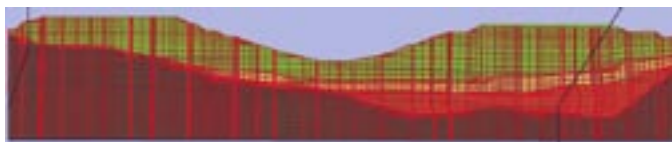
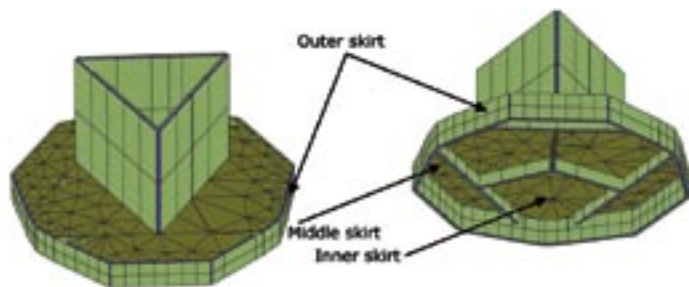
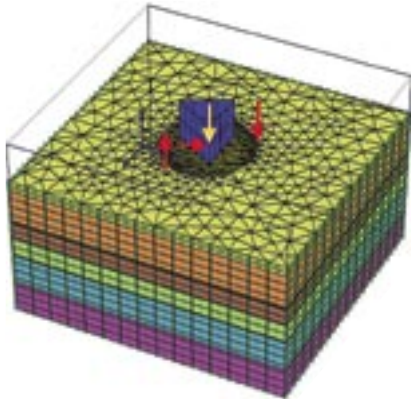


