HYDROPHONE PERFORMANCE IN SEDIMENT

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Abstract: *In situ measurements of acoustic signals in marine sediment are often performed using hydrophones which have been designed for use in water. Typically, these hydrophones are characterised for transmit or receive sensitivity in water. When the hydrophone is submerged in a medium other than water, the sensitivity (both amplitude and phase response) of the hydrophone, and its resonant characteristics, can be dramatically affected as a result of the differences in acoustic impedance of the medium and the different coupling to the medium. To investigate these changes, a series of measurements of electrical impedance and receive sensitivity were performed on a hydrophone in fine sand sediment using a novel method which does not require a priori knowledge of the absorption in the medium. The initial results of this investigation are presented in this paper demonstrating the change in the hydrophone characteristics when used in sediment at frequencies above 40 kHz, and the factors affecting hydrophone performance in sediment are discussed.*

Keywords: *sediment, hydrophone, reciprocity*

1. INTRODUCTION

In situ acoustic experiments are frequently performed on marine sediments in order to determine their acoustic properties [1-7], and are particularly useful for the validation of geoacoustic models for both saturated [1,2,6] and gassy [3] sediments. While such experiments involve the insertion of transducers (sources and / or hydrophones) into the sediment, it is generally assumed that the water-based calibration of the devices is applicable. It is probable that the performance of these devices, namely sensitivity, electrical impedance and directional response, may change with the medium in which the device is embedded and this may influence the results of measurements made. This paper describes a novel method for calibrating hydrophones when immersed in sediment which is based on the reciprocity method but does not require knowledge of the absorption in the medium. An initial experimental study has been undertaken to determine the characteristics of hydrophones when buried in sediment including electrical impedance and receive sensitivity. It also presents an analysis of the reciprocity calibration technique when applied to lossy media and shows how the calibration geometry may be used overcome the complications introduced by the medium attenuation.

2. CALIBRATION METHOD

When undertaking absolute calibrations of hydrophones in water using the three-transducer spherical-wave reciprocity method at kilohertz frequencies, the absorption is usually neglected as insignificant. If necessary, a correction may be made to the measurements to account for the known absorption in water [8].

However, when undertaking such a calibration method in sediment, the finite absorption of the sediment must be taken into consideration. However, the natural variability of the sediment makes it difficult to predict the absorption accurately. The hydrophone sensitivity may nevertheless be determined without knowledge of the absorption if the three hydrophones are positioned in the co-linear arrangement shown in Fig. 1. In this arrangement, some cancellation of terms containing absorption will occur in the formula for the sensitivity of the central hydrophone, thus allowing its sensitivity to be calculated without knowledge of the absorption in the medium. Fig. 1 shows the required reciprocity measurement arrangement. Including the terms for the absorption in the medium, the equation for the pressure, *p,* produced by a projector P at hydrophone H may be written:

$$p = \frac{S_P I_P}{d_1} e^{-\alpha d_1} \qquad (1)$$

where the distance, d_1, is measured from the reference centre of the projector to the reference centre of the hydrophone, S_P is the transmitting current response of the projector and α is the absorption of the medium.

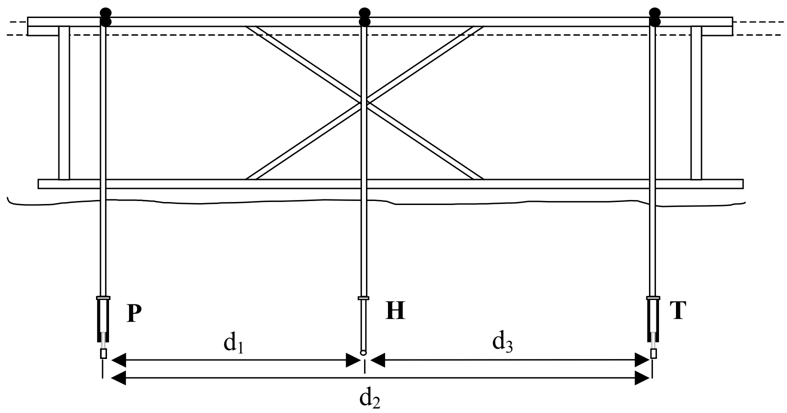

Fig. 1: Co-linear arrangement for three-transducer reciprocity which utilises a projector P and reciprocal transducer T to calibrate hydrophone H.

The transfer impedances Z for P to H (Z_{PH}), P to T (Z_{PT}), and T to H (Z_{TH}) are the quotient of the voltage on the receiver and the current used to drive the transmitter. These are given by:

$$Z_{PH} = \frac{M_H S_P}{d_1} e^{-\alpha d_1}, \quad Z_{PT} = \frac{M_T S_P}{d_2} e^{-\alpha d_2}, \quad Z_{TH} = \frac{M_H S_T}{d_3} e^{-\alpha d_3} \tag{2}$$

where M_H is the receive sensitivity of hydrophone H, M_T is the receive sensitivity of the transducer T, and S_T is the transmitting current response of the projector. The separation between the reference centres of P and T is given by d_2, while d_3 represents the distance between the reference centres of T and H.

