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3D CHIRP SUB-BOTTOM IMAGING SYSTEM: DESIGN AND FIRST 3D VOLUME

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Abstract: *Chirp sub-bottom profilers are marine acoustic devices that use a known and repeatable source signature (1 – 24 kHz) to produce decimetre vertical resolution cross-sections of the sub-seabed. Here the design and development of the first true 3D Chirp system is described. When developing the design, critical factors that had to be considered included spatial aliasing, and precise positioning of sources and receivers. The design incorporates 4 source transducers (1.5 – 13 kHz) that can be arranged into different configurations, including Maltese Cross, a square and two separated pairs. The receive array comprises 240 hydrophones in 60 groups whose group-centres are separated by 25 cm in both horizontal directions, with each hydrophone group containing four individual elements and a pre-amplifier. It was concluded that the only way to determine with sufficient accuracy the source-receiver geometry, was to fix the sources and receivers within a rigid array. Positional information for the array is given by a Real Time Kinematic GPS and attitude system incorporating four antennas to give position, heading, pitch and roll. The complete system is described and initial navigational and seismic data results are presented for a 3D seismic volume over folded geological events within the West Solent (UK). These data demonstrate that the approach of using a fixed source-receiver geometry combined with RTK navigation will provide complete 3D imaging of the sub-surface.*

Keywords: *3D Seismic, Chirp, 3D Acoustics, High Resolution Reflection Seismology*

1. INTRODUCTION

High-resolution sub-seabed seismic reflection imaging is important in areas as diverse as marine archaeology, mineral exploration and extraction, geology and for military applications. Work at the Southampton Oceanography Centre, previously, has focused on the acquisition, processing and interpretation of data from Chirp systems deployed with Differential GPS and mounted on novel platforms to enable operation in shallow water environments [1,2,3]. These sources typically operate in a range of 1-24 kHz, offer vertical resolution on a decimetre scale in the top c. 20 - 30 m of unconsolidated sediments. The potential for migration of high-frequency 2D Chirp data has been demonstrated [1]. However, 2D data never provides information on cross-dip variation and so in the migration of such data the final reflection points are constrained to lie within the plane of the section. Therefore in the presence of rapidly varying 3D topography (i.e. discrete targets) such two-dimensional migration is inevitably an imperfect process.

The ability to collect a high frequency 3D volume will ensure that the limit on the minimum dimensions of objects that can be detected will be controlled by the acoustic characteristics of the source and receiver array rather than the survey design. Furthermore, the ability to locate accurately both source and receiver groups will facilitate full three-dimensional migration in which reflection points can be moved in any azimuthal direction. The ability to conduct full 3D migration has three primary effects: (1) reflections from dipping reflectors will be correctly repositioned; (2) energy scattered from small features will be focused at the scatterer location; and (3) the output volume will be evenly sampled in all three dimensions. The first two of these also act to improve the lateral resolution of the data from the scale of a Fresnel zone (order of a few metres) to the dominant wavelength of the source signal (10 - 20 cm). The limit on the lateral resolution of the data will be ultimately controlled by spatial aliasing criteria based on the horizontal apparent wavelength of the arrivals.

2. THE 3D CHIRP PROBLEM

The aim of this project was to design a 3D Chirp System that would (1) acquire data that would provide a true 3D Volume; (2) provide sufficient data to ensure that the entire sub-surface volume is properly sampled with no spatial aliasing; (3) optimize the resolution capabilities of the Chirp Source - better than 50 cm laterally, and 30 cm vertically; (4) be easily deployable from small survey vessels; (5) in future be utilised for cable-surveys, archaeological surveys, site surveys, environmental surveys, general problems in near-surface geology and geophysics. Our aim was to design a system that would acquire true 3D Chirp data. However given the high frequency content of the Chirp data (up to 13 kHz) there needs to be careful consideration of the underlying physical fundamentals. In particular the following need to be carefully considered: (1) Horizontal positioning and spatial aliasing; (2) Horizontal and vertical positioning accuracy requirements; and (3) Source signature considerations and frequency aliasing. A Chirp sweep (1.5 - 13 kHz) with a linear Instantaneous Frequency Function and a sine-squared taper function with a mean frequency of 7.25 kHz is used for the data illustrated in this paper as this provides an optimal Klauder wavelet [4]. Bull *et al.* (2005) demonstrated that: (1) for the highest resolution sweep a sampling interval of 31.25 μs will result in over-sampled data; (2) that a receiver spacing of 25cm in x and y directions will avoid significant spatial aliasing of the seismic data; (3) that a

RTK GPS system together with an attitude system would give the required horizontal and vertical accuracy in positioning for the system.

