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General Report — Session 9: Case Histories of Offshore Geotechnics

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CASE HISTORIES OF OFFSHORE GEOTECHNICS
General Report – Session 9

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INTRODUCTION

This General Report is presented in the following three sections. The first section will provide a general overview of topics relevant to this session. The second section presents a summary of the papers within this session, followed by general comments on the papers. The final section will consider some of the areas of future development and will conclude with some points for discussion.

SUMMARY OF RELATED TOPICS

Introduction

Increasing global demands for energy is the primary driving force behind the development of offshore geotechnics. Traditionally, advances in offshore ground investigations, geotechnical and geophysical characterization, engineering analysis, design and construction, drive and are driven by the developments in the offshore oil and gas industry. However, in more recent years, there has been increasing interest in offshore developments to service the needs of the renewable energy markets. Knowledge of seabed soils and rocks is essential if offshore and near shore structures are to be properly and safely designed and built.
Deeks (2005) observes that there is clearly a need for developments in the skills and practice of offshore geotechnics which can be related to two specific reasons:

1. Hydrocarbon field discoveries are consistently being made at ever increasing depths, often to depths of 2000m, and within geotechnical materials with properties that are often beyond conventional experience; and
2. The offshore environment provides reliable wave and wind catchments for renewable energy which can be exploited without the constraints evident for onshore sites, such as public perceptions (NIMBY attitudes).

However, as evidenced by the papers presented in this session, it is also clear that the challenges faced by geotechnical engineers working in the offshore environment extend far beyond these forms of development.

Significant engineering challenges need to be resolved in order to facilitate such developments; for example, the United Kingdom (UK) government has pledged to produce 10% of its energy from renewable sources by 2010, which would require approximately 3500 new 5MW wind turbines. The horizontal loading on typical wind turbines is of the order of 5MN, and tends to be of the same order of magnitude as the vertical loading developed by self-weight. This is in contrast to typical oil platforms that generate a vertical loading an order of magnitude greater; new foundation structures are therefore required.

The role of the geotechnical engineer is to assess the properties of the soils at a site in the context of design and construction. However, the offshore geotechnical industry is faced with many new risks and safety issues that need to be accounted for; traditionally offshore engineering has focused on the exploration and production of oil and gas, from relatively shallow water environments. Oil and gas production in these cases was largely from steel jacket platforms and concrete gravity based structures. The need to exploit more economically marginal near shore fields, deep water fields, as well as the demands from other offshore developments, including wind farm projects, has increased the demands placed on offshore geotechnical engineers, presenting them with new and difficult challenges. With developments in general moving further offshore and in regions never previously developed, such as West Africa, not only are the soil conditions encountered considerably variable, but also the types of facility required are evolving; there is a trend away from the fixed steel and concrete platforms, towards floating facilities, incorporating tension leg platforms, with vertical tethers anchored to pile foundations, and spars (moored buoy production facilities) and tankers held in position by mooring chains (Randolph et al, 2005).

The papers presented in this session highlight just a few of these new challenges and how they have been met with success.

Offshore Site Characterisation

Increasing energy consumption has driven the need for further hydrocarbon exploration, initially extending onshore fields in North America and the Middle East, in to shallow, near shore environments. Subsequent large-scale developments have followed further offshore in areas of the North Sea, Australasia, South America, the Far East, India, and in recent years, West Africa. In each of these regions, different soil conditions are encountered, for example, in the North Sea over consolidated clays and dense sands are commonly encountered, whereas soft, very high plasticity clays might be encountered in West Africa, (Randolph et al, 2005). As a consequence, techniques for site investigation and design are evolving as developments move further away from shallow, near shore environments, to locations where foundation conditions and geohazards might be considerably different.

Offshore site investigations tend to be phased, and detailed investigations are not undertaken until the proposed location of the development is fixed. Walker (1998) observed and discussed the high cost of soil borings in deep water and the greater uncertainty faced by design engineers when information from only a few boreholes is available. The traditional approach of a preliminary investigation followed by a detailed ground investigation may eventually be replaced by a single integrated investigation, where ground investigations incorporate geophysical surveys in order to optimize geotechnical data collection. Jeanjean et al (1998), Evans et al (1998) and Nauroy & Dubois (1998) discuss the application of integrated approaches on specific development sites.

