Proceedings of 2013 IAHR Congress
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The Evolution of Mobile Bed Tests. A Step Towards the Future of Coastal Engineering

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ABSTRACT: Coastal Engineering still presents significant levels of uncertainty, much larger for sediment transport and morphodynamics than for the driving hydrodynamics. Because of that there is still a need for experimental research that addresses the water and sediment fluxes occurring at multiple scales in the near shore and for some of which there are still not universally accepted equations or closure sub-models. Large scale bed tests offer the possibility to obtain undistorted results under controlled conditions that may look at sediment transport and associated bed evolution under a variety of wave and mean water level conditions. The present limitations in conventional observation equipment preclude a clear advancement in knowledge or model calibration. However the new developments in opto-acoustic equipment should allow such an advancement to take place provided the new experimental equipment becomes more robust in parallel with a protocol for deployment and data processing.

This paper will present the experimental approach to erosive and accretive beach dynamics, with emphasis on the accretive experiments. These accretive tests still present further uncertainties and sometimes cannot be explained with the present state of the art. Following this there is a presentation of the novel development of an acoustic bed form and suspended sediment imager, able to monitor bed forms near bed sediment transport and their corresponding dynamics. The next section deals with an acoustic high resolution concentration and velocity profiler that is able to infer even the elusive bed level, together with the near bed concentrated sediment transport and the details of fluxes on the stoss and lee sides of moving bed forms. This is followed by a discussion on the merits of novel optic techniques, using structured and unstructured light sources. There is also some remarks on new approaches.

Illustrated by the use of ferro-fluids to obtain directly the shear stresses acting on a wall even under the presence of "some" sediment. The paper ends with some conclusions on the use of such mobile bed tests in present and future Coastal Engineering.

KEY WORDS: Mobile bed, Hydraulic tests, Optics, Acoustics, Performance.

1 INTRODUCTION

Coastal engineering is still struggling with the inherent dynamics of near shore water and sediment fluxes. These dynamics go "against" the rigid infrastructures we built in the coastal zone and they still remain difficult to predict. Morphodynamic formulations and models still present an error level that may exceed by one order of magnitude that of the driving hydrodynamics. Most available observations come from small scale tests, with large distortions (see e.g. Sánchez-Arcilla *et al*, 2013) or from field campaigns without any scale distortion but under "uncontrolled" conditions. Moreover few large scale data sets exist with enough resolution to capture the peaks in water and sediment fluxes that are responsible for most of the morphodynamic evolution taking place in coastal zones at "engineering" scales (Masselink *et al*, 2009; Alsina and Cáceres, 2011).

The available sediment transport formulae have been normally derived for sand, without considering the sorting, the differences in form or density or even less the coexistence of sand and coarser sediments. However the effect of sediment sorting affects bottom friction, infiltration and exfiltration, sediment transport and bed form generation. These limits in knowledge (Summer *et al*, 2011) are starting to be pushed forward thanks to the new developments in optic and acoustic systems that have taken place during the last years (see e.g. Hurther *et al*, 2011). Although typically it is easier to use acoustic systems for large scale facilities where the water quality and clarity do not allow for easy optic measurements, these acoustic profiles are typically 1DV and therefore a large step behind what is needed to understand and model sediment transport processes over the inherently 3D bed form geometry. In addition, because of resonance and instabilities the resulting flow presents a variety of modes both along and across the main flume direction, which further compounds the problem. Because of these reasons it is required to introduce new observational techniques and improve the performance level of present mobile bed tests. The paper will explore that evolution, starting with a review of the conventional experimental approach to eroding and accretive wave sequences (section 2) showing the many remaining uncertainties in the design and interpretation of such tests. We shall next review (section 3) the set of observations that can be nowadays obtained using advanced equipment, prior to any new development in instrumentation. The paper will continue with a short presentation of the novel acoustic probes recently developed and how they can contribute to a better understanding of water and sediment fluxes in regions of high gradients such as the near bed boundary layer. This is followed by a section describing the generation of an optical "mesh" to recover water and sediment motions at the *swash* zone. Finally we shall discuss some new advances that could result in novel techniques to measure traditionally "elusive" parameters such as for instance the bed shear stress acting on a surface. The paper will end with some conclusions on how to link these developments in mobile bed experimental research to the future evolution of coastal engineering.

2 EXPERIMENTAL APPROACH TO EROSIVE AND ACCRETIVE BEACH PROFILES

There is a long tradition in erosive beach profile tests, going from small (the majority) to large scale (the minority) experiments and with a much smaller percentage of studies dealing with the accretive morphodynamic sequences. In this paper we shall describe three sets of experiments (SANDS, Bench Mark and WISE) carried out in the CIEM (Canal d'Investigació i Experimentació Marítima) flume, a large research facility within the Maritime Engineering Laboratory, LIM/UPC (Catalonia University of Technology, Barnatech). This facility is 100m long, 3m wide and 5m deep. The experiments here considered start all from a 1/15 initial bed profile and have been subject to a set of complementary erosive and accretive time series that sweep a certain range of "control" parameters, such as for instance the dimensionless fall velocity or Dean number.

