Ripple Morphology under Oscillatory Flow

Marcelo H. Garcia
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

Francisco Pedocchi
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) 333-8365, fax: (217) 333-0687, email: pedocchi@uiuc.edu

Blake J. Landry
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) 333-8365, fax: (217) 333-0687, email: blandry2@uiuc.edu

Award Number: N00014-08-1-0421, N00014-01-1-0540 (DURIP)
N00014-06-1-0661 (DURIP)

http://www.vtchl.uiuc.edu

LONG-TERM GOALS

Advance in the understanding of bed morphology and sediment dynamics under oscillatory flows. Expand the present experimental database of sand bed configuration and evolution under controlled flow conditions in large scale facilities. Improve currently available tools for the prediction of bed configuration.

OBJECTIVES

This effort studies the final configuration that a uniform sand bed would take under a regular oscillatory water flow. In particular: the identification of dimensionless parameters controlling the occurrence of two or three dimensional ripples; the development of orbital, suborbital or anorbital ripples; and the occurrence of round crested ripples. Attention is also directed to the hydro- and sediment dynamics of the flow over self formed ripple.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
2008		**00-00-2008 to 00-00-2008**

4. TITLE AND SUBTITLE **Ripple Morphology under Oscillatory Flow**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Illinois at Urbana-Champaign,Department of Civil and Environmental Engineering,205 North Mathews Avenue,Urbana,IL,61801**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**9**	

APPROACH

The work has three main components:
(1) Literature review: which was necessary to detect the areas where experimental data was scarce and design the experimental program. It should also allow for the comparison of the new experimental results with the previously published data from both laboratory and field experiments by other researchers.

(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).

(3) Field scale experiments have been performed in both experimental facilities to address the above mention objectives. The LOWST dimensions, its 0.8 m width in particular, make it a unique facility for the study of three dimensional ripples.

The research team is composed by Prof. Marcelo H. Garcia as PI and two PhD students, Francisco Pedocchi and Blake Landry as Co-PIs. Francisco Pedocchi is in charge of the experiments in the LOWST and Blake Landry is in charge of the experiments in the LWCF. Jose Maria Mier, also PhD student at the Hydrosystems Laboratory, participated in the experiments in the LOWST and the small oscillatory tunnel.

WORK COMPLETED

The current status of this effort follows:
(1) The literature review is now completed. Twenty seven data sources were colleted and converted to a uniform format to facilitate its analysis. Apart from the mean flow characteristics and basic geometric description of the ripples, information on the planform geometry of the ripples, the crest shape and the existence of superimposed bed forms was included. The available ripple predictors and our own experimental data are being compared to the compiled dataset.

(2) LOWST is now fully equipped and the installed equipment includes: (a) A micro-ADV attached to an electronic positioning system, which allows for three-dimensional point velocity measurements along a vertical. (b) An Ultrasound Velocity Profiler with three transducers. 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, for the calibration suspended sediment profiles. (d) A pressure transducer connected to two ports at both ends of the tunnel, for global bed friction estimation. (e) A custom design sonar system has been installed to perform three dimensional surveys of the sand bed. Additional post-processing software to measure suspended sediment and generate synthetic stratigraphy is being developed. (f) A camera connected to a computer to record the bed evolution is also dedicated to the experiments in the LOWST.

(3) Experiments are been performed routinely since the beginning of this work. First, exploratory experiments were carried to qualitatively explore the behavior of the selected sediment (250 μm sand). Later, experiments were performed to evaluate the performance and calibrate the installed measuring devices. Finally, a number of experiments to particularly study the bed response under different flow

conditions have been performed. These experiments covered a wide range of flow conditions, including large near-bed excursions at different maximum orbital velocities. The collected data is currently being analyzed and compared with the compiled literature data.

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 report. Part of the work performed in this facility can be found in Landry and Garcia (2007).

RESULTS

The literature review on ripples gave a reference frame for the experimental program design. 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 size 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 compiled data showed that the existing ripple predictors only provide a partial description of the studied phenomena. In particular, for large near-bed excursion it is observed that the near-bed excursion is not enough to predict the bed configuration and that another flow parameter is need (Figure 1). It also showed that sometimes different bed form sizes may coexist for a given flow condition as is the case of long wave ripples and suborbital ripples (Hanes et al. 2001). However, old datasets may not have notice this condition and only the smaller superimposed ripples were reported at the time.