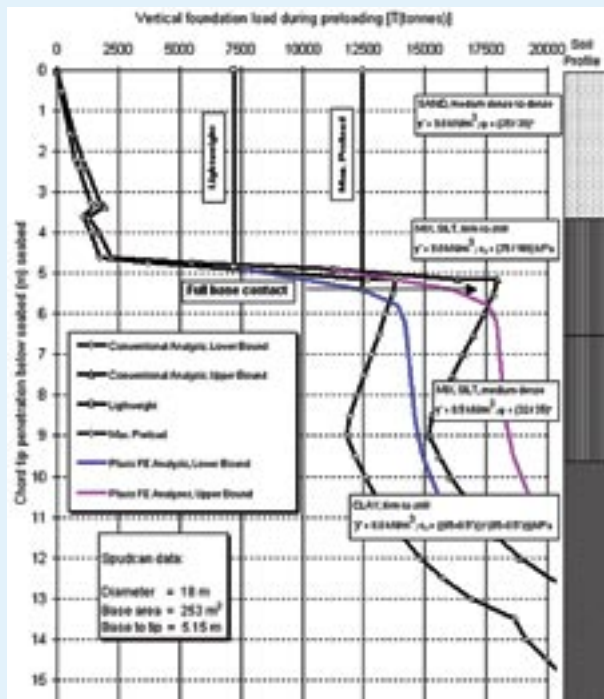
GEOTECHNIC



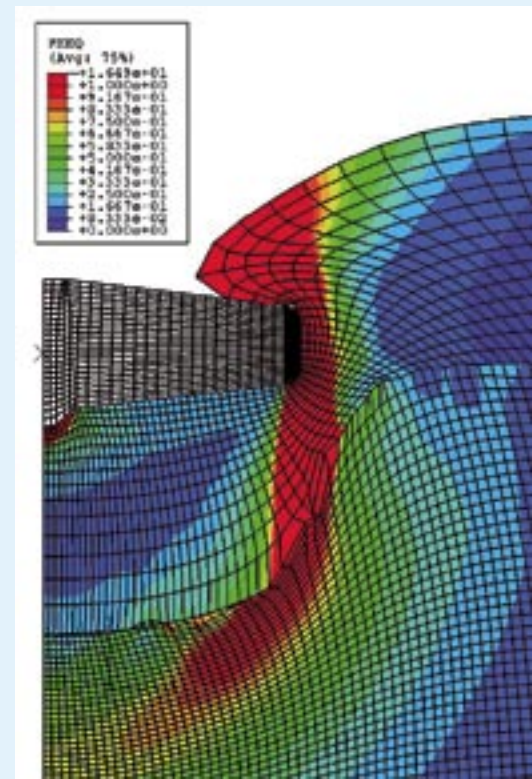
Jack-Up Rig Engineering

Ensuring safe foundations

Self-elevating mobile units, jack-up platforms, perform offshore drillings in water depths up to 150 m or more. Engineering assessment of jack-up rig foundations is one of GEO's fields of expertise considered a great challenge taking into account the size of the structures, their locations all around the world with variety in geology and offshore soil conditions, the increased tendency for installations in deep water and the expected environmental changes and weather hazards.



Conventional and FE skirted spudcan penetration analyses.



ABAQUS FE modelling of spudcan punch through, equivalent plastic strains.

Prediction of footing penetration during

Evaluation of the soil conditions and prediction of the spudcan penetration for different rigs located at specific locations around the world were the main scope of the work started from the Danish Geotechnical Institute since early 80s, to a great extent to satisfy Maersk Contractors requirements to engineering assessment.

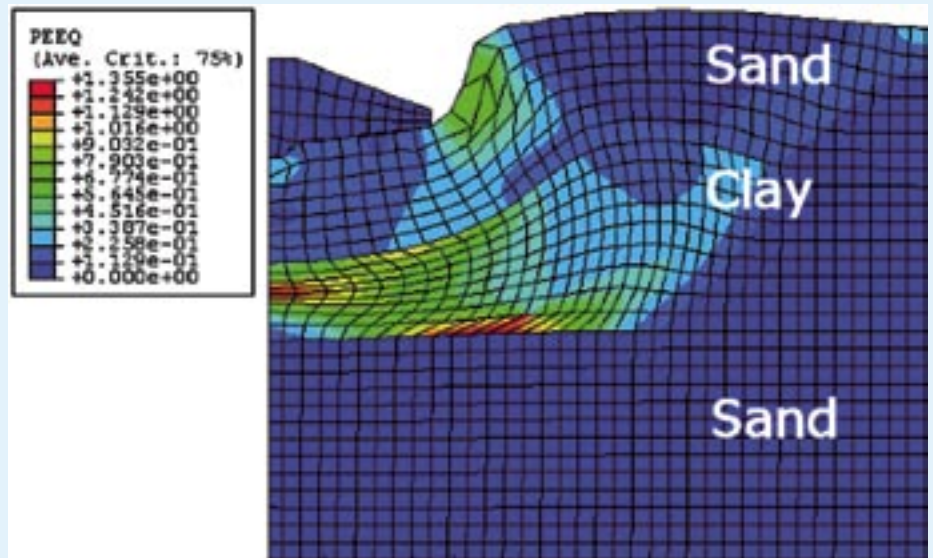
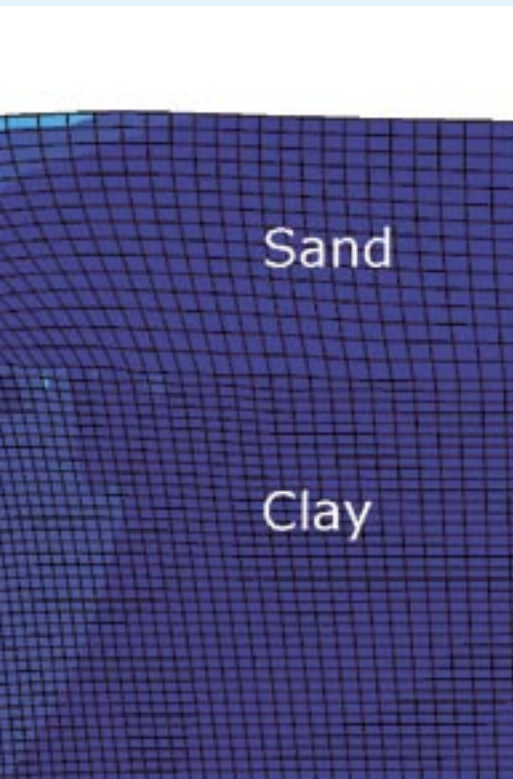
Simple conventional analyses were initially carried out, which were further developed including more advanced methods where soil layering and strength increase with depth were taken into account.

