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Reducing Geo-risks for Offshore Developments

ISGSR 2011 - Vogt, Schuppener, Straub & Bräu (eds) - © 2011 Bundesanstalt für Wasserbau ISBN 978-3-939230-01-4

Reducing Geo-risks for Offshore Developments

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ABSTRACT: This paper describes the systematic and holistic approach to geo-risk reduction that has been developed and applied to numerous deep water oil and gas projects and is now being used for shallow water wind farm developments. Key elements of the approach are:

- Regional Desk Studies to establish the geological context and develop preliminary Ground Models and Risk Management Strategies.
- The use of high and ultra high resolution geophysics to accurately define stratigraphy and geological structure.
- New geotechnical investigation techniques to quantify the physical characteristics of the geological strata.
- Advanced geological and geotechnical laboratory testing of soil samples and long piston cores.
- Analysis of geological/geotechnical processes that will influence areas or structures.
- The use of GIS as a geohazard assessment and screening tool.
- Advanced numerical modelling of soil/structure interaction.

Illustrative examples include projects offshore Angola, the West Nile Delta and the North Sea.

Keywords: Offshore, Geotechnical, Risk Reduction, Geohazard, Ground Model, GIS.

1 INTRODUCTION

Over the last ten years a more systematic and holistic approach to assessing shallow geological and geotechnical risks for offshore oil and gas developments has evolved. This approach is now being used to address similar issues for the offshore renewable energy market – and in particular offshore wind farm developments.

This paper will describe how this approach has evolved, giving some examples of its application off Egypt's West Nile Delta and offshore Angola. It will also explain how data acquisition techniques have developed to better quantify the natural environment and its physical characteristics and thus reduce uncertainties and the associated risks. The role of forensic core logging in Geohazard assessment and advanced laboratory testing of soil samples will be covered as will the use of Geographic Information Systems (GIS) for data management and presentation but also as a risk screening and engineering tool.

Finally, the latest application of the systematic approach to the UK's Round 3 Windfarm licence areas will be described.

But first it is worthwhile to consider the history of geological and geotechnical site investigations and risk assessment in the offshore environments in order to put current developments into context.

Offshore geotechnics was effectively born in the post World War II years; firstly in the Gulf of Mexico and in Lake Maracaibo, Venezuela, when attempts were first made to drill wells and install production platforms in very shallow water close to shore. The industry then spread into deeper water across the continental shelves of many parts of the world, arriving in the North Sea in the 1960's, with a subsequent boom triggered by the oil crisis in 1973. However, throughout this period the primary risk was related to geotechnical variability in one vertical axis and its impact on the bearing capacity and installability of deep piles. This risk was effectively managed by performing one or more geotechnical boreholes incorporating downhole sampling techniques. The development of large concrete gravity base structures as production facilities did require an accurate evaluation of small scale shallow soil variability across a typical footprint of 100m diameter. This was primarily to ensure that radial steel skirts could be evenly penetrated and differential settlements avoided. This was usually achieved by means of a close grid of seabed Cone Penetration Tests (CPTs) to depths of around 10m to 30m below the seabed. At the same time downhole CPT tools were also developed. The use of seismic sub bottom profiling and seabed imaging with sonar techniques tended to play a minor role in this context being primarily used to identify and avoid major foundation constraints, such as near surface bedrock or deep buried channels infilled with highly variable and/or less consolidated sediments .

The picture started to change in the 1980s when Gulf of Mexico oil & gas exploration moved off the continental shelf and into deeper waters down the continental slope, i.e. moving from water depths of a few hundreds of metres to depths in excess of 1,000 metres. This was associated with field developments that were not just based around a single fixed production platform but comprising more dispersed facilities including floating production systems anchored to the seabed and linked to other subsea wellhead and development structures. It was also discovered (Campbell et al. 1986) that these deepwater environments were more topographically dramatic and populated with multiple forms of high risk geohazards (geological features or processes with potentially detrimental impacts on development facilities and/or human activity). Campbell (1984) was also laying the groundwork for the systematic approach to site evaluation. During this period the value of re-interpreted 3D exploration seismic data, as a preliminary site assessment tool, started to be appreciated and applied to deepwater geohazardous projects.

