Installation and Extraction of Spudcans using Abaqus/Explicit

Summary

Spudcans are conical footings used as foundations for offshore platforms. Installation in soft marine soil forces them deeply into the seabed, inducing gross motion and severe plastic deformation in the soil.

A pure Lagrangian-based finite element approach for modeling spudcan installation and extraction can be very difficult. Because the mesh moves with the material, element distortion typically accompanies severe deformation and convergence difficulties follow.

In an Eulerian-based method, material flows through a fixed mesh; it is therefore more amenable to the simulation of large material motion and extreme deformation. Abaqus/Explicit offers the coupled Eulerian-Lagrangian technique, in which chosen portions of the model can be modeled as Eulerian or Lagrangian, while automatically maintaining contact between the distinct regions.

In this Technology Brief the coupled Eulerian-Lagrangian analysis method is used to model the installation, extraction, and in-situ loading behavior of spudcans.

Introduction

The stability of an offshore structure depends on the integrity of its spudcan foundations. Spudcans are installed in the seabed by dropping them in place, and a preload is applied in order to drive them further into the soil. The amount of penetration required to obtain a sufficient bearing resistance is often a few times the diameter of the spudcan. When in service, the offshore platform superstructure can subject the spudcan to uplift forces, moments, and horizontal forces [1, 2]; it thus becomes important to predict the amount of support the surrounding soil can provide against such loading.

The seabed soil undergoes large deformations during the spudcan installation process and also when the spudcan is translated or rotated while in service. Traditional Lagrangian-based finite element analyses often fail in these situations due to excessive element distortions. On the other hand, Eulerian-based analyses offer significant advantages because the soil material can move relative to the mesh.

The Abaqus/Explicit coupled Eulerian-Lagrangian technique combines the advantages of both the Eulerian and Lagrangian approaches by allowing "stiff" objects that do not deform significantly to be modeled as Lagrangian, and "soft" objects (or material regions) that undergo large de-
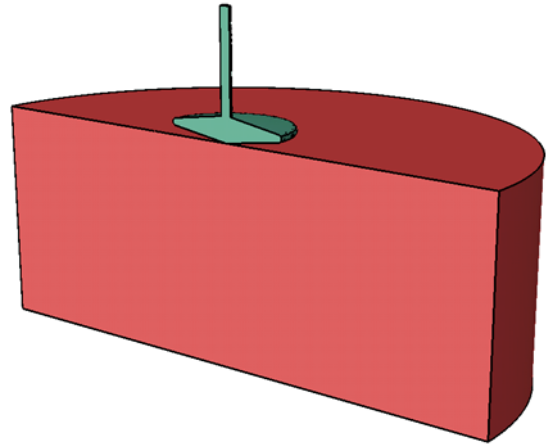
Vertical section of a spudcan touching the seabed

Key Abaqus Features and Benefits

- Coupled Eulerian-Lagrangian analysis technique in Abaqus/Explicit for modeling extreme deformations

- Analysis restart capabilities for performing a series of new analyses starting from a previous deformed state

formations to be modeled as Eulerian. The interaction between the Lagrangian and Eulerian regions is maintained by the general contact algorithm.

In this Technology Brief we describe how the coupled Eulerian-Lagrangian technique can used to model the installation, uplift, translation, and rotation of a representative spudcan.

Problem Description

The cross-section and initial position of the spudcan used for this brief are shown in Figure 1. Only a half-section has been used as the geometry, loading, and deformations are symmetric about the vertical plane. The initial material content of the Eulerian domain must be specified as an initial condition; the blue colored region is initially empty, while the red region is initially full.

The spudcan has a diameter of 36 m, and it has a thickness that reduces from a maximum of 8 m at its center to
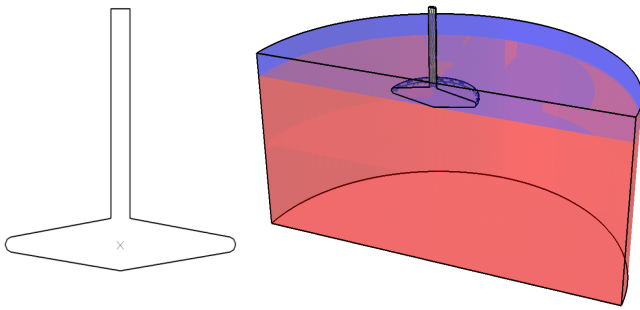
Figure 1, left: spudcan cross-section with the location of the rigid body reference point. Right: spudcan initial position and Eulerian region extent. The initial soil volume is shown in red.