Evaluation of the soil conditions on the basis of the available soil data delivered to GEO by the rig owners and engineering assessment for rig installation, and /or operation phase, is the main product GEO delivers to its clients. The data are explored by

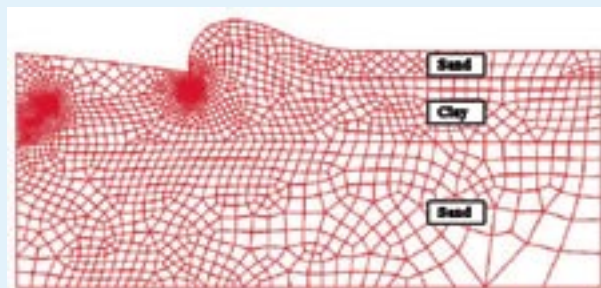
different geotechnical companies around the world and generally include seabed and shallow seismic survey, site investigation, boreholes (BH) combined with cone penetration tests (CPT), laboratory testing etc.

Prediction of spudcan penetrations with the varying loads is an important issue in the process of jack-up rig installation. Unexpected sudden and rapid penetrations or severe differential spudcan settlements can be of major risk for the stability and equilibrium of the jack-up rig structure.

Generally in this area classical conventional analyses, which are applications of bearing capacity equations for homogeneous soil conditions and modified procedures for layered soils, are normally used for penetration prediction. However, for multilayered critical soil profiles the modified



ABAQUS FE model, equivalent plastic strains.



ELFEN FE model and mesh adaptivity.

preloading

conventional procedures seem to be generally unrealistic. It is well known that these analytical procedures have several limitations. For these reasons alternative analyses based on the numerical modelling of the large deformations are investigated and procedures defined.

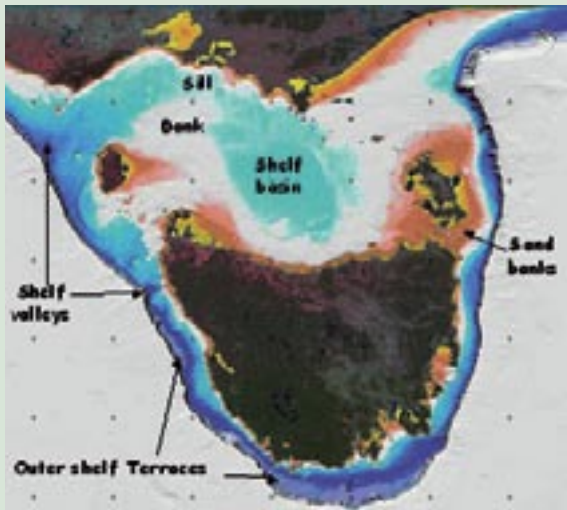
The conventional analyses for lower/upper bound soil parameters are based on classical plasticity for sand, clay or combined soil profiles at different levels of spudcan penetration and predefined failure mechanisms. The numerical analyses in which no assumptions have to be made on the failure mechanism, are based on finite element (FE) method using FE codes like ABAQUS, ELFEN and PLAXIS implementing possible large deformations and mesh adaptivity.

FE design procedure is verified by classical plasticity solutions for rather homogeneous soil conditions and by monitoring results for complicated multi-layered critical profiles. The feed back from the clients regarding the observations during the installation is of a great value for improving our conventional and numerical methods applying back analyses.

