Nonlinear 3D FE-Stability analysis of suction pile

Ralf Lampert[1], Stefan Eckardt[2], Roger Schlegel[2], Kjetil Rognlien[3], Frode Halvorsen[3]

[1)] Dynardo US, Inc. San Francisco, USA; [2)] Dynardo GmbH Weimar, Germany; [3)] EDRMedeso AS, Norway

Introduction

Suction piles are used to anchor off-shore constructions (e.g., oil platforms) in the sea ground. For the implementation, an under-pressure is created inside the device. The task is to make sure that the suction pile does not fail due to buckling of the friction skirt. The consideration of possible imperfections in the friction skirt as well as the interaction of the suction pile with the surrounding sea ground is particularly important for this verification.
The finite element method has especially proven to be suitable for the simulation and verification of suction pile constructions. In the past, the interaction with the sea ground was simulated often by radial springs with non-linear stiffness. This procedure can only describe phenomena in a simplified manner and results in very conservative, even uneconomic design solutions.
This paper presents a procedure for a 3D simulation of suction pile constructions. Here, the sea ground is modelled three-dimensionally for a more physically correct simulation of nonlinear interaction with the sea ground. This approach results in significantly increased working loads and economically improved design or installation options.

Workflow

The 3D FE-Stability analysis of suction pile consists of the following steps:

1. Parametric 3D Finite Element model build up for the suction pile and soil
2. Definition of the model and soil parameter, boundary conditions, nonlinear contacts between suction pile and soil, definition of the nonlinear load history (primary stress state, pore pressure state, suction procedure)
3. Non-linear prestress analysis (suction pressure to active boundary condition by surrounding soil)
4. Linear buckling analysis for introduction of imperfection (prestress from 3. using true contact status)
5. Non-linear stability analysis with geometrical imperfections and soil-structure interaction with Mohr Coulomb material models
6. Model validation and sensitivity analysis for checking model quality and uncertainty of boundary conditions
7. Optimization of the construction

For Finite Element Simulations the software ANSYS® [1] including the elasto-plastic material behaviors from multiPlas [2] and for model calibration, parameter identification and optimization the software ANSYS optiSLang® [3], [4] was used. The analysis model was calibrated to yield a load resistance in line with the Eurocode standard [5].

Example

A quarter-model of the a full ITS (Integrated Template Structure) assembly used in the analyses. The surrounding soil is modelled with a width of 14x14m and a depth of 2m below the suction pile's tip. The inside of the suction pile is filled with soil as well. A shell element mesh was generated for the whole assembly of the suction pile. The mesh can be seen in Figure 1 – left. For the surrounding soil material, a solid element mesh was used (see Figure 1 – right).

The soil segment is supported by frictionless support conditions at all four sides and the bottom. The additional layer below the suction pile is important for the behavior of the soil at the inside of the suction pile. Due to the increasing suction pressure at the inside the soil material has to be able to evade downwards.

To represent the supporting impact of the surrounding soil a nonlinear contact (augmented lagrange) for the interfaces of soil and suction pile was introduced. A frictional contact allows force transfer perpendicular to the interface and force transfer parallel to the interface as a function of the friction factor.

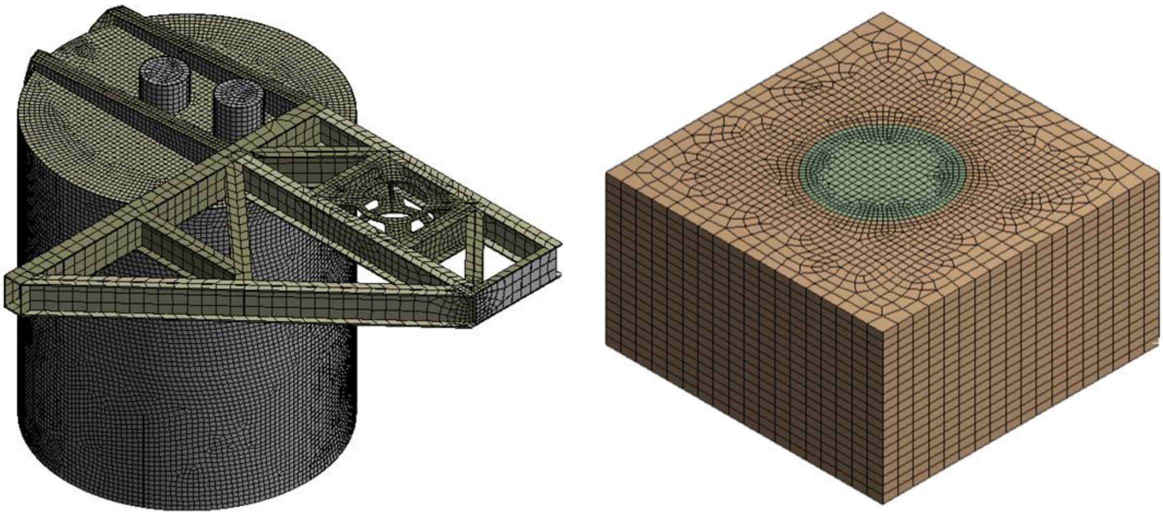

Figure 1 *Finite Element Mesh of suction pile (left) and soil (right)*

A linear buckling analysis based on the stress state found in the pre-stress analysis is performed. To take the supporting behaviour of the surrounding soil into account the linear material behaviour of the non-linear soil material is used. This analysis will give a mode shape for the first relevant buckle mode. The buckling mode of the suction pile with the lowest corresponding load increasing factor defines the first relevant buckle mode (see Figure 2 – left).

