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MEASUREMENTS OF SAND TRANSPORT PROCESSES UNDER BREAKING AND IRREGULAR WAVES

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Morphodynamic modelling systems used in coastal engineering practice consist of coupled models for waves, currents, sediment transport and bed level change. The sediment transport model usually incorporates a "practical" model for the sediment transport near the bed, comprising empirical formulae relating net sediment transport to the local flow and sediment conditions. Well-founded models are based on insights and measurements from laboratory experiments, and capture the key physical processes determining the transport in a parameterised way. An example is the SANTOSS model, which is formulated to account for the effects of wave skewness and wave asymmetry, wave-induced streaming and sediment phase lag effects, and to apply to a wide range of sand size, wave and wave-plus-current conditions. However, like other models, the SANTOSS model is almost exclusively based on transport rates and processes measured in laboratory experiments involving regular, non-breaking waves. In reality of course, sea waves are always irregular and, in many cases of practical interest, the waves are breaking. Research is therefore needed to identify and quantify the key sediment transport processes associated with wave breaking and wave irregularity in order to improve the predictive capability of coastal morphological models.

Researchers from the University of Twente, the University of Aberdeen, LEGI-CNRS in France and the National Oceanography Centre, Liverpool, combined forces to conduct experiments on irregular and breaking wave sand transport processes using a large wave flume - the Canal d'Investigacio I Experimentacio Maritima (CIEM) at the Universitat Politècnica de Catalunya (UPC) - within the framework of the EU-funded Hydralab IV project. Named SandT-Pro and conducted between October 2013 and January 2014, the experiments used advanced instrumentation to measure the physical processes that drive sand transport under breaking and irregular wave conditions.

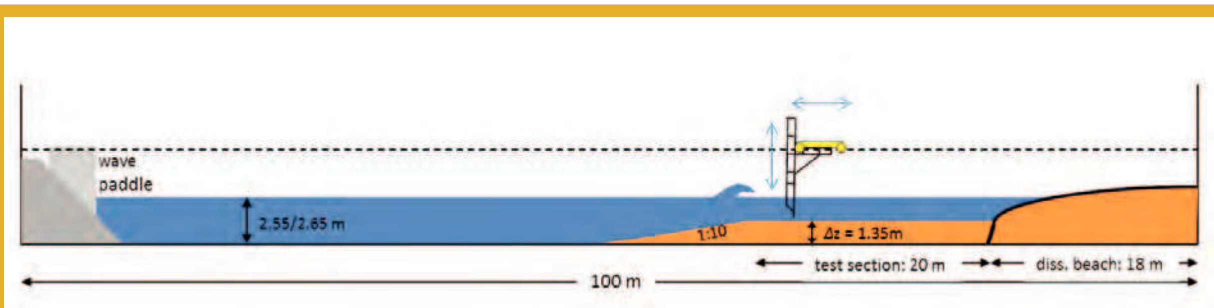
Experimental set-up

The primary advantage in using the CIEM facility for these experiments is its large size: the flume is 100m long, 3m wide and 5m deep, and is capable of producing near full-scale-size waves. A facility of this size eliminates the scale effects associated with sediment-based experiments in smaller facilities and enables measurement of detailed processes not easily measured at small scale. For the SandT-Pro experiments the CIEM flume was configured as shown in Figure 1. A bed of medium sand (D_{50} of 0.25mm) was located approximately 50m from the wave paddle. Initially (i.e. before wave action) the sand bed comprised an offshore slope (1:10 or 1:20), followed by a 20-m long, 1.35-m deep horizontal section; a fixed parabolic beach was located beyond the sand bed for wave dissipation.

Two types of experiment were conducted: (i) Regular breaking wave experiments, which focused on the effects of wave breaking on near-bed sediment dynamics, especially the effects of breaking-induced turbulence and sediment stirring; (ii) Irregular non-breaking wave experiments, in which the waves consisted of groups of waves generated by bi-chromatic superposition or amplitude modulation of regular waves; these experiments focused on the effects of wave sequencing on the near-bed hydro- and sediment dynamics.

The breaking wave experiments were conducted with a 2.55m water depth at the wave paddle and waves with period 4s. The waves started to break at the beginning of the horizontal test section and repeated wave action resulted in the development of a large breaker bar (approximately 7.5m long and 0.6m high after 6hrs of wave action for waves with height 0.85m and profile offshore slope 1:10). As the bed profile evolved detailed process measurements were made at a number of cross-shore positions, from the offshore slope to well shoreward of the bar position, with the highest spatial resolution around the breaking point. For the irregular wave experiments, the water depth at the paddle was increased to 2.65m and experiments were conducted for a range of grouped non-breaking wave conditions with wave period 4.4s and maximum wave height up to 0.8m; for these irregular wave experiments, the measurements were made at