This type of tests are conventionally instrumented with acoustic Doppler profilers, to record velocities, wave heights and mean water levels and surface piercing wave gauges or pore pressure transducers to complement the information on hydrodynamic drivers. The deployment of such conventional, although advanced, equipment needs to consider carefully the bed evolution (Figure 1 and 2). This is because of the high sensitivity of the resulting measurements to the distance with respect to the bed level, which is continuously changing. In our experiments, the sediment volume consisted of specially selected well sorted clean sand with a medium diameter of 0.25mm and a narrow grain size distribution.

The patterns of wave height and near shore 2DV circulation patterns are supplemented with optical back scatter sensors to recover the suspended sediment concentrations.

The ADVs are usually located close to one of the flume walls while the OBs where deployed in the same cross shore location and vertical elevation but close to the opposite wall, with a distance between devices around 2.0m.

The resulting erosive evolution is summarized in Figure 1, which shows the final profiles obtained for the three sets of experiments. It displays a comparison of the breaker bar evolution at comparable type steps, with small differences between the termed Bench Mark and WISE series due to the mechanical profiler errors and to the manual reshaping errors in compaction and initial shape. The differences between the three types of time series also reflect the different energetic content of the incoming wave series, with the SANDS breaker bar at a deeper position and better developed due to the higher relative energetic level of the erosive incoming waves.

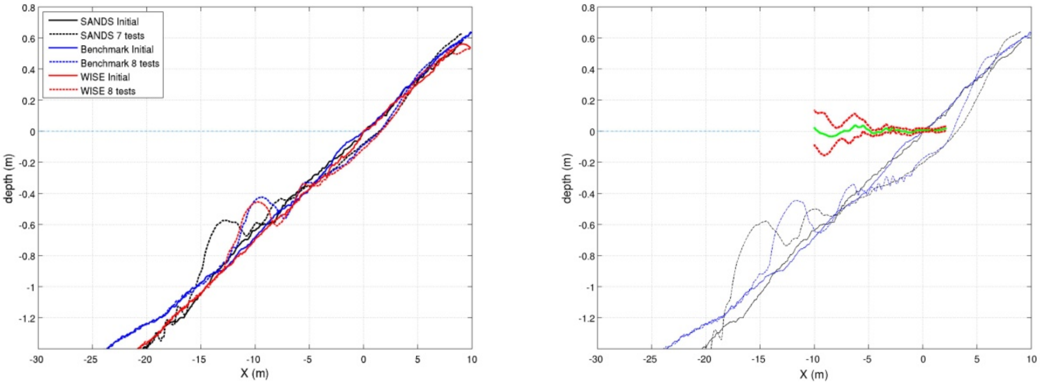


Figure 1 Initial slope and final erosive profiles obtained in the CIEM flume for the SANDS (black), Benchmark (blue) and WISE (red) series of experiments, together with the final profiles after 7 series for SANDS (black dashed), 8 series for Benchmark (blue dash) and 8 series for WISE (red dash) –left panel–. The right hand panel shows the initial (continuous line) and final (dash line) profiles after 35 erosive wave series for SANDS (black) and Benchmark (blue) experiments. The green line represents the mean differences between profiles in equivalent time instants while the red dashed line indicates the standard deviation between these same profiles.

The evolution of the bar appears in Figure 2 (right) and shows that after 35 erosive wave sequences the main differences are found on the bar location height and volume. The surf zone profile shape, in spite of the just mentioned bar differences, turns out to be surprisingly similar with just some minor differences attributed to the different test settings and given the error in the recovery process. In all cases we have studied the accretive behavior starting from this “natural” erosive profile, which provided a more robust approach due to the gentler shapes of the resulting morphology produced by the filtering effect of the bar (Figure 2).

In Figure 1 we also show the differences in mean value (continuous green line) and standard deviation (dashed red line) that have been obtained in the various tests and which appear as a function of the horizontal coordinate. The closer profile evolutions are obtained for the *surf* and inner *swash* zone, in spite of the SANDS wave series having almost 30% higher energetic content than the Bench Mark conditions. The analysis has also been carried out for the main peaks in the time series (in hydrodynamics and morphodynamic terms), showing clearly the differences due to the more energetic pulses and how they affect the morphodynamic evolution (Sánchez-Arcilla *et al*, 2013).

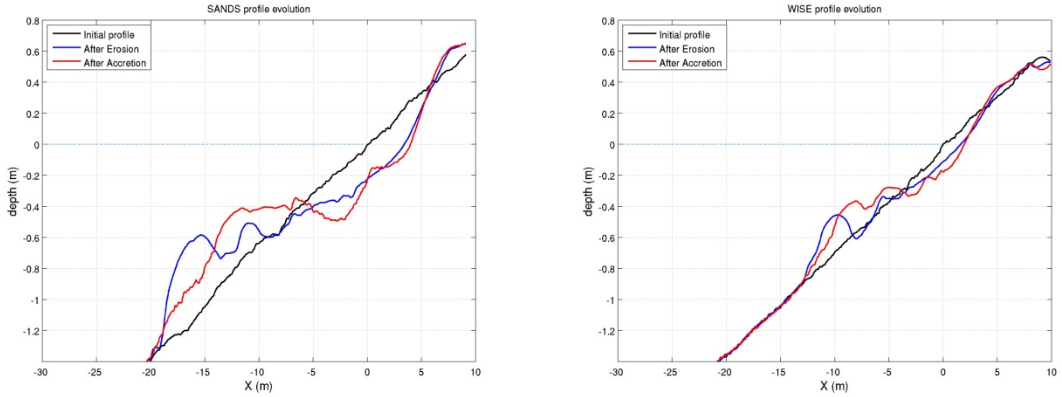


Figure 2 Accretive profile evolutions for the SANDS (left panel) and WISE (right panel) experiments after approximately 30 wave time series that started from the respective erosive geometry of both experiments.