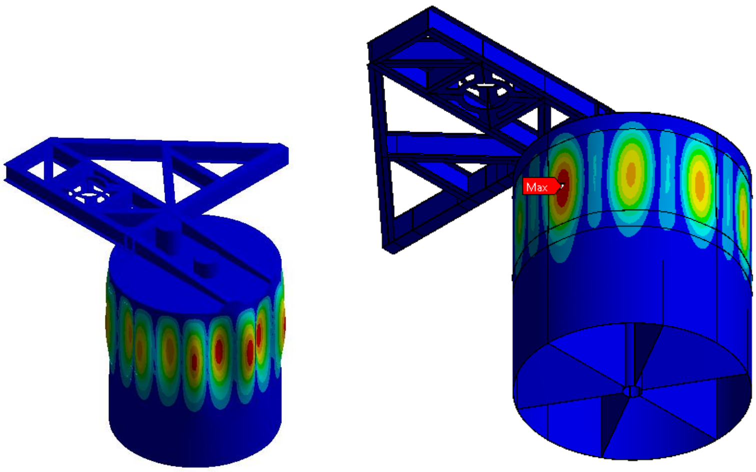

Figure 2 *Buckling mode (left) radial displacement at structural collapse (right)*

A non-linear buckling analysis is performed where the imperfections are included by selecting a scaled version of the mode shape found in the linear buckling analysis. A suction pressure is gradually increased until the model becomes unstable and the simulation crashes. The radial displacement at the time of failure is shown in Figure 2 – right.

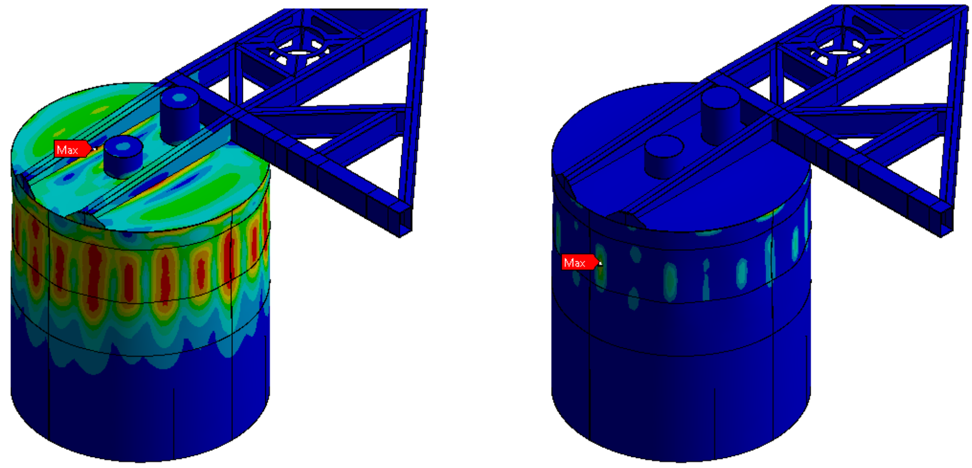

Figure 3 *von Mises Stresses (left) equivalent plastic strain at structural collapse (right)*

To further validate the suction pressure capacity obtained with the new methodology, a series of simulation using different spring stiffnesses was run. The spring stiffness was varied according to specifications from DNV GL. The stiffness was gradually increased from the conservative assumption of an oval deformation pattern of the suction pile, through several versions of spring stiffnesses corresponding to a 6-wave buckling pattern and finally the stiffness to match the buckling resistance found with the continuum model was iterated for one particular load case. The different soil stiffnesses are illustrated in Figure 4, represented by the non-linear spring stiffness for the first layer.