3. FINAL DESIGN

One of the major problems in acquiring 3D data volumes at high frequencies is uncertainty in the position of sources with respect to receivers. The solution reported here is to use a rigid array with known source and receiver relative positions. Fig. 1 shows technical drawing of the 3D Chirp system. The four transducers are shown arranged in the preferred Maltese Cross configuration, which gives enhanced directivity along-track, within the centre of the array together with the electronics bottles that drive the transducers. Careful consideration had to be given to achieving neutral buoyancy. This was solved by using a composite, low-density, reinforced foam central panel to support the transducers and electronics bottles. The design is modular so that the four transducers can be rearranged in a standard square configuration in the centre of the array, or as two pairs towards the edge of the mat to maximise ground coverage.

Eleven longitudinal 2.25 m-long composite tubes containing the hydrophone groups are fitted on the underside (Fig. 1b). Each longitudinal sections contains between 4 and 6 hydrophone groups, such that there are 60 independent hydrophone groups within the array. Hydrophones positions can be changed within the array to accommodate different transducer positions. Each hydrophone group is 25 cm long and contains a pre-amplifier and four elements, each separated by 6.25 cm, which sum the arriving energy, and facilitate an increase in signal-to-noise. The design ensures that the hydrophone groups are protected from reverberation off the water-surface. The array has been designed so that hydrophone cabling is accommodated within the tubes, before being collected together within two splice blocks at the front of the array. The data is then sent up two cables to the recording system aboard the acquisition vessel.

The four GPS antennas at the corners of the array provide positioning. Each of the antennas is 1 m above the top of the array, and one of these antennas provides absolute position, while all antennas are used in the attitude system to give heading, pitch and roll. Data from all four antennas is then used to produce the absolute position of each source point and hydrophone group within the array to centimetric accuracy. This level of navigational accuracy enables not only correct within-line location of targets but also the effective merging of data from adjacent lines, including corrections for tidal variability.

The array has been hydrodynamically designed to tow smoothly and to ride swell and wave activity without tilting and to avoid acoustic noise generation. The total weight of the array including all elements is 176 kg and it has been designed to be deployable from small vessels.

The acoustic data from the system is recorded using a 60-channel Geometrics Strataview R60 system and is merged with the centimetric accuracy navigation data for later data processing. Seismic processing is completed in three phases: geometry processing, including binning; 3D migration; and then standard Chirp processing techniques [2]. Finally the data is taken into a 3D seismic interpretation workstation for interpretation and target recognition.

4. FIRST 3D VOLUME

The array was tested within the Solent (U.K.) and proved to be neutrally buoyant and towed in a stable manner (Fig. 2). The GPS antennas sit c. 0.7 m above the surface of the water with the base of the transducers and hydrophones sitting c. 0.4 m beneath the surface of the water. During the trial the system was tested in sea-states up to a Force 4 and an optimal towing speed through the water was found to be 2.0 ms^{-1}. Seismic data was acquired within the west Solent over an area known to contain dipping and faulted limestones and mudstones. An area 75 m wide by 750 m long was surveyed using repeated lines. Fig. 3 illustrates an in-line through the 3D volume and an associated time-slice. Dipping horizons are imaged within the in-line and are correctly positioned in the time-slice. Fig. 4 illustrates the final migrated 3D volume. The precision of the RTK-GPS and attitude system allowed determination of the reflection midpoints with centimetric accuracy. A pre-stack 3D Kirchhoff migration was applied, outputting the data on a regular 50 cm grid. The application of an instantaneous amplitude function enhances the interpretability of the final volume.

5. SUMMARY AND WORK IN PROGRESS

The 3D Chirp system described has been successfully tested and the first 3D volume has been processed and interpreted. Further data volumes over buried objects have been acquired and processing is underway. The 3D Chirp system is being commercially developed in a collaboration between GeoAcoustics Ltd and Southampton University. Present work is focussed on using novel platforms to mount the 3D Chirp array, and on increasing the size of the final array.