3 THE ACCRETIVE COMPONENT IN MOBILE BED TESTS

Accretive wave series may start from a given profile section or from an eroded section developed within the same facility. In any case the bed evolution rates are comparatively slower and they require a longer time interval to reach morphodynamic equilibrium. Figure 2 shows the bed evolution for the SANDS (left) and WISE (right) experiments after about 30 wave series. Both experiments were carried out sweeping a convenient range of parameters. For erosive sequences the two sets had different energy levels but the same dimensionless fall velocity (Dean number). For accretive sequences the two sets had the same energy level but different Dean number. In all cases we compared the profile evolution at equivalent type intervals, to show the difference due to other elements such as compaction, actually generated wave sequence, etc, within the same laboratory.

The WISE evolution trend shows a more clearly accretive development with a bar migration volume close to twice that found in SANDS. The detailed analysis of the hydrodynamic driver in accretive tests sometimes suffers from the lack of enough spatial resolution due to the time evolution of the bed forms. In our case the WISE experiments featured a more energetic and better defined breaker zone over the main bar location and a secondary breaker zone at the terrace formed behind the trough.

When comparing the suspended sediment concentrations, very relevant since most of the beach deformation is due to such a transport mode, this must be done at equivalent *surf* zone location since otherwise the comparison will lack physical meaning. The concentrations found for the SANDS and WISE experiments (Figure 3) where found to present significant differences. In the figure we display the suspended sediment concentration (g/l) against time starting from the initial "instant" for both SANDS and WISE test and then showing the corresponding concentrations after five additional test series. The suspended sediment measurements show some discrepancies although the suspended concentration remains reasonably similar for the SANDS experiments, while showing an important decrease for the WISE experiments. This decrease in sediment concentration for the WISE test, mainly within the *surf* zone, is attributed to the fact that the bar development within WISE filters out the more energetic waves and suspended pulses and therefore this profile is reaching more efficiently an equilibrium geometry. This underlines also the control played by the breaker bar and the wave-backwash interactions in the overall pattern.

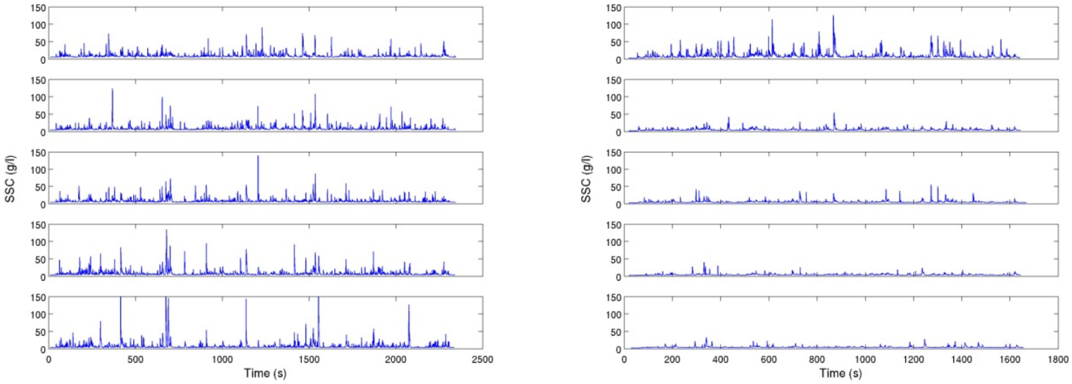


Figure 3 Time evolution of suspended sediment concentration at equivalent time intervals for the SANDS (left panel) and WISE (right panel) experiments. The upper line shows the concentrations after the third accretive sequence and all lower lines corresponds to five additional series (i.e. the 8th, 13th, 18th and 23rd sequences).

4 NOVEL ACOUSTIC OBSERVATIONS

4.1 Bed form and suspended sediment imager

The suspended sediment concentrations in large scale laboratory facilities make it difficult to use optic techniques to resolve with enough accuracy and reliability the details of sharp gradient layers such as the bed boundary. Because of that we have started to develop a device that provides information on bed form and migration and the associated suspended sediment fluxes with a quasi 3D resolution. This means a significant step forward in understanding and modeling sediment transport processes over a bed weigh forms.