The performed experiments have shown that the final bed configuration does not seem to be affected by the initial bed configuration as far as the flow is able to mobilize the sediment. However, the process by which the bed evolves to a particular final state is clearly dependent on the initial bed configuration. The bed evolution was observed to be very slow in some cases, taking several days for the bed to reach the 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. Further study is needed to fully address the bed evolution and the feedback mechanisms that may exist between the "instantaneous" water flow and the bed configuration.

Experiments with large near-bed excursions (2m approx.) have been performed in the LOWST with the purpose of observing the bed response under different flow velocities and periods but under the same near-bed excursion. They have shown that different ripple sizes are obtained for different velocities and periods, emphasizing the importance of a second flow variable in order to predict the bed configuration. These results are being compared with the data obtained from the literature that show similar behavior (Figure 2).

Additionally, exploratory experiments in a small oscillatory tunnel have been performed, to look at possible sediment density effects. The experiments showed that the sediment density does not play a first order role in defining the ripple wavelength under short near-bed excursions. However, the sediment density may play a mayor role in defining other ripple characteristics, as the ripple steepness and crest shape. As it was expected, sediment density also controls the occurrence of sheet flow for a given water flow condition.

The in-home designed sonar system for 3D bathymetry survey has been operating for one year now (Pedocchi and Gracia 2007). The current line of work focus on developing and improving the controlling and post-processing software to expand the sonar capabilities. In particular, allowing for the continuous recording of the bed bathymetry and the spatial distribution of the suspended sediment over the oscillation cycle (Figure 3).

The Ultrasound Velocity Profiler has shown to be very useful for the study of flows with high suspended sediment concentrations, where optical techniques would fail. Using a three probe configuration the mean velocity and Reynolds stresses can be evaluated for the experiments in the LOWST. The use of this device has been extended to compute suspended sediment concentrations over the oscillation cycle using the acoustic backscatter (Figure 4). Part of this work is currently under review (Pedocchi and Garcia, 2007).

A new semi-empirical expression for the friction factor for oscillatory flows that emphasizes the smooth to rough and the laminar to rough transitions has been developed and it is being used in the analysis of the ripple data (Pedocchi and Garcia, under review).

Phase average techniques have been used to study the ADV data. From this preliminary analysis, it is clear that farther study is needed in the area of turbulence characterization of oscillatory flows. This is additionally being addressed by performing direct numerical simulations of oscillatory boundary layer (Figure 5) in collaboration with Mariano I. Cantero, who is currently at the Geology Department of the University of Illinois at Urbana-Champaign (Pedocchi et al. 2008).

IMPACT/APPLICATIONS

Provide the research community with new experimental 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, and there is no generally accepted predictor for the planform geometry of the ripple pattern. Additionally, the prediction capabilities of current semiempirical models depend on the distinction between orbital and anorbital ripples. New experiments (for example Dumas et al 2005 and O'Donoghue et al 2006) and field data (for example Traykovski et al 1999 and Hanes et al 2001) have shown that the data available at the time of development these models were incomplete. This is being done under the light of the new experiments in the LOWST and the data compiled in the literature review.

RELATED PROJECTS

This work is related to the past and present projects associated with the Mine Burial Effort on which our group has been participating, under the ONR Grants N00014-01-1-0337, and N00014-01-1-0540. Also the new equipment (PIV, LDV) purchased with the ONR Grant N00014-06-1-0661 (DURIP), is currently being used in the LOWST.

