3D-modelling of turbulent flow and bed shear stress around vegetation: Effects of scour and bending

Salt marshes and vegetated foreshores have recently obtained more attention. The functions of these vegetated planes are to stabilize the coastline and reduce the flood risk (Temmerman et al., 2023). Sediment transport within the salt marsh happens at lower velocities, due to the vegetation. The erosion of a salt marsh can therefore threaten the flood safety provided by the salt marsh. In several studies the vegetation has been simplified to cylinders (e.g. Baptist et al., 2007). Some studies focused on a straight cylinder and the scour around a cylinder (e.g. Roulund et al., 2005). Based on the studies with scour can be concluded that the effect on the flow field and bed shear stress. Since the bending of vegetation is important for the wave attenuation (Temmerman et al., 2023) and flow field. Others focused on the inclination of a cylinder (e.g. Kitsikoudis et al., 2017. The inclination of a cylinder also alters the flow field. This leaves two important factors for the alteration of the flow, which are bending and scour. This leaves a knowledge gap in what the combined effect is of scour and inclination on the flow field and bed shear stress. This leads to the research question, which is: ”How does the bending of vegetation and scour of the bottom affect the flow structure and bed shear stress?”. The cases were with an inclination angle of 0° and 14° and a flat bed and scoured bed simulation, leading to four cases in total. The problem has been modelled using a RANS k − ωSST model in OpenFOAM. The model has been validated on the experimental data of Kitsikoudis et al. (2017). The validation was for the main regions within 10% of the normalized velocities. The flow field changes for an inclined cylinder. For a straight cylinder the upstream flow bends down upstream of the cylinder resulting in the HV. The flow crosses the cylinder horizontally. Close to the bottom the HV reconnects downstream of the cylinder. In the wake the main fluctuations are in transverse and streamwise direction. For the inclined cylinder the flow partially bends upwards resulting in a weaker HV. Instead of crossing the cylinder horizontally, the flow crosses the cylinder under an angle. Further is there an increase in vertical velocity behind the cylinder. The TKE also decreases for the inclined case, where vertical fluctuations had the largest contribution to the TKE. The introduction of scour resulted in an additional HV inside the scour hole. The scour hole reduces the bed shear stress in the scour hole. Downstream of the scour hole, sediment deposition ridge is formed. At this location the bed shear stress has therefore increased compared to the flat bed case. The bed shear stress is around the same order, but the largest bed shear stresses were measured inside the scour hole. Compared to the bed shear stress amplification is the bed shear stress fluctuation relatively small. In the flow field the TKE decreases due to scour and inclination and the flow field becomes more unstructured, see Figure 1. However, the simulation with an inclined cylinder and scoured bed showed some discrepancies. To conclude the bending of vegetation ans scour around the vegetation is important as it lowers the capacity for sediment transport, meaning that salt marshes will be more stable over time.

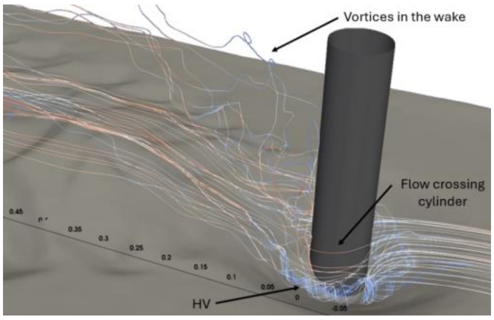

Figure 1: Instantaneous velocities around a straight cylinder inside a scour hole

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20 March 2025

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Baptist, M. J., Babovic, V., Uthurburu, J. R., Keijzer, M., Uittenbogaard, R. E., Mynett, A., & Verwey, A. (2007). On inducing equations for vegetation resistance. Journal of Hydraulic Research, 45 (4), 435–450. https://doi.org/10.1080/00221686.2007.9521778
Roulund, A., Sumer, B. M., Fredsøe, J., & Michelsen, J. (2005). Numerical and experimental investigation of flow and scour around a circular pile. Journal of Fluid Mechanics, 534, 351–401. https://doi.org/10.1017/S0022112005004507
Temmerman, S., Horstman, E. M., Krauss, K. W., Mullarney, J. C., Pelckmans, I., & Schoutens, K. (2023). Marshes and Mangroves as Nature-Based Coastal Storm Buffers. https://doi.org/10.1146/annurev-marine-040422
Kitsikoudis, V., Kirca, V. S., Yagci, O., & Celik, M. F. (2017). Clear-water scour and flow field alteration around an inclined pile. Coastal Engineering, 129, 59–73. https://doi.org/10.1016/j.coastaleng.2017.09.001

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