The bed formed suspended sediment imager (BASSI) is an autonomous battery powered device with four transducer lying arrays, each of which is connected to a single electronic scheduling unit that controls the sampling parameters (Moate et al 2011). A schematic of the system is presented in Figure 4. Each transducer array houses 15 individual narrow beam disc transducers that function with three different frequencies interleaved across the array. The complete system consists of 60 transducers spaced regularly at 33 mm intervals over a 2.0 m range in the horizontal with a 1 metre vertical profile having a spatial resolution of 0.5 cm and with variable sampling rates and onboard averaging.

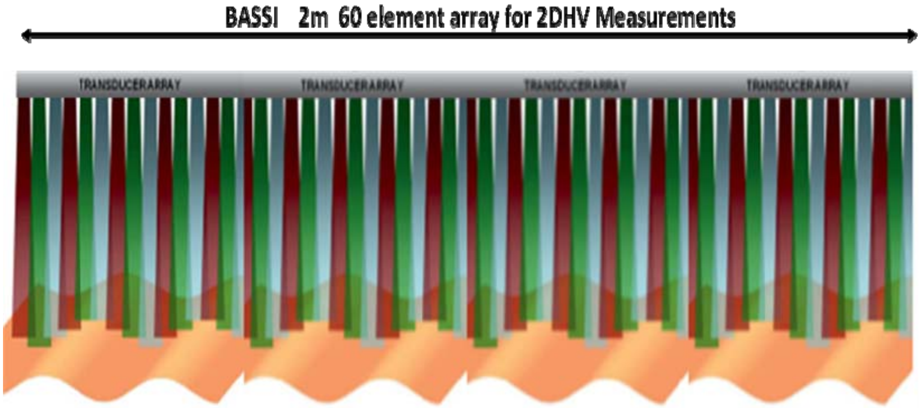


Figure 4 Bedform And Suspended Sediment Imager; BASSI array. The different beam colours represent different acoustic frequencies.

In a recent field trial the whole system was deployed in an estuarine environment and data collected over a 72 hr period. The data has been analyzed to yield relative suspended sediment concentrations (Thorne et al 2011). An illustration from a single image is shown in Figure 5. The figure clearly shows suspended sediment structures over a 2m transect and the profile of the bed. Creating sequential time series images of the kind shown in Figure 4 will provide detailed process measurements above bedforms which can be used to develop and assess process based sediment transport models.

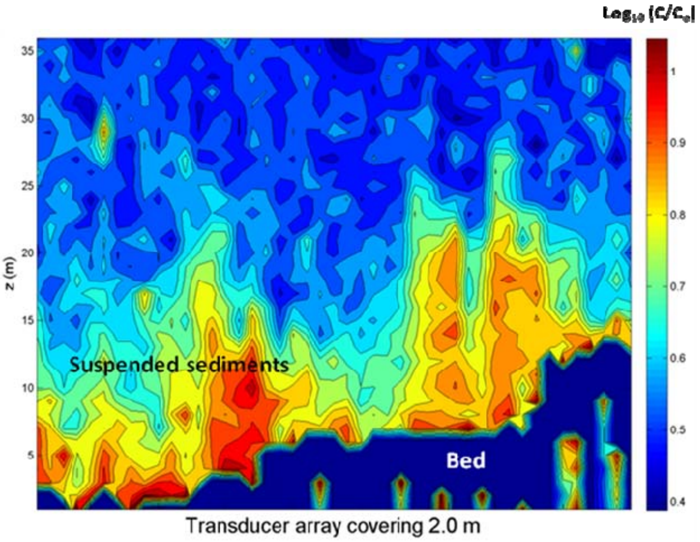


Figure 5 A provisional synoptic image of the bed and suspended sediments over a 2.0 m transect measured with the 60 transducer multi-frequency BASSI in a tidal estuary. The colour bar represents relative concentration.

4.2 High resolution concentration and velocity profiler

The near bed, high resolution concentration and velocity profiler (NB-ACVP) intends to circumvent some of the limitations present in more conventional acoustic profilers named ABS, ADVP, UDVP, CDP or Vectrino II; they are all ultrasonic flow measuring systems used mainly in the coastal and river research communities for the study of flow and sediment transport processes across the benthic flow region. Dependent on the instrument type, these systems provide 1D profile (usually along the vertical direction) of 1C to 3C Doppler velocities, suspended sediment concentration and mean particle size above a sediment bed. Only recently, a system combining ABS and ADVP technologies has been developed within the European project Hydralab3-SANDS under the name of ACVP (Hurther et al. 2011). As a result, sediment flux profiles are measured at rates allowing the resolution of small turbulent flow scales. This measurement capability is considered as an essential step forward in the investigation of sediment transport processes. However, the validity of the measurements is currently limited to the suspension layer. The on-going Hydralab4-WISE project aims at developing a novel nearbed ACVP adapted to the high-resolution profiling across both the suspension and the bedload layers. The main objective consists in evaluating the validity of the acoustic measurements across the bedload layer.