REFERENCES

Dumas S., Arnott R.W.C. and Southard J.B. (2005). "Experiments on oscillatory-flow and combined-flow bed forms: Implications for interpreting parts of the shallow-marine sedimentary record.", *J. Sedimentary Research*, 75: 501-513.
Hanes, D.M., V. Alymov, Y.S. Chang and Jette C. (2001). "Wave formed sand ripples at Duck, North Carolina.", *J. Geophysical Research*, 106(C10): 22575-22592.
Jensen, B. L., Sumer B. M., and Fredsoe, J. (1989). "Turbulent osillatory boundary layers at high Reynolds number." Journal of Fluid Mechanics, 206:265-97.
Jonsson, I. G. (1980). "A new approach to oscillatory rough turbulent boundary layers.", *Ocean Engineering*, 7(1):109-152.
O'Donoghue, T., Doucette, J.S., van der Werf, J.J. and Ribberink, J.S. (2006). "The dimensions of sand ripples in full-scale oscillatory flows.", *Coastal Engineering*, 53: 997–1012.
Traykovski, P., Hay A.E., Irish J.D., and Lynch J.F. (1999). "Geometry, migration, and evolution of wave orbital ripples at LEO-15.", *J. Geophysical Research*, 104(C1): 1505-1524.
Wiberg, P. L. and Harris, C. K. (1994). "Ripple geometry in wave-dominated environments." *J. Geophysical Research*, 99(C1): 775-789.

PUBLICATIONS

Landry, B. J. and Garcia, M. H.(2007). "Bathymetric Evolution of a Sandy Bed under Transient Progressive Waves." *Proceedings of Coastal Sediments 2007*, 1: 2191-2198. [published, refereed]
Pedocchi, F. and Garcia, M. H. (2007). "Observations in a Large Oscillatory Water-Sediment Tunnel." *Hydraulic Measurements & Experimental Methods 2007*, Lake Placid NY, September 10-12, 2007. [published, refereed]
Pedocchi, F., Martin, J. E. y García, M. H. (2008). "Inexpensive fluorescent particles for large-scale experiments using Particle Image Velocimetry." *Experiments in Fluids*. Vol. 45(1), 183-186. [published, refereed]
Pedocchi, F., Cantero, M. I. y García, M. H. (accepted for publication). "Direct Numerical Simulation of Transitional Stokes Boundary Layer." *2nd International Symposium on Shallow Flows, Hong Kong*, December 10-12. [in press, refereed]
Pedocchi, F. y García, M. H. (under review). "Evaluation of an Ultrasonic Velocity Profiler for velocity and suspended sediment measurements in a Large Oscillatory Water-Sediment Tunnel." *Experiments in Fluids*. [refereed]
Pedocchi, F. y García, M. H. (under review). "Friction coefficient for oscillatory flow: the rough-smooth turbulent transition." *J. of Hydraulic Research*. [refereed]

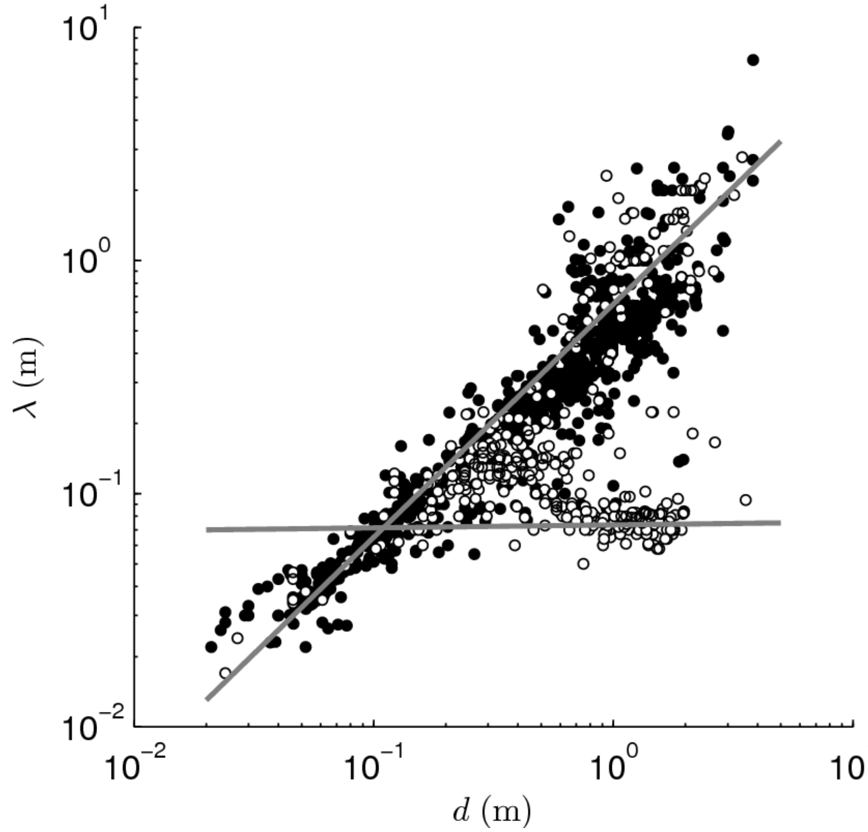

Figure 1: Compiled data from the literature. Relation between the ripple wave length and the near-bed excursion, discriminated by sediment size (black=coarse, white=fine).

