Buckling Analysis of Bucket Foundations for Offshore Wind Turbines

Madsen, Søren

Publication date:
2011

Document Version
Early version, also known as pre-print

Link to publication from Aalborg University

Citation for published version (APA):
Madsen, S. (2011). *Buckling Analysis of Bucket Foundations for Offshore Wind Turbines*. Poster presented at 13th Internal Danish Center for Applied Mathematics and Mechanics Symposium 2011 (DCAMM 2011), Vejle, Denmark.

AALBORG UNIVERSITY

Buckling Analysis of Bucket Foundations for Offshore Wind Turbines

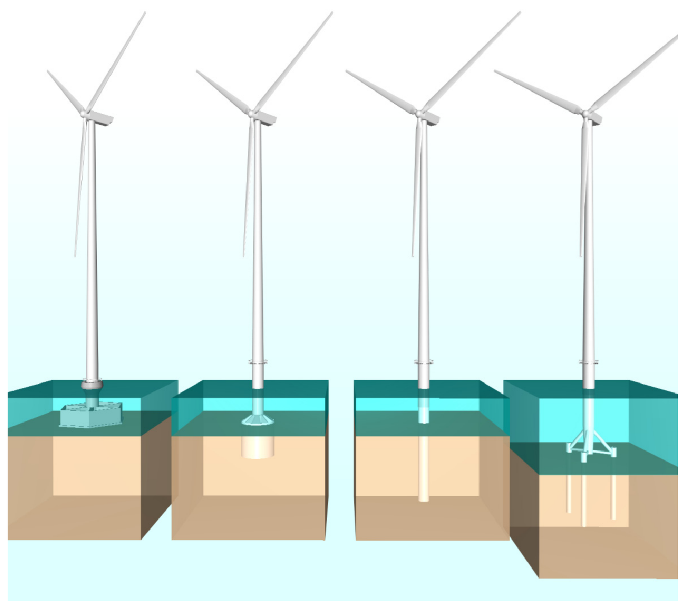
Department of Civil Engineering, Aalborg University, Denmark

BACKGROUND

In the present years, an increased focus has been on offshore wind farms. The expenses related to foundations constitute about one third of the total cost of an offshore wind farm. When wind turbines are located on deeper water, the cost of the foundations increases even further. Thus, a new technology is needed to reduce the total cost of offshore wind turbines. This could be the bucket foundation, also named "suction caisson".

The installation of the bucket foundation is initially caused by self-weight penetration. Subsequent suction is applied inside the bucket. The suction creates a pressure differential across the bucket lid, which increases the downward force on the bucket while reducing the skirt tip resistance.

The geometry of the bucket foundation is a thin cylindrical shell structure. As the water depth increases, the diameter of the suction caisson increases and the aspect ratio between the caisson diameter and the wall thickness becomes very large. Thus instability, in form of buckling, becomes a crucial issue during installation.



Foundation concepts for offshore wind turbines. From the left: gravitational foundation, bucket foundation, monopile foundation, and tripod foundation

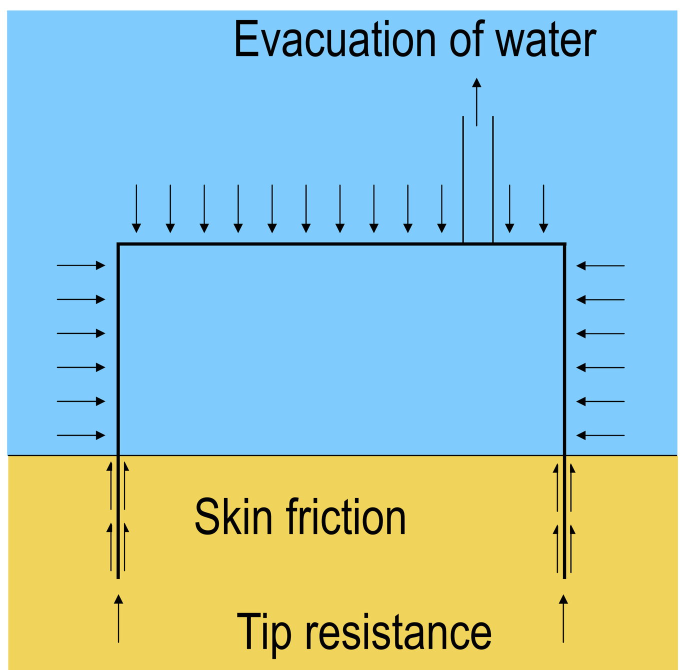
"STATE OF THE ART"