The proposed NB-ACVP (Figure 6) is configured as a 1D2C profiler composed of one central transmitter (T) and two large-angle receivers (R_1 and R_2). Each pair of transmitter and receiver represents a bistatic system capable of profiling a radial velocity component along the vertical acoustic beam. The two radial components are measured in the same plane which is aligned with longitudinal flow plane so that the horizontal and vertical velocity components u and w can be reconstructed. The principles and methods of the pulse-coherent Doppler velocity profiling and the co-located sediment concentration profiling are described in Hurther et al. (2011). Compared to the standard ACVP, the electronics of the novel NB-ACVP has specific characteristics to increase the spatio-temporal measurement resolution. Furthermore, the profiling across both the suspension and bedload layers requires the use of electronics capable of self-regulated amplification in order to avoid problems of signal saturation at the interface between the suspension and the bed load layers.

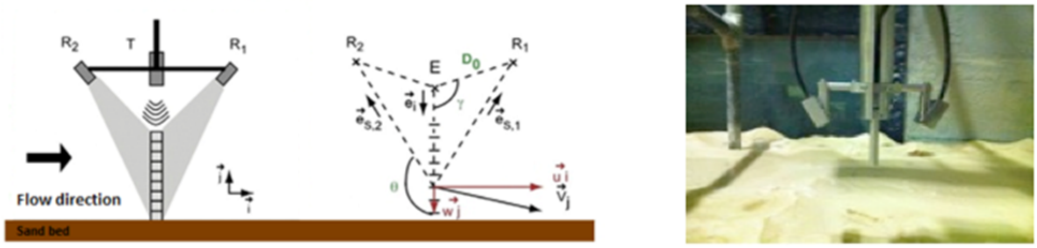


Figure 6 NB-ACVP sketch and corresponding photograph..

An example of 2C velocity and sediment flux profiling is shown in Figure 7a and 7b. The experiment was conducted in January 2013 using a hydraulic open-channel flow facility of the Leichtweiss Wasser Institut at TU Braunscheig, Germany. The flow consists of a steady gravity current forced by the tilted flume bed. The mobile sediment bed is composed of sand particles with a median size of d_{50}=290µm. The flow regime is fully turbulent and subcritical. Sand Dunes under equilibrium conditions are generated before the start of the ACVP measurements. In Figure 7, the vector plots represent the mean 2C velocity field above the dunes migrating in donwflow direction. The superimposed colourplots represent the mean streamwise sediment flux cu in [kg. s^{-1}.m^{-2}]. As can be seen in Figure 7a, the obtained velocity is principally unidirectional and horizontal above the stoss side of the dune. Downward deflected mean velocity is seen on the lee-side due to the presence of a flow recirculation zone in the wake region on the lee-side of the dune. The flow recirculation has anti-clockwise transverse vorticity as shown in the zoomed domain in Fig. 7b. Furthermore, the location of the reattachment point can be clearly distinguished. The sediment flux measurement shown in Figure 7a reveals the presence of a thin bedload layer with high sediment flux values. This red coloured layer is supposed to be associated to the bedload layer and it is oriented in stream wise direction along the stoss side of the dune. In the zoomed recirculation zone (Figure 7b) it can be seen that a negative upflow oriented sediment flux is observed due to the negative mean velocity measured on the lee-side of the dune. These preliminary NB-ACVP measurements show the potential of such a technology for process oriented sediment transport studies as discussed in Naqshband et al (2013).

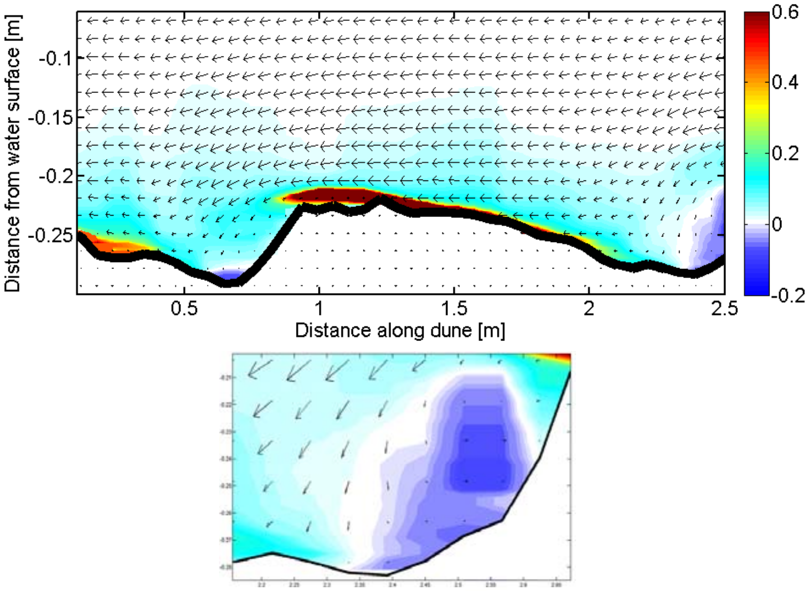


Figure 7 (a) Mean 2C velocity vector field and sediment flux (in kg. s-1.m-2) in measured above a migrating sand dune using the novel Near-Bed ACVP developed within Hydrlab4-WISE. (b) Zoom of the measurements obtained in the recirculation zone on the dune lee-side.

