Ripple Morphodynamics in Oscillatory Flows

Marcelo H. García (PI)
Ven Te Chow Hydrosystems Laboratory
Department of Civil and Environmental Engineering
University of Illinois at Urbana-Champaign
205 North Mathews Avenue
Urbana, Illinois 61801
phone: (217) 244-4484 fax: (217) 333-0687 email: mhgarcia@uiuc.edu

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LONG-TERM GOALS

The long-term goal of our research is to improve our understanding of ripple morphodynamics in wave-current, boundary-layer flows. Our main focus is on the study of sediment transport in oscillatory boundary layers in the presence of unidirectional currents and the associated bed morphology (i.e. 2D and 3D ripples). We hope to improve currently available bed state prediction tools. To this end, both wave-induced and wave-current-induced oscillatory flow conditions are simulated in a Large Wave-Current Flume (LWCF) and in a Large Oscillating Water Sediment Tunnel (LOWST) built and equipped with an ONR DURIP Awards N00014-01-1-0540 and N00014-06-1-0661.

OBJECTIVES

This effort studies the configuration of a uniform sand bed for a given regular oscillatory flow condition. In particular: the identification of dimensionless parameters controlling the transition between two and three dimensional ripples; the development of orbital, suborbital or anorbital ripples; and the occurrence of low steepness ripples. Attention is also directed to the hydro- and sediment dynamics of the flow over self formed ripple beds. The main objective is the development of a bedform predictor as a function of flow conditions and sediment characteristics.

APPROACH

The work has three main components:

(1) **Literature review:** this is necessary to detect flow conditions and sediment characteristics for which experimental data are scarce and to design the experimental program. It also should allow for the comparison of new results with existing data collected by other researchers in both laboratory and field experiments.

(2) **Expansion of the measuring capabilities at the existing facilities:** new measuring equipment has been installed in both the Large Oscillatory Water Sediment Tunnel (LOWST) and the Large Wave Current Flume (LWCF).

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(3) **Full scale experiments:** to be performed in both experimental facilities to address the above mentioned objectives. The LOWST dimensions, in particular its 0.8 m width, make it a unique facility for the study of bed morphology all the way from two to three dimensional ripples. There is no other facility with its characteristics in the world.

The research team is composed by Marcelo Garcia (PI) and two PhD students; Francisco Pedocchi in charge of the experiments in LOWST and Blake Landry in charge of the experiments in LWCF.

WORK COMPLETED

The current status of the different components of this effort follows:

(1) The literature review is almost completed. A number of data sources have been collected and their quality evaluated. Most of the data has been already converted to a uniform data format and only few data sets are awaiting conversion. The analysis of the data in terms of dimensionless variables is been carried in parallel to the data collection.

(2) The measuring capabilities with LOWST have been largely enhanced with the incorporation of new measuring devices: (a) A micro-ADV attached to an electronic positioning system has been installed, which allows three-dimensional point velocity measurements along a vertical. (b) An Ultrasound Velocity Profiler (UVP) with three transducers has been installed. This device allows for two dimensional velocity measurements over a vertical. Additionally the UVP has been calibrated to perform suspended sediment concentration estimations. (c) A peristaltic pump to extract suspended sediment samples at two different depths has also been installed for this last purpose. (d) A pressure transducer connected to two ports at both ends of the tunnel has been installed for global bed friction estimation. (e) A custom design sonar system has been installed to perform fast three dimensional surveys of the sand bed during an experiment. (f) A camera connected to a computer to record the bed evolution is also dedicated to the experiments in LOWST.

(3) Experiments are been performed routinely since the beginning of the work. First, exploratory experiments were carried to qualitatively explore the behavior of the selected sediment (250 μm sand). Experiments have also been performed to evaluate the performance and to calibrate the installed measuring devices. Experiments to particularly address the research objectives are currently being performed.

The new equipment installed in the LWCF and the experiments performed on that facility are reported in the companion Mine Burial by Local Scour and Sand Waves. Part of the work conducted on this facility can be found in Landry and Garcia (2007).

