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A Novel Shear Plate for Direct Measurements of Bottom Shear Stress Induced by a Model Ship Propeller

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A b s t r a c t

The high rotational speed of ship propellers generates a strongly turbulent jet which can impact the stability of channel, river and ocean beds, as well as harbour structures. For the design of protective measures against scouring, the boundary shear stresses induced by propeller jets must be estimated. However, so far there is no general method available for such estimations. This is partly related to the intrinsic difficulties to perform direct measurements of boundary shear stress. We present preliminary results of measurements of bottom shear stresses generated by a ship propeller. To this end a novel shear plate which operates with strain gauges was developed. The measurements result in the expected quadratic relation between bed shear stress and the propeller rotational speed, and also give evidence of a good reproducibility. The new shear plate shows to be an affordable and reliable tool for the measurement of submerged boundary shear stresses.

Keywords: shear stress measurements, ship propeller, scouring, bed stability.

1. INTRODUCTION

The design of stable revetments to protect alluvial beds from the scouring action of ship propellers requires a reliable estimate of the expected forces that would act over the bottom. Different methods are used in hydraulics and river engineering to calculate these forces through indirect estimation of the bottom shear stress (e.g., Rowiński et al. 2005). However, such

methods are mostly restricted to normal flow conditions or contain a large degree of uncertainty. Therefore, they cannot be applied to the strongly turbulent jets generated by ship propellers. Semi-empirical formulas are available to describe the velocity field in the propeller wake, but no general accurate methods have been developed to relate the jet near-boundary flow velocity to the bottom shear stress. This knowledge gap is in part related to the intrinsic difficulties to perform direct measurements of bed shear stress induced by ship propellers, either in laboratory or field.

The objective of this work is to present the design of a novel system for the direct measurement of bottom shear stresses. Although similar devices exist and have been described in previous literature (e.g., Tinoco and Cowen 2013), they are normally based on expensive technology, while the system here presented is made of relatively low-cost components. The general characteristics of the new system are described and preliminary results of measurements of bed shear stress induced by a ship propeller are presented.

2. CHARACTERISTICS OF THE SHEAR PLATE AND PRELIMINARY TESTS

The shear measurement system is composed of a rectangular head plate (HP) resting upon a jointed support (JS) and upon a force measurement system (DFS) (Fig. 1) used by Schoneboom et al. (2008) to measure drag forces of single vegetation elements. The DFS is based on the employment of four double strain gauges mounted on a stainless steel beam. The strain gauges are connected to an amplifier and the corresponding signal is logged by a PC. The function of the JS is to allow a horizontal displacement of HP, and in turn of the head of the DFS, as a reaction to the shear forces exerted by the flow on the HP. The displacement induces deformation of the steel beam embedded in the DFS, generating bending moments and compression strains, which are measured directly by the strain gauges.

To test the novel system, the bottom shear stress was measured for six different rotational speeds of a model propeller. The results are shown in Fig. 2. As expected, the measured shear stresses correlated well with the square of the propeller rotational speed. Moreover, for 6 repetitions of the measurements for each speed, the standard deviation of the measured forces (considering an area of the HP of 0.093 m^2) was in average 0.032 N, giving evidence of the high sensibility of the system and of the good reproducibility in terms of the complex turbulent flow field. These preliminary results show that the new shear plate is a promising device for reliable measurements of submerged boundary shear stress under a wide range of environments and flow conditions.

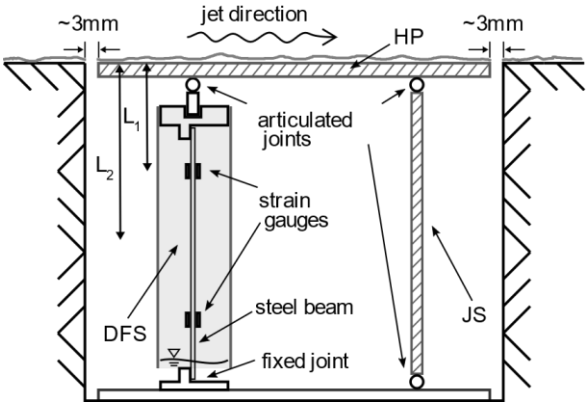

Fig. 1. Components of the new shear plate.

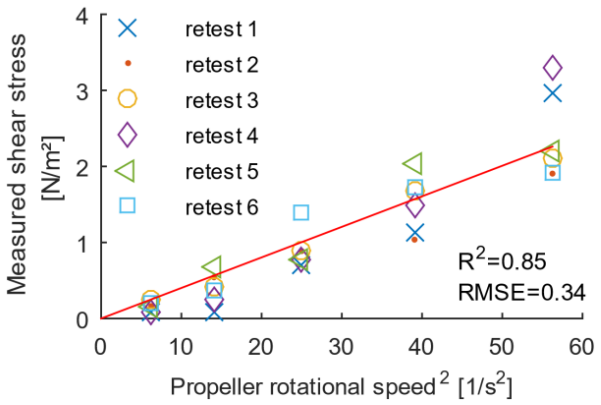

Fig. 2. Variation of bed shear stress with the square of the propeller rotational speed.

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