6. ACKNOWLEDGEMENTS

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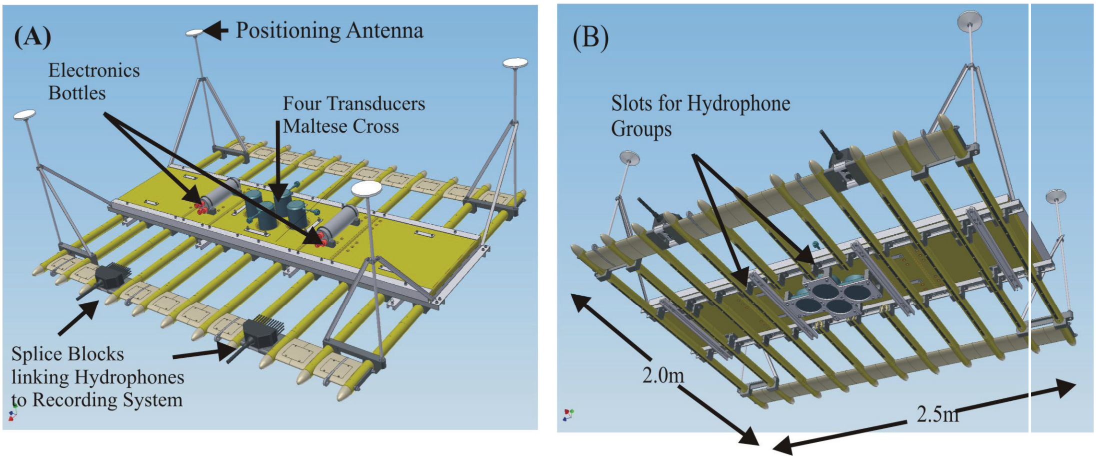

Fig.1: The Final 3D Chirp Design. Perspective view of (a) the top of the 3D Chirp system showing main elements of the design; (b) the bottom of the 3D Chirp system. Note the position of the hydrophone groups in slots on the underside of the longitudinal sections.

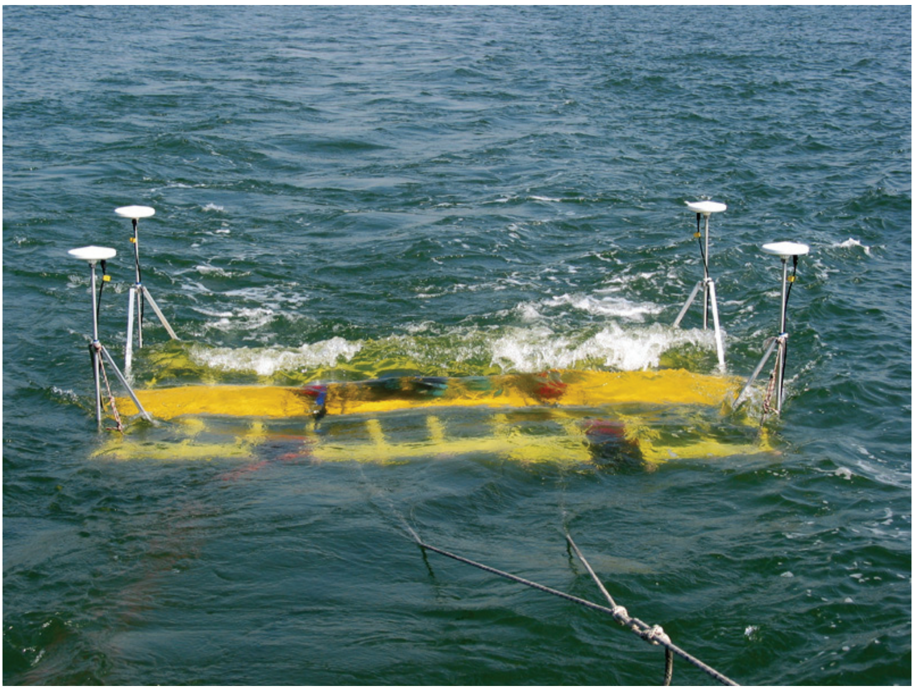

Fig.2: The 3D Chirp system being towed in the West Solent, U.K., during acquisition of the data illustrated in Fig 3. and Fig 4.

