GRAVITY BASED FOUNDATION
SCOUR AND DESIGN OPTIMISATION

by

T.F.A. (Tom) van Eijk

This thesis is submitted in partial fulfilment of the requirements for the degree of

Master of Science
in Civil Engineering, Hydraulic Engineering track
at the Delft University of Technology

and the degree of

Master of Science
in Hydraulic Engineering and Water Resources Management
at the National University of Singapore

to be defended publicly on Wednesday January 6, 2016 at 09:00 AM.

Thesis committee: Prof. dr. ir. S.N. Jonkman, TU Delft
Ir. W.F. Molenaar, TU Delft
Dr. Ir. R.J. Labeur, TU Delft
Dr. J. Yuan, NUS Singapore
Ir. J.M. Van Stralen, Royal HaskoningDHV

Electronic version: Available at http://repository.tudelft.nl/

Contact author: tfavaneijk@gmail.com

Cover: https://beeldbank.rws.nl, Rijkswaterstaat
To become a more competitive cost-effective energy resource, offshore wind energy is moving towards larger wind turbines and larger wind farms. These are placed in deeper waters, due to an increasing resistance against visual shore pollution. Within Royal HaskoningDHV, an innovative concept is thought to be feasible as a new foundation for these larger wind turbines in deeper waters.

To aid the design process of this foundation concept, a numerical tool was developed that is able to calculate the hydrodynamic loads on multiple configurations of this foundation. This tool uses Stokes 5th order wave theory and Morison’s equation. It was extended with analytical geotechnical stability calculations, to compare the stability of different foundations, but the accuracy and reliability of these geotechnical methods are doubted.

Optimisation potential for the foundation concept was found in the base diameter of the foundation, its embedded depth and the weight of the structure. However, due to unknowns in the constraints for structural design, it was not possible to arrive at one optimum foundation. Nevertheless, the conical configuration generally has a higher safety factor on stability than the stepwise configuration.

The second research objective was to determine whether scour protection should be applied at the foundation concepts. After analysing the hydraulic processes of scour and the different scour prediction methods, it was concluded that no accurate scour depth could be predicted with the currently available methods. Some reasons are:

- Prior research on scour at vertical piles focused on bridge piers and monopiles, rather than at large offshore piles, see Figure 1.
- The inability of physical scale modelling to accurately predict scour depths when the ratio between pile diameter and sediment diameter is very large.

Figure 1: Qualitative comparison of the flow regime and relative pile size for historical pile scour research and the foundation proposed by Royal HaskoningDHV.

One formula, by Khalfin [1], allegedly is able to predict scour depths for large offshore piles, but there are issues with the accuracy and application range of this formula. Despite these issues, a scour depth was derived using this formula, with some added scour depth
for safety reasons. This depth is hypothesised to be an upper limit, because Khalfin's formula does not allow low Froude numbers and non-cylindrical piles, both of which apply at the foundation concept by Royal HaskoningDHV. Therefore a computational fluid dynamics model, FinLab, is employed to determine the relative scour potential at the foundation, compared to the conditions which were used with Khalfin's formula.

Furthermore, a new numerical scour depth prediction method is proposed in this thesis, which is especially suitable for unconventional foundation structures. The general idea of this method is to pre-apply a scour hole in a computational domain, after which FinLab calculates the local bed shear stress amplification. If the amplification is about 1 in that scour hole, the pre-applied scour depth is close to the equilibrium scour depth. The first step in the development of this model; the validation of calculated bed shear stress amplification on a flat bed with experimental results, is performed in this thesis.

The validation of FinLab with published experimental results by Hjorth \[2\] showed that the model, with the used settings and k-\(\epsilon\) turbulence closure model, was unable to simulate one of the major causes of scour; the horseshoe vortex system. The model was however able to simulate the downflow in front of the pile. With only the downflow modelled, the hypothesis that a lower Froude number decreases the scour potential, could not be verified. The hypothesis that non-cylindrical piles will face less scour, could be confirmed with the numerical modelling.

Two main recommendations with respect to the numerical modelling of flow are provided in this thesis. The first is to use a more regular and finer grid close to the foundation pile, which could resolve the issues with consistent asymmetric results that were observed in this thesis. The second recommendation is to use the Large Eddy Simulation (LES) turbulence closure model with FinLab for future modelling of the complex rotational flows associated with scour. Some numerical experiments were performed with this turbulence closure model, which resulted in better simulation of the horseshoe vortex and vortex shedding in the wake of the pile.

All in all, it could be concluded that scour protection should most probably be applied, based on the large dependence of the foundation structure on its embedded depth and the uncertainty of currently available scour depth prediction methods. For non-cylindrical foundations, optimisation potential was identified in the amount of scour protection and corresponding stone size. An integrated design approach is therefore recommended, see Figure 2, which not only includes the hydrodynamic loads and the geotechnical stability, but also structural design of the foundation and the design of the scour protection.