Estuarine, Coastal and Shelf Science 182 (2016) 190–201

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

journal homepage: www.elsevier.com/locate/ecss

# Bed shear stress estimation on an open intertidal flat using in situ measurements

Q. Zhu [a, b], B.C. van Prooijen [b], Z.B. Wang [a, b, c], Y.X. Ma [d], S.L. Yang [a, *]

[a] State Key Laboratory of Estuarine and Coastal Research, East China Normal University, Shanghai 200062, China
[b] Department of Hydraulic Engineering, Faculty Civil Engineering and Geosciences, Delft University of Technology, P.O. Box 5048, 2600 GA, Delft, The Netherlands
[c] Deltares, P.O. Box 177, 2600 MH, Delft, The Netherlands
[d] Department of Oceanography and Coastal Sciences, Louisiana State University, Baton Rouge, LA 70803, USA

ARTICLE INFO

*Article history:*
Received 27 February 2016
Received in revised form
24 August 2016
Accepted 26 August 2016
Available online 5 October 2016

*Keywords:*
Bed shear stress
Wave-turbulence decomposition
Wind
Combined wave–current action
Intertidal flat
Yangtze River Delta

ABSTRACT

Accurate estimations for the bed shear stress are essential to predict the erosion and deposition processes in estuaries and coasts. This study used high-frequency in situ measurements of water depths and near-bed velocities to estimate bed shear stress on an open intertidal flat in the Yangtze Delta, China. To determine the current-induced bed shear stress ($\tau_c$) the in situ near-bed velocities were first decomposed from the turbulent velocity into separate wave orbital velocities using two approaches: a moving average (MA) and energy spectrum analysis (ESA). $\tau_c$ was then calculated and evaluated using the log-profile (LP), turbulent kinetic energy (TKE), modified TKE (TKEw), Reynolds stress (RS), and inertial dissipation (ID) methods. Wave-induced bed shear stress ($\tau_w$) was estimated using classic linear wave theory. The total bed shear stress ($\tau_{cw}$) was determined based on the Grant–Madsen wave–current interaction model (WCI). The results demonstrate that when the ratio of significant wave height to water depth ($H_s/h$) is greater than 0.25, $\tau_{cw}$ is significantly overestimated because the vertical velocity fluctuations are contaminated by the surface waves generated by high winds. In addition, wind enhances the total bed shear stress as a result of the increases in both $\tau_w$ and $\tau_c$ generated by the greater wave height and reinforcing of vertical turbulence, respectively. From a comparison of these various methods, the TKEw method associated with ESA decomposition was found to be the best approach because: (1) this method generates the highest mean index of agreement; (2) it uses vertical velocities that are less affected by Doppler noise; and (3) it is less sensitive to the near-bed stratification structure and uncertainty in bed location and roughness.

© 2016 Elsevier Ltd. All rights reserved.

## 1. Introduction

Intertidal flats are ubiquitous in estuarine and coastal areas worldwide. These landforms have been, and still are, used as a source of land that can be reclaimed from the sea. However, it is becoming increasingly apparent that healthy tidal flats provide many other important benefits for both the local population and the natural environment. For example, they protect coastal areas by forming a buffer between land and sea that can attenuate wave energy. Furthermore, these areas provide essential environmental functions, such as habitats and nursery grounds for a wide range of wildlife, and as natural sewage purification systems. However, the impact of natural and human interference, such as sea level rise and the damming of rivers, can result in a reduction in the area covered by tidal flats, and the Yangtze tidal flats in China are one such example (Yang et al., 2011). The precise processes responsible for the degeneration of tidal flats are still not fully understood, and various aspects factors that affect such environments make it difficult to predict the future of tidal flats. One of these key factors is the definition of bed shear stress.

Bed shear stress is a critical parameter in sediment dynamics on tidal flats, especially in the calculation of erosion rates (Friedrichs et al., 2000; Friedrichs and Wright, 2004; Wang et al., 2013), and the total bed shear stress is the combined contributions from waves and currents. Numerous studies have estimated the total bed shear

---

[*] Corresponding author.
*E-mail address:* slyang@sklec.ecnu.edu.cn (S.L. Yang).

http://dx.doi.org/10.1016/j.ecss.2016.08.028
0272-7714/© 2016 Elsevier Ltd. All rights reserved.

stress by means of a wave–current interaction model (Grant and Madsen, 1979; Fredsøe, 1984; Christoffersen and Jonsson, 1985; O'Connor and Yoo, 1988; Huyng-Thanh and Temperville, 1990; Myrhaug and Slaattelid, 1990; van Rijn, 1993; Davies and Gerritsen, 1994; Shi et al., 2015), and an overview is given by Soulsby (2005). These wave–current interaction models have been widely applied in numerical models of estuarine and coastal areas (Villaret and Latteux, 1992; Lesser et al., 2004; Warner et al., 2008; Shi et al., 2016). The waves and currents interact in a non-linear way, leading to a total bed shear stress that is not a simple linear addition of wave-induced and current-induced bed shear stress.

The wave–current interaction model (WCI) is an algebraic equation that combines the pure wave-induced and pure current-induced bed shear stresses to obtain the total bed shear stress that accounts for the direction of the waves and currents. The determination of the wave-induced bed shear stress and the current-induced bed shear stress is based on bulk parameters. The wave-induced bed shear stress is generally obtained by using a linear wave theory (Green and Coco, 2007) for a given wave height, wave period, and water depth. The bed shear stresses associated with currents are generally estimated based on the assumption of stationary uniform flow and using the log law; however, this assumption is often violated.