The international aspect of the projects has given the opportunity for cooperation with different companies and universities around the world.

The projects in areas like Arabian Gulf, Egypt, Persian Gulf etc. where working with carbonate soil is a challenge, in Bass Strait in Australia where calcarenite soil and caprocks are present, in South East Asia where punch through type profiles

are identified, out in the North Sea, South America etc make our service challenging and ambitious for new research and developments insuring 'strong legs' on 'safe ground'!



Geotechnical during site in or rig preload

In areas expected to be critical with respect to jack-up rig installation, for an independent interpretation of the soil conditions and evaluation of the soil parameters for engineering design, GEO has assisted through geotechnical representatives during the site investigations, BHs / CPTs carried out by other / local companies.

Map showing geomorphologic features along the Australian SE margin.

Geological studies

Jack-up rigs are often proposed for unknown locations all around the world. Sometimes in the tender phase a preliminary evaluation of the soil conditions is necessary. When no site investigation BH /CPT or shallow seismic surveys are carried out at the location, area geology studies can be helpful in achieving some kind of approximate prediction of the soil conditions, which later on will be verified by site investigation. In such cases cooperation with other organizations such as Geological Survey or Geoscience's Institutes in different countries and universities has been fruitful in finding proper geological maps, soil data in the vicinity of the location of interest etc.

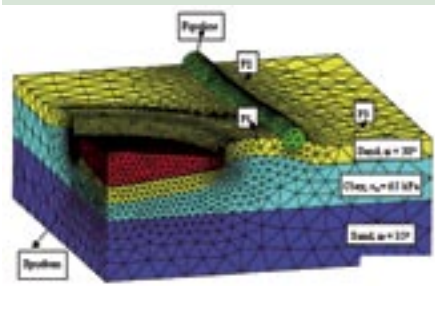
For one project offshore Tasmania GEO was assisted for example by Geological Survey of Denmark and Greenland and Geoscience Australia in finding additional data for a rig location near King's Island. The research on the area geology in combination with some shallow CPTs was considered sufficient for the engineering assessment.



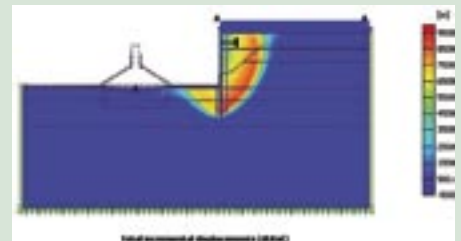
GEO staff at work.

assistance investigations ing

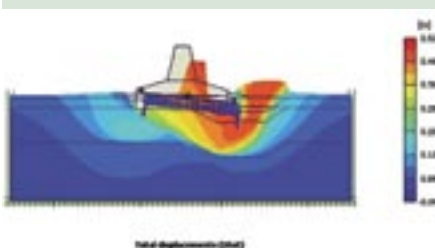
During site investigations in the North Sea, offshore Egypt, offshore China etc an independent geological description of the different soil types is performed and the information forwarded home to GEO ingenious, who in cooperation carry out engineering assessment of the sites for different jack-up rigs.



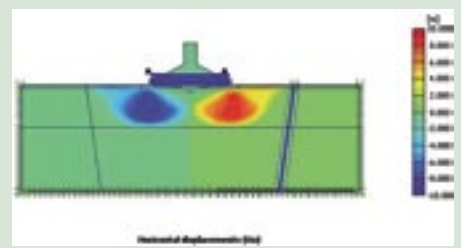
ELFEN FE modelling of spudcan-pipeline interaction.



FE modelling of spudcan-quay wall interaction.



FE modelling of skirted spudcan-footprint/open trench interaction.



FE modelling of spudcan-pile interaction.



