

# Underwater Seismometer Validation

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**Abstract.-** This work verifies and validates the calibration in a marine geophone by means of a hyperbaric chamber before and after the pressure underwater laboratory test. The objective is to characterise the transfer function according to the frequency of coupling between the geophone and the sediment. It is possible to observe the geophone coupling variations through the sediment after the test inside the water pressure at the equivalent of 200 metres depth.

## I. INTRODUCTION

In marine seismic prospecting, the equipment acquires the vibrations of the seabed. The waveforms can be either artificially generated at an oceanographic vessel on board and registered by the OBS (Ocean Bottom Seismometer) that can record natural seismicity too. With appropriated mathematical algorithms, the cortical distribution can be deduced (speed, deepness), and also geological properties of the rocks and constitutive layers can be studied [1]. The OBS measures the refracted vibrations of the seabed by a geophone with three orthogonal sensors GS11 (natural frequency 4,5Hz and 85,8V/m/s of sensibility) and frequency range from 0,1 to 100 Hz, in order to investigate the composition and stratification of oceanic subsoil.

To characterise the underwater performance and the sediment interaction with the geophone we need a precise model to obtain the correct simulated answer.

## II. DESIGN GEOPHONE

Through a finite element analysis using Unigraphics 2.0, with a 40,53 Mpa (400 atm) pressure stress, we can see in red colour at the figure 2, the parts over the elastic limit, over the material aluminium 3005-H18.

The first modification is the addition of a verve that will join the central wall to the side wall, decreasing the point of maximum stress. The next modification will be the increase in rounding of the edge situated in the deepest part of the cavity that holds the sensors, from R7 to R12, smoothing this change of direction. We can observe all this in Figure 1. The points with most tension concentration are very localized, therefore a study of an increase in thickness between the mentioned cavity with external part of the geophone. Both modifications increase the elastic limit stress (225 MPa) until 500 atm but it's not enough to obtain 600 atm, another change in the structure its necessary to do.

Material	Elastic limit (MPa)	Resistance to corrosion
5083 H38	335	Very high
6082 T6	310	high
7049 T6	590	low

Table 1. Mechanical characteristics of materials

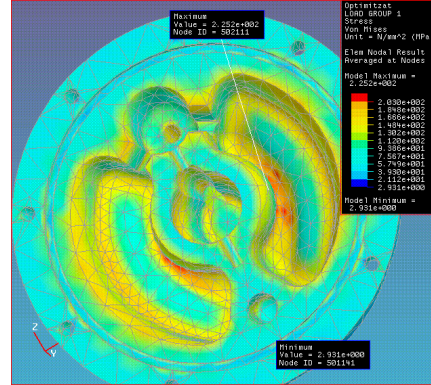


Fig. 1. Finite elements analysis of the initial design at 400atm pressure with aluminium 3005-H18

We have chosen between materials that would bear the marine environment, however some of them do not comply the needed mechanical features. The study of the material has been carried out using the initial design of the geophone and different materials (table 1). Through this design technique, the maximum stress of the geophone has been increased by 20%. For over 500 atm pressure a change of material is recommended. Al-Mg 5083 H38 is the better material but are not available, and at the end Al-Mg 6082 T6 with a thermal and anti-corrosive treatment has been selected and constructed [6].

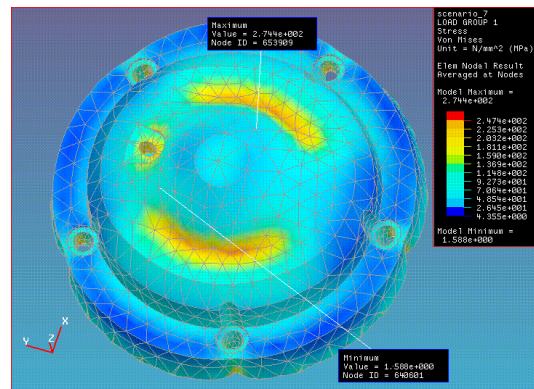


Fig. 2. Finite elements analysis of the final design at 600atm pressure with aluminium 6082 T6

The figure 2 shows the finite element analysis at 600 atmospheres pressure for aluminium 6082 T6 material and the changes of the structure, with the result of 274,4MPa for the maximum stressing of the designed structure, far away of its elastic limit stress (table 1).

## III. MEASURES IN THE LAB

All calibrations of the geophone before and after the work inside the hyperbaric chamber, are the velocity profiles with amplitude vibrations of 3mm/s and 1 to 100 Hz sweep frequency in the same shaker table and the same test conditions.

The initial test is to calibrate the sensors of the geophone "in dry" (without sediment) with a shaker table, put inside the hyperbaric chamber and at the end calibrate in the same conditions and orientations like a first calibration. The figure 3 shows the geophone fixed on the table surface in order to obtain its transfer function of voltage output respect to vibrations in m/s.