Several analytical expressions for the structural buckling pressure of circular cylindrical shells exist (Brush DO 1975), (Farshad 1992).

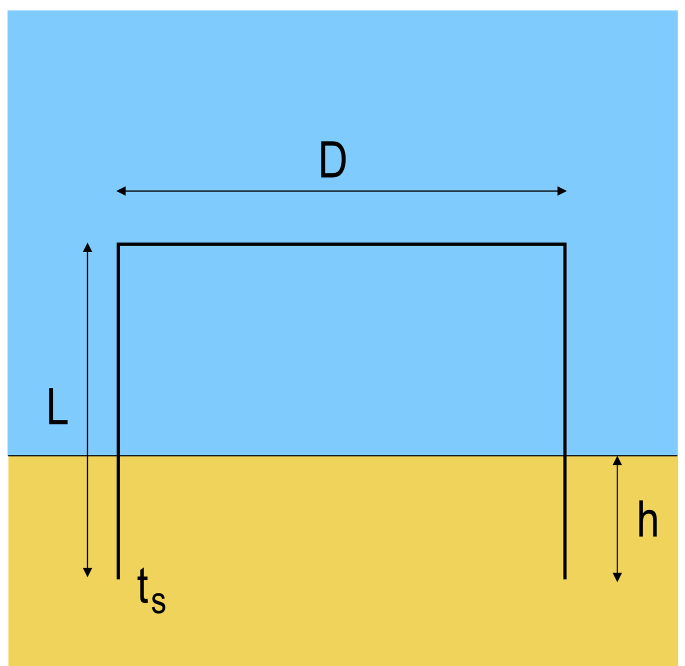
Nowadays cylindrical shell structures are designed according to e.g. (DNV-RP-C202 2002), (EN-1993-1-6 2007) which requires assumptions of idealized boundary conditions, like pinned, fixed or free. Neither of the design regulations takes the lateral restraints offered by the soil into account.

Recently, this lateral restraint offered by the soil has been modelled by elastic Winkler springs in e.g. (Pinna 2000) or by Pasternak type foundations (Pasternak 1954) in e.g. (Sofiyev 2010).

Neither of the abovementioned takes account for the lateral restraints by means of advanced non-linear finite element solutions. It may be beneficial to perform more refined analyses, compared to the abovementioned, taking the real boundary conditions into account. The author will introduce advanced three-dimensional, non-linear, finite element analysis by use of the commercial finite element package ABAQUS (ABAQUS 2010).



Downward pressure on lid and skirt, due to suction



Definition of bucket dimensions.

OBJECTIVE OF THE STUDY

In this study, the risk of structural buckling is addressed using numerical methods to determine the hydrostatic buckling pressures of large-diameter bucket foundations during installation in three different soil profiles. The three soil profile are a soft homogeneous soil profile, a hard homogeneous soil profile and a layered soil profile with varying strength and stiffness. The effect of the lateral restraint offered by the surrounding soil on the hydrostatic buckling pressures is analysed in this study.

For the initial installation phase, the free height of the skirt is large and a low suction pressure is needed. For subsequent installation phases, a larger pressure is needed. Thus, a critical embedded depth is found in this study. Further, the critical skirt thickness will be found.

Furthermore, this study should result in an alternative shape/design of the suction caisson, which has a smaller risk of buckling under high pressure.

