TOWARDS THE INTEGRATION OF NEW GEOPHYSICAL METHODOLOGIES INTO OFFSHORE SITE INVESTIGATION PRACTICE

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Abstract - The marine environment can be a particularly challenging one for the geotechnical engineer. Sea floor soils tend to be highly variable, both vertically and laterally, and given this variability plus the obvious technological and logistical constraints, there remains considerable scope for improvement and development in site investigation practice. Over recent years the role of geophysics as a quantitative measuring tool in engineering site investigation has begun to be recognised. In the marine environment, the geophysical approach should have particular appeal as it is essentially a 'remote sensing technique' and undoubtedly represents the most economic means of obtaining in situ sea floor soil properties with a fine spatial resolution.

This paper briefly reviews the state of the art and details two new geophysical approaches to offshore site investigation.

I. INTRODUCTION

The past few years have seen significant progress and development in high resolution geophysical methodologies resulting in an increasingly important role for geophysics in offshore site investigation. More specifically, using a geophysical approach it is now possible to provide a quantitative description of the physical properties of seabed soils and to predict the in situ engineering behaviour of the soil. This has come about through key developments in long-established methodologies, practical validation of innovative new techniques, and most importantly, an improved understanding of geophysical/geotechnical property relations.

The major thrust of marine geophysical research at the University College of North Wales in recent years has been towards providing practical geophysical solutions to engineering site investigation problems. This paper aims to present the state of the art and illustrate the potential benefits of integrating these new technologies into site investigation practice.

II. BACKGROUND AND UNDERLYING RATIONALE

The purposes of an offshore site investigation are often multi-faceted and dependent on a range of factors. For instance, surveys carried out prior to the installation of a new cable or pipeline will aim both to identify potential hazards and to provide information on ground conditions to aid the contractor installing the pipeline, while those for larger fixed structures such as drilling platforms, storage tanks, jetties etc., might be designed primarily to acquire site specific data for input into the structural design model.

For pipeline route surveys, quantitative data relating to the properties of the materials which the contractor is likely to encounter during subsequent trenching operations are conventionally provided through laboratory analysis of vibrocores and/or spot testing at specified intervals along the route (nominally spaced at 500m or 1000m) using a cone penetrometer device (CPT). Selection of sample points is normally made with reference to continuous analogue geophysical data (from high resolution seismic sub-bottom profiling) previously collected along and parallel to the proposed route. The analogue geophysical data are also used in a qualitative manner to attempt to trace lithological units between the control points i.e. between the core/CPT sample stations, and the geophysical and geotechnical results are also generally integrated to produce 'tentative' profiles of ground conditions along the proposed route. These are then used to determine trenching tools and methodologies for the proposed pipelay. However, while this type of approach may prove acceptable in some regions, problems can arise in regions of geological complexity and particularly where the lithology is laterally highly variable.

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Larger-scale structures founded on the sea floor require a more comprehensive geotechnical site survey. Typically, the site investigation will involve a reconnaissance survey (mainly a geophysical survey for hazard evaluation), a series of in situ geotechnical measurements, an extensive programme of laboratory testing on core samples ranging over the full depth of foundation influence, scaled model experiments. All leading towards an improved foundation design and reliable predictions of soil-structure interaction. Given the operational complexities associated with working in the marine environment and the associated technological constraints, a full-scale geotechnical site investigations can prove to be prohibitively expensive, and thus alternative, more cost-effective approaches are continually being sought.

Through a combination of technological advances and an improved understanding of geophysical/geotechnical relations, it is now however becoming increasingly feasible and economically advantageous to extend the role of geophysics in offshore geotechnical investigation, and more particularly, to use geophysics as a quantitative tool for remote sensing the physical properties of sea floor soils.

III. UCNW APPROACH

Over the past decade, research at the University College of North Wales has been directed towards the development of geophysical techniques for the in situ quantification of seabed properties. Two different approaches have been taken:

(i) developing processing routines for the extraction of geotechnical information from high resolution digital seismic data, and

(ii) studies of shear wave propagation phenomena in relation to geotechnical predictions, leading to the development of specific hardware for measurement of the shear wave velocity in situ.

