Coastal Engineering 56 (2009) 726–732

Contents lists available at ScienceDirect

Coastal Engineering

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

Database of full-scale laboratory experiments on wave-driven sand transport processes

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ARTICLE INFO

Article history:
Received 22 February 2008
Received in revised form 16 December 2008
Accepted 16 January 2009
Available online 13 February 2009

Keywords:
Database
Full-scale laboratory experiments
Oscillatory flow
Sand transport
Non-breaking waves
Currents

ABSTRACT

A new database of laboratory experiments involving sand transport processes over horizontal, mobile sand beds under full-scale non-breaking wave and non-breaking wave-plus-current conditions is described. The database contains details of the flow and bed conditions, information on which quantities were measured and the value of the measured net sand transport rate for 298 experiments conducted in 7 large-scale laboratory facilities. Analysis of the coverage of the experiments and the measured net sand transport rates identified the following gaps in the range of test conditions and/or the type of measurements: (i) graded sand experiments, (ii) wave-plus-current experiments and (iii) intra-wave velocity and concentration measurements in the ripple regime. Furthermore, it highlights two areas requiring further research: (i) the differences in sand transport processes and sand transport rates between real waves and tunnel flows with nominally similar near-bed oscillatory flow conditions and (ii) the effects of acceleration skewness on transport rates. The database is a useful resource for the development and validation of sand transport models for coastal applications.

1. Introduction

To prevent the hinterland from flooding, protect economic activities and further develop coastal areas it is necessary to understand the morphological behaviour of coastal systems and to be able to predict future changes. For this purpose, good knowledge of the sand transport induced by waves and currents is a requirement.

Field and laboratory measurements are important to understand the complex nature of sand transport in coastal waters and to provide data for the development and validation of sand transport models. In this context, laboratory experiments have certain advantages over field studies. In the laboratory, measurements are made under controlled, well-defined conditions and more accurate measurements are possible. Furthermore, very importantly, it is possible to measure the total net sand transport rate, something which is not yet practically feasible in the field.

Laboratory studies of wave-driven sand transport processes are numerous, covering a wide range of flow and bed conditions, and a wide range of measurements from bedform dimensions to detailed sediment particle velocities and concentrations. In this paper we describe a new database of laboratory experiments assembled as part of the SANTOSS research project. The overall objective of the SANTOSS project ('Sand Transport in Oscillatory flows in the Sheet-flow regime') is to establish a new practical model for sand transport induced by waves and currents on the basis of new and existing experimental data.

The database focuses on laboratory experiments with quartz sand under *full-scale* non-breaking wave and non-breaking wave-plus-current conditions, where "full-scale" is taken to mean experiments with wave period larger than or equal to 4 s. The database has been constructed to (i) enable access to a coherent collection of sand transport data from full-scale, oscillatory flow experiments, (ii) examine the coverage of existing experimental data and identify conditions requiring further experimental research and (iii) develop and validate practical models for the prediction of sand transport under waves and currents.

The paper is organized as follows. The facilities used for the experiments included in the database are briefly described in Section 2. Section 3 explains the content and structure of the database. Section 4 presents an overview of the experiments in terms of the type of measurement and the hydraulic parameters, and identifies conditions where experiments are lacking. As an example of the use of the database, Section 5 examines trends in the measured net sand transport data compared with the trend expected using a quasi-steady sand transport model. Section 6 concludes the paper.

2. Laboratory facilities

The generation of field-scale sand transport conditions in the laboratory requires a large experimental facility capable of producing

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0378-3839/$ – see front matter
doi:10.1016/j.coastaleng.2009.01.008

high near-bed flow velocities with periods typical of full-scale waves (4 to 15 s). Two types of facility have this capability: large oscillatory flow tunnels and large wave flumes.

The data included in the database originate from experiments carried out in 5 large oscillatory flow tunnels and 2 large wave flumes. The tunnels are the Aberdeen Oscillatory Flow Tunnel (AOFT, Aberdeen University, UK), the Cambridge Oscillatory Flow Tunnel (COFT, Cambridge University, UK), the Large Oscillating Water Tunnel (LOWT, WL| Delft Hydraulics (now Deltares), the Netherlands), the HR Pulsating Water Tunnel (PWT, HR Wallingford, UK) and the Tokyo Oscillatory Flow Tunnel (TOFT, Tokyo University, Japan). The wave flumes are the Delta Flume (WL|Delft Hydraulics (now Deltares), the Netherlands) and the GWK (Groβer Wellenkanal, Hannover, Germany).

Table 1 summarizes the main characteristics of the experimental facilities. It includes test section dimensions, water depth above sediment bed (h) and typical flow capability, which for the tunnels includes flow period range, maximum oscillatory flow velocity and maximum current velocity (only the LOWT, PWT and TOFT are capable of generating a collinear current), and for the wave flumes includes flow period range and maximum wave height. More detailed descriptions of the facilities can be found in the references listed in the table.

