

## Analysis of Driven Pile Setup with Abaqus/Standard

### Summary

Pullout resistance of driven foundation piles often increases with time in a process known as pile “setup.” The consolidation of the surrounding soil after the pile is driven plays a dominant role in the setup process. Finite element modeling of pile setup can help in obtaining reliable estimates of the increase in pile resistance, which would allow for reductions in pile lengths, pile sections, or sizes of the pile driving equipment. The coupled pore fluid and stress analysis capabilities of Abaqus/Standard can be used for modeling the pile setup phenomenon and can help in estimating the increase in pile pullout resistance with time.

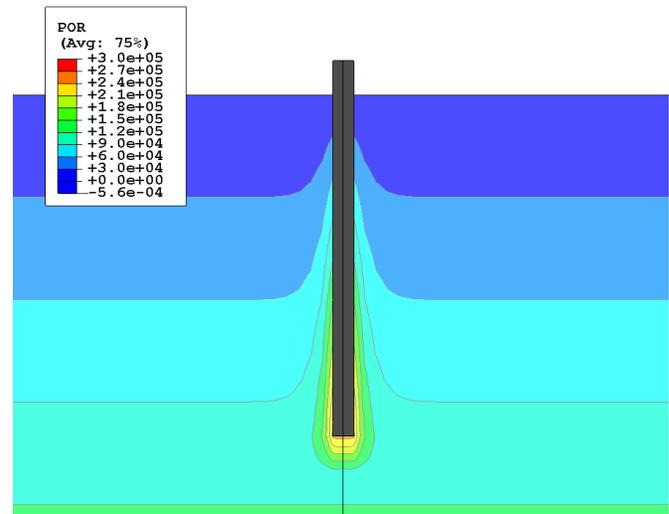
### Background

After a foundation pile is driven in saturated soil, the pullout resistance is often observed to increase with time; this phenomenon is referred to as pile “setup.” Although the exact mechanism by which pile setup occurs is not completely understood, two processes are believed to play an important role: (1) an increase in the soil effective stresses associated with the dissipation of the excess pore pressure built up around the driven pile, and (2) thixotropic bonding between the soil grains. The more significant process is the first one, which is associated with the gradual consolidation of the remolded soil surrounding the pile. As the consolidation progresses, the horizontal (or radial) effective stress in the soil at the interface between the soil and the pile increases. This increase in the effective stress leads to an increase in the maximum frictional resistance offered by the soil to the pile, which results in the increased pullout resistance (Ref. 1-3).

Depending on the soil and pile properties, pile dimensions, and the driving conditions, the pile pullout resistance after setup can be several times that observed immediately after the pile is driven. If a design is based on the pullout value measured immediately after a pile is driven, it may be very conservative. Construction costs for pile foundations can be substantially reduced if the pile designs incorporate the increase in the pile resistance due to pile setup.

### Finite Element Analysis Approach

In this study we consider an 11.0 m long cylindrical pile of diameter 0.6 m driven to a depth of 10.0 m. An axisymmetric model is used; the radius of the soil domain is 20.0 m, and the depth is 20.0 m. The soil is saturated, and the ground water level is considered to be at the top surface



### Key Abaqus Features and Benefits

- Ability to model transient distribution of pore fluid pressure in soils
- Ability to model consolidation, or the deformation in soils associated with the redistribution of pore water and pressure
- Can model contact and frictional interaction between the soil and buried foundation structures
- Supports a variety of constitutive models for soils, including Mohr-Coulomb, Drucker-Prager, Cam-Clay, and Cap plasticity models

of the soil. Constraints against radial displacement are applied on the vertical boundary surfaces of the soil, while constraints against vertical displacement are applied at the bottom of the soil domain.

The soil is considered to have an elastic modulus of 100 MPa and a dry density of 1800 kg/m<sup>3</sup>. A modified Drucker-Prager/Cap Plasticity model with cohesion of 80 kPa, friction angle of 30.0 degrees, cap eccentricity of 0.1, and transition surface radius of 0.03 is used for describing the soil plasticity. The existence of a cap in this model limits the amount of dilation when the soil gets deformed in shear. The ratio of the flow stress in triaxial tension to the flow stress in triaxial compression is assumed to be 1. Permeability of the soil medium is 2.5e-10 m/s and the initial void ratio of the soil is 2.0.

