ADVANTAGES OFFERED BY THE ROUTINE ACQUISITION OF DIGITAL HIGH-RESOLUTION SUB-BOTTOM PROFILING DATA

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Abstract:- *Digital recording of acoustic data will not necessarily result in an improvement on good quality analogue sub bottom profiling records per se. The quantitative nature of digital data does, however, offer significant advantages in terms of quality control and data integrity as well as the possibility of providing acoustic attributes which can be used to improve and expand the geological/geotechnical interpretation of any acoustic survey. Multi-channel, high-resolution, sub-bottom profiling data can provide estimates of sound velocity, reflectivity and absorption for individual sediment layers which will aid their identification and characterisation. Digital processing of the data using standard commercial processing software may improve the record quality and depth range but may be unlikely to improve the resolution beyond what might be obtained by purely analogue instrumentation. The real power in the digital processing of high resolution digital data is to provide the acoustic parameters which can be utilised via acoustical-geotechnical inter-relationships to predict the engineering properties of the seabed.*

1. INTRODUCTION

The digital recording of sub-bottom profiler data (*i.e.* pinger, boomer, sparker, air-gun systems) is becoming commonplace in the offshore site investigation industry. This is partly as a result of new digital acquisition systems becoming available and partly due to quality control considerations. In the majority of cases the digital recording of acoustic data will not necessarily result in an improvement on good quality analogue sub-bottom profiling records *per se*. However, the quantitative nature of the digital data does offer significant advantages both in terms of quality control and data integrity. It also provides the possibility of determining acoustic properties of the sediments (e.g. sound velocity, reflectivity and absorption) from which it is theoretically possible to determine a number of geotechnical properties. This paper explores the possibility of using digitally recorded sub-bottom profiler data to classify marine soils remotely.

In a joint project between UCNW, Bangor, and Applied Geology (NW) Ltd, Deeside, Clwyd, funded as a SERC/DTI Teaching Company Scheme, methods to extract geotechnical information from high-resolution seismo-acoustic data obtained from underway sub-bottom profiling systems are being developed. The ultimate goal of the project is to create a rapid and moderately inexpensive methodology for investigating the physical properties of marine sediments to depths of the order of 30-50 m and which have a resolution of layer thickness

to better than 0.5 m. The development of such a methodology will offer potential cost and technical benefits to the offshore site investigation industry.

Digital processing of the data using standard commercial processing software may improve the record quality and depth range but may be unlikely to improve the resolution. Some recent developments in the processing of seismic data for the hydrocarbon industry and in the processing of basic sonar data has led to methodologies which can be applied to the extraction of geotechnical information from acoustic data. These improvements and the advent of moderately inexpensive but very powerful computers should make it possible to process the large amounts of acoustic data required to obtain useful geotechnical information quickly, cheaply and efficiently.

2. ACOUSTIC-GEOTECHNICAL INTER-RELATIONSHIPS

The inter-dependence between the acoustic and geotechnical properties of a marine sediment allows the possibility of extracting geotechnical information from sub-bottom profiler data. It is known that the most important parameters that control the acoustic response of a marine sediment are (Stoll[1]):-

(i) porosity
(ii) density
(iii) overburden stress
(iv) degree and type of lithification
(v) grain size and distribution
(vi) dynamic strain amplitude
(vii) material property of grains
(viii) sediment structure

It can be seen from the above that many of the parameters that affect the acoustic response are of direct interest to geotechnical engineers (e.g. porosity, density, grain size and distribution).

There is within the literature, a large number of empirical relations between the acoustic impedance, velocity and attenuation of acoustic waves and the geotechnical properties of the sediment (e.g. Akal [2], Buchan *et al.* [3], Hamilton [4]) which are schematically summarised in Figure 1. These empirical relationships have led to the development of specific hardware, e.g. a number of 'sediment classifiers', which are usually modified echo-sounders, which attempt to determine the nature of the sea-floor sediment type using acoustic methods. The degree of correlation of the relationship between the acoustic and geotechnical parameters varies widely; for example, in the case of the acoustic impedance-porosity relationship there is an excellent degree of correlation. In the case of many relationships, however, the degree of correlation may be poor and there still remains a large amount of research to be undertaken to determine the precise nature of the geo-acoustic relationships. If successful commercial systems are to evolve the standard

deviations of the acoustic-geotechnical inter-relationships need to be determined so that appropriate errors can be determined.