Spudcan interaction with other structures

During jack-up installations in locations where the rig is close to a fixed oil platform, a harbour area, or the spudcans are close to the covered or uncovered pipelines the interaction of the spudcans with other structures such as platform pile foundation, quay walls, pipelines etc. are generally taken into account. In addition, the behaviour of the spudcans with/without skirts and the interaction with the jack-up structure are investigated when there are disturbances / footprints in the seabed from previous rig installations or the seabed is inclined or consists of undulating layers.

Spudcan-pipeline interaction modelling is carried out for rig installations in the North Sea. Spudcan-quay wall interaction

analyses are carried out for rig installation offshore Denmark. Spudcan-platform pile interaction is carried out for rig installations offshore Egypt. 3D modelling of the structure-skirted spudcan-seabed instability is carried out for rig installation offshore Norway. Spudcan - footprint interaction analyses are carried out for rig installations in the North sea, UK Sector etc.



GEO's CPT rig, SCOPE.

Foundation stability after preloading, sliding and fixity

Design of offshore foundations is often based on their capacity/integrity under monotonic combined total vertical, moment and horizontal load as limiting conditions due to environmental impacts and other factors during the operation.

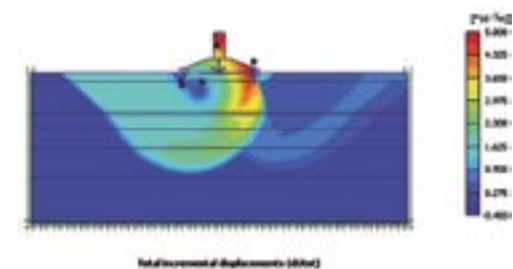
The present industry guidelines applicable to offshore foundations are generally based on the theoretical bearing capacity solution for failure of strip footings under vertical load. Alternative foundation geometry, embedment, load inclination and eccentricity, are accounted for by various

Deep push CPT investigations

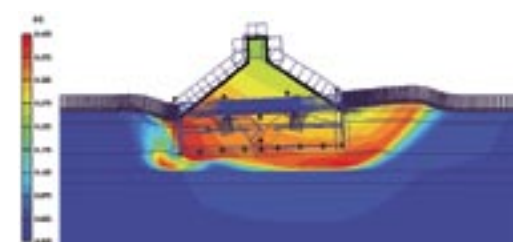
Sub-soil conditions at an offshore site can be investigated in several ways. Among others CPT is a recognised standardized investigation method that provides in-situ measurement of the soil layers penetrated during the test.

The main advantage of the seabed CPT is that the results provide a continue profile over the total investigation depth (no gaps in the data coverage) and the test can be performed relatively fast, e.g. testing to 35 meter depth is completed within approximately 2 hours. GEO's heavy seabed CPT rig 'Scope' can be ballasted up to 28 tonnes which ensures 200 kN effective push force on the seabed.

Is it possible that deep push CPT information alone can ensure the required soil data information at a given site? In short - it depends on the site. In the cases where it is a question of verification of the actual soil condition e.g. at planned spudcan locations in an area with 'known' geology from previous investigations deep push CPT could very well be a cost effective way of gaining the required data. GEO has carried out deep CPT investigations in several locations in the North Sea where different rigs were successfully installed. Despite CPTs, GEO carries out shallow seismic and BH combined with CPT for shallow depths applicable to locations near harbour etc.



2D FE moment failure figure.



Skirted spudcan under storm load, sliding at yield.

modification factors and effective / equivalent area method. However, the conventional approach might not always be reliable for conditions when the combined loads act together on a three-dimensional (3D) footing geometry located on layered soil conditions often encountered offshore.

Furthermore, jack-up rig foundations are often equipped with outer and inner skirts, which penetrate the seabed during installation confining a soil plug. The skirt enhances additional moment capacity, which increases due to suction developed within the skirt during moment loading.

Conventional analyses are widely used by GEO in the offshore industry. When found necessary alternative design methods such as 2D and 3D FE footing-soil interaction modelling are carried out for footings under combined loadings and layered soil conditions. Such analyses are performed for different jack up foundations in the North Sea and elsewhere.