The soil is discretized using 8-noded axisymmetric elements with displacement and pore pressure degrees of freedom. The pile is considered to be elastic with an elastic modulus of 15 GPa and a density of 2500 kg/m<sup>3</sup>. The pile is discretized using 8-noded axisymmetric elements with displacement degrees of freedom. The coefficient of friction between the soil and the pile is 0.7.

When a pile is driven, there is extensive remolding of the surrounding soil and an immediate increase in the soil pore pressure in the vicinity of the pile. The soil remolding phenomenon and the associated increase in the soil pore pressure are however not modeled in this Technical Brief. Estimates are available in the literature on the amount of increase in the soil pore pressure in the immediate vicinity of the driven pile (Ref. 1). Based on the available information, an initial instantaneous pore pressure distribution has been assumed in the vicinity of the pile. This initial distribution is such that the pore pressure is maximal at the pile–soil interface and diminishes exponentially with radial distance from the center of the pile. Specifically, the magnitude of the excess pore pressure at the pile-soil interface over and above the geostatic pore pressure is taken to be equal to the magnitude of the vertical effective stress in the region far away from the pile at the same vertical position.

In Abaqus, pore pressures can be accounted for either by a total pore pressure formulation, wherein the gravity loads on the pore fluid are taken into account, or by an excess pore pressure formulation, wherein the gravity loads on the pore fluid are not taken into account. For the present analysis a total pore pressure formulation has been used.

### Analysis Steps

The initial state of stress in the soil is considered to be that of a geostatic nature with lateral stress coefficients of 1.0. Gravity is considered to act in the vertical direction. The principal stress directions coincide with the vertical and lateral directions. The initial position of the cap is considered to be that corresponding to a volumetric plastic strain of 0.041%, which makes the initial state of stress positioned well inside the yield region on the cap.

The analysis is performed in three consolidation steps. In the first step the gravity loads and the assumed pore pressure distribution are applied over a short time, 0.01 seconds. The pore pressure distribution is applied using user subroutine DISP. The time for the first step is kept short in order to simulate the conditions in the soil immediately after the insertion of the pile.

The second step involves continuing the consolidation analysis for lengths of time ranging from 10 seconds to 600000 seconds (about 6.9 days). In the second step the excess pore pressure dissipates as time progresses and the soil simultaneously consolidates. As the pore pressure dissipates, the radial effective stress in the soil adjoining the pile simultaneously increases with time. This

increase in the radial effective stress results in an increased frictional resistance between the soil and the pile.

The third step involves assessment of the pullout strength by applying prescribed vertical displacements at the top of the pile and monitoring the reaction forces resisting this vertical motion.

### Results

The pore pressure distribution immediately after the insertion of the pile is shown in Figure 1. The pore pressure and the effective stress in the radial direction 10 seconds after the insertion of the pile are shown in Figures 2 and 3, respectively. Figures 4 and 5 show the pore pressure, and the effective stress in the radial direction, respectively, at 600000 seconds after the insertion of the pile.

At 600000 seconds, the pore pressure has dissipated considerably, and the radial effective stress has increased. The pore pressure near the lower portion of the pile decreases from about 200 kPa immediately after the pile is driven to about 100 kPa after 600000 seconds.

Figures 6 and 7 are plots of the pull-out resistance offered by the pile as the pile is uplifted at 10 and 600000 seconds, respectively, after insertion. It is observed that the resistance against uplift has increased from about 90 kN at 10 seconds to about 860 kN at 600000 seconds after insertion of the pile.

### Conclusion

The contact, material model, and coupled pore fluid analysis capabilities of Abaqus/Standard combine to provide a general analysis capability for buried or partially buried foundation structures such as piles, footings, and retaining walls.

