Seabed Boundary Layer Flow around Monopile and Gravity-based Wind Turbine Foundations

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Motivation and objectives

Scour

Bottom-fixed foundations for offshore wind turbines have to withstand the overturning moment created by the wind acting on the turbine. The presence of the foundation increases the average bed shear stress and the degree of turbulence in its viscinity, leading to a local increase in sediment transport capacity and erosion of the sea bed (Roulund et al., 2005). The rate of sediment transport by bed load is connected to bed shear stress by $q_b \sim \tau^{3/2}$. Local erosion, or scour, weakens the stability of the structure. Larges sums are spent on sea bed preparations, surveillance and reparations. A better understanding of the flows around bottom-fixed foundations can improve designs with respect to scour and diminish one of the sources of costs in offshore wind power. An illustration of scour is shown in Figure 1.

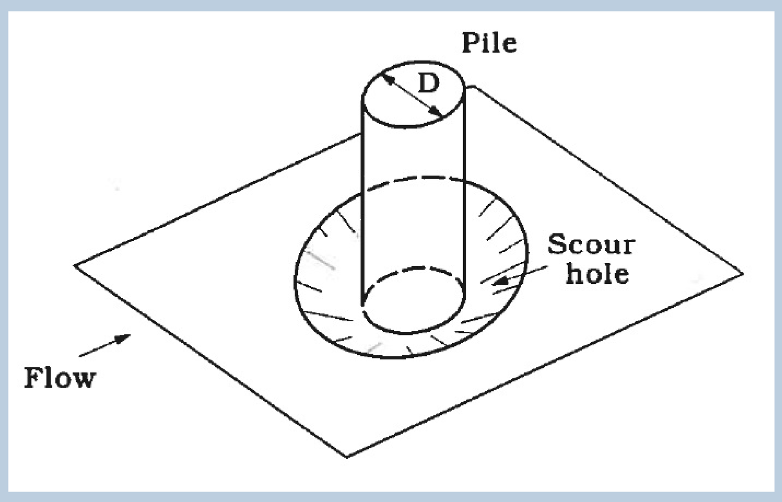

Figure 1: Scour around a circular pile

Horseshoe vortex system

The presence of a circular pile (monopile) on the sea bed in a boundary layer flow leads to: 1) Contraction of the flow; 2) A horseshoe vortex in front of the pile; 3) Formation of vortices on the back side of the pile; 4) A downflow in front of the pile (Roulund et al., 2005). The horseshoe vortex system is illustrated in Figure 2.

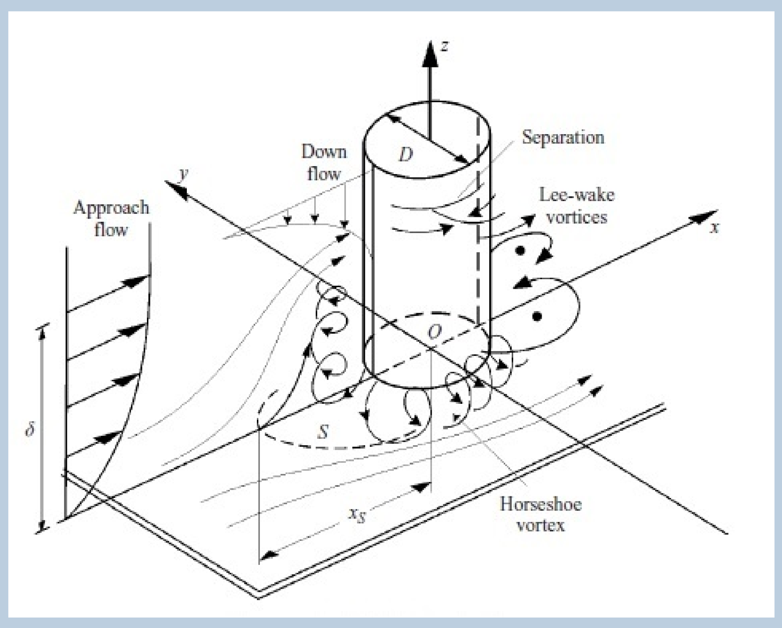

Figure 2: Horseshoe vortex system

Objectives

The aim of the work is to study the flow around monopile and gravity based foundations on a flat sea bed (i.e. before scour has taken place). The horseshoe vortex, shear stress on the sea bed and the flow in general is of interest.