Recent advances in the application of geophysical techniques, has provided geotechnical engineers with a wide range of approaches for reliably determining the seabed terrain. In addition, the accumulation of geotechnical and geophysical data is allowing extensive databases to be developed which facilitate the extraction of geotechnical parameters for design purposes.
In general, offshore site investigations, as with onshore investigations, require a combination of field testing and soil sampling for subsequent laboratory testing. Lunne (2001) provides a comprehensive review of the many forms of in situ testing methods, but the two main forms of test are the piezocone penetrometer test, or the cone penetration text (CPT) and the shear vane test. In more recent years, the T-bar penetrometer has grown in popularity (Randolph et al, 1998). The advantages of penetrometer testing lie in the flexibility of the systems available; Lunne & Powell (1993) for example, discuss the development of piezocones (PCPT) and seismic cones (SCPT), as well as pressuremeter cones, electrical resistivity cones and lateral stress cones, all of which have some advantages over other in situ testing methods. The T-bar penetrometer has specific application to very soft soil sites, as it is more sensitive and thus considered more accurate for measuring the undrained shear strength of such soils.

General guidance on geophysical techniques has been provided by McDowell et al (2002), but in recent years the development of remote data acquisition systems, using Unmanned Underwater Vehicles (UUV), for example, in deep water environments (>1000m), has had the greatest industrial impact. In addition, bottom-towed resistivity and seismic refraction systems have also been employed in depths up to 1500m, in order to provide continuous profiling. These systems can be utilized in conjunction with physical sampling or in situ testing in order to provide more comprehensive ground truth calibration.

Geotechnical Analysis and Design

In general, design practice in offshore geotechnics, has been born out of onshore practice, but as Randolph et al (2005) observed, the application areas have diverged over the last 30 years. This divergence has been driven by two main factors; the scale of the foundation elements employed and the differences in construction techniques.

Geotechnical design and analysis is rife with uncertainty, particularly in relation to the determination of geotechnical design parameters, but also in relation to the applied loads; the role of the geotechnical engineer is to reduce this uncertainty.

In the offshore industry two main types of foundations are employed, deep foundations and shallow foundations. The design procedures for the former have developed in parallel with onshore theory and experience, and these procedures are well developed and understood for many different types of soil conditions, under various loading regimes. Lacasse (1999) observes that the API (1993) design approaches for pile designs are satisfactory for clay soils, but pile capacity predictions in sand are more uncertain. Despite design methods being heavily reliant on empirical correlations, pile foundations are still the most commonly used foundation type. The main limitation to their use is in deep water environments, where developments are required is installation procedures.

Shallow foundation design procedures and guidelines have in some cases required extensive re-evaluation because of the significant offshore loading conditions. The response to loading of shallow foundations can be analysed in a number of different ways; the API (1993) recommends the elasticity solutions proposed by Poulos & Davis (1974), though researchers have identified limitations to this approach in the context of moment and horizontal loads (eg. Bell, 1991). ISO guidelines recommend the use of conventional bearing capacity theory evolved from the work of Prandtl (1921), Terzaghi (1943), Meyerhof (1953), Vesic (1973), and others. More recently, interest has grown in the application of the three-dimensional yield surface approach and work hardening concepts imbued by plasticity theory, as classical bearing capacity formulations have been shown to be inappropriate when combined loading conditions are considered, as apparent offshore, where large horizontal loads and moments might dominate. Additionally, issues such as tensile capacity of the foundation soil and issues of cyclic loading capacity are ignored, (Gourvenec & Randolph, 2003; Anderson, 2004).

The main change that has taken place in offshore design practice over the last 10 years or so, has been the shift away from the working stress design (WSD) approach of the API (1993), towards load and resistance factor design (LRFD), in which partial factors are applied to loads and resistance (eg. material strength), (ISO 2000; 2004; BSI, 2004). This is perhaps a recognition that there is some uncertainty relating to the reliability of design approaches. Laver (1997) states that such approaches result in a more uniform reliability for a wide range of load and load combinations and component types, when compared with WSD approaches.

Jardine & Chow (1996) discuss the theoretical development and application of an alternative procedure for assessing the axial capacity of offshore piles, based on extensive research undertaken by the authors. The advantages of this approach over the WSD and LRFD approaches are also identified.

The increased use of numerical modelling has improved the understanding of offshore soil mechanics and the behaviour of individual foundation types; coupled with advancements in the application of physical modelling techniques, including centrifuge modelling, this is perceived to be an area that is contributing significantly to improvements in geotechnical design and construction processes.

