New Medium-Scale Laboratory Testing of Bucket Foundation Capacity in Sand
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ABSTRACT
This article presents a new testing rig for axially loaded bucket foundations. The medium-scale physical model gives the ability to examine the influence of axial loading on bucket foundations subjected to various levels of overburden stress. The properties of the test set-up allow long-term examination. Tests can be done with specimens of up to one meter in diameter and one meter in skirt length. The overburden pressure can be as large as 70 kPa using a tight latex membrane which covers the specimen and the soil surface. In addition to the description of the rig, results from several monotonic tensile tests are presented.

KEY WORDS: Bucket foundation; laboratory test; medium-scale; dense sand; tension; axial loading; overburden pressure.

INTRODUCTION
Offshore structures, such as wind turbines or wave energy machines, require complex support systems in order to withstand the large environmental loading. Due to the size of the structures and the water depth, jacket and tripod foundations supported with three or four suction buckets are often considered by the engineers. Jacket and tripod foundations are mainly subjected to axial loads. Suction caissons can resist large compressive loads. However, monotonic tensile or cyclic capacity can be rather small compared to the compressive capacity.

Environmental loads are greatly variable, and offshore foundations must bear cyclic wind and wave loads. However, the cyclic loads are difficult to model and predict. Real soil behavior is best analyzed by a proper full-scale physical model. Unfortunately, it is also the most expensive and time consuming method. Until today, most of the examined bucket foundations were modelled using small-scale laboratory equipment. Only a few experiments were done in large-scale, but often the results are not publicly available information. Regarding the ultimate tensile capacity of a bucket, loading rate, and the corresponding displacement, several studies were performed.

Physical Models until Today
Feld et al. (2000) performed axially loaded bucket tests. The physical model had a half bucket with diameter of 200 mm and skirt length of 100 mm installed in sand. Several dynamic pull-out tests with velocities of 2 mm/s, 3.7 mm/s, and 5.3 mm/s and several cyclic loading tests were done. It was found that the tensile capacity is very dependent on the displacement rate. The higher pull-out speed, the higher tensile maximum capacity is.

Kelly et al. (2003) tested a bucket with a diameter of 280 mm and a skirt length of 180 mm installed in dense saturated sand in a pressure chamber. The bucket was subjected to some cycles and dynamic tensile load with velocity of 5 mm/s. Cavitation of the pore fluid did not appear. Conclusion was drawn that the ultimate tensile capacity is mobilized at the displacements of 10-20% of the bucket diameter. Further research with the same small-scale testing equipment and pull-out velocity of 100 mm/s showed that the maximum tensile load was mobilized at the displacement of 3.5% of diameter (Kelly et al. 2004).

Houlsby et al. (2006) performed a series of field trials of bucket foundations in sand. The axially loaded specimen had 1500 mm in diameter and in skirt length. The pull-out velocity was low compared to the previous test, approximately 0.23 mm/s. During pull-out tests it was found that a rather high tensile resistance and large displacements were generated.

Senders (2009) performed many tests with axially loaded buckets in dense sand in a centrifuge. The buckets were manufactured on a scale 1:100 which resulted in diameters of 49-120 mm and skirt lengths of 60-114 mm. It was found out that the resistance under drained conditions depends on the skirt friction. It was stated that in drained conditions, the maximum tensile capacity is mobilized at displacement of 0.2% diameter. However, in partially drained conditions, it is much larger, 2-10% of foundation diameter.

To sum up, most of the present experiments were performed on small-scale suction caissons. Knowledge about displacement mobilization during axial loading of a bucket foundation would be valuable. Furthermore, the researchers and engineers are interested in a realistic...