2.5 m at its periphery. We consider the spudcan to be a hollow rigid body, and assume that it has an equivalent density of 2000 kg/m^3. The installation and other processes are considered to take place over a short duration, which allows us to model these as undrained phenomena. The soil is modeled using Mises plasticity with an assumed shear strength of 20 kPa. The density of the soil is taken to be 2000 kg/m^3. After subjecting the soil and the spudcan to gravity, the spudcan is driven into the soil by a prescribed velocity.

Coupled Eulerian-Lagrangian Analysis

To simulate the installation of the spudcan, a downward vertical velocity of 0.2 m/s is applied. The spudcan penetrates the soil and the analysis is continued until a depth of 20 m is reached.

For investigating the behavior of the foundation when the spudcan is subjected to service loads, we use the Abaqus restart capability. From the installed position, three restart analyses are performed; one each for modeling the uplift, horizontal translation, and rotation of the spudcan. The
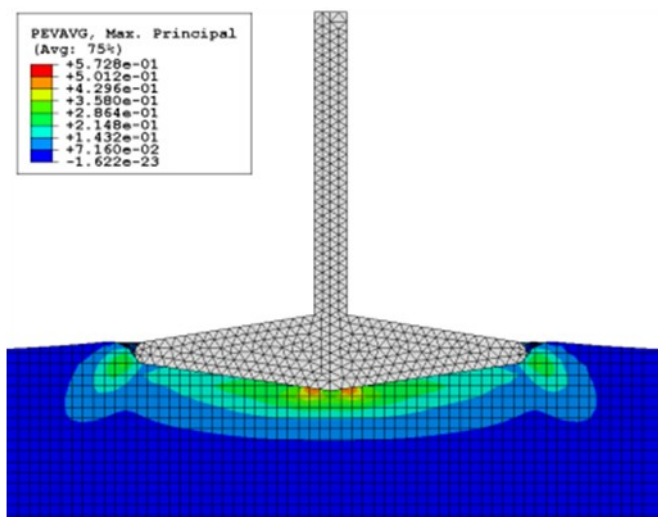

Figure 2: Maximum principal plastic strain in the soil at a spudcan penetration of 4 m.
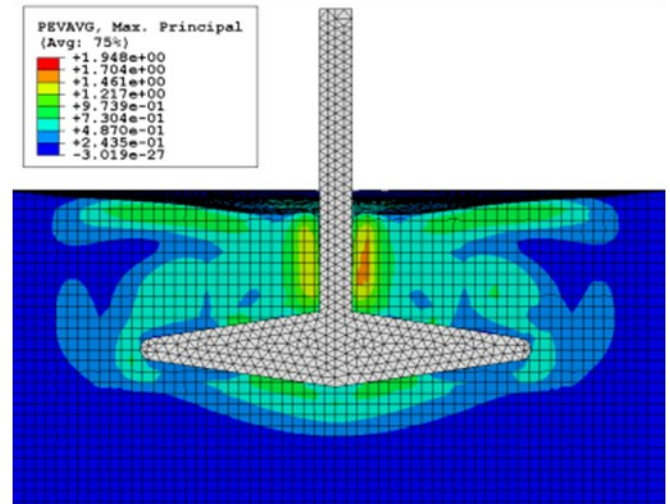

Figure 3: Maximum principal plastic strain in the soil at a spudcan penetration of 20 m.

uplift load is prescribed as an upward velocity of 0.2 m/s until the spudcan comes out of the soil. The translation load is specified as a horizontal velocity of 0.2 m/s until a translation of 10 m is achieved, and the rotation is prescribed with an angular velocity of 0.05 radians/s until a total rotation of 0.5 radians is obtained.

Results and Discussion

Figure 2 shows values of the maximum principal plastic strain in the soil after the spudcan has penetrated 4 m into the seabed. Figure 3 shows these values after a penetration of 20 m.

