Studies on the dynamic response of coastal sediments due to natural and manmade activities for the Puducherry coast

G. Vijayakumar1*, C. Rajasekaran2, T. Sundararajan1 & D. Govindarajalu1

1Dept. of Civil Engineering, Pondicherry Engineering College, Puducherry, INDIA
2Dept. of Civil Engineering, National Institute of Technology Karnataka, Surathkal, INDIA

*Email: gvk@pec.edu

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This paper presents the response of the coastal sediments by the impact of waves and construction of manmade structures in the Puducherry coastal stretch, East coast of India. Based on the real time wave climate data which was collected from the nearshore region of coast using wave rider buoy and wave direction indicator. The quantum of sediment movement is calculated using CERC formula for three years (2007, 2008, and 2009) and compared with Kamphuis method for one year i.e., 2009. In order to achieve a more reliable value on the sediment movement a sand trap was used at the littoral zone to collect the actual sediment samples for a period of two months i.e., February and March 2009. For all the three observation period the predominant sediment transport rate is Northerly. Estimated sediment transport rates were also determined by Kamphuis method. From the results obtained, CERC formula ‘over predicts’ the sediment transport rate when compared with Kamphuis method. The actual sediment transport calculated using sand trap was found to be 60% reliable when compared with theoretical sediment transport rate which has been determined by using Kamphuis method.

Keywords: Coastal sediments, Wave climate, CERC method, Sediment transport, Breakwater

Introduction

Coastal zone is the most dynamic zone since it experiences by erosion, accretion and sea level rise etc. One of the main factors that govern the beach erosion is the long shore sediment transport1–4, which is mainly controlled by wave characteristics and near shore topography5,6. Waves propagating from deep sea into the near shore expend their energy causing lifting of sediments, generating long-shore currents and producing littoral sediment transport7. Onshore-Offshore transport is initiated by the high and short period waves resulting from a storm removing the sand from the beach and transporting it into the sea to form offshore sandbar8. Long-shore sediment transport is more dominant than onshore – offshore transport and of greater significance to coastal engineers who are interested in annual changes rather than seasonal variation9. Due to some obliquity of the crests of the breaking waves with the shoreline, there is a net component of momentum and energy in the direction along the beach. This causes a net alongshore transport of beach sand. Littoral drift (i.e., along-shore transport) rates and distribution are functions of wave and beach parameters10. These littoral currents also get influenced by beach forms, and rip currents.

From the earlier studies, the longshore sediment transport is dominant in the east coast of India. The net transport varies all along the coastal stretch because of the natural and manmade activities. The estimation of the sediment transport rate in the Puducherry coast has been carried. A specially fabricated sand trap has been employed in the measurement of the sediment transport. Two prominent methods of estimating the sediment transport has been taken for the present study in order to observe the response of the sediment transport.

Materials and Methods

The union territory of Puducherry is located on the East Coast of South India facing Bay of Bengal at Latitude of 11°56’N and Longitude of 79°50’E. Due to its geographical location along the Bay of Bengal, which is cyclone prone, it experiences an average of 2 to 3 cyclones annually. From the observation of wave climate data it was found that severe wave climate exists only for less than 1% of a year, but the coast experiences the problem due to erosion for a stretch of nearly 6 km. After construction of the Puducherry fishing harbour and the breakwaters in the Southern part of the Puducherry city, the coastal erosion on the
Northern side has increased significantly and the entire beach area of Puducherry is lost. But on the other side, the beach is developing in the southern side of the southern breakwater (Fig. 1). For protection of shoreline erosion, the Puducherry government has built seawalls using boulders of size 0.50 tons to 1.50 tons for a total length of about 6 to 7 km. The nature and complexity of most coastal problems vary widely with location and hence a proper solution of any specific problem requires a systematic and thorough study of that area. For the above problem, the exact method for estimating the sediment transport rate should be identified.

A sand trap was developed and fabricated for measuring the sediment transport rate in the surf zone. The trap was designed in such a way that it is very easy to handle; durable to withstand maximum current and also capable of measuring transport rates of sand-sized particles moving in any unidirectional fluid flow.

