WAVE PROPAGATION IN THE SHALLOW WATER ENVIRONMENT

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1. INTRODUCTION

Propagation of acoustic energy in shallow water at frequencies below the duct cut-off frequency is attenuated strongly. However significant energy may be propagated at these low frequencies in the form of seismic interface waves, enhancing the possibilities of detection of low frequency sources in shallow waters. The characteristics of these seismic waves are dependent on the geo-acoustics of the marine sediments immediately beneath the sea-floor and thus the detection of these waves can also be an aid in the classification of the sea-bed.

In this study the objective was to characterise the signals received by a three axes geophone sensor as a ship approached from a distance and passed over the sensor in shallow water. Two different forms of noise source were used in the investigations - detonators positioned at a series of distances from a sea-floor sensor package and a 22 m naval support vessel steered on tracks at different abeam positions from the sea-floor package. The results of the analyses of the signals received from the detonators have been used to clarify and characterise the marine environment, which was necessary in the interpretation and assessment of the ship tracking exercise. The studies were conducted in two harbours on the east coast of New South Wales, Australia: Hunters Bay, located within Port Jackson near the entrance to Sydney Harbour, and Darling Road within Jervis Bay.

2. THEORY

The seismic waves of interest are guided waves propagating at the interface between the water and the sea-bed - Scholte waves and shear mode waves in the case of layered sediment beds. The Scholte wave is characterised by an amplitude which decays exponentially with depth in the medium, being evanescent in both the water and the sea-bed. The particle motion of the wave is elliptical in the vertical and propagation or radial direction with a ratio of about 1.5 at the interface. It exhibits no frequency dispersion nor low frequency cut-off and its velocity c_{Sch} and attenuation δ_{Sch} are approximately those of shear waves [1] viz.

$$c_{Sch} \approx 0.9 c_s$$

and

$$\delta_{Sch} \approx 1.1 \delta_s$$

where c_s and δ_s are shear wave velocity and attenuation. In the case of a layered sea-bed or one with a shear gradient the Scholte wave may become dispersive and a number of ducted shear modes each with low frequency cut-off may exist.

3. METHODS AND INSTRUMENTATION

The seismic wave detection system used in these measurements was based on a sea-bed sensor package designed and constructed in the workshops of DSTO, Sydney. An underwater housing was fabricated from 12 mm wall, 300 mm diameter polypropylene tubing fitted with O-ring seal end caps. One end of this housing was bolted to a heavy concrete annulus which sank to make firm contact with the sea-floor. A triaxial geophone was mounted inside the housing on the base end cap and an omnidirectional hydrophone was fixed externally to the top of the package using anti-vibration mountings. The package was also fitted with a pressure sensor to determine depth, and a magnetic compass and a two axes inclinometer to resolve its orientation. The output from the sensors was connected via a 2 km underwater cable to a shore station for data acquisition and storage.

To prepare for a trial the underwater package was positioned and orientated on the sea-bed by a diver team. Once the cable link was made to the shore station the sensors could be interrogated to check the package orientation and inclination and to monitor background acoustic and seismic noise levels. Differential GPS (Global Positioning System) and Syledis (naval navigational data system) were subsequently employed to chart the absolute position of the package, the positions of the detonators exploded on the sea-bed, and the movements of ships relative to the package.

The detonators used in the experiments contained 1 gm of explosive charge placed on a steel plate and were positioned at distances of 50 to 1600 m from the package. In each set of measurements half of the detonations were positioned along the axis of one geophone with the others at a bearing to the horizontal geophone axes. The detonations were triggered by a diving team operating from a boat on the water, the team controller giving a radio message several seconds prior to a detonation, enabling the data acquisition system to be started before each event. It was not possible using this methodology to record the actual time of detonation on the data acquisition system. Thus all signals received from the detonations were referenced to the arrival of the first water borne compressional wave.

In the second experiment, a 22 m naval support vessel with twin screws powered by diesel engines was operated at 10 knots cruising speed on various bearings and tracks relative to the sensor package. Recordings were made of the signals received by the sensors on the complete approach and departure movements.

