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LAGRANGIAN MEASUREMENTS OF SURFACE WATER WAVES: RELATION BETWEEN DRIFT VELOCITIES AND SET-DOWN

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1 INTRODUCTION

Since the work of Stokes on steady progressive surface waves (Stokes, 1847), there has been interest in fluid particle trajectories and associated mass flux. The original result obtained by Stokes was based on linear theory, and implied that there is a net forward drift in the fluid beneath a propagating surface wave. In the non-dimensional case, the drift velocity for a sinusoidal wave on a fluid of depth h is given by

$$\bar{u}_L = a^2 \omega k \frac{\cosh(2k(z+h))}{2\sinh^2 kh} \quad (1)$$

where $\omega = \sqrt{gk \tanh kh}$.

Recent works suggest that in many cases, particularly in waves propagating over a shear flow, a net Eulerian flow may develop, which is opposed to the Stokes drift. Monismith et al. (2007) suggested that in a deep-water setting, the net Eulerian backflow may cancel the Lagrangian Stokes drift on a pointwise basis. Further, Grue & Kolaas (2017) found good agreement with the theoretical findings of Longuet-Higgins (1953), except near the bottom and near the free surface, where boundary layers have a discernable impact on the induced flow.

In recent field measurements, it was observed that the drift velocity correlates positively with the local average fluid depth (Bjørnestad et al., 2021). In other words, a wave with a set-up features a large forward drift, while a wave with a set-down features a negative net drift. The present work aims at investigating what observed in the field by means of laboratory experiments carried out in a wave flume, where monochromatic and bichromatic waves of different characteristics have been run.

2 LABORATORY EXPERIMENTS AND DATA ANALYSIS

The experiments were conducted in the Hydraulics Laboratory of the Università Politecnica delle Marche (Ancona, Italy) using a flume (size: 50m×1m×1.3m, see Figure 1a,b) equipped with a piston-type wavemaker which has been used in previous studies of coastal phenomena (e.g., Brocchini et al., 2022, 2023). The present experiments were designed to investigate the flow field induced by both monochromatic waves and bichromatic waves within the water column, especially in terms of particle trajectories and longitudinal velocity distribution along the vertical. To this aim, a FLARE 12M125 CCD camera with 12 Mpx resolution and 16-bit pixel depth was used together with a light sheet created by a halogen lamp and ground chili peppers as the neutral seeding (Figure 1b). The selected water depth was h = 12 cm, over which several wave characteristics were tested (amplitude a_1 = 1 cm and a_1 = 3 cm), period T_1 = 1 s. The bichromatic wave was produced by superimposing a shorter wave onto a longer wave. The shorter component was based on the same characteristics of the above-mentioned monochromatic wave (a_1, T_1), while the longer component was characterized by a smaller amplitude and a longer period (a_2,

T_2), with the aim to reproduce the natural combination of shorter sea waves with longer infragravity waves that typically occur in the nearshore region (Bertin et al., 2018). The two tests reported in Table 1 are analyzed.

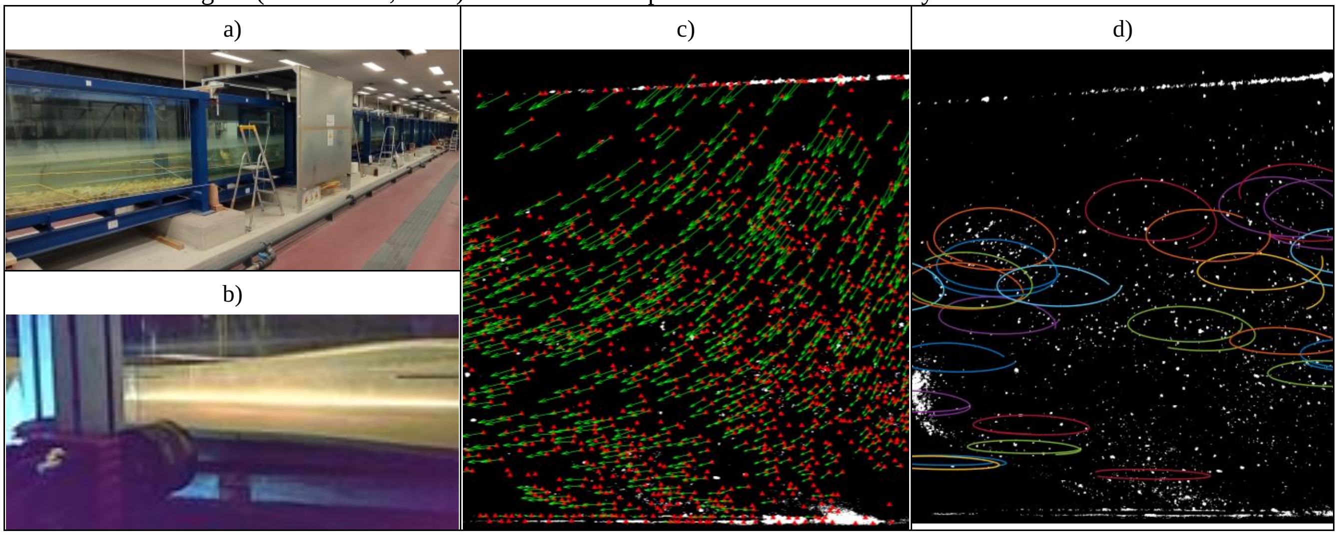

Figure 1: Experimental setup: *a)* wave flume, *b)* investigated area.
PTV analysis: *c)* flow field reconstruction, *d)* trajectory extraction.

Table 1: Main characteristics of the analyzed tests

	h [m]	a_1 [m]	T_1 [s]	a_2 [m]	T_2 [s]
Test 1	0.12	0.015	1	-	-
Test 2	0.12	0.015	1	0.003	10

The images collected by the camera were analyzed using Particle Tracking Velocimetry (PTV), the main purpose being that of tracking the seeding particles in motion inside the light sheet generated within the water column (red vectors in Figure 1c). On the one hand, the single trajectories enable us to investigate the Lagrangian motion of the fluid particles and thus to shed light on the drift velocity at different vertical locations. On the other hand, the Eulerian flow field is reconstructed starting from the Lagrangian framework, thus leading to the investigation of the mean motion at different phases of the tested waves. Figure 1d illustrates the preliminary results from the PTV analysis of Test 1 (regular wave) and highlights the Lagrangian particle trajectories extracted during an entire wave cycle. The Eulerian flow field extracted from the trajectories allows us to calculate the vertical profiles of longitudinal velocity. The experimental trajectories will be compared with theoretical predictions using the approach proposed by Borluk & Kalisch (2012).

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