5 NOVEL OPTIC OBSERVATIONS

5.1 Unstructured light projection

A technique based on non-intrusive stereoscopic photogrammetry has been developed to measure the bed evolution in the swash zone at high temporal resolution at the wave and wave-group scale. To describe the physically relevant bed-evolution at these scales, the measurements (i) need to be acquired at much higher frequencies than the fundamental wave frequency, (ii) should resolve the vertical variation of the order of the grain-scale, (iii) should cover as much as possible the cross-shore extent of the swash zone as well the width of the flume to distinguish non 2D behavior.

Existing stereoscopic techniques have so far been applied to the natural beaches with measurement accuracies of more than a centimeter, for example by Holland and Holman (1997) who used naturally occurring surface patterns (foam) for the stereo-recognition procedure. Astruc et al., 2012, on the other hand, for measurements in a large-scale flume used artificial patterns projected onto the surface and were able to achieve a vertical accuracy of less than a millimeter. Yet, the measurements were limited to a surface of 2 x 3 m2 with an acquisition frequency at 5Hz in a burst mode. Here, our aim is to extend the technique of Astruc et al 2012 to a measurement area to about 2.5 x 8 m^2, covering the entire swash zone, and to increase the frequency to 10Hz in a continuous mode, all while retaining the vertical accuracy. Only with this type of coverage can we obtain reliable results in the swash zone evolution and, at the same time, carry out a check on the two-dimensionality and quality of the hydraulic experiment.

For this purpose we have used high-resolution 4M pixel cameras as in Astruc et al 2012, but with improvements on the lighting quality and power for the projection of the artificial (dot) patterns. Camera lenses were correspondingly adapted, dot-patterns were optimized in size and spacing, the calibration procedure was also optimized and finally the pattern-recognition algorithm was improved for the sub-pixel determination of the dot patterns. The changes have been implemented in the WISE campaign at UPC in the spring of 2012 (see Figure 8).

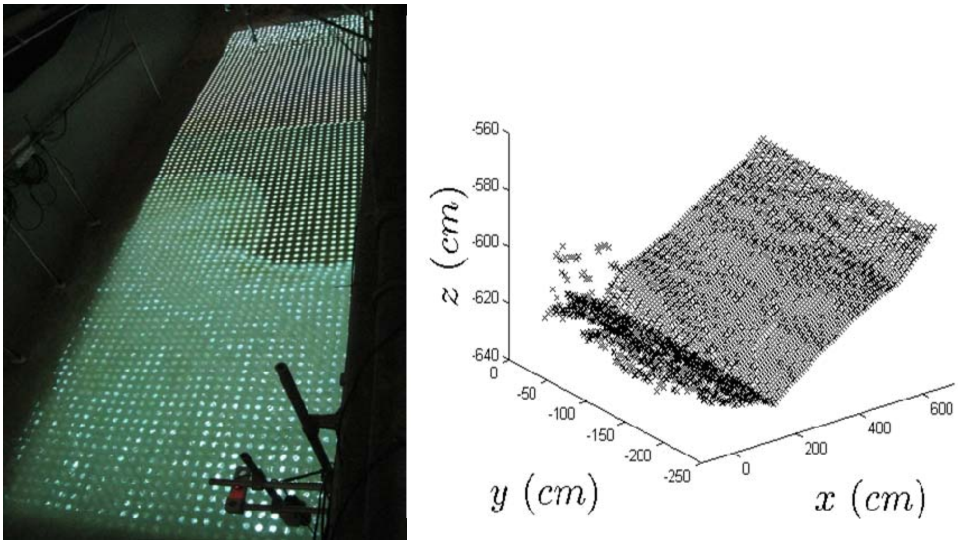


Figure 8 Sample results from the novel optic techniques developed, showing (a) the projected dot-pattern for the stereoscopic photogrammetry measurements with a measurement area of about 2.5 x 7.5 m² and (b) an illustrative example of computed bed geometry.

In Astruc et al 2012, the theoretical stereoscopic vertical error estimate based on Benetazzo (2006) was about 100 μm, while the maximum measured error attributed to the total precision of the measurements was about 600 μm (including vibrations, lighting fluctuations etc). Here, with the new parameters and a much larger measurement field, the theoretical error is slightly larger at about 250 μm while the maximum measured error is about 700 μm (see Astier et al, 2013). Thus, even though the theoretical stereoscopic error was larger, the maximum error did not increase significantly.

It is also important to distinguish wet and dry areas, the technique being focused on measuring the dry bed between up and downwash motions. This is accomplished by temporally filtering the data on the basis that the fluctuations measured over the water-surface are significantly higher than over the dry bed. This technique also permits identifying and tracking the moving water fronts (Astier et al 2013) allowing a new level of observations for the shore-line dynamics.

5.2 Structured light scanner

Terrestrial 3D Laser Scanning (TLS), so far being used extensively in several engineering applications, (Hentschel et al., 2007; Lecking and Wagner, 2011), and is becoming more and more frequently the method of choice for beach surveying (e.g. van Gaalen et al., 2011). At the same time, the coastal community is gradually becoming aware of the high potential of TLS for innovative coastal monitoring techniques and improved data quality. Recent efforts have shown that, apart from the terrestrial LIDARs used for topographic measurements, laser scanning has several unexploited possibilities such as for high-frequency, water surface measurements in the surf (Park et al., 2011) and swash zones (Blenkinsopp et al., 2010), and even for autonomous monitoring of 2D wave fields (Wübbold et al., 2012).