4 RESULTS - DETONATORS

Typical recordings of the signals received from the detonator sources are shown in Fig. 1 These show the responses of the hydrophone and the three geophones when the detonator was positioned 100 m from the sensors along the direction of the x - geophone. The recordings are characterised by these features in the following time sequence:

an acoustic or dilational pulse registered by all sensors;

a secondary dispersed set of signals, the seismic content, registered by the z- and x-geophones and to a lesser extent by the y-geophone when perpendicular to the direction of wave propagation.

Group velocity dispersion curves were derived from these signals using the multiple filter method of Dziewanski et al. [2]. For this signal processing the acoustic signal was discarded and the analysis applied to the later part of the signal containing the seismic components. The method involves Fourier transformation and the application of a series of Gaussian shaped filters of different centre frequency. The in-phase and quadrature components of the filter outputs are then inverse Fourier transformed to yield the instantaneous amplitudes and phases as a function

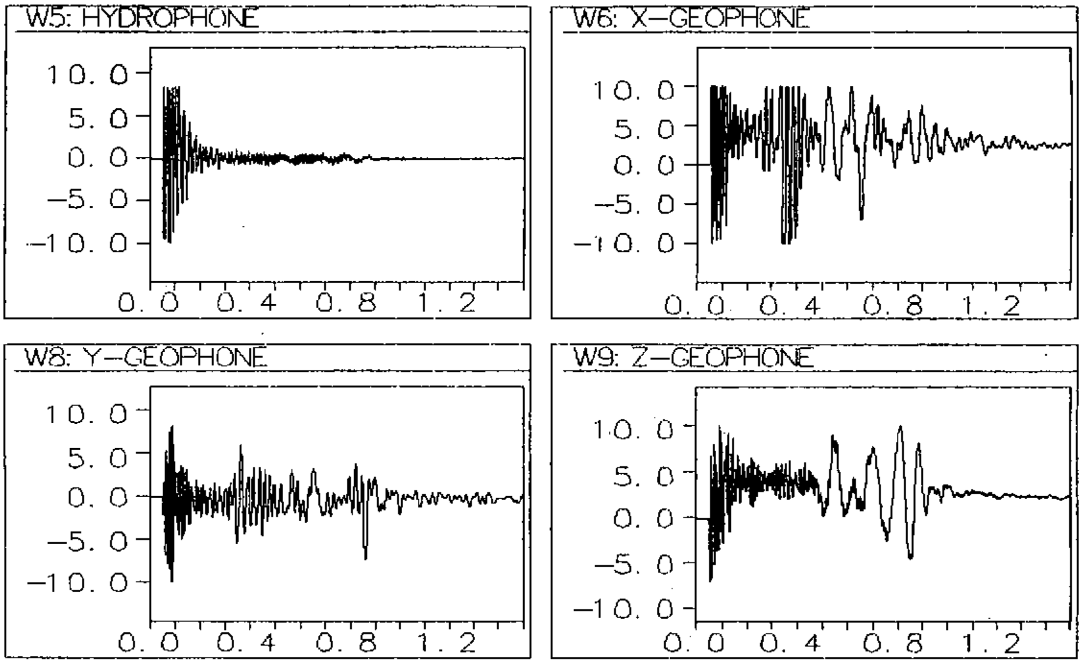

FIGURE 1. Signals received from a detonator source placed 100m from sensors along the direction of the x-geophone. Plots show the hydrophone, x-, y- and z- geophone signals.

of time. The maxima of the instantaneous signal amplitudes correspond approximately with the group velocities.

Figs. 2 and 3 show the contoured instantaneous amplitudes as a function of frequency and group velocity for the z- geophone. These results are in agreement with those of previous workers in the field (Stoll et al. [3], Jensen et al. [4]) and indicate the vertical component of particle motion. The x-geophone, measuring the radial component of particle velocity often yields more information than does the vertical z-geophone, and there may be some signal received by the perpendicularly oriented y-geophone, when there is error in the positioning of the detonators. There is also a satisfactory level of signal over the background seismic noise levels which might dominate at lower frequencies, say below 4 Hz.

