Full-Scale Model Tests on a Gravity Base Foundation for Offshore Wind Turbines
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ABSTRACT
During the last few years Ed. Zueblin AG has been designing a new type of gravity base foundation for multi-megawatt offshore wind turbines. As there is no proven experience available up to now, which allows the verification of calculation models for describing the mechanical behavior of cyclically loaded gravity base foundations, Zueblin decided to carry out full-scale model tests with their novel foundation type. The cyclic loading with more than 1 million load cycles is applied by hydraulic jacks and steel cables to the foundation, which is located inside a flooded construction pit close to the North Sea coast. For the measurements of pore pressures, total stresses and displacements in the subsoil, as well as of the foundation itself, approximately 150 measuring sensors in total have been installed. The tests focus on the possible accumulation of differential settlements and pore pressures in the subsoil due to the cyclic loading.

KEY WORDS: offshore wind turbine; gravity base foundation; cyclic loads; full-scale model test; Ed. Zueblin AG; accumulation; differential settlements; pore pressures; measuring sensors.

INTRODUCTION
The validation and calibration of soil-mechanical models and calculation tools for the dimensioning of gravity base foundations for offshore wind turbines is carried out generally on the basis of monotonic and cyclic laboratory tests and small-scale model tests. Small-scale model tests are useful to get an idea of the principal mechanical soil behavior of this foundation type. Furthermore small-scale tests are an economic way to investigate the influence of different design parameters on the mechanical behavior of the foundation. These tests can be repeated easily after design modifications under identical starting conditions. However, the scale effect of small-scale model tests may lead to impreciseness or even failures, because it is impossible to scale down the grains of sand without changing their mechanical behavior. This scale-effect has to be evaluated and interpreted. The remaining uncertainties then may be eliminated by a monitoring of the behavior of real structures.

Offshore wind farms mostly consist of a high number (a series) of identical structures, which are installed quasi simultaneously. So after an observed malfunction of the foundation-structure the possibilities of economic technical adjustments are strongly limited, particularly due to their location “offshore”. To remove systematic technical defects in the structure design may cause disproportionately high costs. In addition to these costs, the interrupt of power production during repair time may lead to a high economical loss of the whole project. Therefore, especially the first series of new foundation structure types are implying high technical and economical risks if their design is not proven.

Full-scale model tests are carried out to reduce these risks before starting the production of a series of the new gravity base foundation, and to achieve a functional proof of the design. The foundation prototype is build close to the North Sea, where the subsoil conditions are nearly identical, compared to the projected offshore locations. Realistic cyclic loads, which are to be expected during storm events, are applied to the structure. The mechanical behavior of the subsoil and of the foundation is monitored with a set of sensors. The results of the investigations will form the basis for the validation and calibration of the mechanical soil models, and for the numerical calculation tools.

THE GRAVITY BASE FOUNDATION
Structure
The cross-shaped concrete structure has a length of 40 m, a height of about 65 m and a dead weight of about 6,500 t. The foundation consists of cross-shaped pre-stressed and sand filled box girders, see fig. 1 and 2. Isolated footings with a footprint of approximately 100 m² each are placed at the end of each girder to transmit the loads into seabed. The footings have a lower base level, compared to the base plate of the girders. The pre-stressed and sand filled shaft is located at the center of the cross-shaped girders. The foundation will be pre-fabricated onshore. After the installation of the steel tower and the turbine, including rotor blades, it will be shipped to the offshore location. After placing the whole construction on the seabed, the foundation will be ballasted by around 4,500 t of sand.

By the use of a dissolved structure the foundation has a large inner lever-arm. So the structure has a section modulus, which enables the foundation to resist the environmental, mainly wave-induced cyclic loading with comparable low alternating ground pressures. The load will be transferred by isolated footings at the end of each box girder into the seabed. So bottom contact due to settlements at the center of the base-plate can be excluded. This is an important part of the design, because soil-structure contact near the center may result in a “rocking” of the structure under alternating loads.