Comparison between subcritical penetration models and in situ data

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Abstract: This paper presents the recent results of a study whose overall objectives are to determine the mechanism(s) contributing to anomalous subcritical acoustic penetration into ocean sediments, and to quantify the results for use in sonar performance prediction for the detection of buried objects. In situ acoustic measurements were performed on a sandy bottom whose geoaoustic properties were carefully identified. A parametric array mounted on a tower moving on a rail was used to insonify hydrophones located above and below the sediment interface. An extensive dataset covering grazing angles both above and below the estimated critical angle and frequencies between 2-50 kHz was acquired and processed. The results are compared to models. For the specific bottom type examined, it is shown that for frequencies below 5-7 kHz the sound field into the sediment due to subcritical insonification is dominated by the standard evanescent field, while scattering due to the surface roughness is the dominant mechanism for higher frequencies.

EXPERIMENTAL DESCRIPTION

A recent experiment was conducted in order to study low grazing angle acoustic penetration into ocean sediments and target backscattering characteristics under such conditions. A special interest was the phenomenon of subcritical acoustic penetration. Besides the standard evanescent wave, two prominent explanations for this phenomenon are: (a) the existence of Biot slow wave [1], and (b) scattering due to surface roughness [2,3]. The experiment was performed on a sandy bottom in 10 meters water depth in the Biodola Gulf on the North side of Elba Island (Italy). Various environmental measurements, such as cores and a sub-bottom profiling, were performed. The measured sound speed (at 200kHz) into the sediment was found to be 1720m/s, resulting in a nominal critical angle of 28 degrees. Divers estimated a 2.5 cm rms height and a 20cm correlation length for the bottom roughness. The acoustic measurements addressing the penetration hypotheses were performed using the TOPAS parametric source covering the frequency range 2-15 kHz. For acquisition under variable conditions of trial geometry, the transmitter was mounted on a variable-height chassis which in turn was mounted on a 24 m linear rail deployed on the bottom, along which it could be moved in a precise and controlled manner. The rail was equipped with a pneumatic motor which allows accurate and reproducible displacement of the chassis along the rail. The TOPAS transmitter was mounted in a Pan-and-Tilt assembly with a MRU (Motion Reference Unit) so that arbitrary transmission directions could be accurately measured.

Figure 1 gives the experimental set-up and examples of the signals that were received on the hydrophones both in the water column and into the sediment. The hydrophone in the water column (used as a reference) was put 60cm above the sea floor. Two hydrophones were buried into the sediment at respectively -30cm and -60cm. Different grazing angles (both below and above the critical angle) were achieved by moving the tower along the rail. Both
primary and secondary frequencies of the parametric sonar were acquired. The range from the sonar to the hydrophones was far enough so that truncation of the primary near field by the water-sediment interface did not play a part in anomalous acoustic penetration [4].

**COMPARISON OF IN-SITU DATA RESULTS WITH MODELS**

The bottom penetration data have been modeled using two different theoretical approaches. The first model uses a combination of the standard OASES code and a perturbation approach to compute the 3D scattered field in the ocean waveguide [3]. The second model corresponds to a 3D simulation of the penetration ratio (defined as the magnitude of the ratio in dB of the acoustic pressure in the sediment to the incident pressure in the water at a given frequency) using the Helmholtz-Kirchhoff theory on a generated rough surface [5]. Both models used the same statistically generated rough surface of similar direction to that observed by divers during the at-sea experiment.

![Figure 2](image1.png)  
**FIGURE 2.** Penetration ratio for hydrophone at –30 cm

![Figure 3](image2.png)  
**FIGURE 3.** Penetration ratio for hydrophone at –60 cm

The comparison between the data and the two different models cited above clearly shows the presence of two different regimes according to the frequency range (note that supercritical data and models appear on the upper portions of the plots, sub-critical on the lower portions). For low-frequency (up to 7 kHz), the main contribution to the sound field is due to the standard evanescent wave, while for higher frequencies the roughness scattering appears to be the dominant mechanism (note that the small perturbation approach is not intended to model the evanescent field). The small discrepancies between the in situ data and the models may be explained in several ways. The underestimation of the penetration ratio in the 1-7 kHz region obtained with the Helmholtz-Kirchhoff approach is due to the fact that the simulation uses a frequency independent directivity which is not the case for the TOPAS. Moreover, the exact geometry of the experiment (the depth of the hydrophones (known at +/- 2 cm), the roughness spectrum and the exact grazing angles, ...) is not perfectly known. The model analysis suggested a 1685 m/s sound speed. Another experiment with 13 hydrophones buried into the sediment (up to –50 cm) was performed in November-December 1997 in a much more controlled geometry. Preliminary results show the same important conclusion concerning the predominance of the evanescent wave contribution under 5-7 kHz and the roughness scattering above this frequency.

**REFERENCES**