

STOKES DRIFT AND CURRENT PROFILES IN THE NEARSHORE: LABORATORY EXPERIMENT USING 3D PARTICLE TRACKING VELOCITY

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INTRODUCTION

The presence of marine pollutants such as marine plastics has increased significantly over the last decades and poses a major environmental problem. In the nearshore zone, extending from the shoreline to a few kilometres offshore, waves propagating at the surface of the ocean generate currents that play an important role in the transport, mixing and diffusion of marine pollutants. The modelling of marine transport in the nearshore area is therefore crucial for mitigation purposes, and rely on a good understanding of wave-induced currents in the water column (Moulton et al., 2022).

Laboratory experiments have been performed in the last decades to address these questions and enhance our understanding of cross-shore wave-induced currents profile in the nearshore. However, despite numerous experiments (more than 40 laboratory experiments), results are very broad and show different profile patterns. Therefore, there is still no complete understanding of cross-shore wave-induced currents in the nearshore, especially near the shoaling zone where a lot of processes interact with each other.

In parallel, the development of new flow measurement techniques and technologies over the last decades has significantly improved our capability to accurately measure particle trajectory, hence investigate the Stokes drift (van den Bremer et al., 2019) and current profiles. The present study performs a laboratory experiment using for the first time 3D Particle Tracking Velocity (PTV) to investigate wave-induced currents in the nearshore.

METHOD

An experiment was performed in November 2023 at TUDelft Hydraulic Engineering Laboratory, in the 39 m long, 0.79 m wide and 1 m height wave flume (Figure 1).



Figure 1 - Hydraulic Engineering wave flume (TUDelft)

The flume is equipped with a piston-type wave generator, with second-order wave generation and active reflection compensation. The flume has a local 30 cm wide by 100 cm long glass window at the bottom as well as glass walls to allow optical access. A 1/25 fixed planar and impermeable slope is installed in the flume (Figure 2), allowing wave dissipation through breaking. Note that an optical access window, matching in size and location the flume bottom window, is built in the slope.

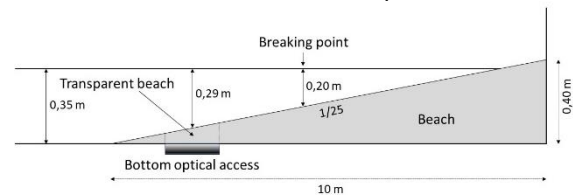


Figure 2 - Sketch of the flume set-up.

The still water level is kept constant at 0.35 m during the entire experiment. Four regular wave conditions are tested during the experiment (the important parameters are given in Table 1). These conditions ensure an intermediate water depth regime at the wave paddle, an Ursell number below 25 to limit non-linearities and a Reynolds number above 2000 (*i.e.*, turbulent regime).

Table 1 - Regular wave conditions used in this experiment (Wave height, H ; Wave period, T ; Wave steepness, ka ; Water depth regime, kh ; Ursell number, $Ur=HL^2/h^3$; Reynolds number, $Re=aU_{orb}/\nu$, with U_{orb} the wave orbital velocity at surface and ν the kinematic viscosity taken as $1.3 \times 10^{-6} \text{ m}^2/\text{s}$; Theoretical surface Stokes drift. Note $h=0.35 \text{ m}$.

	H (m)	T (s)	ka	kh	Ur	Re	Stokes drift (cm/s)
W1	0.10	1.80	0.10	0.71	22	12500	3.3
W2	0.13	1.40	0.18	0.96	16	22300	7.3
W3	0.06	1.20	0.10	1.18	5	5000	2.0
W4	0.07	1.40	0.09	0.96	8	6500	2.1

Measurements of fluid velocity are obtained with a state-of-the-art 3D PTV system from La Vision, which consists of a 'MiniShaker' apparatus (a box containing 4 cameras at fixed angle, recording at 50 fps), two LED light boxes (pulsed light synchronised with the cameras) and the 'Shake-the-Box' data processing system. The conceptual approach of 3D PTV is to illuminate a volume of fluid seeded with particles, and record images at high frequency to track these particles through space and time

(Figure 3). To optimise the tracking under the action of surface waves and limit the effect of light reflection, fluorescent particles of 125 μm in diameter are used. The system should provide a field of view of 60 cm wide, 40 cm high and 40 cm deep. In addition, measurements of surface drift are obtained using an overhead camera, looking down over the same area (Figure 3), tracking 4 mm diameter floating plastic balls. The PTV and surface drift measurements are synchronized and triggered together as 'currents measurement'.

Five consecutive repeats of two-minute 'currents measurement' are taken for each wave conditions, after generating waves for one hour to allow currents stabilisation.

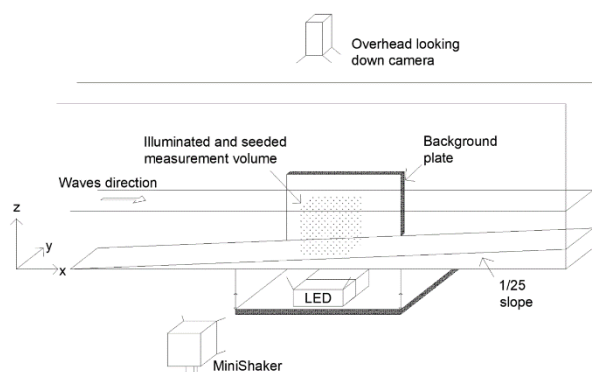


Figure 3 - Sketch of the experimental set-up. Note that the MiniShaker is located at 0.5 m from the centre of the illuminated volume.

The surface elevation is recorded during the entire duration of each test, on the flat section of the flume before the beach (*i.e.*, $h=0.35$ m, offshore), at the location of the 'currents measurement' ($h=0.29$ m) and around the breaking point ($h=0.20$ m), using resistive wave gauges. The wave gauges at the 'currents measurement' location are offset from the centerline of the flume to avoid direct interference with the flow and field of view. The surface elevation measurements are also time synchronized with the 'currents measurement'.

DISCUSSION

Although the literature on laboratory experiment investigating wave-induced currents is rich, more than 3 over 4 papers measured only the Eulerian current. Given that the most used mass transport by waves theories (*i.e.*, Stokes' irrotational solution and Longuet-Higgins (1953) 'conductive' solution) lead to the Lagrangian current profile, it appears crucial to measure in a Lagrangian frame to fully address this research question. Most of the few studies focusing on Lagrangian measurements date back to a few decades when visual and dye based methods were the only options. The present PTV Lagrangian measurements approach allows the recording of current profiles to a level of accuracy never reached before. In addition, state-of-the-art grid reconstruction method enables Eulerian velocity to also be retrieved from the trajectories, thus providing a full description of the flow.

The theoretical surface Stokes drift for this experiment is in the order of 5 cm/s (Table 1), and the Eulerian return current in the order of 2 cm/s. The interactions between these currents, the undertow and any other set-up-induced currents will be thoroughly investigated. A particular attention will be given in the detection and analysis of the vortex train described in Matsunaga et al. (1994), as this train of offshore propagating vortices are expected to occur for wave condition W1 and 4 but not for W2 and 3.

The influence of the beach (shoaling and breaking) will be analysed from the recorded profiles, and compared with the intermediate and deep water profiles from the laboratory literature. This study also aims to provide a better understanding of the processes involved in the formation of wave-induced current profiles observed in the field in the nearshore area (*e.g.*, Lentz et al., 2008). This experiment will also include, via an associated co-project, SWASH modelling and experiments under rotation to further explore this topic.

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