Deepwater exploitation expanded around the world in areas such as South America, particularly Brazil, and West Africa. In the 1990's the UK joined the deepwater club with exploration and development on the Atlantic margins West of Shetlands (Power, 1997). Figure 1 compares the typical site area that needs to be evaluated for a shallow water, platform-based oil field development with that of a deepwater Floating Production, Storage and Offloading (FPSO) system. The combination of large dispersed development areas and multiple geohazards also encouraged a more risk-based approach to site evaluation in deepwater (Clayton & Power, 2002).

It is this approach that has been adopted and dramatically enhanced by BP and described by JeanJean et al. (2005) and Evans (2011). The latter describes the work of their UK based Geohazard Assessment Teams (GATs), the process they have developed, and how they have been applied to multiple deepwater field developments offshore Angola and the West Nile Delta (WND). Some of the challenges encountered in these areas and how risks are dealt with are described below.

The sequence of steps described by Evans involves an initial desk study for the development area incorporating all available public domain data and any site-specific seismic data that may have been collected for exploration purposes. The desk study is then used as the basis for a geotechnical and geohazards risk assessment that takes into account potential development scenarios and infrastructure.

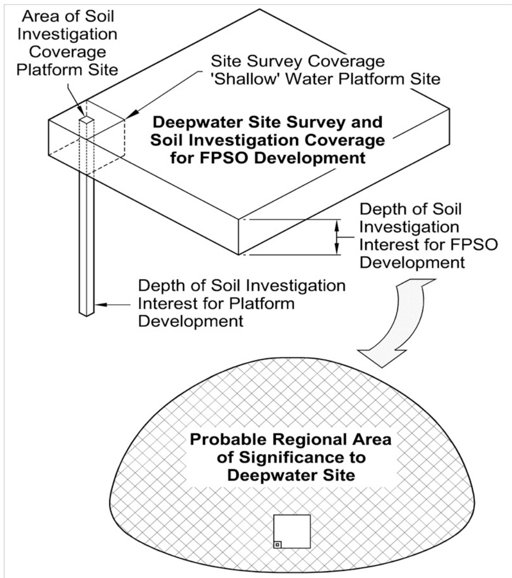

Figure 1. Comparative Survey Coverage Shallow vs Deepwater (Power 1997)

This approach is also used to start the process of creating a ground model and design preliminary geophysical surveys and geotechnical investigations. The data collected are then fed into the ground model and the wider risk management strategy including a more quantified assessment of probabilities and consequences of encountering the potential hazards indentified. More detailed programmes of data acquisition are defined and the tools required to quantify them are identified. In some cases the necessary tools have not existed and have therefore had to be invented. The quantification process also requires new laboratory testing techniques and analytical models to be developed. Examples of some inventions and developments are given below.

The aim is to evolve the conceptual ground model, developed at the desk study phase, to a geological model, by utilising subsequent geophysical survey data. It is then transformed into a geotechnical model based upon detailed site investigation data and finally translated into an engineering ground model in which soil- structure interaction can be accurately quantified (see Figure 2).

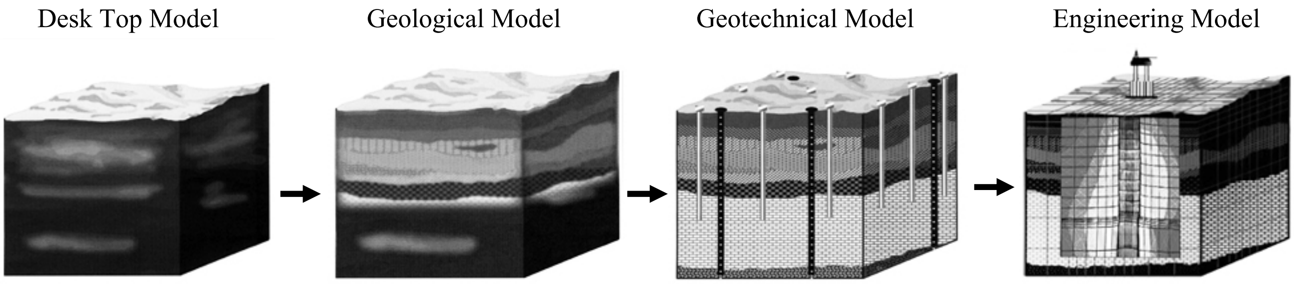

Figure 2. Evolution of the Advanced Ground Model from desk study to engineering design

2 OFFSHORE ANGOLA

Figure 3 illustrates the sort of natural hazards being encountered in deepwater offshore Angola and other parts of West Africa and why the described approach is needed to avoid, manage or mitigate the associated risks to offshore hydrocarbon developments.