The former approach, (i), has become feasible as a direct consequence of recent advances in computer technology in the commercial sector (i.e. the introduction of fast-sampling digital acquisition systems and appropriate seismic processing software) and essentially represents an extension of current commercial practice; the latter, (ii), represents a novel new approach to remote sampling of seabed properties.
IV. STATE OF THE ART

A. Seismic reflection methodologies

With regard to (i) above, theoretical and empirical studies were initially consulted before proceeding with a software development programme. From a review of the literature it was demonstrated that it should be possible to map the spatial variability of parameters such as density, shear strength and permeability using seismic reflection responses given high quality digital data and the appropriate computer programmes (Fig. 1). Following on from this, a computer workstation was set up and the SierraSeis ISX software package acquired with the express purpose of developing processing routines for the "geotechnical" analysis of high resolution seismic data [1]. Thus it is now possible, by applying the optimum processing parameters, to process digitally recorded seismic reflection data to produce geotechnically-significant acoustic impedance logs which, given sufficient control, can be inverted to produce continuous density profiles. It now only remains to validate the methodology through a controlled field experiment, and particularly one allowing reference to site specific borehole data/geotechnical information.

B. Seismic shear waves

The seismic shear wave velocity is the geophysical parameter which is rapidly gaining acceptance by the engineering community as a definitive soil property. The reason for this is that for a propagating shear wave, shear vibrations are translated through the skeletal frame of the sediment thus making the velocity indicative of the structural stiffness of the material. Over the past decade researchers from UCNW have been involved in a wide range of projects, both onshore and offshore, some directed towards hardware development [2] and others to solving specific site investigation problems, see [3] and [4]. The UCNW marine hardware development programme has been supported by the EC Energy Directorate with the equipment evolving over a period of several years. The initial development was of instrumentation (a geophysical sledge - see Fig. 2) to sense the physical properties of the upper few metres of seabed sediments; the second phase aimed to extend the depth sensing capability down to a few tens of metres below seabed surface. Fig. 3 shows an example data set collected with the geophysical sledge during initial sea trials off the North Wales coast. It clearly illustrates the systems capability to record subtle variations in seabed properties which are dependent on grain characteristics.

Since its development, the hardware has been used to investigate a number of offshore sites covering a range of applications. One site investigation carried out in the Firth of Clyde (for the Defence Research Agency, under the Mine Counter-measures programme) demonstrated the system's potential for spatial mapping of the properties of the sea floor surface soils in a pseudo-underway fashion (see Fig. 4); another, carried out in the Southern North Sea (as part of an EC research programme), produced information on the in situ shear wave velocity gradient down to 50 metres below the seabed surface. Most recently, the UCNW geophysical sledge has found application in a collaborative research programme between UCNW and the Geological Survey of Canada. The major aim of this project is to provide an assessment of the stability of the sea floor around the Fraser River Delta, British Columbia, with in situ shear wave velocities being used to provide an initial

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Fig. 2 The UCNW pseudo-underway sea floor geophysical system.

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estimate of the liquefaction potential of sea floor soils under earthquake loading [4].

Shear wave research at UCNW is on-going and the above only represents but a brief précis of recent work. More comprehensive reviews of the Group’s shear wave research can be found in [5], and [6]. It is likely that future work will be directed towards validation of the methodology for predicting pipeline trenchability, developing predictive models for earthquake risk analysis, and towards seabed modelling in relation to mine burial predictions.

V. INTEGRATING GEOPHYSICAL METHODOLOGIES INTO SITE INVESTIGATION PRACTICE

In the past few years considerable progress has been made towards enhancing the role of geophysics in geotechnical site investigation. Some of this progress can be attributed to an improved understanding of geophysical soil’s theory, some to practical demonstrations of geophysical/geotechnical relations. In terms of the latter, the seismic cone penetrometer is probably the in situ measurement tool which has best demonstrated the potential for shear waves to the engineering community (e.g. see [7] or [8]), while in the laboratory the development of two key soils apparatus - the resonant column [6] and the geophysically-instrumented triaxial [9] have certainly furthered the cause of geophysics. To realise the full commercial potential of the new UCNW shear wave and seismic reflection site survey methodologies described in this paper will inevitably require a similar validatory approach.

VI. SUMMARY AND CONCLUSIONS

The major innovative aspect of the UCNW research lies in the derivation of geotechnical quantities from geophysical data. As such, the research developments offer new approaches to geotechnical site investigation, and approaches which will ultimately provide significant improvements in the spatial resolution of knowledge on ground condition variability. It is also likely that the successful integration of the new technologies into commercial site investigation practice will result in significant cost benefits to the engineering programme through the ability to predict soil conditions between controlled sample points with a good degree of confidence.
(a) Water depth in metres below O.D.
(shaded area >48)

(b) Apparent Formation Factor
(shaded area <2)

(c) Sediment size distribution
(classification according to

(d) Shear wave velocity in m/sec.
(shaded area <40)

Scale:
0 1 2 3 kms

Fig. 4 Physical property distribution maps for a part of the Firth of Clyde: (a), (b) and (c) constructed from sledge data.
REFERENCES


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