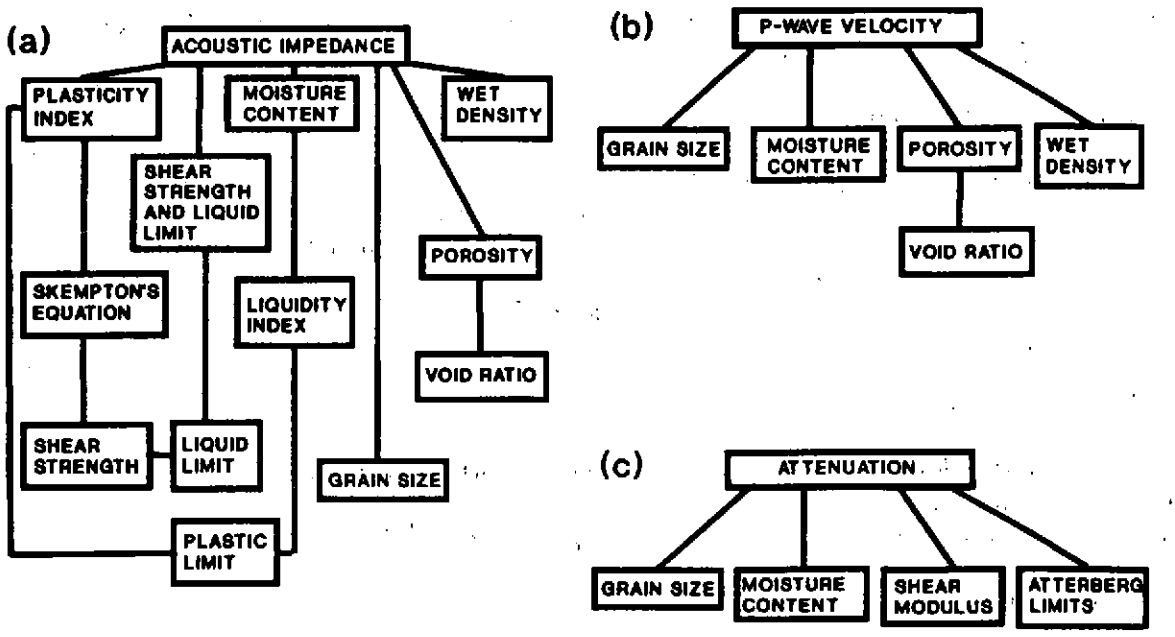

Figure 1. *Schematic diagrams showing the empirical inter-relationships between the geotechnical properties of a marine sediment and its seismo-acoustic properties ((a) acoustic impedance, (b) P-wave velocity and (c) attenuation) (from Haynes* et al [5]).

The inter-relationships between the acoustic properties of a surficial sediment and many of its geotechnical parameters are relatively well understood but variations of acoustic properties with depth (or effective stress) are not nearly so well known. Relations do exist, however, between the porosity (void ratio), velocity and effective stress (depth) such that it is possible to estimate the porosity and sediment type given the velocity and effective stress (depth) (Taylor Smith [6]).

3. ADVANTAGES OF DIGITAL RECORDING

The recording of acoustic data and the measurement of seismic properties (e.g. velocity, acoustic impedance and attenuation) are not straightforward and a number of intrinsic problems (Table I) have to be overcome. When using analogue systems these problems are often insurmountable, e.g. multiple events masking later reflections. This can result in a serious degradation of the quality of the analogue paper output which renders the data difficult, if not impossible, to interpret. Also as there is no quantitative information it is not possible to use the inter-relationships between the acoustic and

geotechnical properties of a marine soil to estimate its geotechnical parameters.

Table I. Problems Associated with the Acquisition of Sub-Bottom Profiler Data (after Haynes *et al.* [5])

Environmental Problems			
(i)	*noise*	*- self-induced*	*- ship noise*
			- electrical noise
			- hydrophone turbulence
		- ambient	*- cultural*
			- natural
(ii)	*waves*		
Geological Effects			
(i)	*multiples*		*- water-bottom multiples*
(ii)	*diffractions*		
(iii)	*apparent attenuation*		*- peg-leg multiples*
Instrumental Effects			
(i)	*source*		*- repeatability*
			- directionality
			- bandwidth
(ii)	*receiver*		*- array directionality*
(iii)	*acquisition system*		*- dynamic range*
			- sampling rate

Although recent technological advances in the design of analogue acquisition systems (Richardson *et al.* [7]) means that some of these problems can be alleviated to some degree, most, in particular the geological effects, cannot. However, by recording the data digitally and by careful post-processing it should be possible to alleviate these problems to a major degree in nearly all cases. In addition the digital recording of the data provides quantitative information about the acoustic response of a marine soil such that it is possible to estimate its geotechnical properties.