In the meantime, there are numerous applications of video techniques for hydrodynamic and morphodynamic measurements in field or laboratory set-ups (e.g. Foti et al., 2011; Holman and Stanley, 2007; Vousdoukas et al., 2011) and it is often the case that the geo-rectification errors are among the most important uncertainty factors, especially in the case of mono-scopic vision. Stereo-vision provides a solution and has been successfully applied to measure wave fields (Benetazzo et al., 2012; Mironov et al.,

2012) and topography (Astruc et al., 2012; Foti et al., 2011); it is usually rather computationally intensive. Moreover, implementation on the field is even more tedious since; (i) the measurement accuracy is usually reduced with increasing sampling area, resulting in observations of limited spatial extent; and (ii) the inability to control the light conditions can make robust feature matching a practical and scientific challenge.

Under the WISE project we are developing a hybrid monitoring system (Figure 9) consisting of several components (2D and 3D laser scanners, video cameras), which can also integrate arrays of standard water level gauges, in order to monitor rapid morphological change at the beach face. The present approach, even though not matching the sub-mm accuracy reported in the previous section, has the benefits of easy implementation and simple pre- and post-processing. The 2D scanner, by providing instantaneous surface elevation measurements, minimizes the geo-rectification errors and enhances our capacity to extract quantitative information from coastal imagery. Moreover, the colour information provided by the video imagery simplifies the processing of the 2D laser scanner data. Typically, ‘beach’ or ‘water’ zones are identified from the ultrasonic elevation measurements based on objective, signal-related criteria (Turner et al., 2008) such as low variability of the signal (for a given duration) and local minima. Local 2D scanner measurements can be processed in a similar fashion, but this approach still presents considerable uncertainties. In contrast, the accurately geo-rectified image information allows an easy and robust classification of the ‘dry’ and ‘wet’ parts of the monitored area, as well as rapid validation on a GUI environment (Vousdoukas et al., 2012).

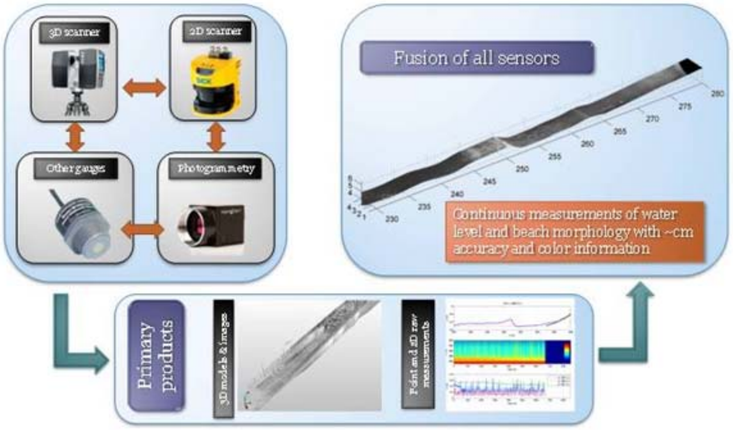


Figure 9 A hybrid laser scanner/video system to monitor wave-by-wave beach-face evolution using a set of laser scanners and video cameras, with the capacity to integrate other sensors.

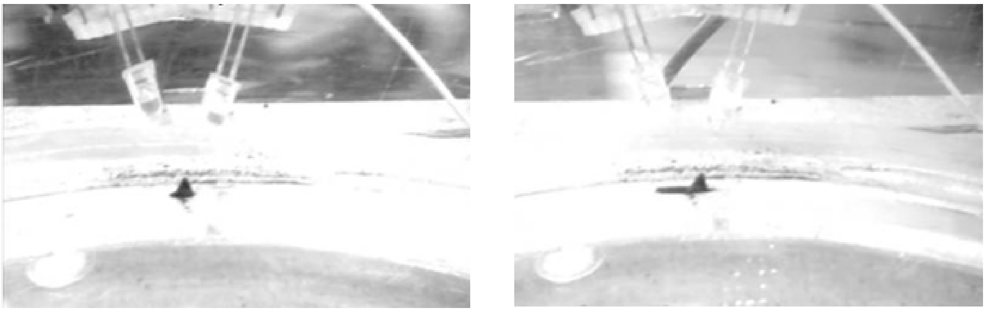
6 NOVEL SHEAR STRESS OBSERVATION SYSTEM

The problem of measuring the wall shear stress directly is relevant in the coastal and maritime context, since right at the boundaries large flow resistances develop, affecting both the hydrodynamics and the morphodynamics of coastal areas at large extent. However, a number of difficulties are usually associated to the direct shear stress measurement, above all in unsteady conditions, due to the presence of turbulent boundary layers, characterized by velocities and shear stresses with varying intensity and direction. In literature, different solutions have been proposed: mechanical approaches by means of shear plates located at the bottom (Riedel et al. 1972, Rankine and Hires, 2000), thermal anemometry by hot-film and hot-wire probes to measure the shear stresses generated at the bottom in the presence of waves and currents (Sumer et al., 1993). However, such instruments present several limits. The mechanical probes are able to provide only integral measures, since the measuring area is large few square decimeters, while the measurements by thermal probes, despite being more accurate (measuring area O (1cm2)) than those by shear plates, in the turbulent regime are based on a calibration performed in the laminar regime. Moreover, such probes are extremely sensitive to the external operating conditions and they cannot be used in the presence of sediments. Finally, several methods for estimating the shear stresses are based on the measure of the velocity profile close to the bottom by means of acoustic or optic instruments, such as ADV, LDA, PIV and PTV (Cox et al. 1996, Musumeci et al. 2006, Wallace and Vukoslavčević, 2010).