Fig. 2 is derived from the Jervis Bay recordings and shows that the majority of the seismic energy propagates in the form of a Scholte wave. Frequency dispersion is evident suggesting strong shear gradients in the top layers of the sediment, the energy being concentrated in the 9 Hz frequency range and showing a group velocity of about 85 m/s. The geology of this environment indicated a deep, 10 m, top layer of sand.

Fig. 3 shows the dispersion curves, for propagation in Hunters Bay, an estuary sandy bay, derived from z-geophone signals. It can be seen that the seismic energy propagates mainly in two distinct modes, the slowest being the Scholte mode with energy centred around 7 Hz. The first shear mode is also excited with maximum energy around 10 Hz, and is more evident in the x-geophone signal. These results generally indicate a layered sediment - a soft top layer sitting on a harder substrate is indicated by geo-sounding data.

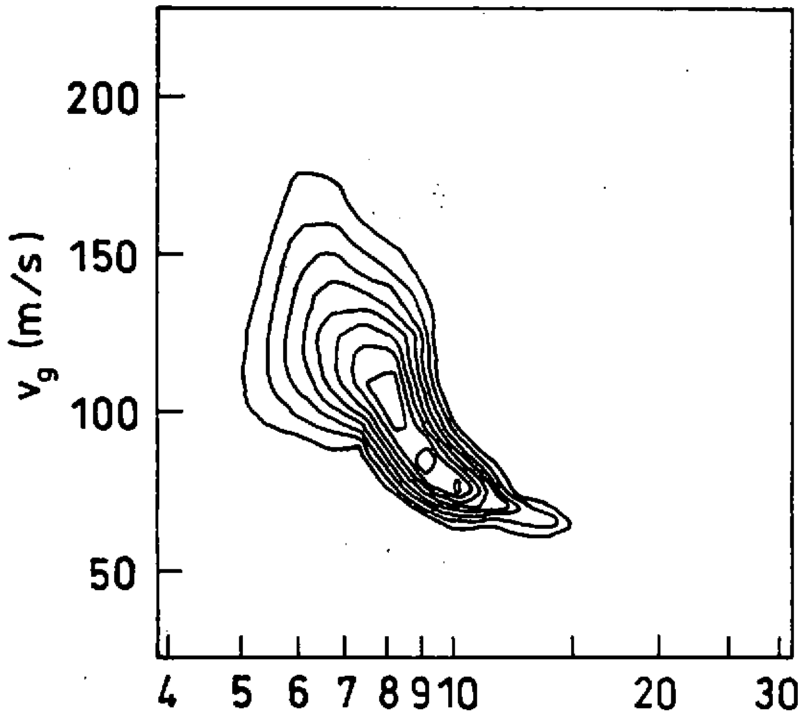

FIGURE 2. Z-geophone seismic wave dispersion contour plot from Jervis Bay study. V_g group velocity, f frequency.