4. DIGITAL DATA PROCESSING

The application of data processing techniques which are already routinely employed in the processing of seismic data in the hydrocarbon exploration industry should enable the processing of acoustic data to a form suitable for the subsequent determination of geotechnical parameters. The application of processing algorithms designed for exploration data with frequencies of the

order of tens of hertz to sub-bottom profiler data with frequencies of the order of kilohertz is not entirely straightforward. The main problem is that high-resolution sub-bottom profiler data do not satisfy the criteria of statistical stationarity and minimum phase on which many exploration algorithms are based (McGee [8]). However, many algorithms to process data digitally do not depend on these criteria and in the case of those that do it is highly unlikely that the errors introduced will be greater than the uncertainties associated with the inter-relationships between the acoustic and geotechnical properties.

As mentioned in the previous section careful digital processing of the acoustic data can alleviate many of the problems associated with analogue data. For example, the effects of certain types of noise can be almost eliminated by the application of filters, and the effects of multiples severely attenuated by predictive deconvolution. In addition the appearance of the paper records can be enhanced by the application of various gain functions. However, the use of digital post-processing should not be used as an excuse for poor data acquisition, as the final output is always a function of the quality of the input and the adage 'garbage in, garbage out' should always be borne in mind.

From the viewpoint of classification of the marine sediment the three digital data processing procedures of most interest are velocity analysis, seismic inversion to determine acoustic impedance, and estimation/determination of attenuation. All three data processing procedures are becoming increasingly sophisticated due to their use in reservoir evaluation studies. The potentially most rewarding and productive avenue of approach in determining the geotechnical parameters of a marine sediment is to determine its acoustic impedance which requires that the 'seismic inverse problem' is solved. A large number of methods have and are being developed to solve this 'inverse' problem and it is presently an active area of research in the hydrocarbon exploration industry due to its potential value in reservoir studies. Recently high-resolution velocity analysis techniques have emerged from the field of multi-channel sonar array processing which can be applied to seismic reflection data (Key and Smithson [9]) and provide results superior to the widely used semblance measure. These techniques provide a degree of resolution not previously attainable and which will be required if meaningful estimates of geotechnical parameters are to be made from the velocity determinations. The problem of determining attenuation from acoustic data is probably a much more exacting problem than the other two processes and it may prove to be the case that accurate determination of attenuation will be difficult to achieve *in-situ* and only relative estimates will be able to be made (White [10]).

5. PRACTICAL ASPECTS

From the above it should be readily apparent that there are many advantages to the digital recording of sub-bottom profiler data, particularly if sea-bed classification is an aim. However, there are a number of practical

considerations which should be borne in mind. These considerations and the solutions adopted at the Univerisity College of North Wales (UCNW), Bangor, are discussed below:-

5.1 Data Acquisition

The acquisition of the highest possible quality digitally-recorded data is always important, but it is imperative if any kind of geotechnical classification of the sea-bed is to be attempted. This has meant that a lot of time has been spent designing optimum acquisition procedures both for digitally recorded data (Haynes *et al.* [5]) and for analogue data (Richardson *et al.* [7]). On the instrument side the source should be as broadband as the required depth of penetration to the investigation target will allow. Studies indicate that if the depth of interest is of the order of 30-50 metres a 'boomer'-type system is presently the best available source type (McGee *et al.* [11]). The digital data acquisition system should be suitable for high-resolution sub-bottom profiler work and have 10-12 channels capable of recording at sampling rates in excess of 25 kHz (40 μs) with a dynamic range of at least 16 bits. At present such systems exist in research institutes only but commercial systems approaching this are appearing (e.g. GeoAcoustics Sonar Enhancement SE880 System and Elics - Delph Systems). The system presently used at UCNW, Bangor, is a Carrack SAQ-V which is capable of sampling up to twelve channels with a total throughput of 48 kHz (i.e. 3 channels at 16 kHz, 12 channels at 4 kHz, etc.). This is a PC-based system which can be installed on small boats making it suitable for very shallow water work. The hydrophone streamer employed should ideally have 10-12 channels with a group length of the order of 1 m (for water depths of the order of 10-30 metres) and individual hydrophone elements having a frequency cut-off at about 15 kHz (there are currently few, if any, suitable commercially-available streamers).

5.2 Data Processing

There are two possible avenues of approach to the processing of acoustic data; the first is that the data are processed in real-time as they are being acquired, and in the second, the data are recorded digitally and then post-processed. At UCNW the data are being recorded digitally first on to magnetic tape and then post-processed using a commercial seismic data processing package. The processing package is the Sierra Geophysics ISX/SierraSeis system which permits rapid processing of the acoustic data. Computer modules are presently being written by which geotechnical parameters may be derived from the processed acoustic data. It is possible that if some optimum processing parameters can be determined then some processing can be undertaken in real time, especially if multi-tasking computers are employed during acquisition. An example of a digitally-acquired dataset (using the Carrack SAQ-V) displayed using the Sierra ISX system is shown in Figure 2.