Figure 1 - Set-up in the CIEM for the SandT-Pro experiments



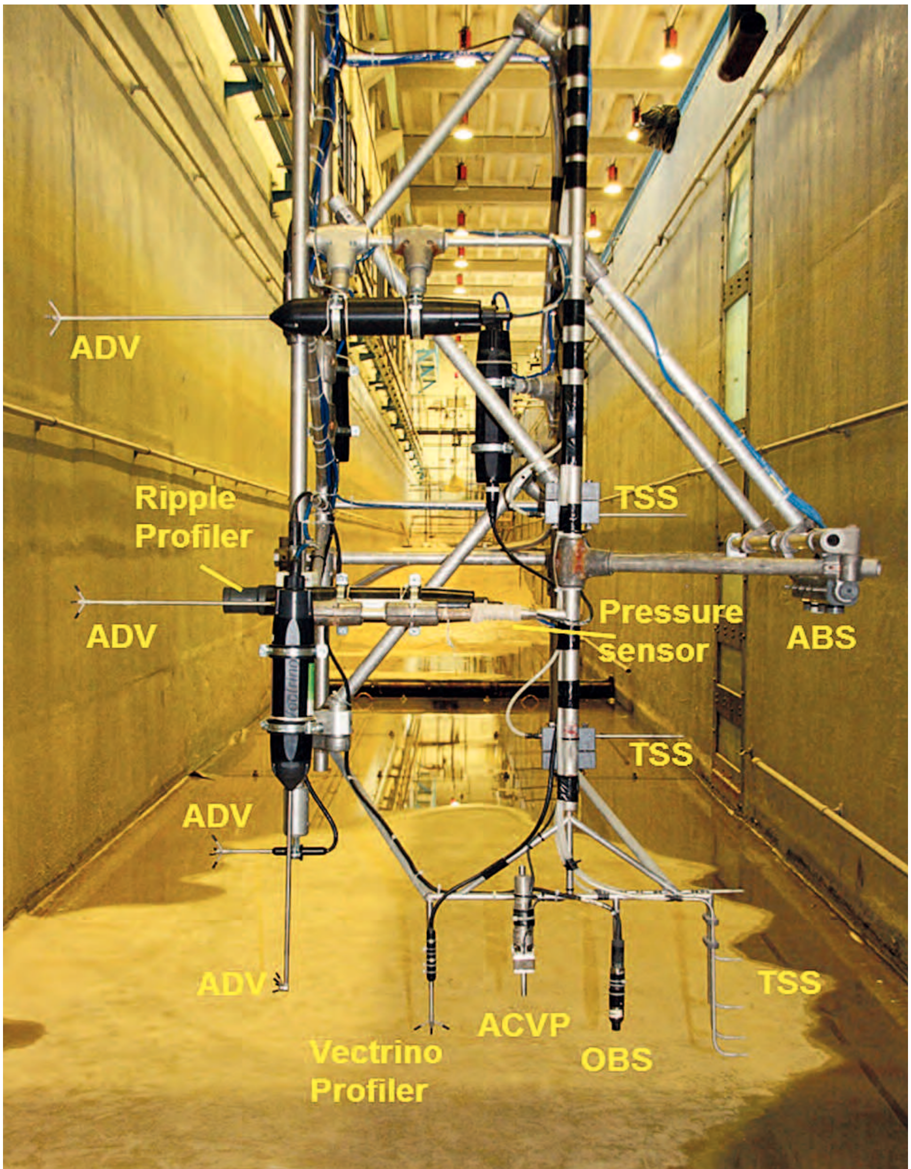


Figure 2 - Instrument set-up on mobile frame.

one cross-shore location in the middle of the 20-m long horizontal section.

Measurements

State-of-the-art instrumentation deployed from a mobile measuring frame custom-built for the experiments (Figure 2) was used to obtain the process measurements. The frame is a stiff construction of small-diameter, steel tubing, and was mounted to the flume's carriage, which runs on rails located at the top of the flume. A spindle adjustment enables the instrument frame to be vertically positioned with 0(mm) accuracy.

The instrument set-up on the frame is shown in Figure 2. Flow velocities were measured using 4 acoustic Doppler velocimeters (ADVs), a Vectrino profiler and a high-resolution acoustic concentration and velocity profiler (HR-ACVP). Sediment concentrations were measured using the HR-ACVP, 3 optical backscatter sensors (OBS), an AQUAscat acoustic backscatter system (ABS) and a 7-nozzle transverse suction sampling system (TSS). Besides the instruments deployed on the instrument frame, two conductivity concentration measurement (CCM) tanks for sheet flow measurements were installed in the sand bed, below two additional HR-ACVPs. Water surface elevation was measured along the flume with 13 resistive wave gauges and, near the breaker location, with 9 pore pressure transducers. Net transport along the profile was calculated using mass conservation principles applied to pre- and post-test bed profiles measured with acoustic bed profilers.

While all instruments are important to the experiment, it is the instruments measuring close to the bed, within the wave bottom boundary layer, which are of primary interest here. Of these, the HR-ACVP is especially important as it simultaneously measures sand concentration and 2 velocity components over a 10-cm vertical profile, with 1mm vertical resolution, thereby revealing the detailed intra-wave sediment fluxes in the near-bed region.

Ongoing work

The experiments have generated a large dataset, the analysis of which is ongoing. Early results show that the bar develops due to the combined effect of onshore-directed sand transport from seaward of the break-point and offshore-directed sand transport from shoreward; the former is mainly driven by wave asymmetry with sheet-flow conditions, while the latter is dominated by the offshore-directed suspended sand transport driven by undertow.

The Hydralab IV SandT-Pro experiments are integrated within a larger research project on sand transport processes under breaking and irregular waves. Named SINBAD, the project is led by the Universities of Twente and Aberdeen and funded by the Dutch STW and the UK's EPSRC. SINBAD involves two additional experimental campaigns in the CIEM, one in which similar detailed process measurements to SandT-Pro are made, but focused on a particular stage of the bar development, and a second in which hydrodynamics only are measured over the barred profile made rigid by laying concrete on the sand bed. The results from the combined set of experiments will be important for the future development of well-founded sand transport models, such as the SANTOSS model.

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