Management of Risk

Risk of geotechnical failure is an inherent part of civil engineering design and construction in both the onshore and offshore environments. Many of the geotechnical risks apparent onshore, can be considered for offshore structures also, eg. inadequate soil investigation, soil variability. It is a consequence of this uncertainty that many design approaches implicitly incorporate methods of reducing the risk of geotechnical failure, by way of either a global factor of safety, in the context of WSD or partial factors in the case of LRFD approaches. However, it is considered that such implicit assessments of risk, as imbued in deterministic approaches to design are inadequate and possibly inappropriate in the offshore environment, where there may be the greater potential for uncertainty, eg. applied loads. This raises the possibility of using more explicit techniques to quantify the risk, assuming that the hazards have first been identified.

Interest in the application of probabilistic tools to the assessment of risk in geotechnical engineering has increased in the last two decades (see Smith, 1981, for example), and the application of such techniques are already being explored in the area of offshore geotechnics, (see Morandi & Virk, 2000; Lacasse & Nadim, 1996, for example).

PAPER REVIEW

The papers are briefly summarized and their conclusions discussed in this section.

Paper #9.01 by Wolfgang G. Brunner and Manfred Beyer

The authors present a case study of the installation of pile foundations for the BOWind farm project, located in the East Irish Sea approximately 7km south west offshore of Walney Island, near Barrow-in-Furness, Cumbria.

The project comprises 30 no. 3MW wind turbines and one offshore substation, arranged in a rectangular grid on a site area of approximately 10km^2. Tubular steel monopiles of 4.75m diameter and varying wall thickness ranging from 45mm to 80mm provide the wind turbine foundations with the monopiles varying in length between 49.5m and 61.2m, weighing 452 tonnes and achieving seabed penetration up to 40.7m.

The ground conditions across the site are variable and complex; in particular the authors note the presence of stiff to hard formations of completely weathered mudstone and siltstone and weak to moderately weak siltstone and sandstone across parts of the site, underlying superficial soils and glacial deposits of varying thickness. Concerns were raised regarding the potential disruption (refusal) to the installation of the monopole foundations. As a consequence the foundation construction process documented by the authors involved the use of traditional pile driving combined with drilling to achieve final target penetration.

The case study allows the authors to document the use of a new type of pile drilling system, the Bauer Flydrill system, which in contrast to fixed pile-top drilling systems, is a highly versatile ‘mobile’ pile-top drilling system for applications in kelly mode in all types of soil and weak rock as well as in RC mode for drilling rock sockets in hard rock. Integrating the power packs fully into the setup without the need for an umbilical cord has enabled the Flydrill to be suspended from a crane, placed on top of an isolated monopile in the sea and operated fully independently from any other power source on board the support vessel. All operations are carried out by a fully integrated remotely controlled operating system via radio controlled link. Deployment of the Flydrill in kelly mode with large-diameter drilling buckets offers an environmentally friendly method of spoil disposal.

Paper #9.03 by A. Arulrajah, M. W. Bo and H. Nikraz

This paper provides an account of the Changi East reclamation project, carried out between 1992 and mid-2004 in the Republic of Singapore. The project required the deposition of some 200 million cubic metres of well-graded, free draining sand dredged from nearby sources in order to increase existing ground levels to above sea level, over a total land reclamation area of approximately 2500 hectares.

Two main issues are emphasized by the authors: firstly the placement of large quantities of fill material on to highly compressible marine clay foundation soils; secondly, the placement of the granular fill required deep compaction in order to achieve an appropriate density, strength and stiffness. Under normal circumstances, such fill materials would be placed hydraulically, with little or no control over the final density characteristics; in this case, deep densification of the granular fill was carried out over an area of approximately 114 hectares.

Although the authors provide an excellent account of the overall project, the main focus of the paper is a discussion of the importance of consolidation and compression of the marine clay layers underlying the project area. The authors provide a detailed account of the application of pre-fabricated vertical drains to increase the rate of consolidation, combined with preloading, and highlight the use of in situ testing and observations at pilot scale and at full scale.