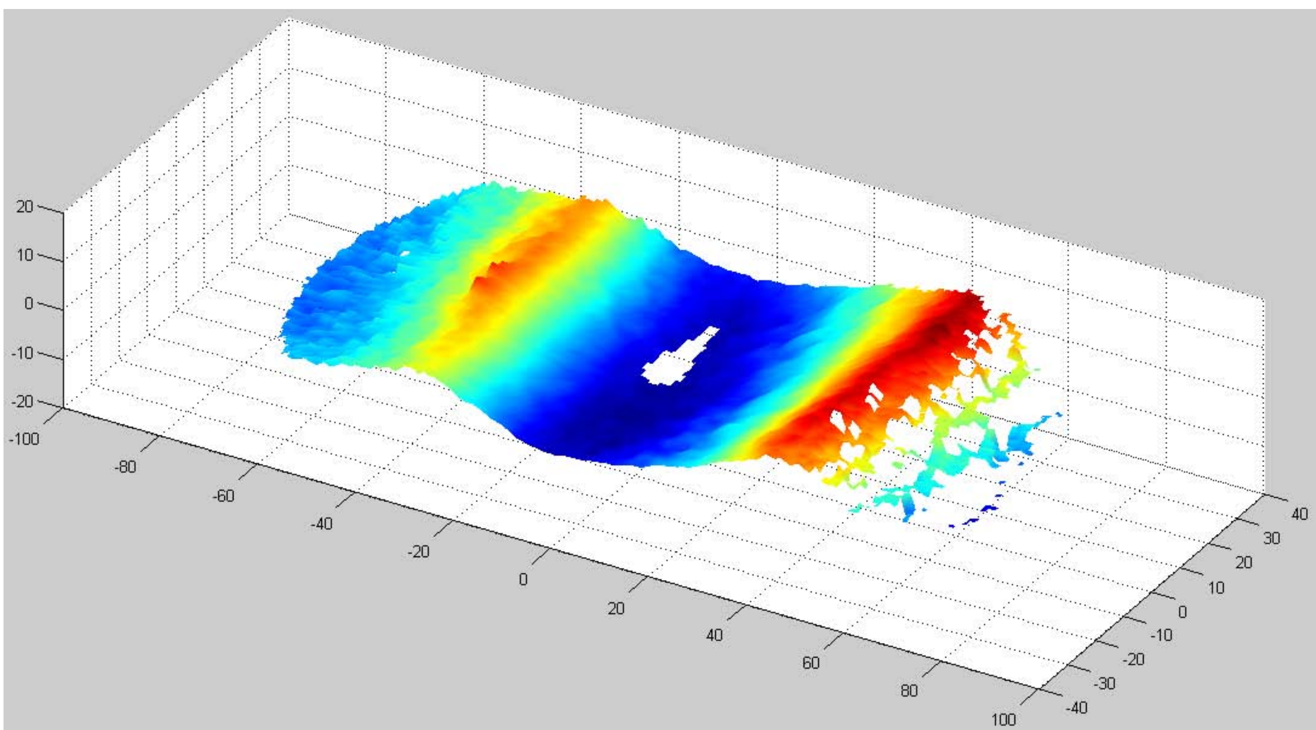

Figure 2 (a): Large sharp crested orbital ripple.