A substantial effort went into testing of equipment to be purchased with DURIP funding (N00014-06-1-0661). A vendor has been selected and the state-of-the-art Particle-Image-Velocimetry (PIV) and Laser Doppler Velocimetry (LDV) systems are expected to be delivered before the end of this calendar year. This acquisition will enhance the existing measuring capabilities in both the LOWST and the LWCF.

RESULTS

Motivated by the discrepancies that are observed between the different friction factor expressions currently available in the literature, efforts were directed to the collection of reported experimental data and the elaboration of a new expression for the friction factor computation. The obtained expression, shown in Figure (1), emphasizes the smooth to rough and the laminar to rough transitions (Pedocchi and Garcia, submitted for publication). The newly developed formulation is being used in the analysis of the ripple data.

The literature review on ripples has provided a frame of reference for the design of the experimental program. The preliminary analysis of the collected literature data and some of the performed experiments have shown that the parameters controlling the two or three dimensional configuration of the ripples are different for orbital and anorbital ripples. The particle and the wave Reynolds number seem to be the controlling parameters in the case of regular orbital ripples. The results are not yet conclusive for the case of anorbital ripples.

The performed experiments have shown that the final bed configuration does not seem to be affected by the initial bed configuration. However, the process by which the bed evolves to a particular final state is clearly dependent on the initial bed configuration. For example evolution from three dimensional ripples formed under a flow with a period of 5 sec. and a maximum orbital velocity of 0.3 m/s to two dimensional ripples when the maximum velocity is reduced a 0.25 m/s can be seen in Figure (2). The bed evolution was very slow in some cases, and it took several days for the bed to reach its final configuration. The evolution process in those slow cases was observed to be very rich in transient bedforms. Superposition of small bedforms on top of larger ones has also been observed. From our observations we have concluded that in some cases the time available for the bed evolution could be a limiting factor for the morphology observed in the field.

The use of the pressure transducers to compute the ripple bed friction factor requires very accurate synchronization of the velocity and pressure measurements. The triggering system installed has allowed for that synchronization and preliminary results are being obtained for beds with self-formed orbital ripples. The results seem to confirm the 0.3 constant value of the friction factor for large relative roughness originally obtained by Jonsson (1980). Nevertheless, further work is needed comparing with the friction factor values obtained from velocity profile measurements.

The Ultrasound Velocity Profiler has shown to be a powerful piece of equipment for the study of flows with high suspended sediment concentrations, where optical techniques would fail. Using a three probe configuration mean velocity and Reynolds stresses can be evaluated. The use of this device has been extended to compute suspended sediment concentrations from the acoustic backscatter (Figure 3). Part of this work has been reported in Pedocchi and Garcia (2007).

The ensemble of the new sonar system for 3D bathymetry survey was completed and the device is installed and working. The construction of this device, apart from the mechanical components, included the development of the controlling and communication software, the improvement of the bed detection algorithm, and the development of data post-processing tools. Figure (4) shows an example of the results that can be obtained.

Phase-averaging techniques have been used to study the ADV data (Figure 5). From this preliminary analysis, it is clear that farther study is needed in the area of turbulence characterization of oscillatory flows. This will be addressed in future work.

IMPACT/APPLICATIONS

Provide the research community with new ripple data generated under controlled flow conditions and long duration experiments. The two or three dimensional ripple bed configuration is one of the main limitation of current ripple predictors (e.g. Wiberg and Harris 1994), which only predicts the dimensions of two dimensional ripples. Three dimensional ripples have been shown to present smaller dimensions than their two dimensional relatives (O'Donoghue et al 2006). However, there is no generally accepted predictor for the two or three dimensional ripple configuration that is widely accepted. On the same path, the prediction capabilities of current semi-empirical models depend on the distinction between orbital and anorbital ripples. New experiments (Dumas et al 2005 and O'Donoghue et al 2006) and field data (Traykovski et al 1999 and Hanes et al 2001) have shown that the data available at the time of development of these models were incomplete, and that these models need more exhaustive revision. The new experiments are expected to help in achieving this goal.