A total of 7246 geotechnical instruments were used at the project site, these included piezometers (pneumatic, open type, standpipes and electric), settlement plates and gauges, inclinometers and earth pressure cells. In addition, a wide variety of in situ tests were undertaken to characterize the marine clays, such as shear vane tests, piezocones, dilatometers and self-boring pressuremeters.
Results from the instrumentation and from the in situ tests are presented and discussed for different phases of the project and for different areas of the project site.
Another challenge faced by the designers on this project related to the placement of the sand fill material; normally this would be placed hydraulically, however, using such methods limits the ability to control the placement density of the fill. Different

approaches to soil improvement adopted at the Changi East site have been discussed, and include Dynamic Compaction, Vibroflotation and Muller Resonance Compaction; the relative advantages and disadvantages of each of these is discussed at length.

The authors conclude by observing that the in situ monitoring indicates that the installation of the vertical drains increased the rate of consolidation significantly.

Paper #9.04 by Paul Doherty and Kenneth Gavin

The authors present details of the installation of, and cyclic load tests carried out on a highly instrumented driven steel pile. The main focus for the paper is the changing effective stress conditions in the vicinity of the pile at different loading levels and differing number of cycles of loading, and in particular, the mechanisms controlling the degradation of axial resistance under cyclic loads.

The paper commences with a useful contextualization of the study which examines the issues of design of piles to be used in the offshore environment.

It is highlighted that effective stress design approaches for static pile design have become commonplace in recent years, however, due to a lack of field data relating to effective stress changes due to cyclic loading of piles, it is difficult to apply the same design approaches.

Some studies have been undertaken in to shaft friction degradation under cyclic loading, based primarily on field testing, and these are commented on by the authors.

The experimental pile has an external diameter of 73mm and a length of 2m, with additional 1m sections to give an overall pile length of 6m. This has been instrumented using strain gauges and pressure transducers, allowing measurements to be made of radial total stresses, pore water pressures and shaft shear stresses during installation, cyclic loading and subsequent loading to failure. Additionally, the applied load during testing was recorded by way of a load cell located on the pile head, and displacement by means of LVDT's.

The authors conclude with a summary of the main observations drawn from the testing programme, in which it is stated that there appears to be a relationship between the static and dynamic pile capacity and pore water pressure changes during loading, and that changes in effective stresses are a function of displacement, number of cycles of loading and the magnitude of loading.

Paper #9.07 by Al Gokalp and Rasin Duzceer

The Artificial Islands Project in the northern Caspian Sea, Kazakhstan which commenced in May 2001 and was completed by November 2007, is the subject of the fourth paper in this session.

The authors provide an interesting discussion of the ongoing project to construct artificial islands to facilitate the exploration and exploitation of one of the regions largest oil fields. Since 2005, in addition to the construction of three artificial islands, ice protection barriers and auxiliary cofferdams have also been constructed to protect the islands from drifting ice ridges during the winter season.

A combination of steel sheet piles and steel pipe piles have been used for the ice protection barriers, combined with rockfill; the associated ground investigations and construction methods have been summarised by the authors.

The project has progressed under very difficult environmental and climatic conditions, with summer time water conditions exceeding 27^{o}C, whilst winter water temperatures drop below -25^{o}C; it is this latter issue that has necessitated the construction of ice barriers to protect the islands from drifting ice flows, ranging from 0.5m to 10m in height. Additionally, the region is designated as a Specific Ecological Region and a Specially Protected Zone.

Paper #9.08 by Gareth Swift and David Bone

The results of a geotechnical investigation are presented as part of a process of soil characterization for the proposed site for an offshore shallow foundation system.

The geotechnical data is used to carry out a preliminary analysis of the stability of a Gravity Base Structure to be used as a clump weight for a buoy located in the northern North Sea area.

The geotechnical ground investigation related to CPT and geophysical tests carried out on the seabed soils, combined with laboratory test data for soils in adjacent areas. The authors indicate that this process is somewhat unsatisfactory, and highlight the importance of an adequate site specific geotechnical investigation to support offshore design.

The geotechnical analysis initially considers the ultimate limit state of the proposed foundation in terms of bearing capacity and sliding resistance. The analysis concludes that due to the anticipated hydrodynamic loads, the sliding limit state is potentially compromised, and the designers recommended the installation of perimeter skirts/shear keys in order to mobilize the shearing resistance of geotechnically more competent strata at depth. An additional design consideration therefore, was penetration resistance of the skirts.

Paper #9.09 by Eric J. Parker, Francesco Mirabelli and Lorezo Pauletti

The bearing capacity of spud can foundations calculated from closed form solutions are compared with field observations from 15 offshore sites.