Hill et al. (2011) describe in some detail the occurrence of such features. Pockmarks for example, which are conical seabed depressions formed by fluid expulsion which may be hundreds of metres in diameter and tens of metres in depth (Figure 4). The hazards they represent are multiple but can include the expulsion of corrosive fluids and slope instability. Sediment compression and movement due to the mechanism of salt diapirism (the uplift of deeper salt stratum due to their lower density) can result in anomalously hard layers and slope instability. The migration of deep hydrocarbons to the surface has, amongst other manifestations, resulted in atypical conditions such as carbonate-rich claystones or hard asphaltic mounds or lenses.

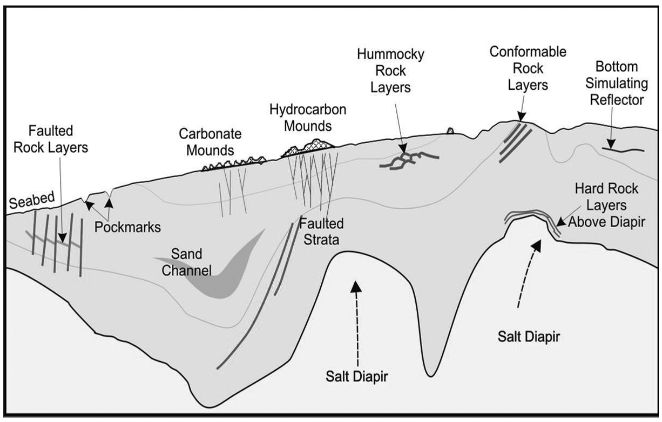

Figure 3. Surface & subsurface hazards offshore Angola

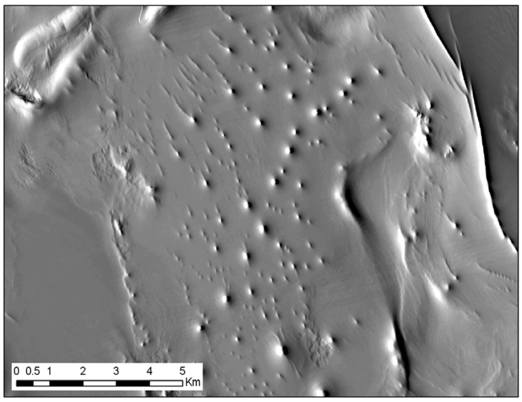

Figure 4. Typical pockmark field (Hill et al 2011)

Cauquil (2009) also describes the approach that Total are proposing for analysing and managing the risks posed by naturally occurring gas hydrates in deepwater offshore areas including West Africa. The methodology is based upon field data, interpretation and knowledge which can be adapted for other non-recurrent geological processes for which probabilistic analysis is not possible due to the absence of historical records at a specific location. The proposed Risk Management approach is illustrated in Figure 5 below.

All of these features can have a profound impact on field layout and engineering design resulting in significant financial costs. The fracture of pipelines or well casings can also have a devastating environmental consequence if they involve significant oil spillage.

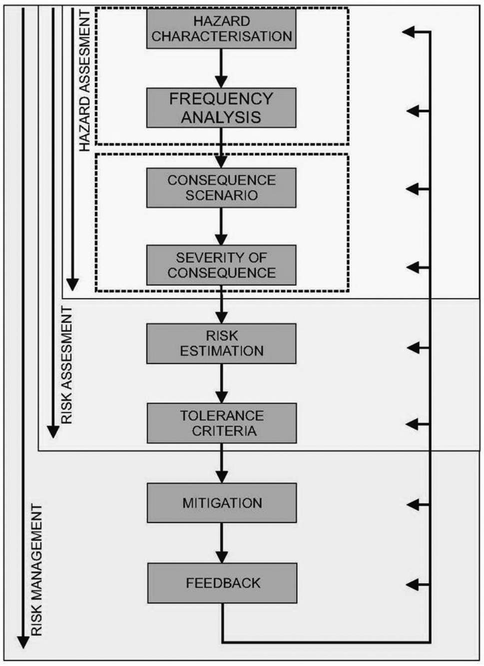

Figure 5. Risk Management Flow chart (Cauquil 2009)