RELATED PROJECTS

This work is related to the past and present projects associated with the Ripples DRI and the Mine Burial effort in which our group has been participating under ONR Grants N00014-01-1-0337 and N00014-01-1-0540 (DURIP) and N00014-06-1-0661 (DURIP).

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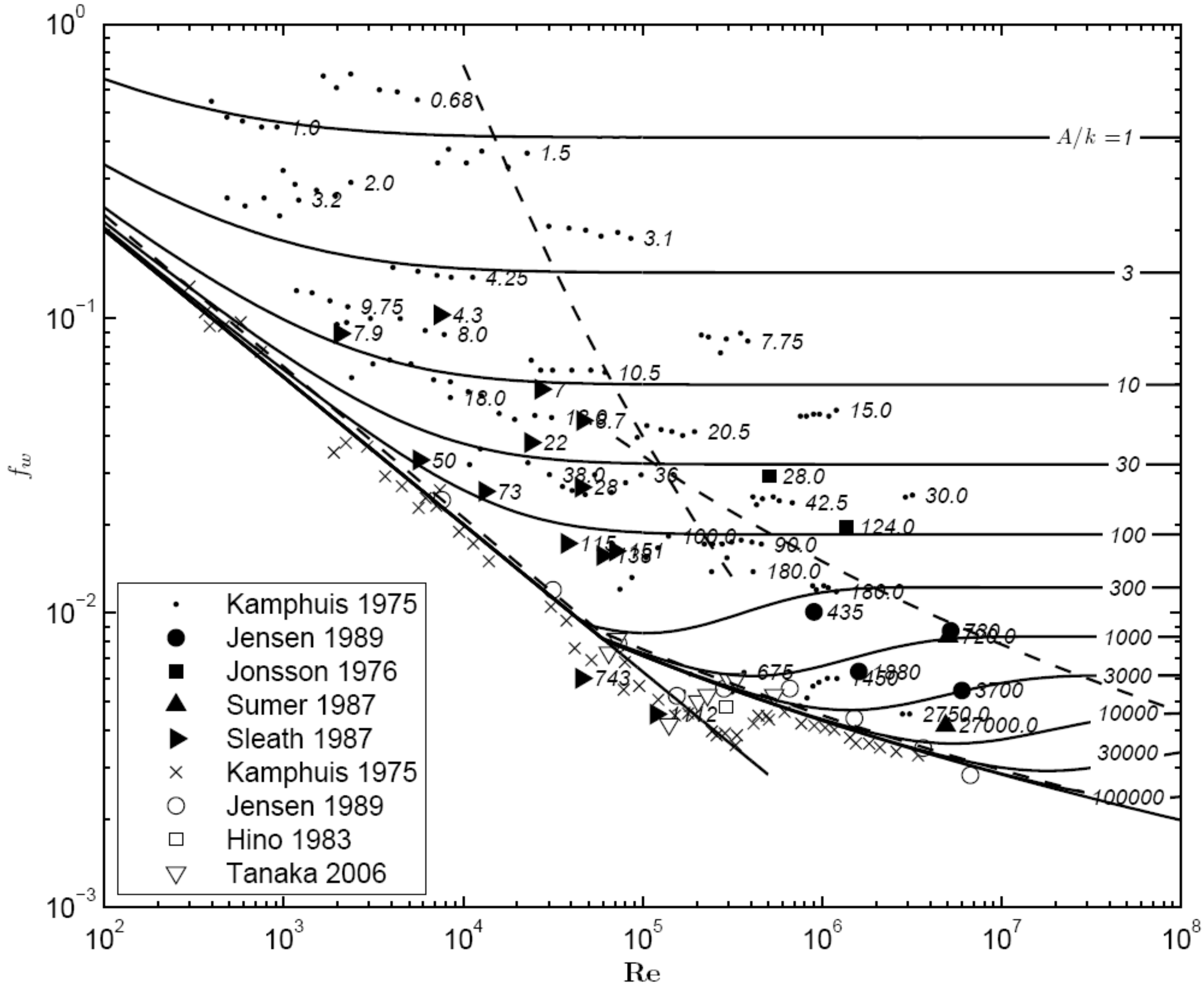

Figure 1: Moody type diagram showing experimental data from different bibliographic sources and the equations obtained for the friction factor. The rough turbulent to laminar transition and the rough to hydro-smooth transition are indicated with dashed lines.