The vertical resistance offered by the soil to the spudcan changes with the spudcan penetration. Because we have exploited symmetry and only modeled half a spudcan, the resistance offered by the soil for the full spudcan can be obtained by doubling the computed resistance. Figure 4 shows the resistance plotted against the downward vertical displacement of the spudcan. We observe that the bearing reaction from the soil increases with increasing penetration of the spudcan until it reaches a maximum of about 185 MN. This maximum resistance is obtained
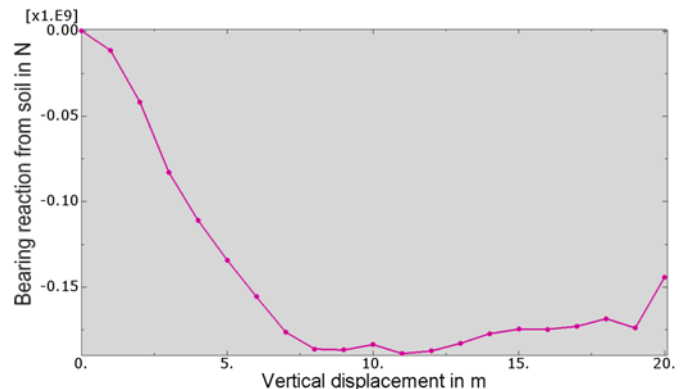

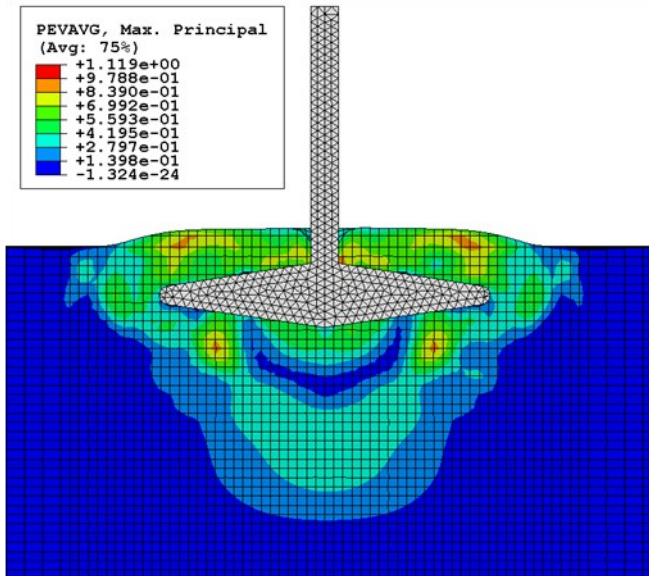Figure 4: Vertical reaction at the spudcan reference point

Figure 5: Maximum principal plastic strain in the soil when the spudcan has uplifted by 10 m.

when the spudcan has penetrated a distance of about one third of its diameter. This resistance is then seen to reduce slightly with increasing penetration.

From [2], the bearing capacity factor for spudcans is given by

$$N_C = \frac{F}{As_u}$$

where N_c is the bearing capacity factor, F is the vertical force, A is the maximum spudcan plane area, and s_u is the soil strength. The computed N_c for this case comes to about 9.1, which agrees well with the experimental results by Puwana [2]. The experimental results also show a slight reduction with increasing depth of N_c from its maximum value. This corroborates with the computed results.