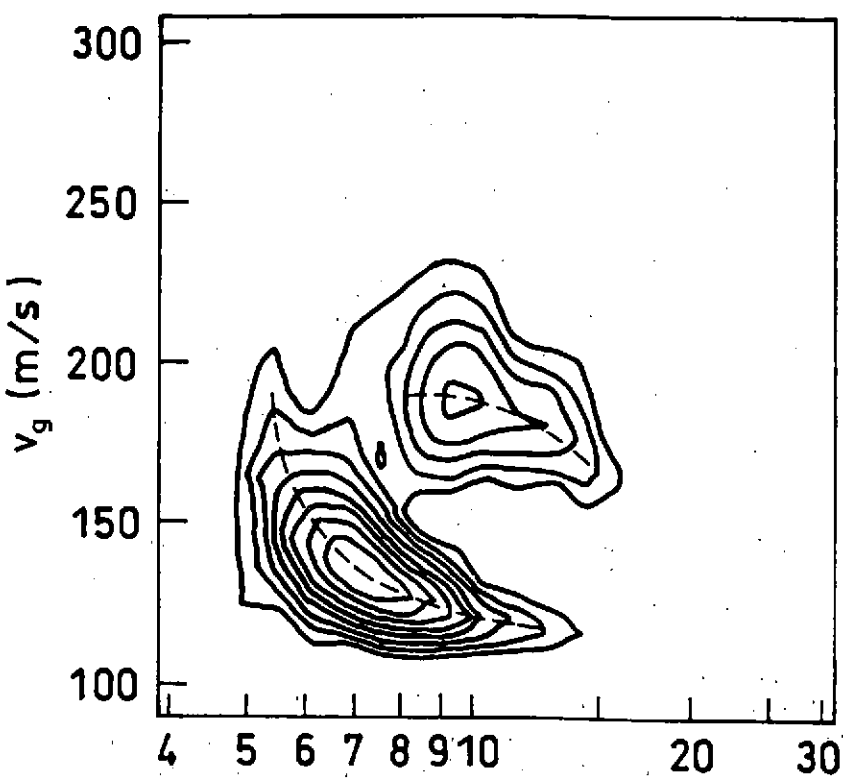

FIGURE 3. Z-geophone seismic wave dispersion contour plot from Hunters Bay study. V_g group velocity, f frequency.

WAVES IN SHALLOW WATER

The azimuthal spectral power distributions derived from the responses of the x- and y- geophones in the frequency range of the seismic signals were subsequently determined using the technique described by Schmafeldt and Dieter [5]. This involves correcting the spectral responses from the x- and y-geophones for their directivities, assumed to be of a dipole or cosine squared pattern. Fig. 4 shows one of these patterns and illustrates the tracking capabilities possible from analysis of the interface waves from a distant source.

The attenuation of these seismic waves is of interest in this work and was obtained by measuring the signal levels of the Scholte and shear mode waves at different frequencies and ranges. The observed attenuations, after allowing for divergences, varies from .06 dB/m (at 8 Hz) to .12 dB/m (at 14 Hz) for the Scholte wave. The first shear mode wave exhibits a constant attenuation of 0.1 dB/m in this frequency range. These values are slightly lower than those reported recently by Stoll et al [3].

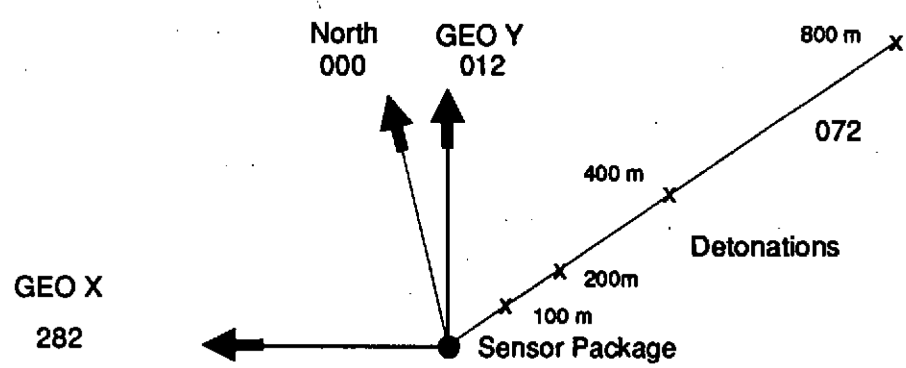

Figure 4a. Sensor, Detonator Geometry Hunters Bay
x are the detonation positions along the bearing 072 from north. GEO X and GEO Y are the axes of the two horizontal geophones. The third geophone axis is out of the plane.