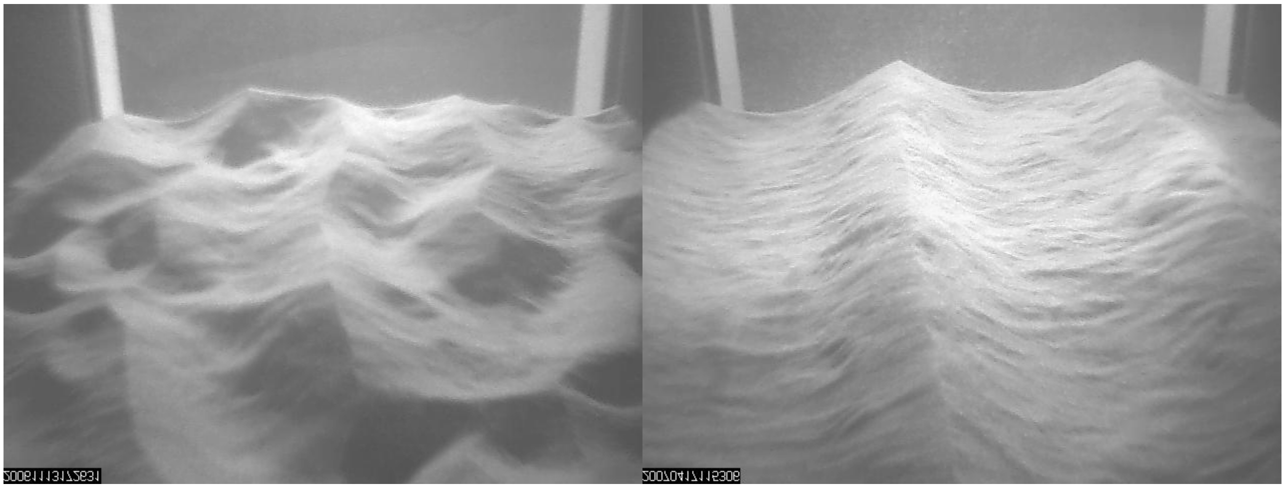

Figure 2: Final bed state after 2 hours (left) for 5 sec period and 0.3 m/s maximum orbital velocity. Starting from this previous condition the maximum orbital velocity was reduced to 0.25 m/s. After 20 hours regular two dimensional ripples covered the whole bed (right).