The authors initially present empirical bearing capacity formulations, modified for the offshore environment, for different soil conditions. Predictions of jack-up leg penetrations are made based on these relationships, and are compared with observed penetrations from 15 case study sites located in the northern Adriatic Sea.

It is shown in the results, that predictions are reasonably accurate, in general, though a mild tendency towards over estimation is noted, and in two cases penetration was significantly under-estimated.

The authors were able to conclude from this study that predictions in sand were the most reliable, whilst those in clay soils tended to over-estimate the penetration. Penetration through inter-bedded soil layers were the most difficult to predict with any degree of accuracy, and the authors highlight the difficulty in applying simple bearing capacity theory to complex soil conditions.

Paper #9.10 by Masaru Fujimoto, Takechiho Tabata, Tsuyoshi Emura and Masato Nakamichi

The final paper in this session relates to the construction of an underpass located on the man-made island on which Kansai International Airport (Japan) is situated. The island is located 5km offshore in Osaka Bay, and is underlain by in excess of 20m of soft Holocene clay deposits. The island comprises of fill material, 95% of which is sandy gravel. The authors describe in detail the construction of the first phase of this man-made island; the second phase of construction is now underway, with a second island being constructed adjacent to the first island.

Both islands impart a pressure to the upper surface of the Holocene soils, which as a consequence, undergo consolidation, leading to excessive surface settlements; settlement due to the second phase is anticipated to be of the order to 18m over the 60 year construction period. Ground improvement methods were employed during the first phase of construction, and will be employed during the second phase also.

Extensive ground investigation and laboratory testing has allowed the authors to develop a method by which the settlement of the island structure can be accurately predicted; these predictions are continually being compared with observations, to confirm their accuracy.

After considering the construction of the two islands, the authors turn their attention to the design and construction of the underpass that will connect these two islands. The authors highlight the problem that the two islands are at different stages of their settlement profile, and will continue to settle. It would be normal practice to begin construction of such structures on reclaimed land once the anticipated settlement had taken place, however, in this case, this was not feasible.

In this instance, the designers are confident of the long term behaviour (settlement) of the two reclaimed areas, and have allowed for this in the design of the underpass; this is discussed in some detail by the authors. In addition, by supplementing these predictions with ongoing observations (horizontal and vertical settlement and horizontal and vertical displacement of the structure), the stability and structural integrity of the underpass can be assured.

It should be noted, that any misunderstanding or misinterpretation of the papers reviewed for this session is the responsibility of the General Reporter and to those Authors whose papers may be misrepresented, apologies are offered. Comments regarding the papers have been expressed from the perspective of stimulating lively discussions during the session.

FUTURE TRENDS

The challenges facing offshore geotechnical engineers are considerable, and it is of value to consider at this stage issues that maybe of future interest.

<u>Site Characterisation</u>

Increased interest in 'one pass', integrated site investigations, using a combination of geotechnical ground investigation techniques (boreholes, in situ testing, sampling) and geophysical investigations, based largely on economic arguments, particularly for larger sites. However, there are issues with the level of detail and the interpretation of geophysical datasets, which need to be addressed, as well as technological issues associated with existing geophysical processes. It is likely that advancements will be made in geophysical techniques to overcome these limitations for application in deep water environments; many techniques are limited currently to shallow water investigations.

It is considered that the degree of sample disturbance and associated parameter uncertainty is one of the most significant issues in geotechnical design and analysis. Buckley et al (1994) observed that sampling and subsequent handling of the soil or rock samples before and during testing, will involve some form of breakdown of the material fabric, due to the actions of the sampler or alterations in the stress conditions during removal; such concerns become more significant as developments, and hence investigations move further offshore in to deep water environments, and Lunne et al (1998) summarise the main reasons for this as:

- less control over sampling process;
- use of simple sampling equipment from non-specialist survey vessels;
- soil is more sensitive due to geological factors;
- stress relief during sample recovery causing expansion and disturbance;
- melting of gas hydrates and subsequent expansion and disturbance of soil structure

Studies of deployment techniques to minimize disturbance in specific types of soils, are ongoing, and techniques for the reduction of uncertainties and correcting for the effects of sampling disturbance are the subject of continuing research.

Clearly the development of sampling techniques and in situ testing will continue, driven by the need to sample at greater depths and the costs associated with sampling time – the mobilization costs for a field exploration ship is of the order of £0.5million per day.