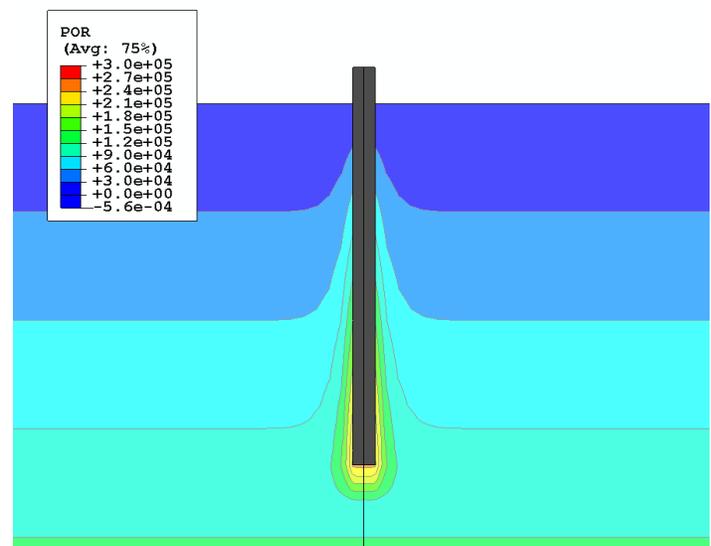


Figure 1: Distribution of pore pressure immediately after insertion of the pile

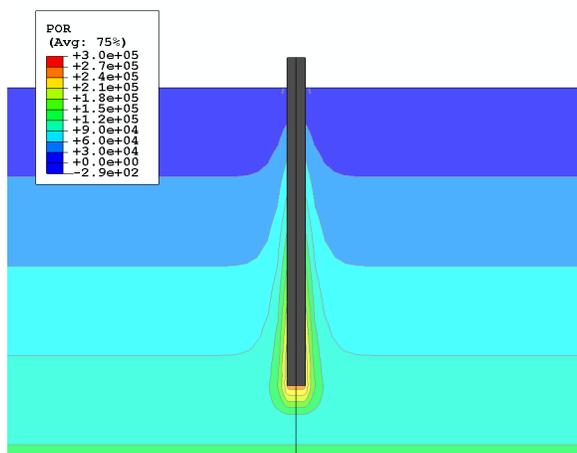


Figure 2: Distribution of pore pressure 10 seconds after insertion of the pile

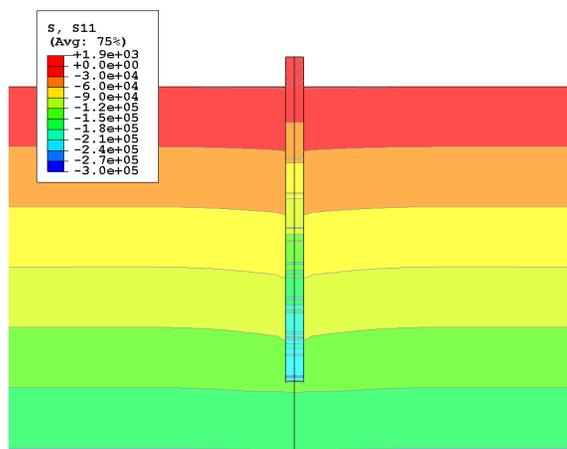


Figure 5: Distribution of radial effective stress 600000 seconds (6.9 days) after insertion of the pile

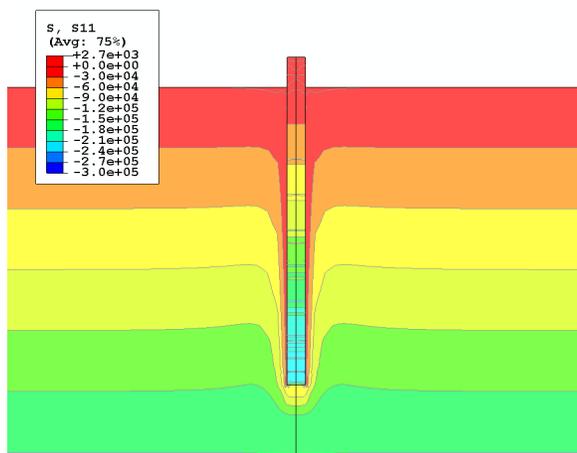


Figure 3: Distribution of radial effective stress 10 seconds after insertion of the pile