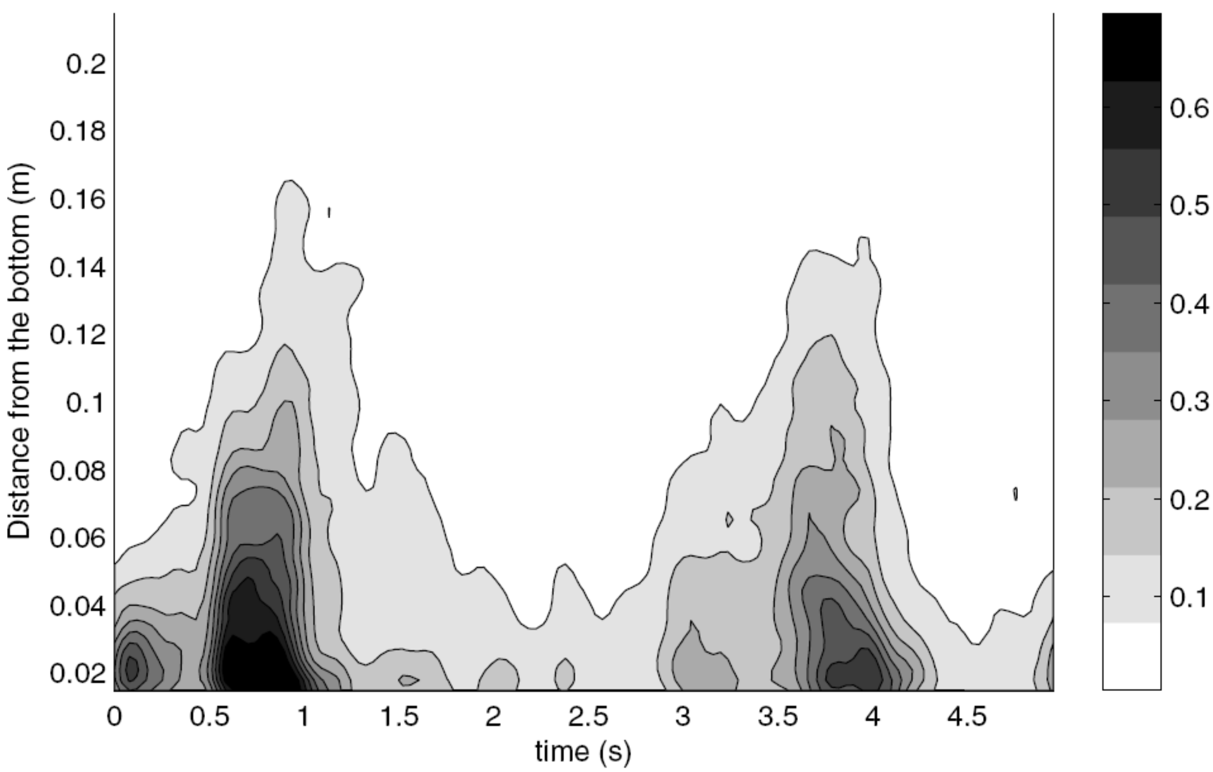

Figure 3: Contours of suspended sediment concentration profiles along the wave cycle, for a 5 second period and 0.3 m/s maximum velocity oscillation, the sediment size is 250 μm. The bed was at dynamic equilibrium covered with 3D ripples. Concentration units are g/L.