<u>Geotechnical Analysis and Design</u>

There has been considerable effort in recent years to develop new codes for the offshore industry in Europe and in the US, as opposed to the design approaches that have dominated in the past, developed by the American Petroleum Institute (API) and the American Institute of Steel Construction (AISC). These efforts have been coordinated by the International Organisation for Standardisation (ISO) and the API.

There is an increased interest in the role of physical/centrifuge modelling in understanding fundamental mechanisms, as well as the importance of numerical modelling in supporting the design process.

Although the use of numerical analyses is not widespread, finite element analysis has been applied to offshore foundation behaviour for some time (see Meimon, 1992; Zdravkovic et al, 2001; Martin & Houlsby, 2001; Hu et al, 1999, for example). Much of this work has been to produce design charts that might be used in routine design work. The main limitation to its widespread application as a design tool however, is the requirement for high quality soil property data for the proposed development site. This could be possible with integrated investigations, assuming that geotechnical data and geophysical data were mutually complementary. Many of the input parameters required for FEM analysis can be obtained from standard in situ tests

<u>Risk Assessment and Uncertainty Modelling</u>

As Clayton (2001) observes, the first stage in the geotechnical risk management process is the identification of the hazards and their associated risks. The most significant risk from a geotechnical perspective is structural or facility failure as a consequence of geotechnical foundation failure. Such a failure might be as a result of inadequate site investigation, poor foundation design and/or construction, or it might be as a consequence of offshore geohazards (which relates to the ground investigation).

Discussions relating to site characterization have already been presented and some concerns and issues relating to geotechnical design have also been highlighted. In addition to these discussions, it is also worth observing further sources of geotechnical risk.

There is a growing trend in the use of suction piles/caissons and anchors for floating platforms, but there is very little data regarding the field performance of such foundation types. Additionally, there is a poor understanding of the nature and effects of geohazards on offshore structures, in terms of additional loading.

Risks associated with structural or foundation failure are not at present quantified explicitly within current design procedures. It is common practice, instead, to address such risks using factors of safety embedded within design models, for example, the global factor of safety in WSD approaches, or partial factors in the LRFD format.

Alternative approaches might be to adopt probabilistic analysis rather than deterministic approaches, in order to explicitly quantify the risks and uncertainties associated with loadings, resistance, sampling errors etc.

Statistical approaches embedded within reliability analysis, such as Bayesian random field modelling or kriging for soil characterization and spatial variability based on limited borehole data or Monte Carlo simulations as part of a parametric analysis for design, are possible means of reducing uncertainty, and hence risk.

FINAL REMARKS AND TOPICS FOR DISCUSSION

<u>Introduction</u>

The papers presented in this session cover a wide range of important topics in the design, construction, and monitoring of offshore geotechnical structures and they illustrate some of the significant advances that have been made in these fields.

The purpose of this section is to establish a systematic communication between the authors and the delegates of this Conference in order to create a dialogue. It seems that this is the best way to provoke a wide discussion using open questions with the purpose of creating new propositions and to contribute to the advancement of the knowledge.

The topics for discussion are divided in to three main areas, as indicated by the Introduction to this Report, and these are, Site Characterisation; Geotechnical Design and Analysis and; Risk Management.

<u>Site Characterisation</u>

The following issues are considered as a basis for discussion:

1. The role of integrated (geotechnical and geophysical) ground investigations and the relative attraction of 'one pass' investigations
2. Understanding the role and importance of geophysics as a ground investigation tool (levels of detail; interpretation; bridging the gap between seismic and geotechnical data)
3. Importance of sample disturbance in the context of empirical design procedures
4. Trend towards smaller sub-sea structures with shallow foundations, so accurate characterization of near-surface soils is critical
5. The importance of geohazards at the local and regional scale

<u>Geotechnical Analysis</u>

The following issues are considered as a basis for discussion:

1. The role of empirical approaches in design
2. The attitude towards theoretical approaches to design, including the role of physical and numerical modelling
3. Input parameters, verification and validation
4. Cyclic loading and lateral response of shallow and deep foundations
5. How important is the observational method in offshore geotechnical design?

<u>Geotechnical Risk Management</u>

The following issues have been identified as areas for further discussion:

1. The role of probabilistic techniques in offshore geotechnical design
2. Reliability based design

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