The results from this study will hopefully lead to more cost-effective foundation solutions for offshore wind turbines at deep water.

INITIAL ANALYSIS

Some initial analyses have been made on a bucket with diameter, D = 16 m, skirt length, L = 15 m, and a skirt thickness, t_s = 25 mm. Three different boundary conditions have been considered:

- Skirt tip free
- Skirt tip pinned
- Skirt embedded in elastic soil with Young's modulus, E = 5 MPa

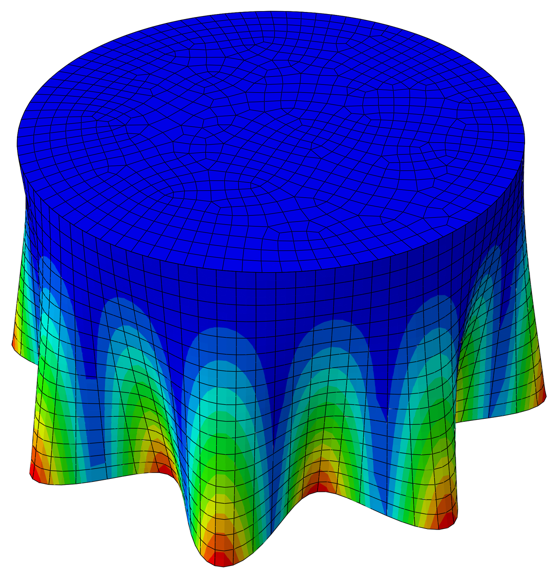
For all three cases, the bucket lid is considered rigid.

The first pre-buckling mode for the three different boundary conditions, at a penetration depth of 5 m, is shown to the right. In the graph, the pre-buckling load is illustrated at different penetration depths.

As expected, it was found that the pre-buckling load is largest for the pinned support, and the buckling load decreases when taking the lateral restraint offered by the soil into account .

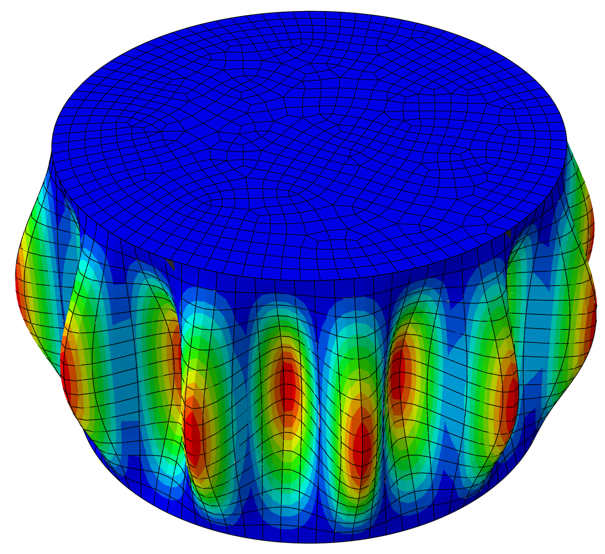
MONOPILES

Instability is also an issue for monopiles during installation, where imperfections and possible boulder impacts can lead to structural buckling. The effect of the lateral restraint offered by the surrounding soil is interesting to investigate by advanced finite element solutions for this problem as well.



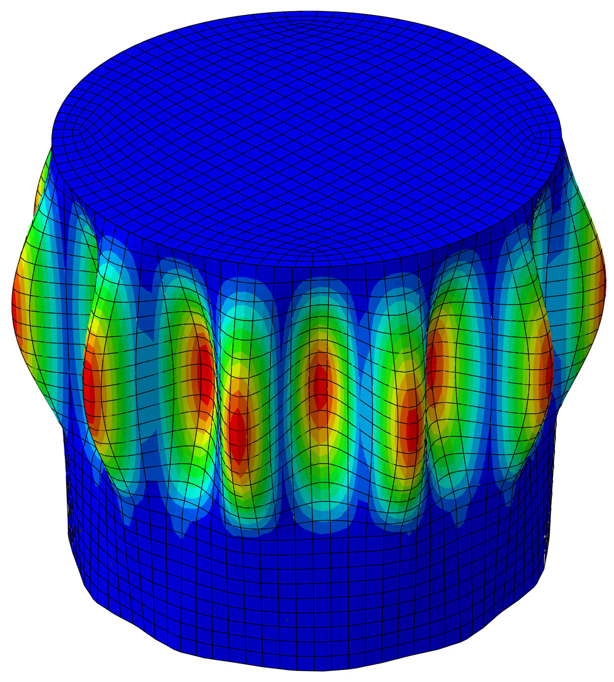
Pre-buckling mode of bucket with free boundary conditions at the skirt tip.