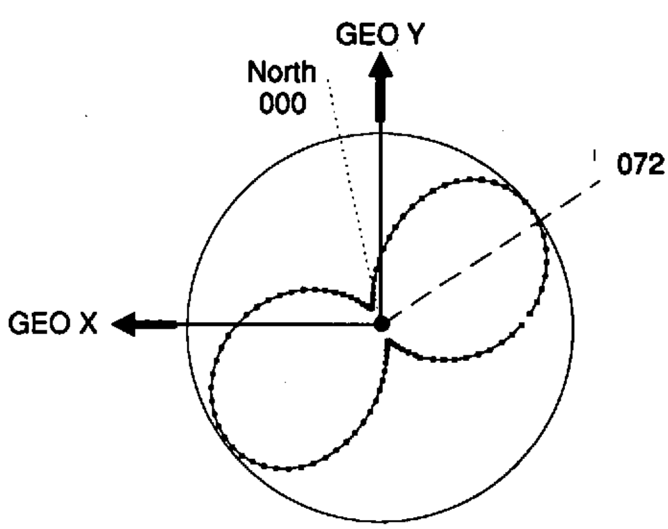

Figure 4b. Detonator Induced Noise
Plot of the azimuthal power distribution for interface waves arriving at the sensor package. Frequency range of analysis 8 to 12 Hz.

5. RESULTS - SHIP TRACKING

It has been shown previously [5] that ship induced infrasonic noise may propagate in the form of seismic interface waves, and that plots of the azimuthal power distribution of this wave energy can be used to determine the bearing of the source. When the source is some distance from the sensors the shallow water duct cut-off phenomenon can be expected to attenuate strongly the infrasonic compressional wave, thus enhancing the relative signal level of the seismic interface wave. As the ship approaches, however, and passes over the sensors the contribution of the water borne compressional wave impinging directly on the geophones and surrounding sea-bed may mask the seismic wave contributions.

Typical recordings from the geophones as the source ship passes overhead show strong increases in signal level of all geophone signals. In the horizontal plane the largest increase occurs for a geophone orientated transverse to the direction of motion of the source. Azimuthal plots of spectral power distribution in the 10 Hz frequency range show definite tracking capability when the source is in the far field. In the near-field, however, these plots have generated bearings that tend to be orthogonal to the true bearing, as indicated in Fig 5. Extensive signal processing such as that offered by using the hodographic features to separate the seismic from the acoustic responses of the hydrophones has not made significant improvements in the accuracy of the tracking.

The most probable explanation of these observations is that the received signals are dominated by the compressional wave component. Further, at close range the ship will not appear as a point source but as a distributed source complicating the wave field and hence the signals received by the geophones.

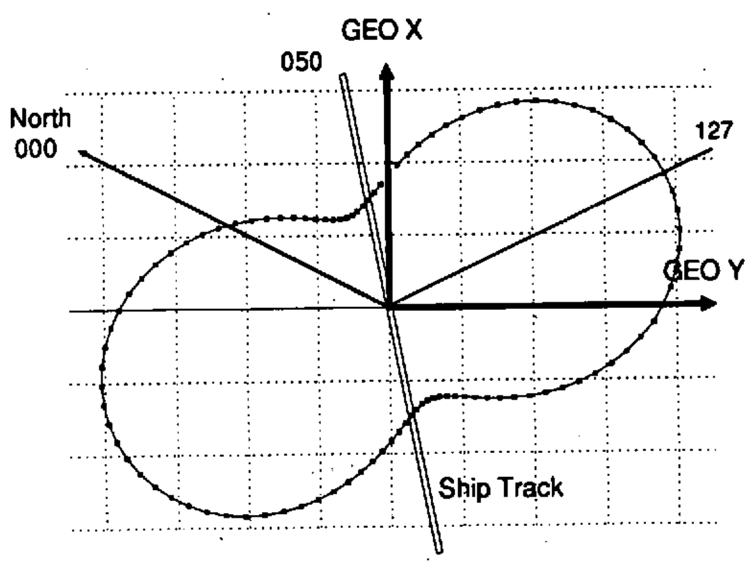

Figure 5. Ship Induced Noise
Typical plot of the azimuthal power distribution computed from the horizontal geophone signals for a ship passing close to the sea-bed package.

6. CONCLUSION

The results obtained in these studies have indicated the potential of utilising the detection of seismic interface waves for tracking ships in shallow water. The tracking appears to be most effective when the source is in the far field. Complications arise as the source ship enters the near field, and these have not been resolved by the techniques reported here.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

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