



## Simulation of turbulent wave boundary layers on spatially varying bottom roughness

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*Published in:*  
ICCE 2010

*Publication date:*  
2010

*Document Version*  
Publisher's PDF, also known as Version of record

[Link back to DTU Orbit](#)

*Citation (APA):*  
Fuhrman, D. R., Sumer, B. M., & Fredsøe, J. (2010). Simulation of turbulent wave boundary layers on spatially varying bottom roughness. In *ICCE 2010: Book of abstracts* (pp. 334). American Society of Civil Engineers.

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## SIMULATION OF TURBULENT WAVE BOUNDARY LAYERS ON SPATIALLY VARYING BOTTOM ROUGHNESS

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This work presents numerical results investigating the effects of spatial bottom roughness changes on turbulent oscillatory wave boundary layers, as depicted conceptually in Figure 1. This idealized problem is of considerable coastal engineering interest, having relevance to the scour protection of coastal structures e.g. at the foundation of offshore wind-turbines. The problem is likewise of geophysical interest, having relevance to coastal flows over naturally sorted sediments.

The numerical model utilized solves Reynolds-averaged Navier-Stokes equations coupled with the two-equation  $k-\omega$  turbulence closure of Wilcox (2006), making use of the open source CFD toolbox OpenFOAM®. As initial validation, the experimental conditions of Fredsøe et al. (1993) are considered, who studied oscillatory flow in a u-tube facility over plane beds with sudden pebble-to-smooth and pebble-to-sand paper bottom roughness transitions (see again Figure 1). They showed that such roughness changes induce period-averaged streaming velocities, asymmetric turbulence levels during the two half-periods, and significantly amplified bed shear stresses, relative to uniform roughness conditions. Example results are provided in Figure 2 for the period-averaged streaming profiles and in Figure 3 for the bed shear stress amplification due to a pebble-to-sand paper roughness change. Similar agreement has been found for the pebble-to-smooth transition case, including vertical distribution of turbulence properties in the two half-cycles (not shown here for brevity).

The comparisons against the available experimental measurements will be complemented by a detailed parametric study, where roughness combinations and wave boundary layer characteristics in the model are systematically varied, so as to cover a full range of practical engineering interest. New design diagrams for both bed shear stress amplification and induced streaming velocities will be presented. Additionally, the related effects of a gradual (rather than a sudden) roughness change will be considered, as will those from a difference in spatial orientation (e.g. oscillatory flow perpendicular to the page in Figure 1). The present numerical study is believed to be the first where both spatial and temporal resolution are directly considered for this class of problem, improving on the earlier 1D Lagrangian description utilized by Laursen et al. (1994).

The authors wish to acknowledge financial support from the Danish Council for Strategic Research (Seabed Windfarm Interaction Project), as well as computational resources made available by the Danish Center for Scientific Computing. This support is greatly appreciated.

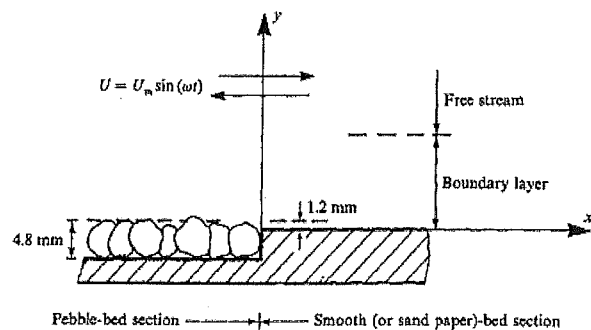


Figure 1 - Definition sketch, with a close-up junction of the two bed sections (from Fredsøe et al. 1993)

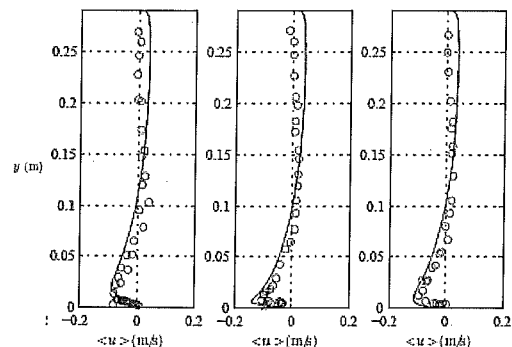


Figure 2 - Comparison of some measured (circles) and computed (lines) period-averaged streaming velocities

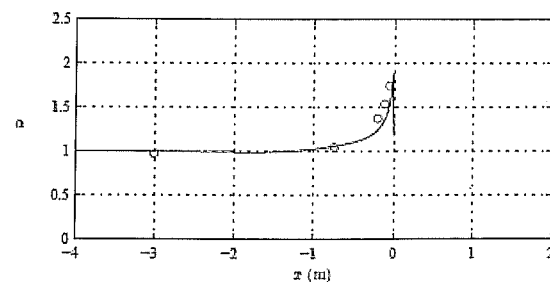


Figure 2 - Comparison of measured (circles) and computed (line) spatial variation of the maximum phase resolved bed shear stress amplification caused by a pebble-to-sand paper roughness change

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