VERIFICATION OF A BUBBLE CURTAIN MODEL USING AN IMPULSE RESPONSE FUNCTION FOR A TOWED SOURCE

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1. INTRODUCTION

The effects of a bubble curtain on acoustic propagation from a towed source was investigated using a bubble curtain wavenumber integral acoustic model. The model was tested using an impulse response function as a source with direct path, surface reflected paths, and curtain reflected paths included.

2. METHODS

Sound propagation and back-scattering in bubbly water has been studied extensively in problems encountered in acoustic oceanography and ultrasonic imaging (Leighton, 1994). Even a very small fractional volume of air bubbles in water can significantly change the sound speed. The primary reason for this effect is that the compressibility of bubbly water is much greater than for non-aerated water. Sound pressure waves incident on the boundaries of bubbly water layers can be reflected strongly due to the large change in acoustic impedance across the boundaries.

The curtains were modelled as uniform layers 4.3 m in thickness, extending 20 m below the surface and separated by 36 m. The source was placed mid-way between the curtains at a depth of 5 m. The fraction of curtain containing air was 15% and each bubble had a 2.8 mm radius. Water sound speed was 1540 m/s.

Attenuation by the bubble curtain was calculated according to the method in Commander and Prosperetti (1989) and was incorporated in the air curtain layer reflection and transmission coefficients by using complex internal sound speeds. The relationship between the attenuation coefficient and frequency is shown in Fig. 1. Bubble layer sound speeds were computed to give frequency dependent curtain layer sound speeds from 105 m/s to 115 m/s, as shown in Fig. 2.

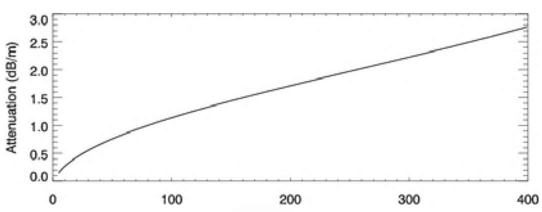

Fig. 1. Attenuation of the bubble curtain due to impedance mismatch, as a function of frequency.

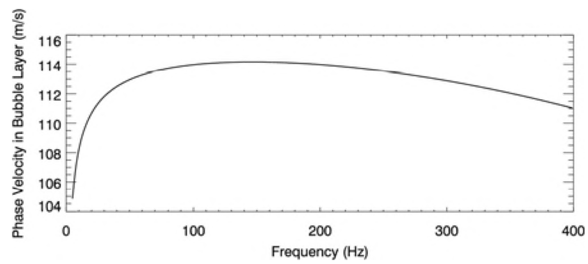

Fig. 2. Phase velocity in the bubble layer as a function of frequency.

Full waveform modelling was carried out from 5 Hz to 400 Hz. Frequencies below approximately 20 Hz are strongly attenuated by destructive interference of surface reflections (ghosts) that are treated here as surface images.

2.1 Wavenumber Integral Model

A wavenumber integral acoustic modelling method was used to compute the pressure fields presented here. Detailed descriptions of the approach are provided by Jensen *et al.* (1993) and Frisk (1994). The wavenumber integral approach is appropriate for the current problem of planar reflectors because it decomposes the spherical pressure field emitted by each of the airguns into a continuum of outward-propagating plane cylindrical waves. Reflections of the plane waves from the planar sea surface and air curtain walls were performed by treating each reflection as a multiplication by the appropriate plane wave reflection coefficient. Plane wave transmission through the air curtain upon each interaction was treated by multiplying by the plane wave transmission coefficient.

The model approach developed here makes two primary assumptions that have not been validated. The first assumption is that reflections from the curtains can be treated as mirror images with appropriate complex reflection coefficients applied. This would be a valid assumption if the curtains were infinite in planar extent, or at least much larger than the Fresnel zone size. The assumption is likely valid at high frequencies (shorter wavelengths) but may have reduced accuracy at lower frequencies. The second assumption is that diffraction around the bottom edges of the curtains is not important.