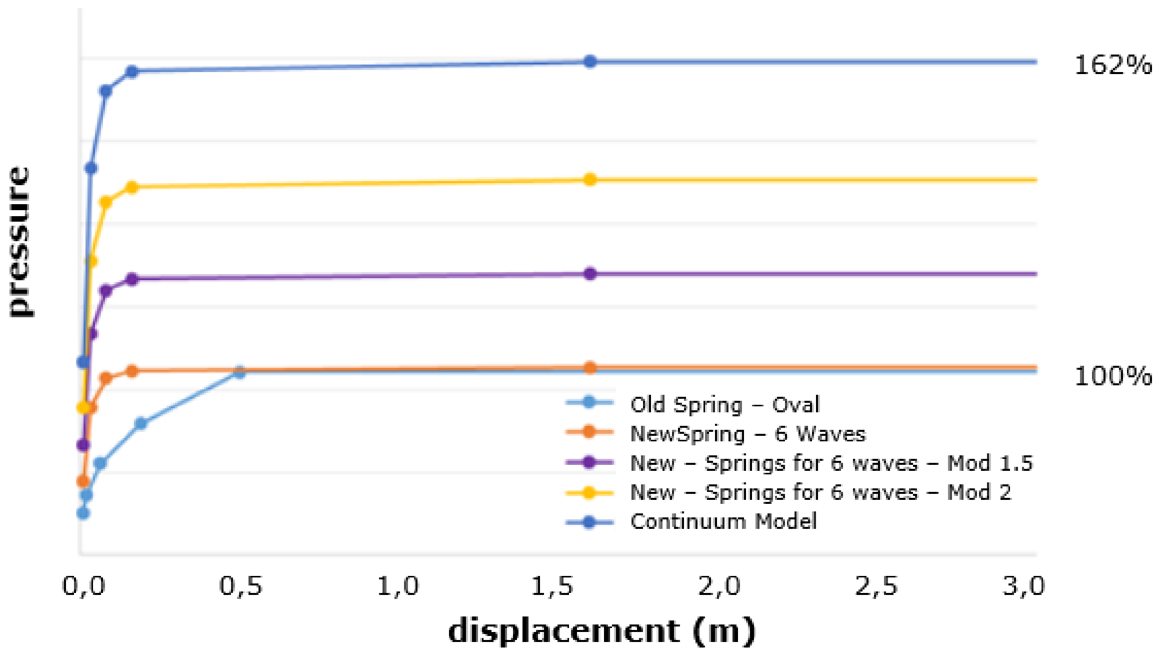

Figure 4 *Non-linear spring stiffness used in the results validation*

The results from the series of simulations are summarized in
Figure 5. It is seen that the spring stiffness that takes all effects into account (denoted "Springs – Continuum Model) result in a suction capacity of the same order as the 3D soil model.

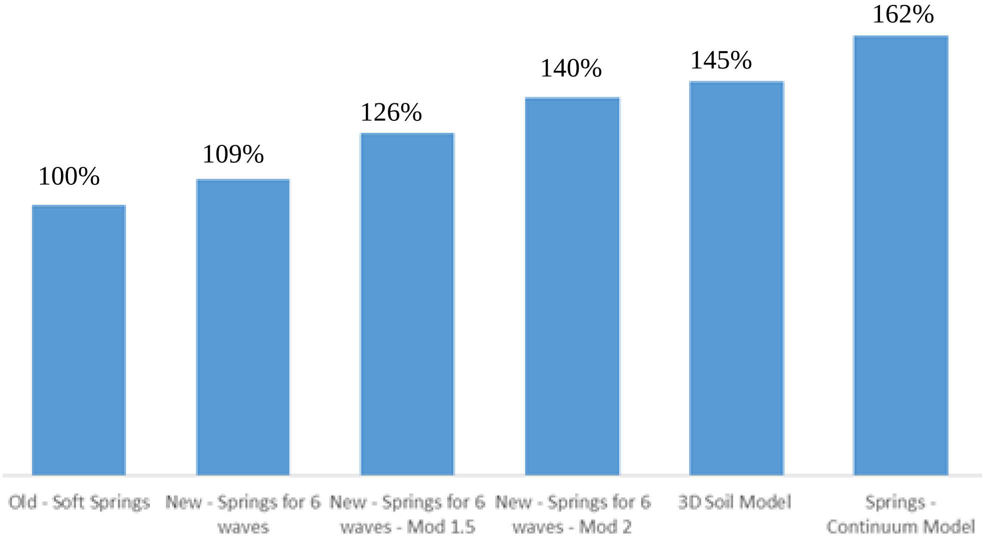

***Figure 5** Suction capacity obtained with the different soil/spring stiffness*

Based on this, it is concluded that the results obtained by the new methodology is reasonable.

Conclusions

The calculation using the soil modelling generally showed a higher failure load than the calculation with the nonlinear spring.

It is noticeable that the number of waves given by the linear buckling analyses increases with the increasing penetration depth, this is very reasonable because of the higher stiffness given by the backing behavior of the soil.

A verification done for penetration depth 5.5m and five different positions at the suction anchor skirt shows a very good accordance, therefore the shown soil model approach is confirmed.

References

[1] ANSYS Inc, „ANSYS Mechanical," ANSYS Inc, September 2016. [Online]. Available: http://www.ansys.com/Products/Structures/ANSYS-Mechanical-Enterprise . [Zugriff am September 2016].

[2] Dynardo GmbH, Dynamic Software and Engineering GmbH, „multiPlas- Elastoplastic material models for Ansys," Dynardo GmbH, 2014. [Online]. Available: http://www.dynardo.de/en/software/multiplas.html

[3] J. Will und T. Most, „Metamodell of Optimal Prognosis (MOP) - an Automatic Approach for User Friendly Parameter Optimization," in Weimar Optimization and Stochastic Days, Weimar, 2009.

[4] J. Will und T. Most, „Sensitivity analysis using the Metamodel of Optimal Prognosis," in Weimar Optimization and Stochastic Days, Weimar, 2011.

[5] European Standard. BS EN 1993-1-6, Strength and Staibility of Shell Structures. 2007.