The direct measurement of bed shear stresses presents some difficulties (Grant and Madsen, 1979; Soulsby, 2005). Further advances in acoustic instruments have allowed systematic velocity measurements to be made over longer periods, at higher sampling rates and with greater accuracy (Wang et al., 2006, 2012). The ADV (Acoustic Doppler Velocimeter) makes high-frequency measurements of the 3D velocities at a single point, whereas the ADCP (Acoustic Doppler Current Profiler) measures velocities over a profile. Despite these improvements, the difficulty remains of selecting the most appropriate theory to obtain the current-induced bed shear stress. The most widely used theories are: (1) the LP (log-profile) method; (2) the TKE (turbulent kinetic energy) method; (3) the TKEw (modified TKE) method; (4) the Reynolds stress (RS) method; and (5) the ID (inertial dissipation) method. The LP method uses the mean component of a velocity profile series, whereas the other methods use the turbulent velocity. Kim et al. (2000) systematically compared the current-induced bed shear stresses obtained using the LP, TKE, RS, and ID methods, and found differences of up to 19% between the TKE and LP methods. No significant wave events were recorded. They suggested that all methods should be applied simultaneously to help better estimate bed shear stress. On many tidal flats, the conditions are generally more complex than in their study. As the water depth changes significantly, the relative locations of the fixed measurement positions change. Due to the shallow water depth, wind-driven flow may have a significant influence and disturb the logarithmic flow profile.

Having recognised this inaccuracy, several studies have been conducted to compare some of the above methods of obtaining the bed shear stress (Kim et al., 2000; Andersen et al., 2007). One of the assumptions is that the vertical component of velocity is not contaminated by waves (see also Stapleton and Huntley, 1995). Wave motion is expected to have a great impact on the velocity distribution near the bed on tidal flats, especially in wavy conditions; e.g., during storms or typhoons.

In this paper, we compare the methods used to determine the bed shear stress on intertidal flats. In such areas, the assumptions on which the methods used to determine current-induced bed shear stress are based, are possibly violated. We conducted high-frequency, in situ measurements of water depth and near-bed velocities, as well as near-bed current profiles, on an intertidal flat in the Yangtze Estuary, China. Our specific goals were to: (1) investigate how, and by how much, the wind influences the near-bed velocity distribution; (2) compare and summarize the calculation methods used to determine the total bed shear stress; and (3) develop an optimum solution for estimating the total bed shear stress in intertidal areas.

## 2. Study area and instrumentation

In situ observations were conducted on an exposed tidal flat on the Eastern Chongming mudflat, located on the Yangtze River Delta (Fig. 1A). The tides in the Yangtze Estuary are mixed semidiurnal, and the average tidal range, based on records from the Sheshan gauging station, which is 20 km east of the study site, is 2.5 m, reaching 3.5–4.0 m during spring tides. The monsoon-driven winds are southeasterly in summer and northwesterly in winter. The wind speed in this area is highly variable, with multi-year averages of 3.5–4.5 m/s, and a maximum value of 36 m/s recorded at the Sheshan gauging stations (GSCI, 1988; Yang et al., 2008).

The southern part of the Eastern Chongming tidal flat is interrupted by a secondary channel that runs in an east–northeast direction. The observation site, which is close to mean sea level, is 1.65 km seaward of the sea wall. The bed sediment on the present mudflat is mainly silt (median grain size < 63 μm), with a coarse silt (32–64 μm) fraction that exceeds 50% (Yang et al., 2008).

Our observations were carried out from July 23 to August 3, 2011. Wave heights, wave periods, and water depths were measured using a self-logging sensor, the SBE-26plus Seagauge (Sea-Bird Electronics, Washington, USA), which was developed for wave monitoring using a data collection system comprising a 45-psia Paroscientific Digiquartze connected to an oil-filled tube via the pressure port (Sea-Bird Electronics, 2007). The instrument was horizontally placed on the sediment surface with the pressure probe located 8 cm above the sediment surface (Fig. 1C). The measuring burst interval was 10 min. Pressure data were collected at a frequency of 4 Hz over a duration of 256 s, yielding 1024 measurements per burst.

An ADCP (1.0 MHz high-resolution profiler, Nortek AS, Norway) was used to measure 3D current velocity profiles. The burst interval was 5 min. Each velocity profile is the mean value collected at a frequency of 1 Hz over a duration of 60 s. The ADCP was attached to the tripod with the transmitters facing downwards and located 85 cm above the sediment surface. The blanking distance was 40 cm, and the cell size was set to 2 cm.

An ADV (6.0 MHz vector current meter, Nortek AS, Norway) was used to measure the 3D velocity at a high sampling frequency in a small measurement volume (2.65 $cm^3$). The sampling volume was located 9.3 cm above the bed. The ADV recorded velocities and pressure with a burst interval of 5 min, and for a period of 90 s at a frequency of 8 Hz. The water pressure in a high sampling rate, measured by a silicone piezoresistive pressure sensor (Nortek, 2005), was also used to analyse wave characteristics. Finally, wind data at 122.25°E, 31.5°N were obtained from the European Centre for Medium-Range Forecasts (ECMWF) at an interval of 3 h.

## 3. Bed shear stress formulations

### 3.1. Bed shear stress caused by combined wave–current action

To determine the bed shear stress caused by combined wave–current action (referred to as total bed shear stress hereafter) ($\tau_{cw}$, Pa), we used the method of Grant and Madsen (1979), which introduces a combined wave–current friction factor and is expressed as

Download English Version:

https://daneshyari.com/en/article/6384461

Download Persian Version:

https://daneshyari.com/article/6384461

Daneshyari.com