References

[1] Roulund, A., Sumer, B. M., Fredsøe, J., Michelsen, J. *Numerical and experimental investigation of flow and scour around a circular pile*, J. Fluid Mech. (2005), vol. 534, pp. 351-401

[2] Ong, M. C., Utnes, T., Holmedal, L. E., Myrhaug, D., Pettersen, B. *Numerical simulation of flow around a circular cylinder close to a flat seabed at high Reynolds numbers using a k-ϵ model*, Coastal Engineering (2010), vol. 57, pp. 931-947

Computational model

The flow around three different foundations is analysed with OpenFOAM. The Navier-Stokes equations are solved with Spalart-Allmaras Delayed Detached Eddy Simulation. This is a hybrid model which uses the Spalart-Allmaras turbulence model as a RANS model close to walls and as a subgrid scale model in LES regions away from walls.

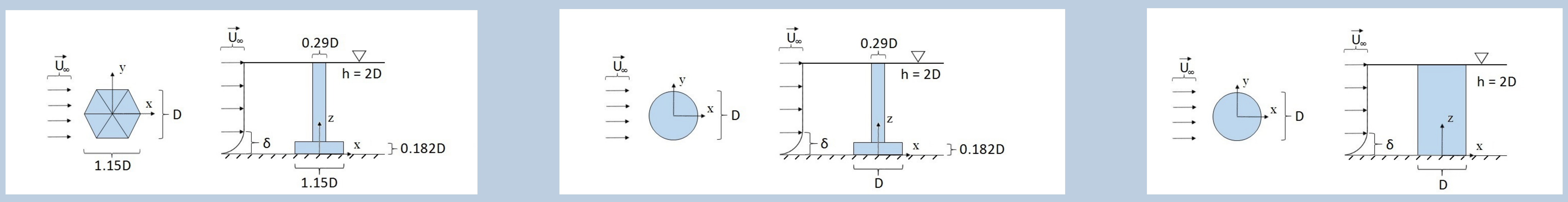

Figure 3: Left to right: Hexagonal gravity-based foundation, circular gravity-based foundation, monopile foundation

The gravity-based foundation with a hexagonal bottom slab is a simplified model of the foundations used at Lillgrund wind farm in Øresund, Sweden. A Reynolds number $\frac{U_\infty D}{\nu} = 4 \times 10^6$ is used, where U_∞ is the free stream velocity, D as shown in the figure and ν the kinematic viscosity.

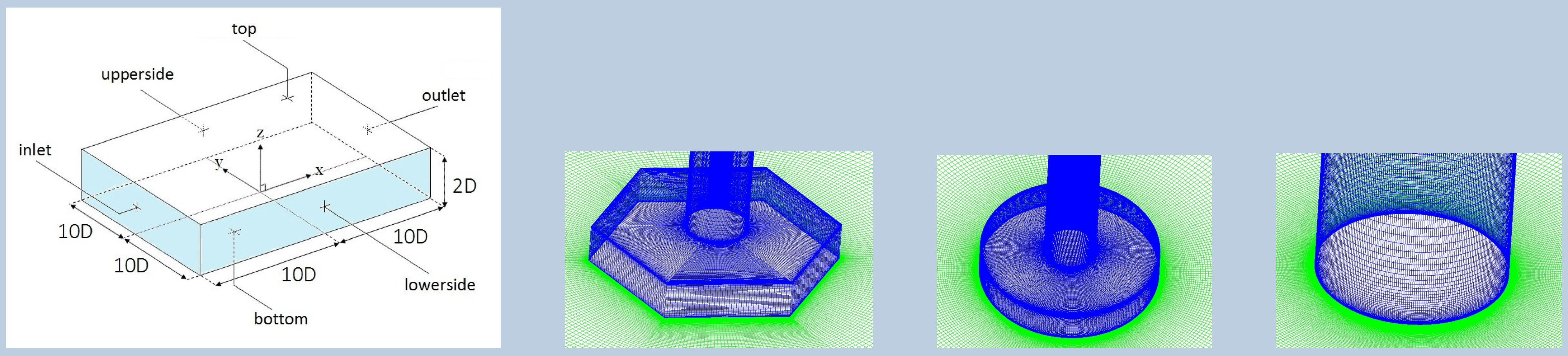

Figure 4: Computational domain and mesh (left to right: Hexagonal gravity-based foundation, circular gravity-based foundation, monopile foundation)

The computational domain measures $20D \times 20D \times 2D$ (see Figure 4). A logarithmic velocity profile with boundary layer thickness $\delta/D = 1$ is used at the inlet for velocity in the x-direction. The shape of the velocity profile and viscosity distribution at the inlet is according to Ong et al., 2010. The mesh has a normal distance to the first node away from walls $h_p = 0.0005 \times D$ and wallfunctions are employed. The number of cells is in the range 3-5 million.