Using the formula for the spherical-wave reciprocity parameter,

$$J = \frac{M_T}{S_T} = \frac{2}{\rho f} \tag{3}$$

it is possible to combine the expressions for the transfer impedances Z_{PH}, Z_{PT} and Z_{TH} to derive an expression for the complex sensitivity of the hydrophone H:

$$M_H = \sqrt{\left(\frac{2 d_1 d_3}{\rho f d_2}\right) \exp\left[-\alpha\left(d_1 + d_3 - d_2\right)\right] \left(\frac{Z_{PH} Z_{TH}}{Z_{PT}}\right)}. \tag{4}$$

The difficulty of determining the sensitivity of hydrophone H is that Equation (4) explicitly contains the absorption in the medium, which is difficult to predict accurately. However, this difficulty can be avoided by positioning the three transducers P, T and H in the co-linear arrangement shown in Fig. 1, with H located between P and T. This ensures that $d_2 = d_1 + d_3$ which simplifies Equation (4) to

$$M_H = \sqrt{\left(\frac{2 d_1 d_3}{\rho f d_2}\right) \left(\frac{Z_{PH} Z_{TH}}{Z_{PT}}\right)}. \tag{5}$$

3. EXPERIMENTAL MEASUREMENTS

The impedance measurements and the co-linear three-transducer reciprocity measurement were performed in a tank of saturated sediment measuring 0.67 m by 0.49 m with a sediment depth of 0.45 m, with a 0.05 m head of water. The sediment was prepared by sprinkling 290 kg of fine silica sand into the tank containing around 60 litres of degassed water, providing a saturated sediment density of around 2250 kg m^{-3}. This was performed in such a way as to minimise aeration of the water and thus the sediment.

The transducers used were an ITC1042, a B&K8100, a B&K8104 and two customised Neptune Sonar D140's. The D140's were modified by Neptune Sonar to have a cylindrical boot for easy insertion and removal in sediment. The method used for inserting the transducers was to insert an open ended tube into the sediment to the required depth, remove the sediment within this tube using a second smaller tube, insert the transducer into the empty tube and finally remove the surrounding tube to allow the sediment to envelope the transducer. After each insertion, the sediment was given time to settle.

Initially, only the D140s were inserted into the sediment to establish the propagation speed. The transmitter was driven with a HP33120A function generator at 300 mV_{p-p} through a B&K2713 power amplifier with a gain of 40 dB and the received signal was captured on a HP98410A Vector Signal Analyser. A 5-cycle 140 kHz tone-burst was transmitted between the two D140s, which were separated by 0.17 m. The propagation speed was estimated to be 1600 ± 50 m/s from a number of these measurements. The received waveform indicated that the transducers were not performing as intended in sediment, taking longer to reach steady-state conditions than in water.

Impedance measurements were performed on the receiving D140 using a HP4294A Impedance Analyser. A continuous wave method was used at discrete frequency steps of 1 kHz between 10 kHz and 250 kHz for sediment and compared with measurements performed in a large water tank. The results are shown in Fig. 2.

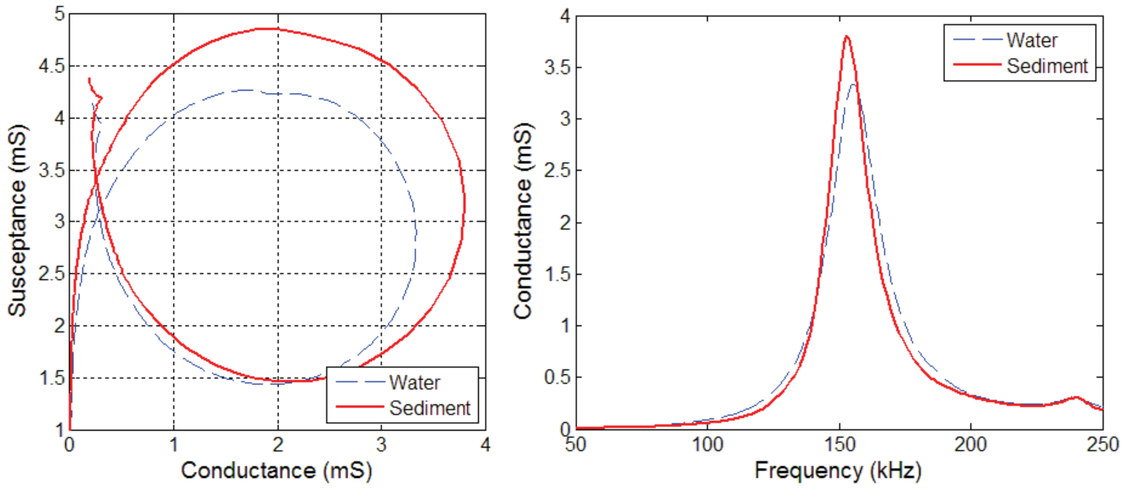

Fig. 2: Admittance loops (left) and conductance plots (right) for a D140 both in water (dashed) and in sediment (solid).