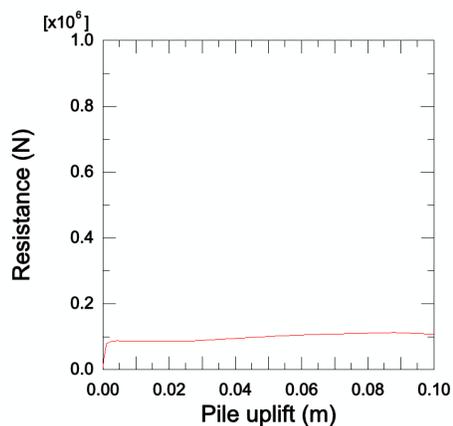


Figure 6: Resistance offered by the pile against

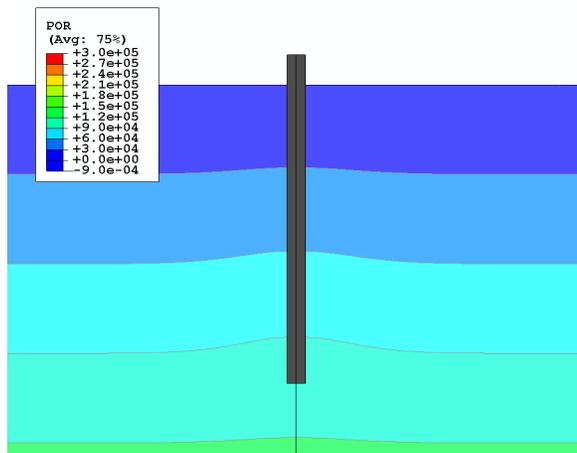


Figure 4: Distribution of pore pressure 600000 seconds (6.9 days) after insertion of the pile

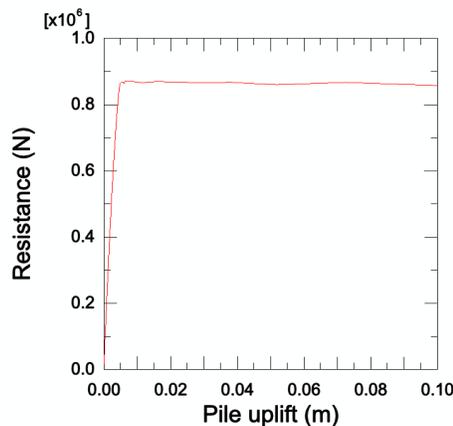


Figure 7: Resistance offered by the pile against uplift 600000 seconds (6.9 days) after insertion

## Acknowledgements

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## References

1. Komurka, Van E., Wagner, Alan B., and Edil Tuncer, *Estimating Soil/Pile Set-Up*, WHRP Report No. 03-05, Wisconsin Highway Research Program #0092-00-14, Wagner Komurka Geotechnical Group, Inc., and the Department of Civil & Environmental Engineering, University of Wisconsin-Madison, September, 2003.
2. Karna Upendra, L., *Characterization of Time Dependent Pile Capacity in Glacial Deposits by Dynamic Load Tests*, Dissertation for the degree of Engineer in Civil Engineering, New Jersey Institute of Technology, May 2001.
3. Paikowsky Samuel, G., and Hart Leo J., Development and Field Testing of Multiple Deployment Model Pile (MDMP), Federal Highway Administration Report No. FHWA-RD-99-194, Pruitt Energy Sources, Inc., and Geotechnical Engineering Research Laboratory, UMASS-Lowell, June 2000.

## Abaqus References

For additional information on the Abaqus capabilities referred to in this brief please see the following Abaqus 6.11 documentation references:

- Abaqus User Subroutine Reference Manual
  - "DISP," Section 1.1.4
- Analysis User's Manual
  - "Coupled pore fluid diffusion and stress analysis," Section 6.8.1
  - "Pore fluid contact properties," Section 35.4.1
- Example Problems Manual
  - "Plane strain consolidation," Section 10.1.1

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