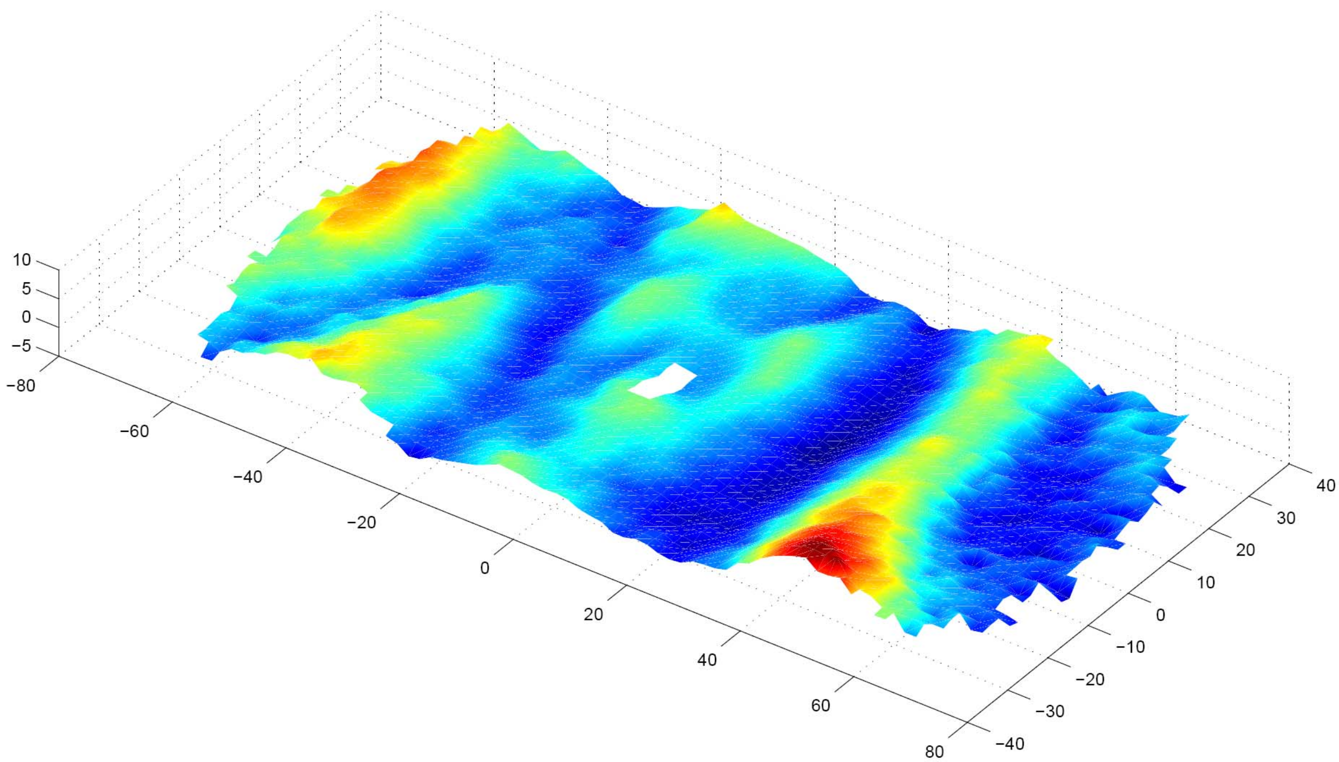

Figure 4: Three-dimensional image obtained with the new sonar system. Dimensions are in cm.

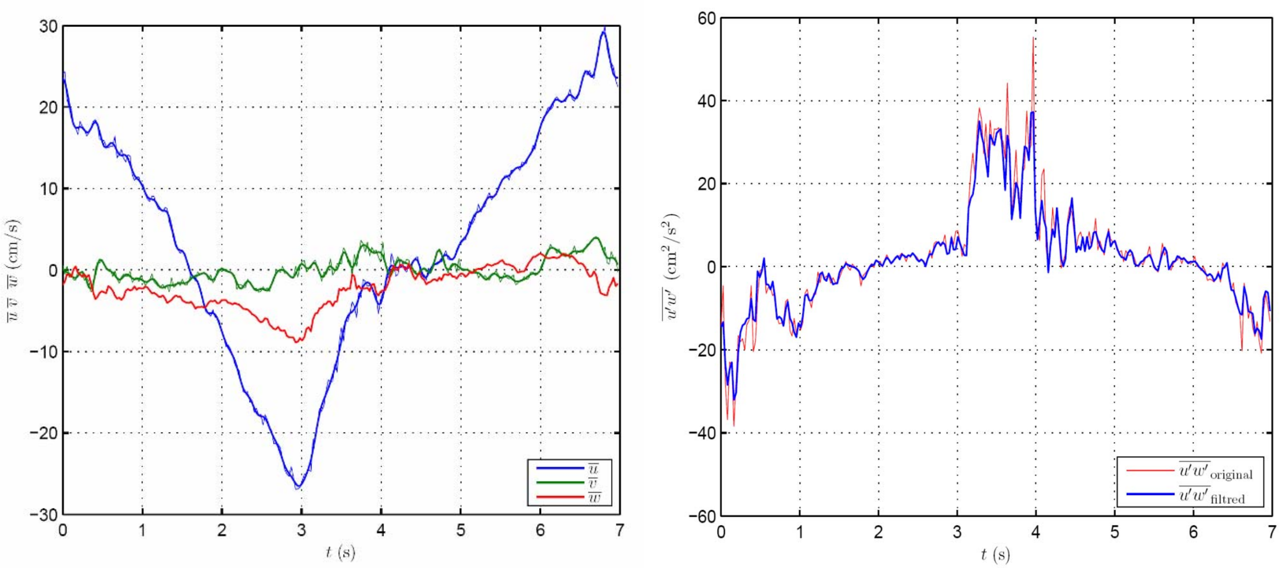

Figure 5: Phase-averaged results for the mean velocity and the longitudinal Reynolds stress from a record taken 15 cm above the original bed level. The oscillation period was 7 sec. and the maximum orbital velocity was 0.3 m/s. The bed was at dynamic equilibrium covered with 3D ripples.