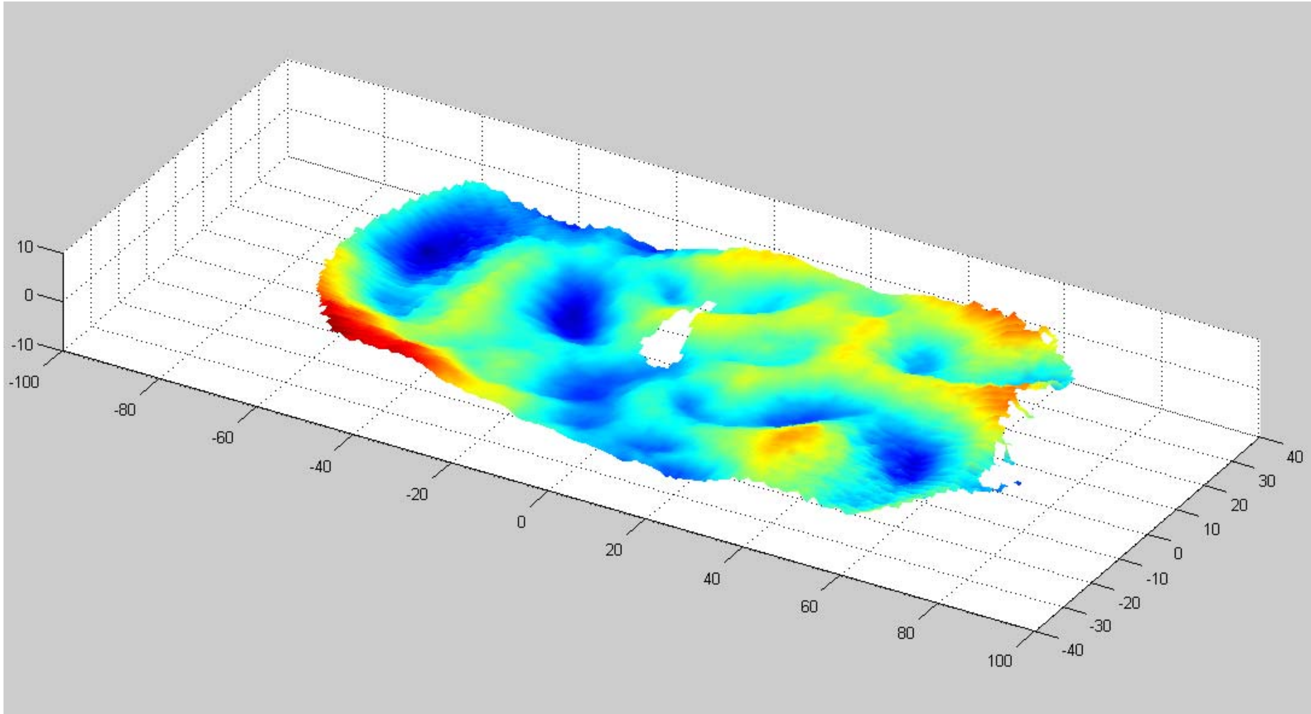

Figure 2 (b): Small 3D ripples.