Pre-buckling load: 49.3 kPa.



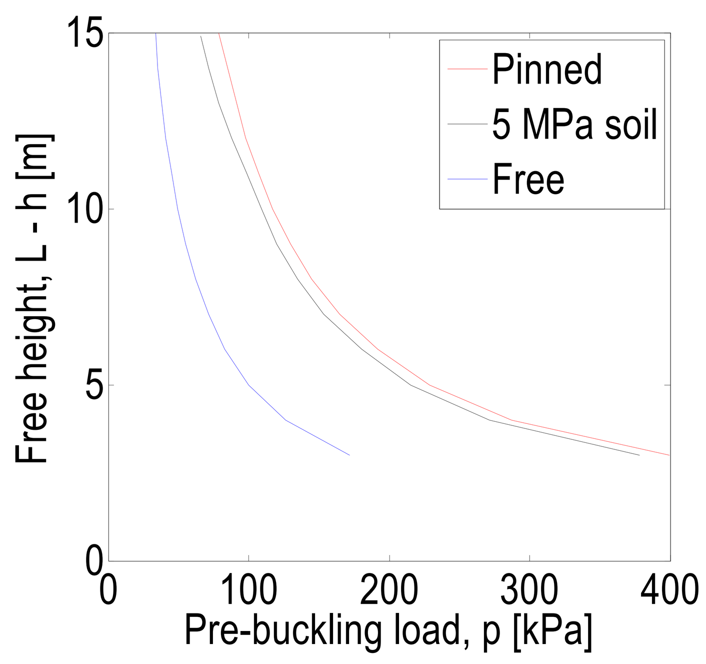
Pre-buckling mode of bucket with pinned boundary conditions at the skirt tip.

Pre-buckling load: 116.9 kPa.



Pre-buckling mode of bucket at a penetration depth equal to 1/3 of the skirt height. Lateral restraint offered by surrounding soil with Young's modulus, E = 5 MPa.

Pre buckling load: 109.4 kPa.



Pre buckling load as function of the free height (L - h).

REFERENCES

ABAQUS. *Version 6.10: Documentation.* Dassault Systèmes, 2010.

Brush DO, Almroth BO. *Buckling of bars, plates and shells.* New York: McGraw-Hill, 1975.

DNV-RP-C202. *Recommended practice: Buckling strength of shells.* Norway: Det Norske Veritas, 2002.

EN-1993-1-6. "Eurocode 3 - Design of steel structures - Part 1-6: Strength and Stability of Shell Structures." 2007.

Farshad, M. *Design and Analysis of Shell Structures.* Kluwer Academic Publishers, 1992.

Pasternak, P.L. *On a new method of analysis of an elastic foundation by means of two foundation constants.* Moscow, Russia: Gos. Izd. Lit. po Stroit I Arkh, 1954.

Pinna, R., Ronalds, B.F. "Hydrostatic buckling of shells with various boundary conditions." *Journal of Constructional Steel Research*, 2000: 56 (1), pp.1-16.

Sofiyev, A.H. "Buckling analysis of FGM circular shells under combined loads and resting on the Pasternak type elastic foundation." *Mechanics Research Communications*, 2010: 37 (6), pp. 539-544.

Søren Madsen
sm@civil.aau.dk
First year PhD student