Figure 5 shows an intermediate stage during the uplift of the spudcan, and Figure 6 shows a graph of the vertical
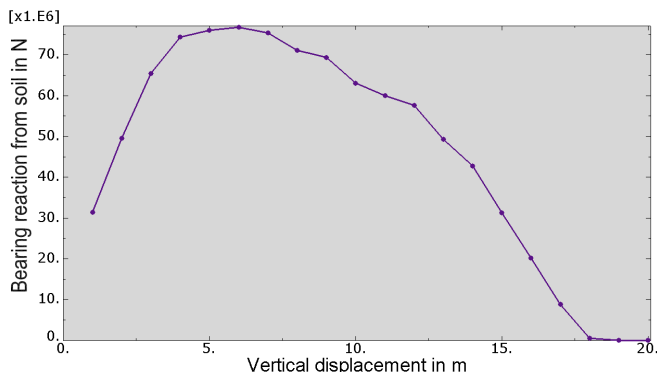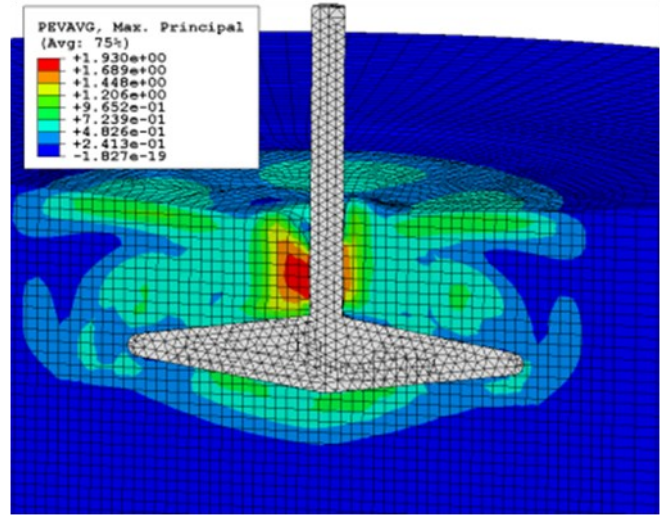

Figure 6: Uplift resistance from the soil

Figure 7: Maximum principal plastic strain when the spudcan is translated horizontally by 2.5 m.

resisting force from the soil on the full spudcan. The vertical reaction is the contribution from the soil only; the contribution from the weight of the spudcan has been subtracted. As the spudcan is uplifted from a shallow depth, the maximum uplift resistance is only about 76 MN, which is much smaller than the maximum bearing resistance. Figures 7 and 8 show the intermediate stages during the horizontal translation and rotation of the spudcan, respectively, after its initial embedment.

Conclusions

In this Technology Brief we have demonstrated the use of the Coupled Eulerian-Lagrangian technique for simulating the installation and in-service loading of spudcans. The resistance offered by the soil against spudcan uplift, translation and rotation can also be obtained using this technique. These resistances can help designers assess the efficacy and strength of spudcan foundations.
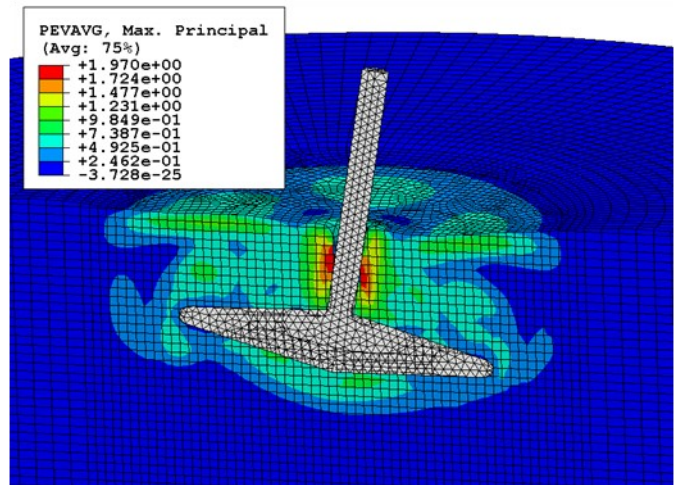

Figure 8: Maximum principal plastic strain when the spudcan is rotated by 0.15 radians

References

1. Yu, Long, Hu, Yuxia, and Liu, Jun, Spudcan penetration in loose sand over uniform clay, Proceedings of the ASME 2009 28th International Conference on Ocean, Offshore and Arctic Engineering, OMAE2009-79214.

2. Liu, Jun & Hu, Yuxia, Numerical simulation of the installation and extraction process of spudcan foundations in clay, Proceedings of the ASME 2009 28th International Conference on Ocean, Offshore and Arctic Engineering, OMAE2009-79222.

Abaqus References

For additional information on the Abaqus capabilities referred to in this brief, please see the following Abaqus 6.10 documentation references:

- Analysis User's Manual
    - 'Eulerian analysis,' Section 13.1.1
    - 'Restarting an analysis,' Section 9.1.1

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