2.2 Method of Images

Source pressure signatures were modelled by using the method of images to account for multiply-reflected acoustic paths between the air curtains and from the surface. Because a wavenumber integral approach was applied, a solution was computed independently for each wavenumber before reconstruction by the integral. The horizontal wavenumber is preserved through reflection off the vertical reflectors and surface. This method is represented in Fig. 3, where the paths of several parallel rays, corresponding to one wavenumber, are shown (solid lines) and their images (dashed lines). For each reflection, the corresponding image position was calculated and a finite number of images were identified, corresponding only to the specular reflections that led to sound escaping in the direction of measurement. This calculation accounted for the geometry of curtains and was independent of receiver position. Transmission and reflection coefficients of the curtain were accounted for at each image and applied to waves propagating through the curtain and escaping under the curtains.

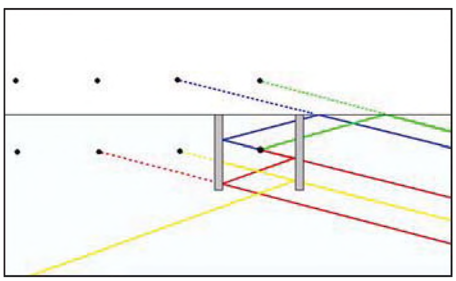

Fig. 3. Source reflection images for horizontal reflections off the bubble curtains and vertical reflections from the surface.

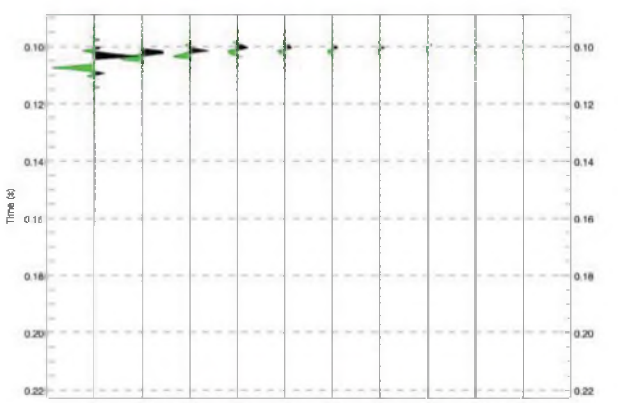

Fig. 4. Impulse response from a source at 6 m depth of direct and surface reflected paths without air curtains at ranges from 50 m to 500 m at a fixed receiver depth of 30 m. Signals have been time-aligned so the direct path signal occurs at approximately 0.1 seconds.

3. RESULTS

Testing of the acoustic model was carried out by examining the impulse response function with only direct path and surface reflected paths included. Fig. 4 shows the impulse response (5 Hz to 400 Hz) for a single towed source with no air curtains and no bottom reflections. The source depth was 6 m and the receiver depth was 30 m. This test shows the direct and surface reflected paths converging with increasing offset as expected. Fig. 5shows a scenario similar to that treated in Fig. 4, but with air curtains present. The individual paths are spaced as expected and with the proper polarity based on the respective numbers of curtain and surface reflections.

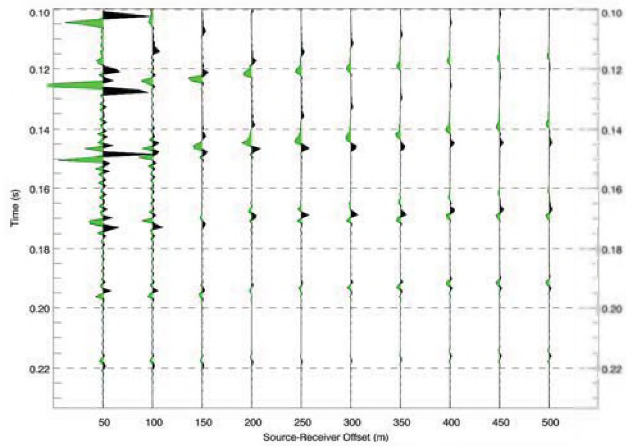

Fig. 5. Impulse response from a source at 6 m depth of direct transmission and multiple internal reflections with bubble curtains at ranges from 50 m to 500 m at a fixed receiver depth of 30 m. Signals have been time-aligned so the direct path signal occurs at approximately 0.1 seconds.

4. DISCUSSION AND CONCLUSIONS

Comparison of Fig. 4 and Fig. 5 show that the shielding effect is observed with the bubble curtain present. Interference between multiple reflections from the bubble curtain influenced the modelled impulse response of the towed source in the horizontal direction. Subsequent investigation will examine the effects of a bubble curtain on a towed airgun array.

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