DEFECT FUNCTION MODELS FOR THE WAVE BOUNDARY LAYERS

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ABSTRACT

The boundary layer flow induced by surface waves has been extensively investigated due to its significance in engineering applications such as sediment transport and hydrodynamic forces on subsea structures. Several forms of defect functions (referred to as *DF* hereafter) were developed in the past decades, e.g. Sleath (1970, 1982), Nielsen (1985, 2016) and etc., due to their good efficiency in the description of the velocity distribution in one dimensional wave boundary layer (WBL).

In this work, two forms of *DF*s are proposed: (i) *DF-I* describes the velocity distributions and bottom shear stresses in phase space with 4 model parameters; (ii) *DF-II* describes the maximum WBL profile with 3 model parameters. A number of datasets to support the validation of the *DF*s were obtained through experimental and numerical tests. Two sets of experiments were conducted individually in a free-surface-wave flume located in Dalian University of Technology and an oscillating-flow flume located in the University of Western Australia. For the free surface wave tests, the velocity was measured by an ADV (Acoustic Doppler Velocimetry) probe. Three kinds of rough bottoms were modelled. The ratio of A / k_s is in the range of 0.4 ~ 7.7, and the Reynolds number $Re = U_\infty A / \nu$ ranges from 1×10^3 to 1.4×10^4, where A is the semi-excursion of the water particles in the streamwise direction, k_s is the Nikuradese bottom roughness, U_∞ is the velocity amplitude and v is kinematic viscosity of the fluid. For the oscillating flow tests, the flow field was measured by a PIV (Particle Image Velocimetry) system. One smooth bottom and two rough bottoms were investigated. The parameter A / k_s is in the range from 2 to 3200, and Re varies from 3×10^4 to 3×10^7. Besides, a few two dimensional numerical simulations in the laminar flow regime were conducted. The roughness elements on the bottom are modelled by semi-circles. The range of A / k_s is from 0.5 to 2 and the Re is from 1250 to 5000.

Three typical features were observed from the measurements and simulations: (i) the WBL structure evolves periodically (ii) the velocity in WBL is larger than the free stream in certain conditions, namely the so-called velocity overshoot and (iii) the phase information of the bed shear stress leads the free stream velocity, i.e. the phase difference. The performance of the *DF*s on the description of these features is examined. *DF-I* has 4 model parameters and is designed to predict the velocity profiles in the whole phase space. *DF-I* is demonstrated to describe all these three features well. Besides, *DF-I* is also demonstrated to fit the bed shear stresses well in the phase space. *DF-II* has 3 model parameters and is designed to predict the maximum velocity profile only. It is demonstrated that *DF-II* gives good description of the maximum velocity overshoot. Some comparisons between the existing *DF*s are shown in Figure 1.

Further investigations based on the present experimental measurements and numerical simulations show that the maximum velocity overshoot increases with the decreasing A / k_s, due to the vortex formation and shedding in the gaps between adjacent bottom roughness elements; and the phase difference decreases when flow transits from laminar to turbulent regimes.

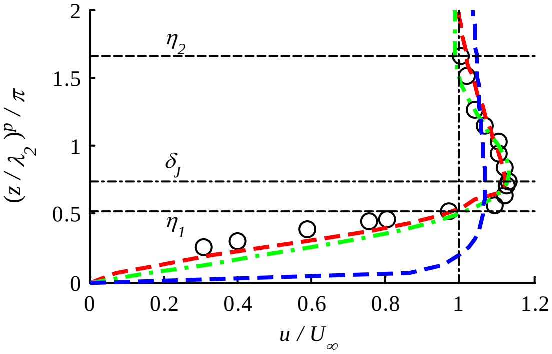

Figure - 1. The performance of *DF*s on the description of the maximum velocity profile. The data in black circles is obtained from the profile at ωt = 78° in test p4 from Dixen et al. (2008). The fitting of *DF-I* is plotted in red dash, *DF-II* in green dash-dot, and *DF-N* (the *DF* proposed by Nielsen 2016) in blue dash.

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