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DETERMINATION OF DRAG AND INERTIA COEFFICIENTS BY AN ANALYTICAL MODEL

GARANCE MARLIER[1,2,5], FREDERIC BOUCHETTE[1,2], SAMUEL MEULE[2,3], RAPHAEL CERTAIN[2,4], JEAN-YVES JOUVENEL[5]

1 Géosciences-Montpellier, University of Montpellier, CNRS, France, garance.marlier@umontpellier.fr

2 GLADYS, University of Montpellier, France, frederic.bouchette@umontpellier.fr

3 CEREGE, University of Aix-Marseille, CNRS, IRD, INRAE, Coll France, France, meule@cerege.fr

4 CEFREM UMR-CNRS 5110, University of Perpignan Via Domitia, France, certain@univ-perp.fr

5 P2A Développement, France, jouvenel@p2adev.com

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1 INTRODUCTION

Hard structures like dykes or groins have been recognized for their negative environmental impact and limited durability in the face of climate change (Sutton-Grier *et al.*, 2015). The concept of Shore Soft Engineering (SSE) has allowed ecological considerations to be embedded in the design of coastal protection (Hartig *et al.*, 2011). Among emerging defense structures, nature-based solutions are built with natural materials and rely on physical properties and mechanisms observed in nature. They aim to protect, manage and restore ecosystems while providing some benefit to the human-being and biodiversity (Cohen-Shacham *et al.*, 2016); they offer an interesting alternative to hard structures. However, implementing these solutions in urbanized coastal areas where ecosystems are vulnerable can be challenging. Another alternative approach is using biomimetic solutions, which can provide the functions of natural systems like seagrass, dunes, or coral through robust human-made constructions. Natural habitats exist in a variety of more or less complex forms, ranging from rigid (mangroves, coral) to flexible (seagrass) (Mullarney and Henderson, 2018); and they drive changes in the current profile, in wave dissipation or in sediment motion. Understanding how to mimic these systems, in particular their internal geometry and hydrodynamic effects, is challenging. This complexity makes the development of biomimetic solutions difficult (Perricone et al., 2023). In this context, this study strictly focuses on wave dissipation by flexible systems.

Wave dissipation by natural habitats has been extensively studied through laboratory experiments (Houser *et al., 2015*) and in-situ measurements (Bradley and Houser, 2009). The pioneer analytical model (Dalrymple *et al.*, 1984) depicted aquatic vegetation as rigid cylinders; however, the rigidity assumption fails to capture the inherent flexibility of plants. Alternative strategies emerged to account for this flexibility, such as using an empirical drag coefficient (Mendez and Losada, 2004) or introducing an effective length, representing the length that a rigid cylinder would have to dissipate the same wave height as flexible cylinders (Luhar and Nepf, 2016). However, to define this effective length or an empirical drag coefficient, it is necessary to carry out in-situ measurements. Numerous analytical models based on force balance (Luhar and Nepf, 2016; Leclercq and de Langre, 2018) have been developed to represent the movement of flexible vegetation like seagrass. These models depict the flexible vegetation as a series of segmented rigid stems attached to each other and subjected to oscillating flows. Some models attempt to link stem motion with wave dissipation to integrate this coupling into numerical models (Yin *et al*., 2022). However, these models still require unknown quantities such as drag and inertial coefficients. The present study aims to develop an analytical model for determining drag and inertial coefficients based solely on the geometry, the structure flexibility and wave forcing. At last, the method could help better represent the dissipation into numerical simulations without the need for prior parametrization.

2 METHOD

The development of such an analytical model is based on linear theory and on the choice of some constraints on the motion of the modelled stem. Intrinsic frequency, amplitude and phase shift of the stem motion are chosen relatively to that of the wave forcing thanks to a 2-term parametrization which represents in some way the global rheological properties of the flexible structure. The stem is assumed to be rigid, anchored to the bottom at one of its ends. The stem motion is assumed to be driven by drag, buoyancy and inertia forces in the presence of waves; however shear stress is not accounted for because of the stem rigidity. A force balance over the entire stem is calculated, in which the two-term parametrization is inserted. From the resulting laws, drag and inertia coefficients are expressed as functions of known parameters (structure geometry and hydrodynamic forcing). These last expressions are finally employed to explore relationships between hydrodynamic forcing, geometry, and dissipation properties of the flexible system considered.

3 RESULTS

Drag and inertia coefficients from the analytical model are compared against existing in-situ and laboratory findings from the literature, as well as data gathered from a field campaign conducted at Palavas-les-Flots (France; April 2023). During this campaign, biomimetic kelp structures similar to rough flexible stems were deployed in 3 m of water depth in the nearshore to mitigate sediment accumulation next to the Lez river outlet. Wave gauges deployed before, within and after the flexible structures provided new information on wave dissipation under various wave forcing conditions. Wave dissipation of the order of 10% was measured over the flexible system. It is demonstrated that the drag coefficient derived from those measurements has the same order of magnitude as that calculated after several formulations in the literature (Houser *et al., 2015*), although none considering inertial effects. The results derived from the present analytical model do introduce the inertial effect and thus might improve the fit between measured and calculated wave dissipation over flexible systems.

4 CONCLUSION

The analytical model presented here is a first attempt to better quantify the impact of artificial flexible structures on wave dissipation in the natural environment. The reformulation of some hydrodynamic/structure interactions allows the writing of adapted functions to describe wave dissipation. Such formulations could be embedded into realistic wave propagation numerical models from which more advanced analysis of hydrodynamic / flexible structures could be captured.

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