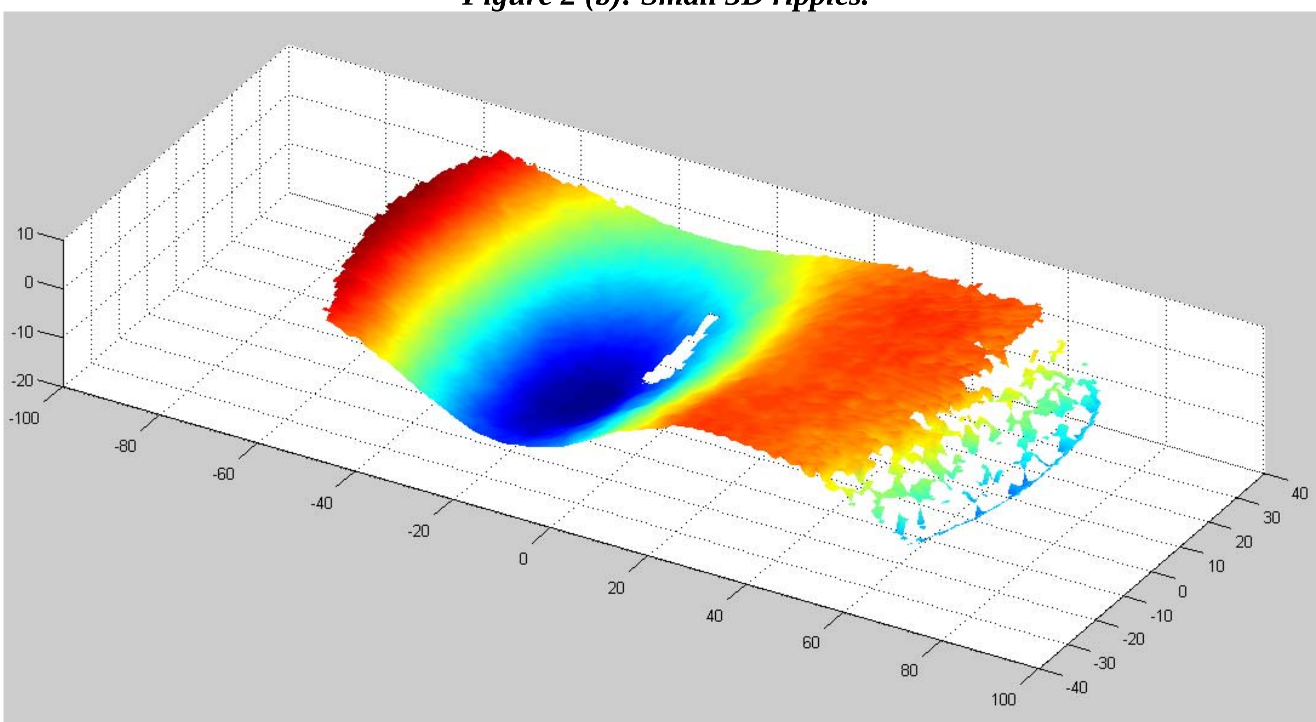

Figure 2 (c): Large round crested orbital ripple

Figure 2: All the ripples shown in the subfigures were generated with near-bed excursions of about 2 m but with different maximum orbital velocities. The velocity for (a) was 0.25 m/s, for (b) was 0.5 m/s and for (c) was 1.0 m/s. The displayed bed surveys were obtained with the in-house developed sonar system.

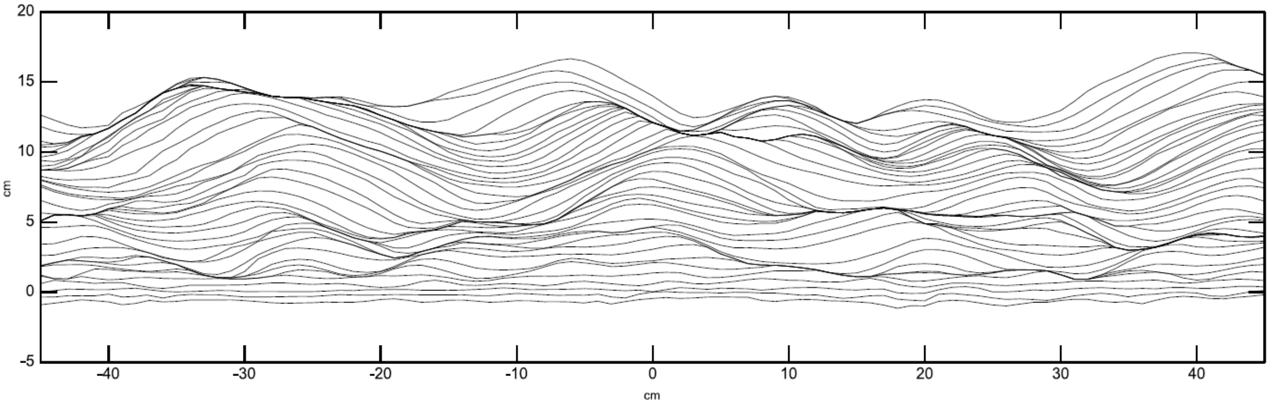

Figure 3: Synthetic stratification generated from consecutive bed surveys with the sonar starting from flat bed.

