Acoustic propagation in the ocean surf zone

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Abstract: This paper presents acoustic propagation loss measurements obtained during the SandyDuck'97 surf noise experiment. The source was located outside of the nominal surf zone region at a distance of 490 m from the shore in about 6.5 m of water. The receivers were spaced at 6-m intervals, 65 to 203 m off-shore in 1.5 to 4.5 m of water. The results indicate that for frequencies greater than 800 Hz, the propagation loss decreases with frequency at almost all source ranges in the 286 m to 484 m range interval and shows significant temporal fluctuations at all frequencies with a fade rate comparable to the wave period. A comparison of the measured results with computed results suggests that the frequency dependent locations of the nulls and the substantial increase in the loss at the shoreward ranges observed in the measurements is largely due to the decrease in the number of modes with decreasing water depth.

INTRODUCTION

During September and October, 1997, a multi-laboratory field experiment was conducted at the US Army Corps of Engineers Field Research Facility on the Outer Banks of North Carolina to study surf zone physics. As part of that experiment, researchers from NRL conducted measurements of the space-time-frequency distribution of the noise generated by the individual breaking waves in the surf zone, the broadband propagation of that sound to a transition region located just outside of the surf zone and the angle-time frequency distribution of the noise observed in the transition region. This paper presents preliminary results of the propagation measurements obtained using a mutli-tone signal consisting of six tones spanning a band from 400 Hz to 2400 Hz at 400 Hz intervals.

Due to the inherent difficulty of deploying and maintaining an acoustic source within the harsh surf zone environment, the source was deployed in the transition zone and the received signal was observed on an array located within the surf zone. The propagation characteristics from the surf zone to the transition zone can then be determined from the reciprocity principle. The source was located about 484 m from the nominal shoreline and about 30 cm above the bottom. The bottom deployed receiving array consisted of 24 phones at 6 m spacing spanning a distance of 60 m to 198 m from the nominal shoreline. The water depth varied from about 1.8 m at the shoreward phone to about 4.5 m at the seaward phone to about 6.5 m at the source under nominal tide conditions. Both the source and the array were located along a line orthogonal to the shore.

RESULTS

The measured results presented here were obtained over a five minute interval under calm surf conditions using a mutli-tone source signal consisting of six tones spanning a band from 400 Hz to 2400 Hz at 400 Hz intervals.

Figure 1(a) shows the temporal distribution of the propagation loss at 800 Hz as a function of source range over the 138 m aperture. As seen in the figure, the propagation loss exhibits an interference pattern in range with significant fluctuations in the low loss regions but with comparatively stable nulls (high loss regions). Furthermore, the fluctuations increases with source range becoming highly regular in both space and time in the shoreward half of the array with a period comparable to the measured wave period (7.3 s). This increase in regularity with range is likely due to the increase in the fractional change in water depth associated with the wave motion as the distance from shore, and hence, the nominal water depth decreases.

Figure 1(b) illustrates the frequency dependence in the propagation loss for the six tones in the 400 to 2400 Hz band. An inspection of these curves indicates that, except for the lowest frequency (400 Hz), the propagation loss increases with frequency at almost all ranges. Furthermore, excluding 400 Hz, all curves exhibit a range structure consistent with the time stable nulls seen in the 800 Hz range-time plot except that those nulls do not occur at the same ranges. Finally, the propagation loss curves for the four highest frequencies (1200 - 2400 Hz) show a sharp increase in loss for ranges greater than about 390 m. The 400 Hz curve shows considerably less range variability with values between 40 and 45 dB in the seaward region and between 47 and 50 dB in the shoreward region.

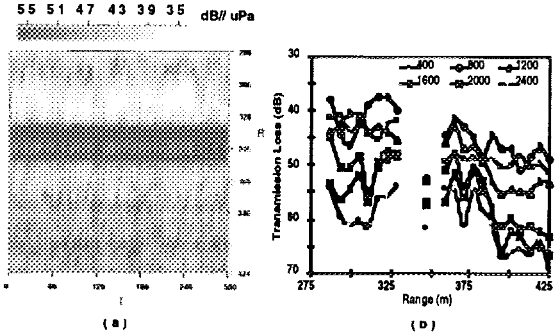

FIGURE 1. (a) Temporal distribution of the propagation loss for the 800 Hz tone plotted as a function of source range over a 5 min interval. The analysis bandwidth of 0.37 Hz corresponds to a time increment of 2.7 s. (b) Time-averaged propagation loss vs. source range for the six tonals. The dark bands in 1(a) and the missing segments in 1(b) results from three dead hydrophones.

To interpret these results we have computed the propagation loss along the array as a function of frequency using an FEPE propagation model with near concurrent measurements of the bathymetry adjusted for the prevailing tidal conditions. The geoacoustic model used in the computations was developed for this site by Fabre and Wilson (1) as part of an analysis of surf noise data acquired in the Duck 94 experiment.

The figure shows a broad low-level region at the shorter ranges and lower frequencies which breaks up into a series of upward sweeping arcs as the frequency increases. The upward sweep is due to the decrease in the number of modes that are supported as the water depth decreases with increasing source range (decreasing offshore distance) The broad slowly varying region at the longer ranges (>350m) and lower frequencies (<1400 Hz) is due to the sharp decrease in water depth that occurs at this range.

The propagation loss curves of figure 1 exhibit the same general range dependence as the computed propagation loss except that the computed values are roughly 6 dB less than the measured values. Part of this disparity may be due to the scattering of the energy from the irregular sea surface and the effect of bubble clouds on the sound speed and attenuation that are not included in the computation. Excluding this disparity, the computed results suggest that the frequency dependent locations of the nulls and the substantial increase in the loss at the shoreward ranges is largely due to the decrease in the number of modes with decreasing water depth.

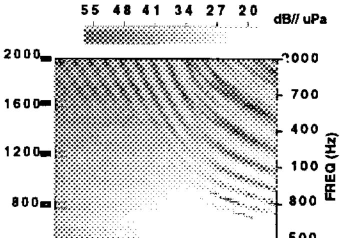

FIGURE 2. Computed range-frequency propagation loss. Five of the six signal frequencies are indicated by tic marks on the left hand side of the plot

ACKNOWLEDGMENTS

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REFERENCES

1. Fabre, J., and Wilson, J., *IEEE J. Ocean. Eng.* **22**, 434-444 (1997)