Results and conclusion

Instantaneous shear stress on the sea bed (z = 0) and vorticity in the symmetry plane (y = 0) in the stabilized flow is shown in Figure 5 and 6, respectively. The results show that the sea bed around the gravity-based foundations experience a lower average shear stress, and that the hexagonal gravity-based foundation is the best design with respect to average bed shear stress. It is seen for the gravity-based foundations in Figure 6 that the horseshoe vortex is broken up into two vortices, one over the sea bed and one over the bottom slab of the foundation. The former is smaller than the vortex in front of the monopile vortex, and this decreases the shear stresses.

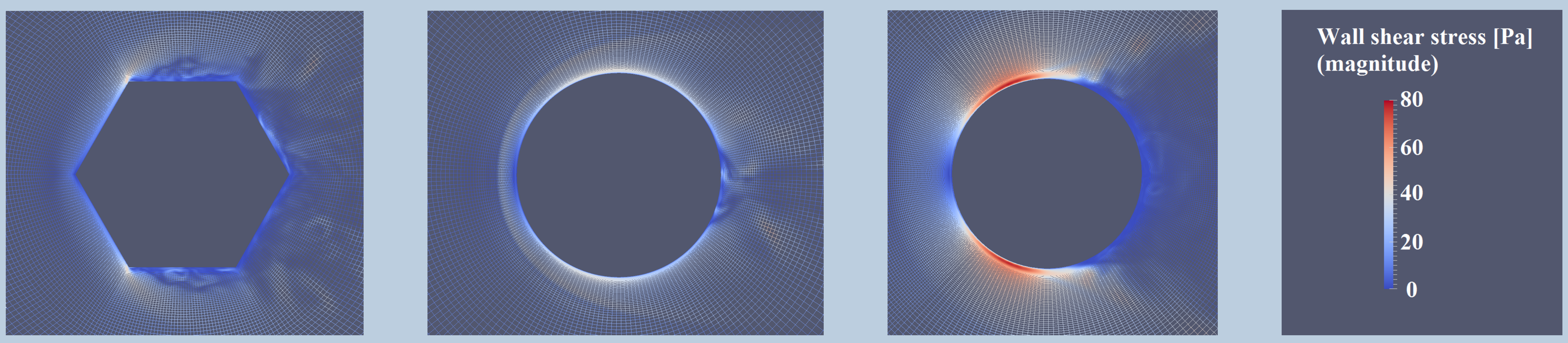

Figure 5: Comparison of shear stress (magnitude) on the sea bed (left to right: Hexagonal gravity-based foundation, circular gravity-based foundation, monopile foundation)

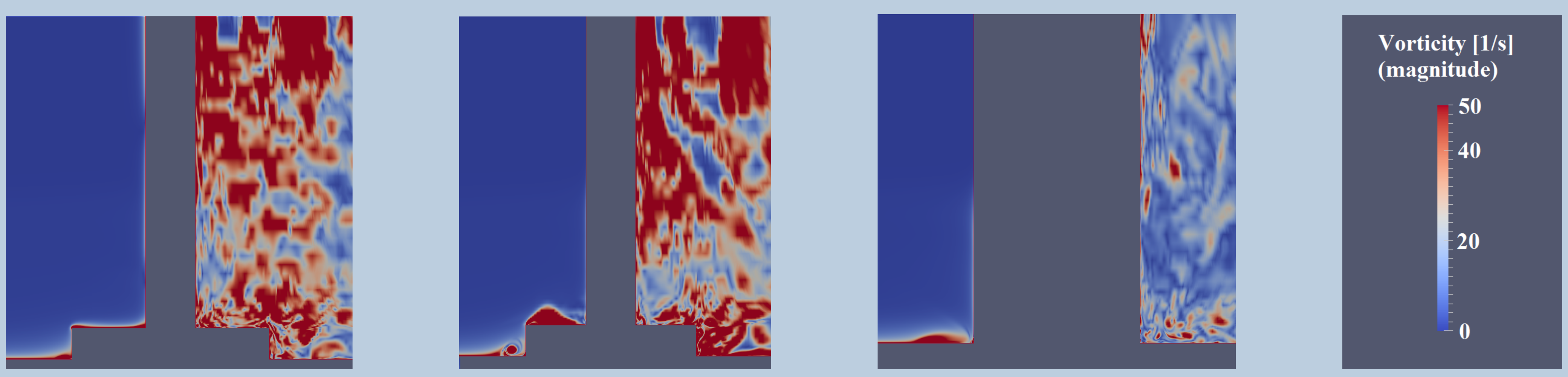

Figure 6: Comparison of vorticity (magnitude) in the symmetry plane (y = 0). Left to right: Hexagonal gravity-based foundation, circular gravity-based foundation, monopile foundation

The results for the monopile foundation are qualitatively similar to results by Roulund et al. ($Re = 1.7 \times 10^5$ and $\delta/D = 1$, where Re is based on the average inflow velocity). The horseshoe vortex in the present work is smaller, as expected because an increase in turbulence delays the separation.