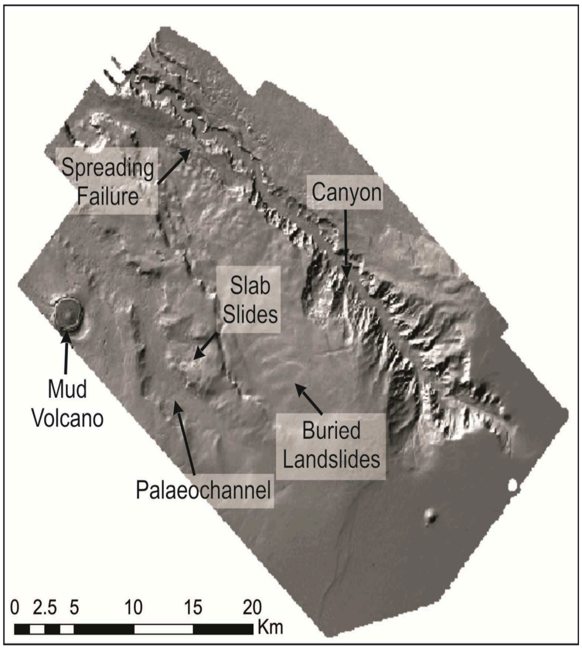

Figure 6. West Nile Delta seabed features (Moore et al..2007)

3 WEST NILE DELTA

The deep waters off Egypt's West Nile Delta also represent a new hydrocarbon province that incorporates significant natural hazards that require a co-ordinated and systematic geo-risk management approach.

Moore et al. (2007) and Evans et al. (2007) describe in detail, the approach that BP has taken to address the challenges posed by hazards such as:

- Seabed slope failures of all scales from a few hundred cubic metres in volume to many cubic kilometres.
- Mud volcanoes.
- Pockmarks and fluid expulsion features.
- Deep channels and scour features on the seabed.
- Variable soil conditions including biogenic hard grounds within soft clay strata.
- Deep seated faults and their surface expression.
- Seismic activity.

Figure 6 illustrates some of the seabed surface features, clearly defined by Autonomous Underwater Vehicle survey data.

4 COMPLEMENTARY DATA ACQUISITION, LABORATORY & ANALYTICAL TECHNIQUES

- *Geophysics /AUV/ downhole logging*

High and ultra high resolution reflection seismics are essential tools in modeling subsurface geological structure and imaging surface features to a sufficiently accurate level to define avoidance strategies or design mitigation measures. The most recent development has been in the use of Autonomous Underwater Vehicles (AUVs) to provide ultra high resolution surface imaging and near surface sub-bottom profiling (Bingham, et al. 2002). In addition downhole geophysical logging tools have also been refined to give a much higher density and resolution of data to further populate the ground model with more accurate information (Digby, 2002).

- *New Geotechnical tools and techniques*

New geotechnical tools developed to help improve the quantification of the physical characteristics of the ground include the downhole piezoprobe (Whittle et al. 2001) that can provide in-situ measurements of equilibrium pore pressures essential in assessing slope stability risks. Downhole sampling devices for recovering naturally occurring gas hydrates at their in-situ confining pressures in order to prevent disassociation during the recovery process are now being regularly used in the investigation of Hydrates not only as a hazard but also as an alternative energy source (Amman et al. 1998). The uncertainties and risks to seabed pipelines in very deepwater represented by extremely soft soils has been addressed through the development of the Fugro SMARTPIPE® to investigate in-situ soil-pipe interaction (Evans 2011). Laboratory testing techniques are also being developed to provide design input parameters which more reliably represent soil behaviour not conventionally accounted for in geotechnical design (Rattley et al. 2010). In addition, increased attention has been paid to very small strain soil behaviour and measurements of dynamic soil response are also being made as part of advanced laboratory testing programmes. Such measurements allow better definition of soil stiffness and degradation parameters for input into soil structure interaction and seismic response studies such as those carried out as part of the West Nile Delta site response analysis. Only when these techniques are applied consistently enough can accurate design parameters be generated to feed into advanced 3D Finite Element analyses that allow us to model soil structure interaction with an increased confidence.

- *Geohazard (Forensic) Core Logging*

Crucial to the assessment of hazard, and ultimately risk, of processes such as mass movements is an understanding of the frequency and magnitude of events. Ultra high resolution geophysical data, such as Chirp, deployed from an AUV, provide a useful platform from which to interpret sub-surface features; however experience has shown that these data should not be used in isolation for geohazard assessment. Thomas et al. (2011) suggest that reliance solely upon geophysical data may often overestimate magnitudes of events such as landslides, debris flows and turbidity currents. In one example from the West Nile Delta, multiple stacked mass movement deposits appeared as one large seismic unit on AUV Chirp profiles; however the individual event deposits were below the limits of resolution on seismic records and could not be differentiated (Figure 7). The application of detailed sedimentological logging highlighted the individual deposits, thus increasing the interpreted frequency of events, but decreasing the magnitude and hence the perceived risk to the sub sea development. This example, coupled with many others in the authors' experience identifies the critical place of detailed sedimentological logging as part of a comprehensive geohazard assessment.

