at station B and C. Part of the change in the transport rate may be due to the onshore-offshore transport of the materials and which is not studied in this case.

The study shows that the average annual net sediment transport was 0.173×10^6 m^3 in the northeasterly direction and average annual gross sediment transport was 0.371×10^6 m^3. The net sediment transport is towards northeast since the wave direction is in that direction during majority of the period (8 months).

The annual net sediment transport computed using the estimated breaker angle gives a low value of 0.025×10^6 m^3 and the difference between the estimated gross transport rate based on two methods is around 6%. This is due to the error in estimation of the surf zone width or due to the error in the estimation of breaking wave characteristics. Since the gross transport estimated based on surf zone width is comparing well with that estimated based on CERC formula, the error in the estimation of surf zone width will be low and the large difference in net transport is due to the error in estimation of the breaker angle. The coastal inclination of the study area is 72° with respect to north. The wave direction more than 162° will cause a northeasterly sediment transport and less than 162° will cause a southwesterly transport. The average direction of sea waves was 162° and that of the swell waves was 159°. Hence a small error of the order of 0.5° in the estimate of the breaker angle may cause a change in direction of the sediment transport rate. ALLEXANDER and KIT (1999) also found that the error in wave directions can lead even to a wrong direction for the net calculated sediment transport. Hence the sediment transport rates estimated using Walton's equation can be taken as the representative value for this coast.

Limitations in the present study are:

1. The wave data sets are limited in time, only one year data is used.
2. The computations are valid for long and straight sandy beaches only.
3. The value of surf zone width used in the Walton's equation is estimated based on visual observation.
4. The wave-wave and the wave-current interaction in the surf zone is not considered.

Other Studies along Nearby Areas

Based on the ship reported deep water wave data and using the shore protection manual equation, CHANDRAMOHAN *et al.* (1988) found that the coastline having 80° east of north would experience large movements of sediments with a net volume of 1.09×10^6 m^3 and a gross volume of 1.52×10^6 m^3 in a year. Also the estimated longshore sediment transport for Visakhapatnam which is 30 km north of the study region was 0.323×10^6 m^3/year towards the southwest and it was 0.851×10^6 m^3/year towards the northeast. SAXENA *et al.* (1976) reported northeasterly transport of 0.88×10^6 m^3 and a southwesterly transport of 0.18×10^6 m^3 in a year at Visakhapatnam. SARMA and REDDY (1988) based on the monthly average of the visually observed daily breaker height and breaker angle found that along the Visakhapatnam, a northerly littoral drift of 0.822×10^6 m^3/year and southerly littoral drift of 0.278×10^6 m^3/year with a net sand movement of 0.54×10^6 m^3/year towards north.

Based on the 5 year average of the monthly mean sediment transport, SUNDER and RAJU (1997) found that northerly drift was predominant during southwest monsoon with a maximum value of 0.2×10^6 m^3 in June and southerly drift during the northeast monsoon with a maximum value of 0.12×10^6 m^3 in November. Visakhapatnam port dredge 0.66×10^6 m^3 sand from the approach channel during SW monsoon which is the mean annual northerly littoral drift.

CONCLUSIONS

The measured wave data shows that highest significant wave height of 1.9 m observed in November 1998 when a cyclonic storm crossed the coast very close to the study region. The ratio of spectral energy at first and second spectral peak shows that energy at second peak was more than 50% of energy at first peak in 35% of the data collected. So it is important to consider the characteristics of both the sea and swell waves for this location. The daily longshore currents measured at Tikkavanipalem beach shows that the average longshore current speed was 0.3 m/s and the longshore current was predominantly towards northeast during February to September and it was towards southwest during October to January. The longshore current speed computed based on Longuet-Higgins was about 25% more than the measured speed. The current speed computed based on Galvin was 22%

more than the measured. The sediment transport estimated based on Walton's equation can be considered more realistic for this coast. The sediment transport using Walton's equation shows that average annual gross transport was 0.371×10^6 m^3/year and the average annual net transport was 0.173×10^6 m^3/year (towards northeast).

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