GEO course on jack-up rig foundations

When requested by its clients GEO holds a geotechnical course applicable to jack-up rig foundations. New developments in the analysis with illustrations from completed or upcoming projects are discussed.

The course includes:

- Geological processes and seabed soil sediments. Geological description and classification tests
- Offshore site survey, (bathymetry, side scan sonar, seismic), geotechnical site investigation, (borehole / CPT), and data interpretation
- Workshop at GEO laboratory on the advanced soil strength laboratory testing, (triaxial tests, shear box etc.)
- Evaluation of design upper / lower bound soil profiles and parameters applicable to jack-up rig foundations
- Prediction of spudcan penetration during preloading, punch through risk assessment, conventional, experimental and numerical approaches
- Spudcan stability after preloading, conventional and numerical bearing capacity for pinned conditions and footing fixity including suction effects
- Spudcan interaction with other seabed structures considering spudcan-footprint interaction, spudcan-pipeline interaction, spudcan-pile interaction, and seabed instability.
- Guidelines for jack-up rig site assessment with particular reference to foundation integrity

Laboratory testing

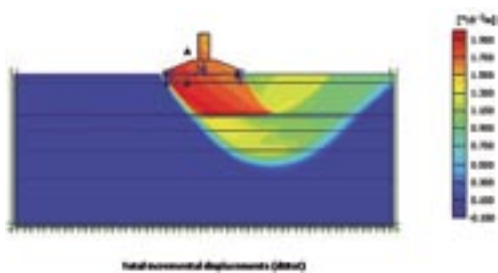
Depending on the project, soil samples are sometimes brought home from GEO's engineers assisting during the site investigations carried out by other geotechnical companies, or site investigations, BHs / CPTs, carried out by GEO Marine Investigation.

The soil samples are used for geotechnical index testing (water content, unit weight, particle size distribution etc.), geo-chemical testing (organic, carbonate content etc), compressibility testing (oedometer), strength index testing (torvane, pocket penetrometer etc.), strength testing (triaxial unconsolidated undrained (UU), consolidated undrained (CIU and CAU) and consolidated drained (CID and CAD). Tests are performed for projects in North Sea, Norwegian Sector and Egypt, where soil

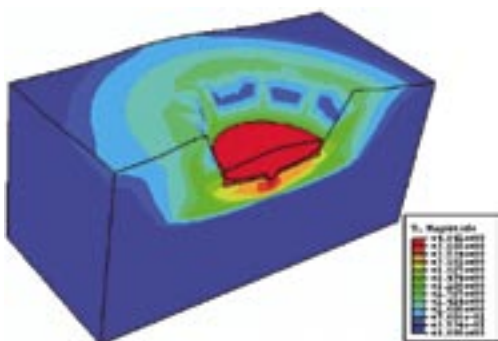
parameters applicable to the analyses are defined.

GEO has the largest soil mechanic laboratory in Denmark and experienced engineers that carry out and interpret the tests. For a rig installation offshore Australia, in cooperation with local companies, which carried out the advanced laboratory tests, GEO expertise in calcareous soil was used in the interpretation of the tests and soil profiles/parameters applicable to the engineering design.

Soil profile interpreted from the varying laboratory strength tests at one location offshore Australia