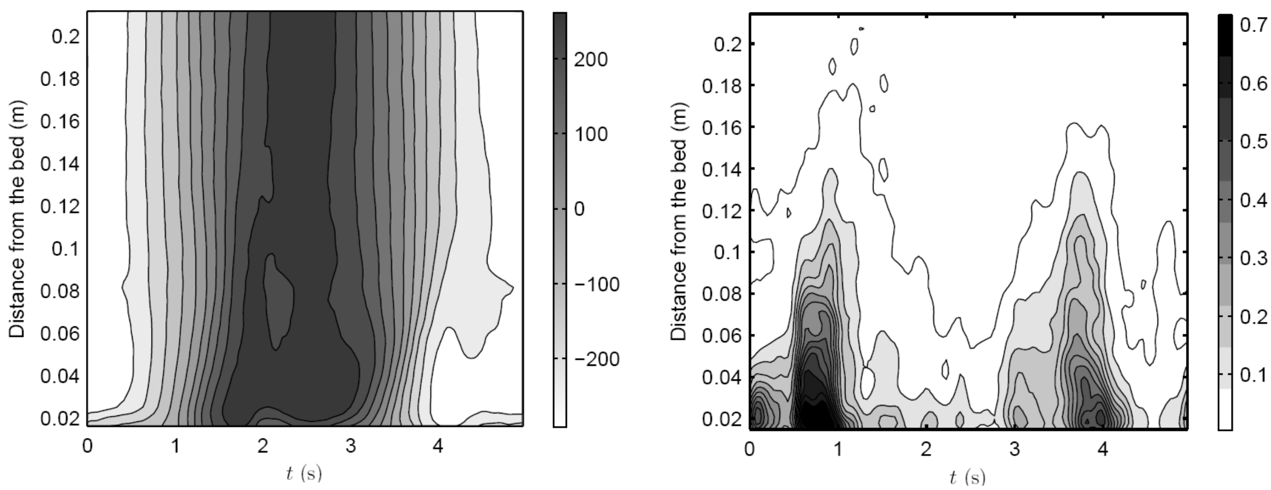

Figure 4: Contours of mean velocity (mm/s) and suspended sediment concentration (g/L) profiles along the wave cycle, for a 5 second period and 0.3 m/s maximum velocity oscillation, the sediment size is 250 μm. The bed was at dynamic equilibrium covered with 3D ripples.

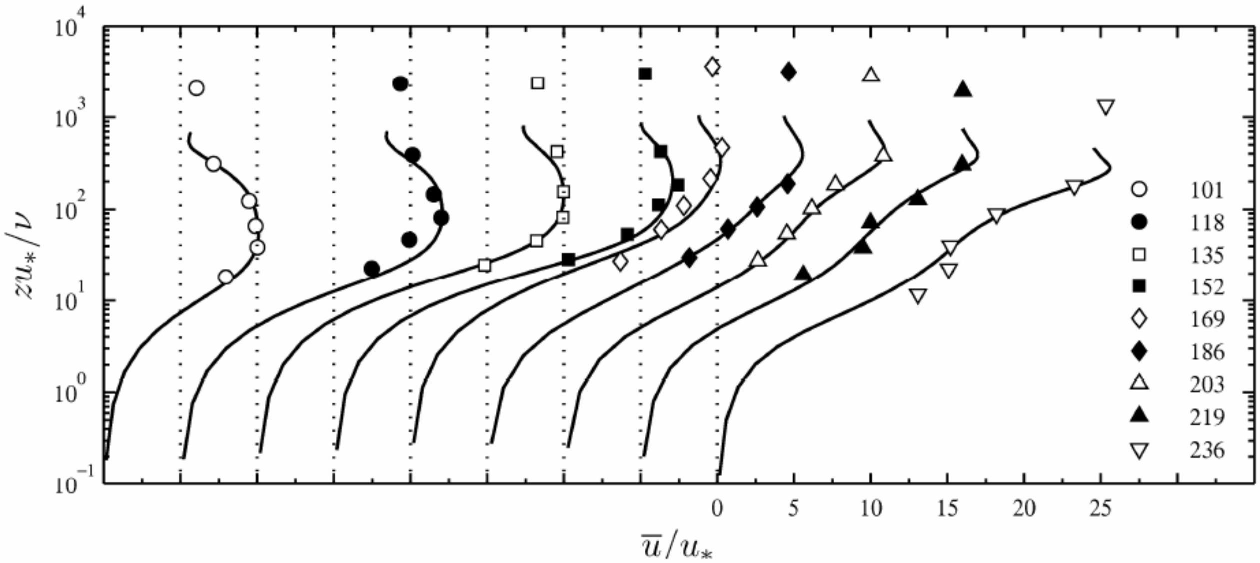

Figure 5: Mean streamwise velocity profiles for different oscillation phases. The numbers in the legend indicate the values of the phase in deg. Experimental data from Jensen (1989).