Location of instrument

The jetty structure was selected for hoisting the sediment trap (Fig. 2). Sampling was taken at five meters interval across the surf zone. The samplers were arranged in such a way that the mouth of the sampler faces the longshore current. After a few initial trials, it was found that an inclination of 45° was best suited for collection of sediment samples. After a sample run was complete, the sampler bottle was detached from the instrument and carried to the laboratory for analysis.

The trap was deployed across the surf zone for one hour and three samples were collected each day, during the sampling period. The samples were taken directly without disturbing the sampler bottle and taken to the laboratory for analysis. Every time a new sampler was attached to the system for the collection of samples. The sediment collected was weighed and the sediment transport rate achieved per unit width of surf zone per unit time was calculated and tabulated. Soil samples were also collected along the study area at 20 m intervals on the surf zone, each week of the month during the year 2009. Based on the above, K values were estimated for this coastal stretch for each month for the above year.

Estimation of sediment transport rate for the Puducherry Coast

CERC method (Eqn. 1) and modified Kamphuis method (Eqn. 2) were used to estimate the bulk sediment transport rates.

\[ Q_{th} = 330 H_{sb}^{5/2} \sin \alpha_b (m^3/hr) \]  
where, \( H_{sb} \) near-shore breaking waves (m); \( \alpha_b \) – breaker angle. It can be seen that \( Q_{th} \) is a function of ‘H’ and ‘\( \alpha \)’ only.

\[ Q = 7.3 H_{t}^{2} T_{s}^{2} m_{b}^{0.75} \sin^{0.6} 2a_{b} (m^3/hr) \]  

where,

- \( m_{b} \) – beach slope in the breaking zone;
- \( D \) – median grain size (mm)

It is to be noted that Eqn. (1) is applicable, for sediment size in the range of 0.2-0.6mm.
According to Shore protection Manual\textsuperscript{13}, the evaluation of longshore energy flux at breaking requires approximation since the wave breaking is outside the linear wave theory. The equation for longshore energy flux at surf zone is given by:

$$P_{ls} = \frac{\left(\rho gH_s^2C_b\sin 2\alpha_b\right)}{16} \quad (3)$$

where,

- $P_{ls}$ = longshore energy flux in watts/m;
- $H_s$ = significant wave height at breaking;
- $C_b$ = velocity at breaking;
- $\alpha_b$ = breaker wave angle w.r.t. shore-line;
- $\rho$ = fluid density.

The generalized relationship for estimating the actual sediment transport rate using energy flux relation is (CERC 1984):

$$Q = k P_{ls} \quad (4)$$

Eqn. (4) is based on the assumption that the longshore sediment transport rate ($Q$) depends on the longshore component of wave energy flux ($P_{ls}$) in the surf zone. ‘$k$’ is generally treated as a constant equal to 0.39. However, the effects of the sediment hydraulic properties and the fluid transporting medium are not included in a constant value of $k$. But a number of studies carried out by several investigators CETN\textsuperscript{14} have suggested that ‘$k$’ is not a constant, but, rather a variable dependent on sediment size and density, which may be represented by fall velocity. The suggested relationship for $k$ (where $k$ is a dimensionless and consistent with SPM methods for calculating $P_{ls}$), using the dimensionless parameter $(gh_b/w_f^2)$ is given by Eqn.(5). It takes into account the breaker height and fall velocity of the sediment. The fall velocity accounts for the effects of viscosity and density of water, as well as, sediment density, size and shape characteristics. The expression for $k$ as suggested in CETN (1985) is

$$k = 0.1637 \log \left(gh_b/w_f^2\right) - 0.0773 \quad (5)$$

where,

- $H_b$ = breaking wave height;
- $w_f$ = fall velocity of sediment.

