



Measuring and modelling longshore sediment transport

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ARTICLE INFO

Article history:

Received 28 October 2008

Accepted 17 March 2009

Available online 27 March 2009

Keywords:

longshore sediment transport

suspended load

sediment traps

field measurements

prediction

concentration profile

Brazil, Paraná, Rio Grande do Sul

Portugal, Faro

Denmark, Skallingen

ABSTRACT

Field measurements of longshore sediment transport (LST) was undertaken on barred and non-barred beaches composed of fine, medium and coarse sands in Brazil, Denmark and Portugal. Measurements and predictions of vertical suspended sediment concentration profiles (*C-Profiles*) and cross-shore hydrodynamic parameters were then combined in a new semi-empirical model for prediction of LST (*LT-MOD*). Instantaneous LST predictions from *LT-MOD* and well-known bulk LST formulae were compared. Tests using *LT-MOD* to simulate measured changes in shoreline position in southern Brazil for periods of c. two years showed that *LT-MOD* gave more accurate predictions than existing bulk LST formulae. Results indicate that *LT-MOD* may have practical utility at sites where access to equipment is limited and where reliable estimates of LST are required over extended periods.

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1. Introduction

Accurate estimates of longshore sediment transport (LST) are required to predict the morphological evolution of sandy coasts at a range of temporal and spatial scales and in a range of practical engineering and beach management applications (cf. Bayram et al., 2007). LST can be estimated: (a) from direct measurements of longshore sand transport flux; (b) from empirical formulae using hydrodynamic and sediment data acquired in the field; or (c) by inferring net LST from observed large-scale changes in shoreline position and/or beach accretion and erosion. Approaches (a) and (c) require considerable resources to acquire the necessary data. Similarly, data required by LST formulae are normally only available at a single or few cross-shore locations, and beach profile surveys are normally restricted to a few kilometres at best with repeat surveys usually spanning only a short period. Furthermore, investigators wishing to quantify LST do not always have access to specialist equipment to measure all the hydrodynamic and sediment parameters required by the formulae. For this reason the majority of LST studies rely only on empirical predictions based on

scant data and empirical calibration constants that may not always be site applicable. As a consequence, predicted rates of LST often have large errors especially when the time- and/or spatial-scales considered are large.

In an attempt to develop a more robust methodology to quantify total LST when only limited field data are available, use is made here of data from field experiments undertaken on different coastlines: two located in southern Brazil, one in Portugal and one in Denmark. The experiments employed a range of well-known measurement techniques to acquire sedimentological and hydrodynamic data. Where required, theory is used to derive some key environmental parameters from the measured data to allow prediction of the observed suspended sand concentration profiles. These are then used to estimate the total longshore sand flux in a LST model (*LT-MOD*) that necessarily makes a number of simplifying assumptions about the cross-shore distributions of sediment and wave properties. Results are then compared with some widely-used bulk LST formula and the performance of *LT-MOD* over extended time- and spatial-scales assessed using field data from southern Brazil. It is acknowledged from the outset that many of the components in the approach described here are not new. Here the aim is simply to demonstrate that *LT-MOD*, constructed using robust and well-tested methods, and requiring simple, easily obtained input data, can out-perform some well-known LST formulae, especially for predictions over longer periods.

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2. Background

Attempts to simulate LST in large-scale laboratory tests have had mixed success owing to scaling problems (e.g. Wang et al., 2002; Okayasu et al., 2004). Numerical modelling approaches (e.g. Castelle et al., 2006; Ellis and Stone, 2006; Falqués, 2006) are not yet sufficiently advanced to accurately predict LST over time and spatial scales required by practical engineering or morphological studies. The measurement of sand transport in the nearshore region also presents many challenges. In the surf zone, air bubbles preclude the use of the acoustic instruments frequently employed in studies of suspended sediments, and optical techniques are better suited to fine sediments. Further, instruments designed for work in deeper water are relatively delicate and unable to withstand the energetic conditions in breaking waves. Methods employed in the past to measure LST include optical, interception and impoundment, tracer techniques and inference from measured changes in morphology (e.g. Knoth and Nummedal, 1977; Dean et al., 1983; Bodge, 1986; Kraus, 1987; Ciavola et al., 1997; Wang et al., 1998; Houser and Greenwood, 2005; Tonk and Masselink, 2005; Ari et al., 2007; Silva et al., 2007). Much of the available field data is subject to errors (cf. Bayram et al., 2007) and most studies highlight considerable discrepancies between measured and predicted LST.