The conductance measurements at low frequencies (below the reasonance) show that the conductance is slightly decreased in sediment compared with water. This is to be expected from the higher acoustic impedance of the sediment. The admittance loop for the in-sediment measurement is noticeably bigger, however, indicating a higher Q value. The bandwidth of the conductance peak reduces from 24 kHz to 19 kHz with the peak frequency reducing by about 2 kHz. The origin of this is unclear but may be associated with the complex nature of the sediment impedance as a result of attenuation. Alternatively, the hydrophone may be less well matched to sediment than water, in this frequency range. However, this simple explanation does not fully explain the observed results.

The reciprocity measurements were performed using the ITC1042 as the Projector (P), the B&K8100 as the Transducer (T) and the B&K8104 as the Hydrophone to be calibrated (H). The transducers were mounted as shown in Fig. 1, with their reference centres separated by the distances d_1, d_2 and d_3 as indicated, where $d_2 = d_1 + d_3$. The reference directions were aligned, with P and T pointing toward each other, and the required transfer impedances Z_{TP}, Z_{PH} and Z_{TH} were measured. Ideally, the hydrophone H should remain in place throughout the measurements (including P to T measurements) so as not to disturb the sediment and change the propagation medium during the calibration procedure. However, because the hydrophone H had the potential to generate an acoustic shadowing effect when transmitting from P to T, Z_{PT} was obtained both without and with H inserted. This was achieved by determining Z_{PT} twice, first without H inserted and second with H inserted. In each case, the transfer impedance Z_{TP} allows the reciprocal nature of the transducers P and T to be assessed. The sensitivity curves obtained for H in each case were sufficiently similar, considering the other sources of uncertainty present, for the shadowing effect of H to be considered negligible between 40 kHz and 90 kHz. Fig. 3 shows the sensitivity obtained for the B&K8104 in sediment between 40 kHz and 90 kHz compared with a similar calibration performed in water.

The frequency range used for the calibration was limited by the dimensions of the tank at lower frequencies and the increase in the internal reflections in the transducers as a result of the sediment at higher frequencies. Performing the calibration on a steady-state portion of the waveform was extremely difficult outside this frequency range. The results in Fig. 3 display a substantial drop in the B&K8104's sensitivity when used in sediment. This was also observed for the D140 hydrophone. This may be attributed to the increased impedance of the sediment. Since sediment can support shear waves, it is possible that these may also be detected by the hydrophone. These results have implications when using hydrophones in sediment which have been designed for use in water, particularly if using sensitivity calibration data obtained in water.

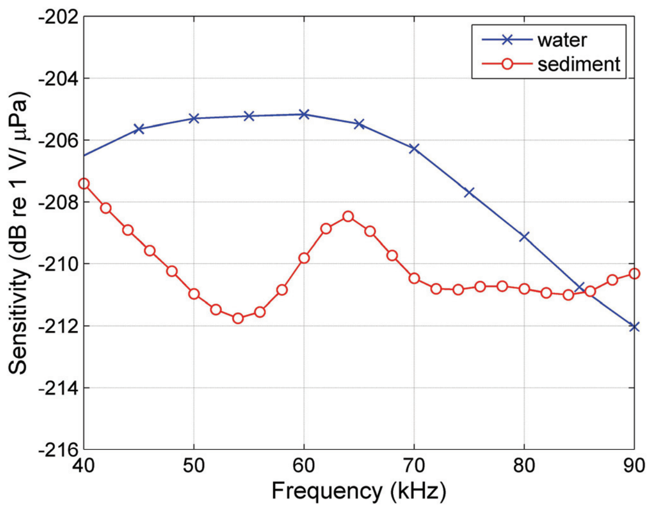

Fig. 3: Sensitivity plot (H inserted for P to T) for a B&K8104 (H) in both water and sediment obtained using reciprocity calibration method.

4. CONCLUSIONS

A series of measurements, including an in-sediment reciprocity hydrophone calibration has been performed which demonstrate the change in hydrophone performance when used in marine sediment. Although the reciprocity calibration performed in the sediment is subject to relatively large uncertainties when compared to that of water, the results show a general trend for a reduction in sensitivity. It is possible that this reduction in sensitivity is a result of an acoustic impedance difference between that of sediment and water.

For the hydrophones examined in this initial study the observed changes in sensitivity are sufficient to indicate that in-water calibration data cannot be assumed reliably describe the performance of these devices when inserted in sediment.

5. ACKNOWLEDGEMENTS

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