Thomas et al. (2011) suggest that multiple data acquisition techniques essential, promoting that as well as obtaining standard geotechnical samples there is a need for long core samples to be taken specifically for the purposes of detailed geohazard core logging. Where cores have been sub-sampled for geotechnical testing, often significant sections of the stratigraphic record are removed, thereby allowing for whole event deposits to be missed, adding uncertainty to derivations of event frequencies and magnitudes. Specialist geohazard core logging of long piston cores identifies key sedimentological features, thus facilitating the interpretation of depositional and post-depositional processes. The use of geochronological tests, including biostratigraphic and radiometric analyses, assist in providing a temporal framework from which to determine a frequency of events such as mass movements. It is essential to ensure interpretations from the geohazard core logging are used to target the testing on sediments with a known depositional process to ensure the success of the geochronological testing program.

As stated by Thomas et al. (2011), it is only through the integration of the complete event stratigraphy with the geophysical data and geomorphological interpretation can the magnitude, spatial extent and distribution of the mass movement deposits in the area be fully understood. Outputs from this integration can be used to inform and focus risk assessments and guide mitigation studies.

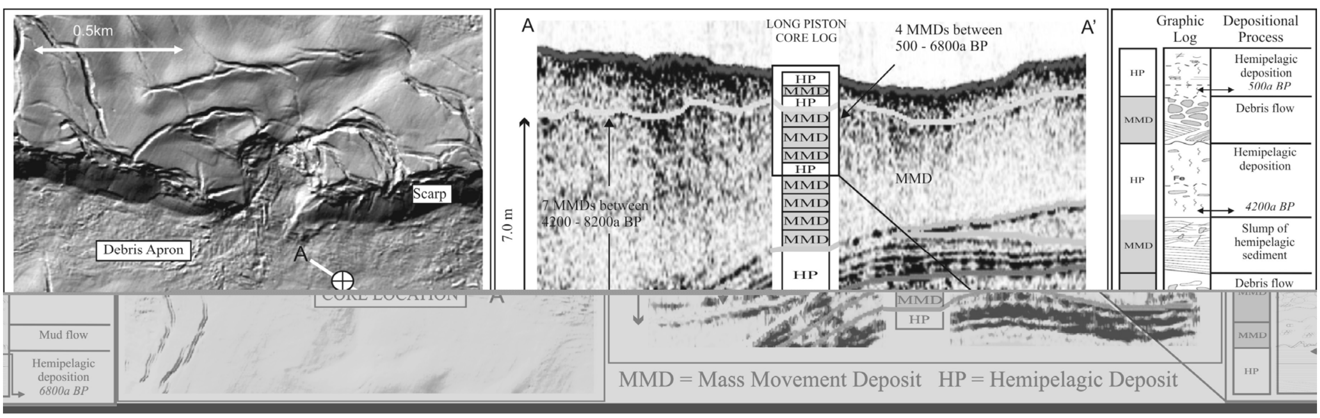

Figure 7. Example of multiple mass movement deposits identified from detailed sedimentological logging where only one MTD (mass movement deposit) was previously interpreted from AUV Chirp data (Thomas et al. 2011)

- *GIS*

GIS is now routinely used as a platform on which to manage, view and interrogate spatially-referenced data acquired during the development of offshore sites. Within a GIS, spatial analysis techniques can be used to apply deterministic methods for identifying and mapping areas susceptible to shallow submarine mass movements. This allows spatially widespread, rapid, repeatable and cost-effective evaluation of shallow submarine slope risk. A deterministic approach of this nature has the advantage of providing a quantitative output, useful in subsequent project risk assessment. The emphasis is placed on GIS modelling of the full three-dimensional variation of geotechnical input parameters, which allows a sophisticated ground model, including output from regional engineering geological and geohazard studies, to be harnessed and exploited. This approach has been applied on deepwater oil and gas projects having development areas of over 1,000 square kilometres (Mackenzie et al. 2010).