Bulk formulae used to predict LST make simplifying assumptions regarding hydrodynamics and sediment processes, and most do not consider any beach parameter (slope, grain size, morphodynamic or other). In spite of these apparent deficiencies, the CERC formula (USACE, 1984) is used widely to predict LST and is believed to have an accuracy of ± 30 –50% in ideal conditions (Wang et al., 2002). A second widely-used approach (Kamphuis, 1991) follows closely the CERC formulation and includes additional terms expressing the influence of median grain size (D_{50}), wave period (T) and beach slope (m). Most recently, Bayram et al. (2007) have developed a new bulk LST formula based upon a transport coefficient validated and calibrated against six high quality data sets of LST, including laboratory and field data. The formula is given as

$$Q = \frac{\varepsilon}{(\rho_s - \rho)(1 - p) g w_s} F \bar{S} \quad (1)$$

where ε is a dimensionless transport coefficient expressing sediment diffusivity, ρ_s is the sediment density, ρ is the water density, p is the sediment porosity, g is the acceleration due to gravity, w_s is the sediment settling velocity, F is the flux of wave energy towards the shore and $\bar{S}$ is the mean longshore current velocity across the surf zone.

3. Proposed method

In a new semi-empirical model (*LT-MOD*), predicted suspended sediment concentration profiles (*C-Profiles*) obtained at cross-shore locations are integrated to obtain an estimate of LST over the required time-period. The approach set out below accounts for sediment properties, the bed roughness (including bedforms), wave-current interactions and tidal level.

3.1. Bed roughness

In the surf zone, where there may be bedforms and active sediment transport, the bed roughness (z_0) comprises: (a) roughness due to the bed sediments defined here by the bed roughness length (z_{0G}) as $D_{50}/12$ (Soulsby, 1997); (b) roughness due to bedforms (form drag, z_{0R}); and (c) roughness due to sediment transport (z_{0Q}). z_{0R} can be defined as

$$z_{0R} = \Theta \frac{\eta_r^2}{\lambda_r} \quad (2)$$

(Soulsby, 1997), where η_r and λ_r are the height and wavelength of bed ripples and $\Theta = 4$ as suggested by Madsen et al. (2007). A widely used equation for z_{0Q} that does not require knowledge of z_0 *a priori* is $z_0 = 0.00533 U_w^{2.25}$ (Raudkivi, 1990), where U_w is the wave orbital speed defined below. Thus, from Soulsby (1997)

$$z_0 = z_{0G} + z_{0R} + z_{0Q} = \frac{D_{50}}{12} + \Theta \frac{\eta_r^2}{\lambda_r} + 0.00533 U_w^{2.25} \quad (3)$$

Bedforms, if present, contribute appreciably to the hydraulic roughness of the bed and influence significantly the nature of the *C-Profile*. In the absence of direct field measurements, there are no well-established methods for calculating the dimensions of current-generated and wave-generated bedforms in the surf zone. In cases where it was not possible to measure bedform dimensions directly, the predictive equations of Grant and Madsen (1982) and Van Rijn (1984) are used to estimate η_r and λ_r for wave-generated (η_{rw} and λ_{rw}) and current-generated (η_{rc} and λ_{rc}) bedforms, respectively.

3.2. Bed shear stress

Time-averaged cross-shore profiles of the longshore current were computed in *LT-MOD* using a 1-D time- and depth-averaged longshore momentum balance approach between forcing terms (waves, wind and longshore slope), bottom stress and lateral mixing (cf. Ruessink et al., 2001). Cross-shore changes in wave height were also obtained using the well-known wave energy balance and included the momentum equation for wave-induced setup (Van Rijn et al., 2003). These models are appropriate for barred and unbarred beaches, and the present field sites meet approximately the model requirement of homogeneous alongshore waves and bathymetry.

Laboratory experiments with broken and unbroken waves of the same height show that wave-induced shear stresses under breaking and shoaling waves are not on average significantly different from unbroken waves (cf. Nielsen, 1992, p. 219). This is further supported by Deigaard et al. (1991). It is appropriate therefore to estimate the cross-shore distribution of wave-induced bed shear stresses using the model data. Using predicted values of H_s and T_p , estimates of the peak wave induced oscillatory flow close to the bed (U_w) were obtained using Matlab routines¹ to solve Deans stream function wave theory. Although this method gives accurate estimates of wave properties in shallow water conditions, it does not account for wave breaking. Estimates of the peak wave-induced bed shear stress ($\hat{\tau}_w$) were obtained using

$$\hat{\tau}_w = 0.5 f_w U_w^2 \quad (4)$$

where the wave friction factor (f_w) is defined in terms of the relative roughness (r) by Swart (1974) as $f_w = 0.3$ for $r \leq 1.57$ and $f_w = 0.00251 \exp(5.21 r^{-0.19})$ for $r > 1.57$. Here $r = A_0/k_s$ where A_0 is the orbital amplitude of the waves ($U_w T_p / 2\pi$). For rough turbulent, flat bed conditions, the Nikuradse equivalent sand grain roughness (k_s) is given by $2.5 D_{50}$, and $\hat{\tau}_w$ is the peak wave-only skin friction bed shear stress. In cases where ripples are present on the bed, and sediment is transported as bedload, k_s is defined by the total bed roughness z_0 so that $k_s = 30 z_0$ (Eq. (3)). It is noted here

¹ Available at <http://faculty.gg.uwyo.edu/borgman/DSF/dsfwav.html>, accessed 4 December 2007.

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