Unfortunately, due to the bottom induced reflection, all this instruments do not provide very accurate velocity measurements very close to the wall.

Only very recently a new methodology for the measurement of the bottom shear stress in a quasi-noninvasive manner has been proposed based on the use of ferro-fluids (Andò et al. 2009) and it is now being systematically developed and tested within WISE-Hydralab IV.

The principle of operation of such a technique is based on the use of super-paramagnetic two-state systems made up by small ferromagnetic particles (size 1 15 nm) dispersed in an organic non-magnetic solvent, called ferro-fluids. The measurement strategy is to use very small quantities of ferro-fluid (order of few thousandths of milliliters) located at the wall, under the action of a permanent (DC) magnetic field. More in details, in the hydrostatic conditions, i.e. when only the DC magnetic field is present, due to the Rosensweig effect (Cowley and Rosensweig, 1967) and the on purpose developed setup, the ferro-fluid drop has a conical shape. In dynamic conditions, in the presence of an either steady or unsteady flow such a cone will deform due to the drag force the fluid exercises on it and therefore it will move in the flow direction as a consequence of the applied bottom shear stress. Figure 10 shows the deformation of a ferrofluid drop due to an oscillating motion, both at lower speed and higher speed (wave period respectively equal to 15 s and 10 s). The displacement of the mass of the drop of ferro-fluid depends on the velocity of the fluid. To detect and quantify this displacement an optical and an inductive readout strategy by using two planar coils have been developed. The main advantage of the technique as opposite to thermal anemometry is that it is able to reach very close to the bottom by potentially less sensitive to the presence of impurities, and it could be used also in the presence of a moderate sediment transport.



(a) **(b)**

Figure 10 Deformation of a drop of ferro-fluid within an annular cell rotating at a: a) lower speed (wave period T=15 s) and a b) higher speed (wave period T=10 s).

7 CONCLUSIONS

The error in morphodynamic observations or numerical simulations may exceed by more than order of magnitude the uncertainty level in the hydrodynamics drivers, applied especially to waves of various frequencies and currents; the role of turbulence lies in between and is part of the reason for the increase in error when dealing with sediment fluxes and the associated bed evolution. This justifies the need for high resolution observation, particularly near high gradient regions such as the bed boundary layer, that allow generating new knowledge and calibrating new formulations and, eventually, numerical models. The uncertainty in conventional observations, due to the poor resolution in space (eventually also in time) or to the uncertain bed level and therefore high of the measuring point with respect to the bed, is so large that the integration from such point wise data to more aggregated estimates cannot be easily performed. This precludes any direct advances in sediment transport formulations or morphodynamic simulations, so that the link between many of present day measurements and the available modeling tools cannot be easily established.

Because of these reasons we suggest further development and validation of the opto-acoustic techniques we have been preparing in WISE-Hydralab IV and their use in hydraulic facilities of various characteristics, so that the performance limits can be robustly established and their use can be generalized to other facilities. The new wealth of observational information will allow an improve understanding of the sediment entrainment and transport processes particularly in regions of high gradients like the near bed boundary or like the inner *surf* zone or *swash* zone. The complexities due to "layers" that are alternatively wet and dry such as the crest to draft layer or the *swash* zone further compound the problem of obtaining physically meaningful estimations for the water and sediment fluxes.

The transition to more aggregated bulk parameters is also a challenging task due to the compound errors obtained when aggregating the high resolution in time and space measurements. Moreover even the aggregated behavior of beach profiles when subject to erosive or accretive wave conditions remains still only partly predictable or understandable with the present level of knowledge. For instance the differences between in principal similar tests mentioned in the first sections of the paper or the occurrence of shoreline erosion even under accretive wave sequences inside a flume are two of the many possible examples illustrating this limit in knowledge. The combination of improved observations, contributing to develop further inside into the controlling processes and an improve calibration of the transport formulations will lead to a better assessment of morphodynamic evolution under varying wave and mean water level conditions. This will lead in turn, to more reliable coastal engineering predictions. In any case the knowledge we are obtaining with our improved observations on the "details" of water and sediment fluxes even determining the elusive sea bed level, will contribute to an increase awareness of the scientific and engineering communities about the limitations and capabilities of present instruments and numerical tools.

ACKNOWLEDGEMENTS

This research has been supported by the European Research Project "WISE-HYDRALAB IV More than water, dealing with the complex interaction of water with environmental elements, sediment, structure and ice" (contract nº261520). It has also received partial support from CTM2010-19709.

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