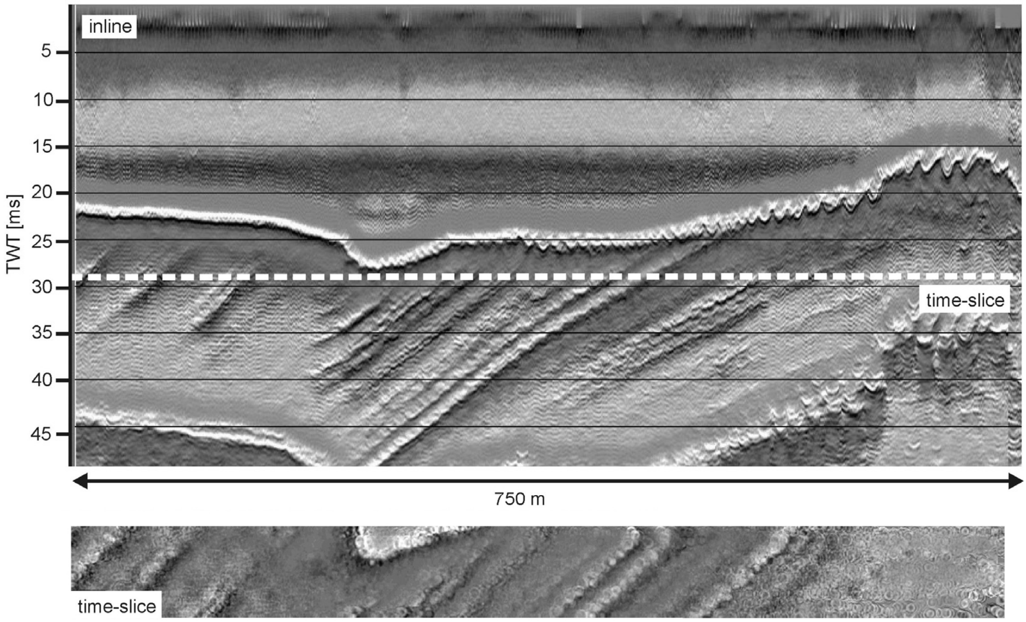

Fig.3: Top – In-line through the 3D volume shown in Fig. 4. Below is a time-slice through the 3D volume. The position of the time-slice is shown above. The profile shows rotated and faulted limestones and mudstone layers of Eocene-Oligocene age.

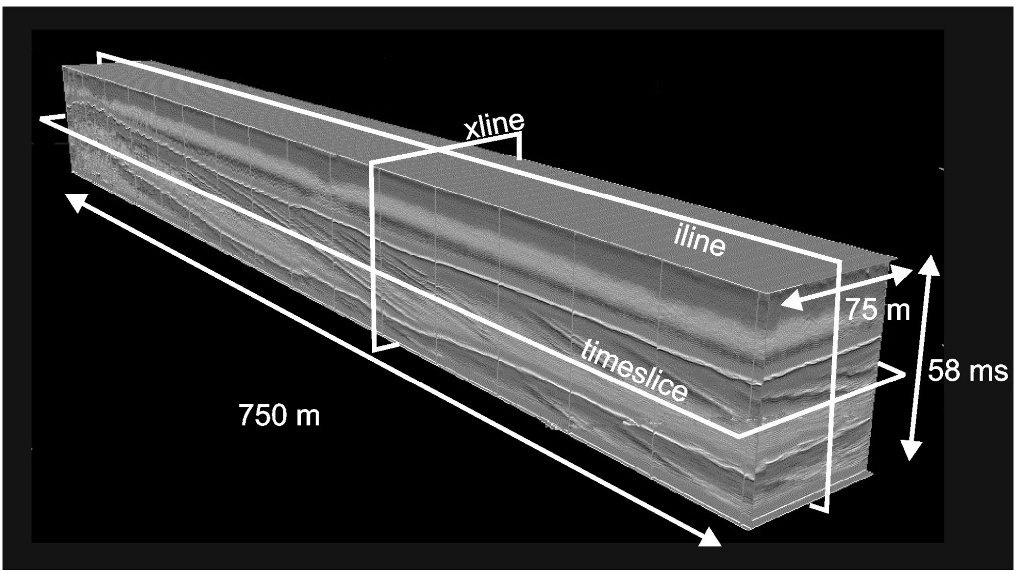

Fig.4: Final 3D Volume collected in the West Solent, U.K.