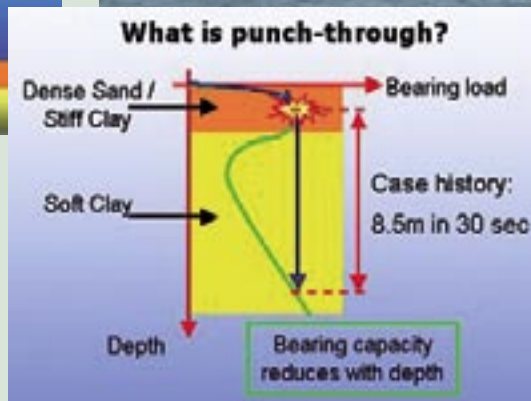
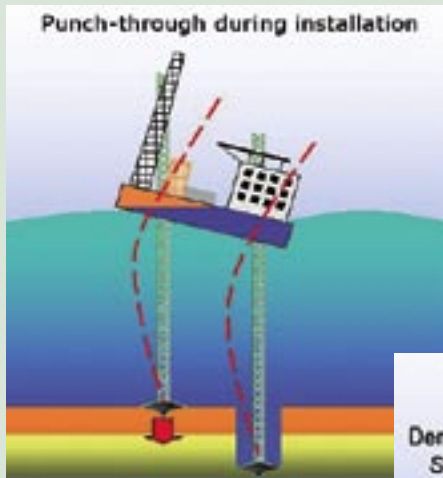


2D FE sliding failure figure.



Spudcan under storm load, total displacement.

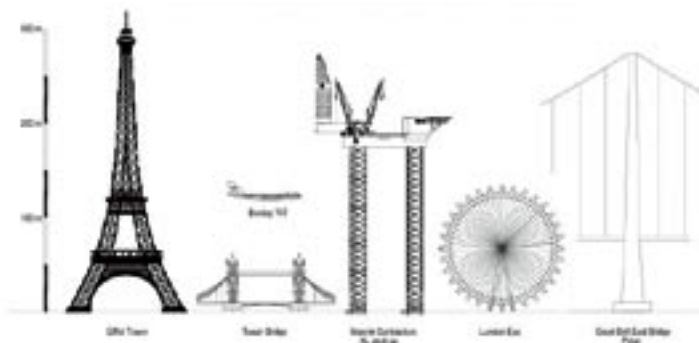
Punch through risk assessment



GEO's engineering consultancy for jack-up rig foundations follows the international (SNAME, DNV, ISO) as well as the Danish guidelines and has increased during the years, counting until 2006 about 350 projects all around the world. A database covering soil investigations offshore is established and continuously updated. The main issue is preventing jack-up rig installation in areas with punch through hazards. Figure below gives schematically an idea on the punch through phenomena.

GEO recent publications on jack-up rig foundations

1. L. Kellezi, H. Denver, G. Kudsk and H. Stadsgaard, (2007), FE Skirted Footings Analyses for Combined Loading and Layered Soil Profile. Submitted to 14th European conf. On Soil Mech. and Geotechnical Eng. Proceedings, Madrid, September 2007.
2. L. Kellezi, H. W. L. Hofstede and P. B. Hansen, (2005), Jack-up Footing Penetration and Fixity Analyses. Proceedings, Frontiers in Offshore Geotechnics, ISFOG 2005, September, Perth, Australia, page 559 – 565.
3. L. Kellezi, G. Kudsk and P. B. Hansen, (2005), FE Modelling of Spudcan – Pipeline Interaction. Proceedings, Frontiers in Offshore Geotechnics, ISFOG 2005, September, Perth, Australia, page 551 – 557.
4. L. Kellezi and H. Stromann, (2003), FEM Analysis of Jack-up Spudcan Penetration for Multi-Layered Critical Soil Conditions. Proceeding of BGA International Conf. on Foundations, ICOF2003, Dundee, Scotland, 410-420.



Maersk Contractors is a world leading drilling contractor. The picture below where world's largest platform Maersk Inspirer / Innovator is shown in comparison to great structures such as Eiffel Tower and others, gives an idea on the type of the structures we are dealing with on the geotechnical aspects and the challenge of installing them on safe ground.

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Maglebjergvej 1
DK-2800 Kgs. Lyngby
Phone: +45 4588 4444
Fax: +45 4588 1240

Saralyst Allé 52
DK-8270 Højbjerg
Phone: +45 8627 3111
Fax: +45 8627 6706

Danalien 1
DK-9000 Aalborg
Phone: +45 9818 9144
Fax: +45 4588 1240

geo@geoteknisk.dk
www.geoteknisk.dk