6. CONCLUSIONS

The digital recording of sub-bottom profiler data provides a number of advantages over conventional analogue recordings. These range from being

ADVANTAGES OF DIGITAL ACQUISITION

purely quality control and data integrity considerations, to the attenuation of noise and multiples which so often contaminate analogue paper records. It is, however, the quantitative nature of the digital data which allows the possibility of extracting geotechnical information about a marine sediment, which may provide the greatest advantage over analogue sub-bottom profiler data. The extraction of geotechnical parameters from acoustic data is possible theoretically, and with recent technological improvements is becoming practically feasible. These recent improvements now make it possible to record sub-bottom profiler data digitally with enough signal fidelity and at the required sampling rates to enable digital seismic data processing techniques to be applied subsequently. The data processing of the acoustic data should produce data of sufficiently high quality to enable the many empirical relationships that exist between geotechnical and acoustic properties to be used to extract geotechnical parameters.

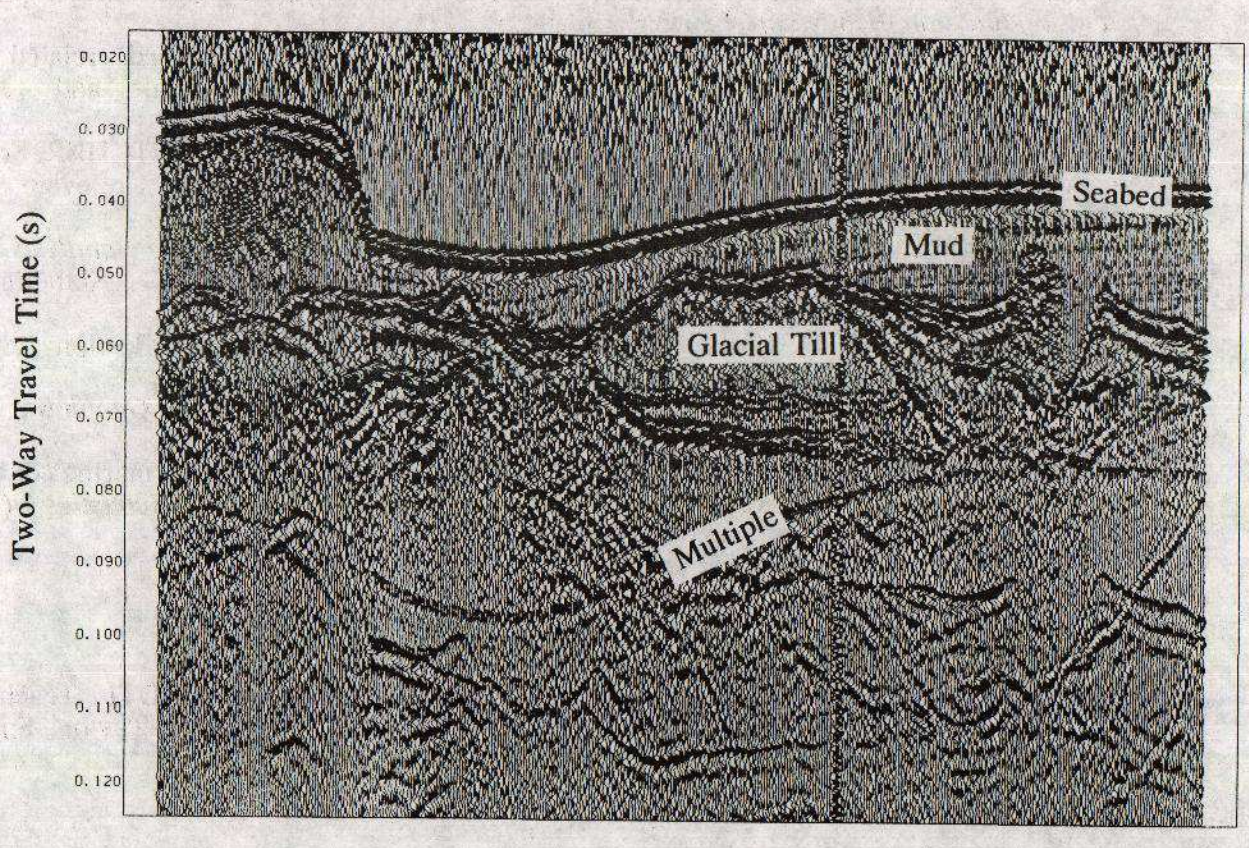

Figure 2. *An example of sub-bottom profiler data obtained from Cardigan Bay in the Irish Sea using a 5 in^3 air gun. The line was acquired using the Carrack SAQ-V acquisition system (250 μs sampling rate and with a trigger cycle length of 2 s) displayed using the Sierra ISX seismic processing package. (Horizontal distance 2.5 km)*

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