It is noted that oscillatory flow tunnels provide an approximation of the flow experienced at the seabed under real waves. Phase differences in wave orbital motion, vertical orbital motions, wave-induced boundary layer streaming (Longuet-Higgins, 1953; Davies and Villaret, 1999) and undertow at higher levels above the bed are not present or are different in wave tunnels. Some of these differences in the detailed hydrodynamics may result in significant differences between tunnel and wave flume net sand transport rates for nominally similar near-bed oscillatory flows, which will be discussed further in Section 5.

3. Database content and structure

Table 2 lists the datasets included in the database. For each dataset the table gives the literature reference, the facility in which the experiments were carried out, the number of experiments (number of different flow-sand bed combinations), the type of flow (wave-only or wave-plus-current), the type of sediment (well-sorted or graded), the range of median grain sizes (D_{50}), the range of flow periods (T) and the bedform regime. In total, the database contains information relating to 298 different experiments carried out in 7 different laboratory facilities.

The database contains full-scale laboratory experiments involving horizontal, mobile sand beds and non-breaking wave and non-breaking wave-plus-current flows. Experiments with artificial sediments are not included. Only experiments involving measurements of flow velocities, suspended sand concentrations and/or net sand transport rate are included. This means, for example, that experiments involving measurement of ripple dimensions only, or measurement of sheet flow layer thickness only, are excluded.

For each experiment the database contains the flow and bed conditions, information on which quantities were measured and the value of the measured net sand transport rate. The database does *not* contain detailed velocity or concentration data. The information and data are stored in five categories as follows.

1. General information: contains the literature reference, the experiment code, the experimental facility and the water depth above the sand bed.
2. Sand characteristics: contains the characteristic grain sizes (D_{10}, D_{50}, D_{90}), the sand fall velocity, sand density and an indicator of whether the sand was well-sorted (uniform) or graded (mixture of sizes).
3. Flow characteristics: type of flow (waves and/or currents, regular, irregular, skewness type, etc.), wave/flow spectrum (for irregular waves/flows), wave height, flow period, root-mean-square orbital velocity, 'onshore' and 'offshore' velocity peaks (both are positive quantities), degree of velocity and acceleration skewness, magnitude, orientation and reference level of measured net current velocity.
4. Bed characteristics: indicates whether the bed was fixed or mobile, the type of bedform produced (flat bed, 2D ripples, quasi 2D ripples, 3D ripples), measured bedform height and length.
5. Measured parameters: indication of which quantities were measured (intra-wave velocities, intra-wave concentrations, wave-averaged concentrations) and the values of the measured net sand transport rates.

More detailed information on the database content and structure can be found in Schretlen and Van der Werf (2006).

4. Data overview

Table 3 and Figs. 1 and 2 present an overview of the experiments in terms of the type of measurement (intra-wave velocities, $u(t)$), intra-wave concentrations, $c(t)$, wave-averaged concentration, $<c(z)>$ and net sand transport rate, $<q_s>$), the type of sediment (well-sorted or graded) and the type of flow (wave-only or wave-plus-current). In Figs. 1 and 2 experiments are placed in $T-\psi_w$ space, where T is the flow period and ψ_w, is the wave mobility number defined by:

$$\psi_w = \frac{u_w^2}{(s-1)gD_{50}} \tag{1}$$

where $s=\rho_s/\rho_w$ is the relative sand density with ρ_s the sand density and ρ_w the water density, g is acceleration due to gravity and u_w is a representative orbital velocity given by:

$$u_w = \sqrt{0.5\hat{u}_{\mathrm{on}}^2 + 0.5\hat{u}_{\mathrm{off}}^2} \tag{2}$$

which is the equivalent sinusoidal orbital velocity amplitude in terms of u_{rms} for second-order Stokes orbital flows (see Eq. (5)).

Table 1
Main characteristics of the experimental facilities.

Facility	Type	Test section			Typical hydraulic conditions				Reference
		length (m)	width (m)	h (m)	H (m)	T (s)	$\hat{u}$ (m/s)	$<\bar{u}>$ (m/s)	
AOFT	OFT	10	0.30	0.5	–	≤13	≤1.5	–	O'Donoghue and Clubb (2001)
COFT	OFT	3.7	0.15	0.3	–	≤7.1	≤2.2	–	Zala Flores and Sleath (1998)
Delta Flume	WF	240	5.0	≤7	≤1.3	≤6.0	–	–	Thorne et al. (2002)
GWK	WF	300	5.0	≤7	≤1.6	≤9.1	–	–	Dohmen-Janssen and Hanes (2002)
LOWT	OFT	14	0.30	0.8	–	≤12	≤1.8	≤0.55	Ribberink and Al-Salem (1994)
PWT	OFT	9	0.51	≈2	–	≤10	≤1.1	≤0.39	Murray et al. (1993)
TOFT	OFT	2	0.24	0.2	–	≤7	≤1.8	≤0.22	Sato (1987)

'OFT' means oscillatory flow tunnel; 'WF' means wave flume. h is flow depth over sediment bed; H is wave height; T is wave/flow period; $\hat{u}$ is maximum oscillatory flow velocity; $<\bar{u}>$ is steady current velocity. The typical hydraulic conditions are based on the experiments included in the database.