The fall velocity, $w_f$ can be estimated using the following equations\textsuperscript{15}, wherein, consistent units may be used.

$$A = \frac{(\rho_s - \rho)gM_d^2}{\rho v^2} \quad (6)$$

where,

- $A$ = grain buoyancy; $\rho_s$ = sediment density; $\rho$ = fluid density; $M_d$ = sediment median grain diameter; $v$ = fluid kinematic viscosity. The fall velocity equations and their ranges of applicability are:

$$w_f = \left[ \left(\rho_s - \rho\right)gM_d^2 \right]/\left[18\rho v\right]; \text{for } A < 39 \quad (7)$$

$$w_f = \left[ \left(\rho_s - \rho\right)gM_d^2 \right]^{0.7}M_d^{1.1}/\left[6\rho v^{0.4}\right]; \text{ for } 39 < A < 10^4 \quad (8)$$

$$w_f = \left[ \left(\rho_s - \rho\right)gM_d/0.91 \rho \right]^{0.5}; \text{ for } A > 10^4 \quad (9)$$

The above relationships [i.e., Eqns. (7) to (9)] have been used to compute the value of $k$ for the Puducherry coast, and for estimating the longshore sediment rate using the energy-flux method.

**Results**

Monthly estimated sediment transport rate by CERC formula along with the direction from the measured data in the field for three years (2007 – 2009) are given in Fig. 3. The sediment transport rate has been estimated for the year 2007 were $9.7 \times 10^5$ m$^3$/yr in northerly direction and $7.2 \times 10^5$ m$^3$/yr in southerly direction. The estimated net sediment transport is $2.4 \times 10^5$ m$^3$/yr in the Northerly direction during 2007. The sediment transport rate for the year 2008 were $9.4 \times 10^5$ m$^3$/yr in northerly direction and $5.2 \times 10^5$ m$^3$/yr in southerly direction and estimated net sediment transport is $4.1 \times 10^5$ m$^3$/yr in the Northerly direction. The sediment transport rate for the year 2009 were $7.8 \times 10^5$ m$^3$/yr in northerly direction and $6.9 \times 10^5$ m$^3$/yr in southerly direction and estimated net sediment transport is $0.95 \times 10^5$ m$^3$/yr in the Northerly direction.

The sediment transport rates estimated by CERC and Kamphuis method have been compared (for one year) for better understanding. The breaking wave height, $h_b$ has been obtained by ‘wave ray method’ and used in CERC formula for computing ‘$Q$’. The beach slope, $m$ has been taken as 0.03 which was obtained by field measurements and used in Kamphuis formula. The breaking wave height and the median grain size (from field measurement) for a period of one year 2009 for the comparison of sediment transport rates is shown in
Fig. 4. The comparison has been done for one year i.e., 2009, as the field data for ‘m’ and ‘D’ are available for that period only. The comparison of sediment transport rates by CERC and Kamphuis methods is shown in Fig. 5. Daily values of actual sediment transport rate ($Q_{act}$) and the computed rate ($Q_{th}$) by Kamphuis method (i.e., by the sand trap method) for two months in 2009 are calculated and compared is shown in Fig. 6.

**Discussion**

From the results of field measurement and estimation made, CERC formula consistently over predicts the sediment transport rate than all other methods adopted in this study (Fig. 3). Moreover, Sediment transport rate actually measured by the ‘sand trap’ method developed and used in this study is comparable to the theoretical rate estimated by the ‘Kamphuis’ method (Fig. 5), it is found that the actual and theoretical values are in very close agreement. This shows that the ‘sand trap method’ developed is an acceptable method for actually measuring the longshore sediment transport rate and can be used with confidence. The conservative estimate made by CERC method can be used for the purpose of sediment budgeting. The ‘Kamphuis’ and ‘sand trap’ methods can be taken into consideration before embarking on any development activity on this coast such as coastal structures and coastal protective measures. Hence, before contemplating any developmental activity on this coast, a scientific study on the impact of such activity (i.e., man – made interventions) shall be made mandatory, so as to prompt and prevent irreparable and irreversible losses on the natural coastal environment of the region.
Fig. 6. Comparison $Q_{act}$ and $Q_{th}$ for the months of February and March in 2009.

References