5 APPLICATION OF THE ADVANCED GROUND MODEL APPROACH TO UK ROUND 3 WINDFARM SITES

The application of a ground model has been successfully demonstrated by various authors including Evans (2011) and Hill et al. (2011) to assist in the characterisation of soil conditions across large-scale deepwater developments. Key to its effective development is the integration of multiple disciplines as outlined by Campbell et al. (1982). The model developed in this manner evolves from a solely predictive base to an engineering tool based upon calibration with site-specific data (Campbell, 1984). A ground model provides an ideal mechanism to assess sites that feature multiple locations, cover a large area, have more potential for variability, require unconventional engineering considerations, or have a short lead in time requiring highly efficient integration and interpretation of multiple datasets. UK Round 3 windfarm sites provide a good example of all of these considerations, often featuring up to 140 structures, within large offshore sites, that are affected by dynamic and transient lateral and vertical loads that may require innovative foundation solutions. Water depths range between approximately 10m and 50m.

Certain aspects of the Round 3 windfarm sites differ significantly from the deepwater domain. Deepwater Angola is dominated by hemipelagic deposition, while the West Nile Delta development has been shaped to a large extent by large scale landslide events and turbidity current inflows. In contrast, the UK continental shelf has largely been modified by the effects of a series of glaciations over the last few hundred thousand years having featured diverse environments including fluvial, glacial, glaciomarine and subaerial exposure conditions. The combination of different processes that have been operational at a single site over the Quaternary timescale may result in a greater variability compared to even the largest deepwater development.

While direct process analogues may not be immediately transferable to shallower, glacially influenced UK sites from deepwater geohazard-focused developments, the same ground model approach provides a mechanism to identify and understand the depositional and post-depositional processes and their resultant geotechnical character. Fookes (1997) provides several onshore examples, demonstrating the application of a ground model to a variety of settings including glacial, periglacial and fluvial.

A thorough synthesis of geomorphological, geological, geophysical and geotechnical observations within a 3D conceptual block diagram provides a powerful communication tool to explain and portray the diversity of expected or proven ground conditions.

Crucially, the understanding of ground conditions and their spatial variation allows for an optimisation of foundation design as the project moves from concept appraisal, through design, and into the installation phase. The ground model illustrates the spatial variation and serves to highlight any areas of potential risk to foundations, such as is shown in Figure 8.

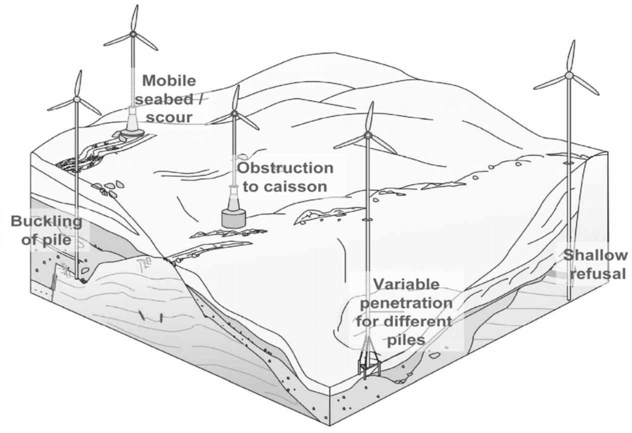

Figure 8. Identification of foundation constraints for offshore wind turbines through use of a conceptual ground model.

6 SUMMARY/ CONCLUSIONS

The reduction of shallow geological and geotechnical risks for offshore developments has advanced significantly over the last 10 years through the application of a systematic and holistic approach. Originally developed for deepwater sites, prone to multiple geohazards, it has now evolved and is being applied to shallow water wind farm sites covering large areas and encompassing significant geological variability.

To be most effective, the approach needs to incorporate the following elements and sequence:

- Initial desk study, based upon all available existing data and incorporating a conceptual geological model, a preliminary risk assessment and recommendations for further data acquisition.
- Geophysical and geotechnical surveys and investigations incorporating specialist tools to ensure that appropriate data of the highest quality and resolution is acquired.
- The application of advanced geological and geotechnical logging and laboratory testing techniques to maximise the value derived from the samples and cores recovered.
- The use of these data and GIS technology to progress the ground model from a geological model to a geotechnical model and finally to an advanced engineering ground model that facilitates quantified risk assessment and the mitigation or management of risk through the optimised design, siting and installation of wells and seabed structures.

7 ACKNOWLEDGEMENTS

The authors would like to thank BP and Total for their support and encouragement and for giving permission to reproduce some of the illustrations used in this paper.

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