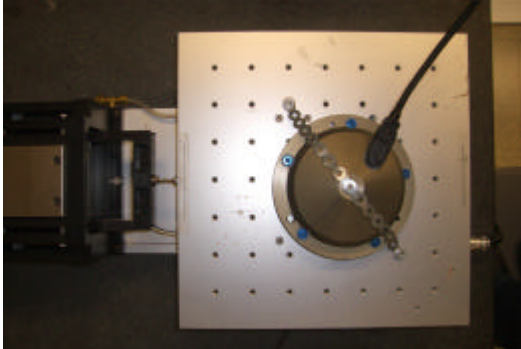


Fig. 3 Geophone on a shaker table for the first calibration

In order to obtain the transfer function of the geophone respect to the coupling sediment,  $T_h$ , we calibrate the geophone over the sediment (figure 4). The expression (1) shows the geophone intrinsic parameters playing in this coupling where the impedance between a seismometer and the seabed which accounts for the seabed stiffness  $k$  and damping  $R$ , where  $m$  is the mass of geophone and  $m_{bot}$  denotes the bottomed added mass [2][3].

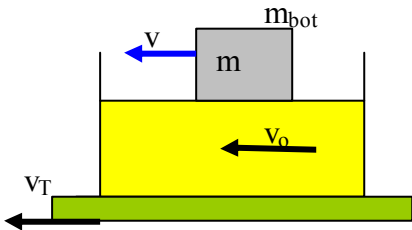


Fig. 4. Bottomed geophone to horizontal seabed motion

$$T_h = \frac{v}{v_o} = \frac{\frac{R}{m + m_{bot}} \left( s + \frac{k}{R} \right)}{s^2 + s \frac{R}{m + m_{bot}} + \frac{k}{m + m_{bot}}} = 1 - \frac{r}{r_\infty} \quad (1)$$

When we have the velocity signals of the table  $v_T$ , sediment  $v_o$ , and that of the geophone  $v$ , the expression (2) shows the sensibility of a seismic sensor in V/m/s unity and how to obtain the transfer function of coupling by calibration [3].

$$Sens_{BERAN} = \frac{Voltage_{G,S}}{v_T} = H_G \cdot \frac{v}{v_o} \cdot \frac{v_o}{v_T} \quad (2)$$

The geophone is calibrated in the sediment box by a shaker table shown in figure 5 by BERAN calibrator and reference accelerometer sensor. The parameters of this coupling can be deduced of the graphic representation of calibration H2 channel shown in figure 7.

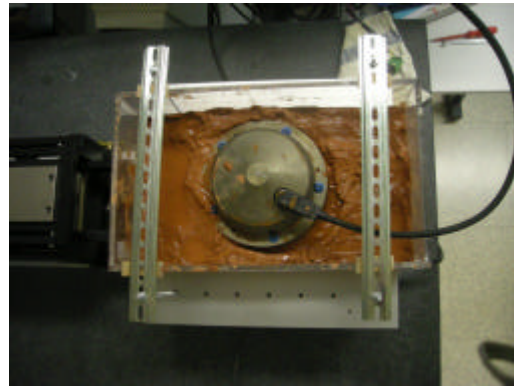


Fig. 5 Sediment box and geophone in a shaker table

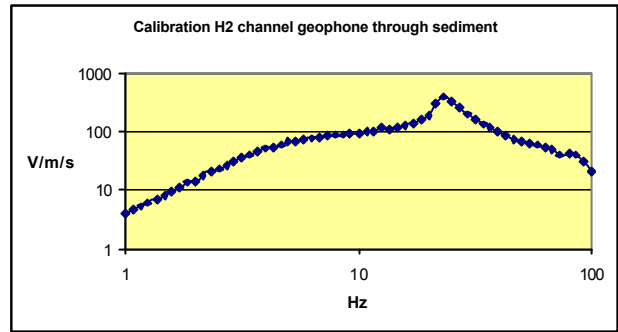


Fig. 6 First calibration H2 channel geophone through sediment

We can observe in the figure 6 the real channel H2 calibration of the geophone through the sediment that represents the  $Sens_{BERAN}$  showed in expression (2), with a typical frequency response of electromagnetic seismic sensor (high pass frequencies)  $H_G$  and transfer function of coupling interaction  $T_h$ .

From the geophone under test we can obtain the data of the horizontal mass suspended in the water,  $m_{sus}$ , which is about 0.588 kg while the weight of the equipment is 3.17 kg. Considering a good coupling ratio for higher frequency of 0.95, we can infer that the value of the bottom added mass is 0.78 kg according to equation (4). The other parameters of the coupling [5] are seabed stiffness  $k = 19380 \text{ kg/s}^2$  and damping  $R = 69.2 \text{ kg/s}$ .

The similar calibrations of geophone channels through the sediment on the shake table in this case over water is shown in figure 7.

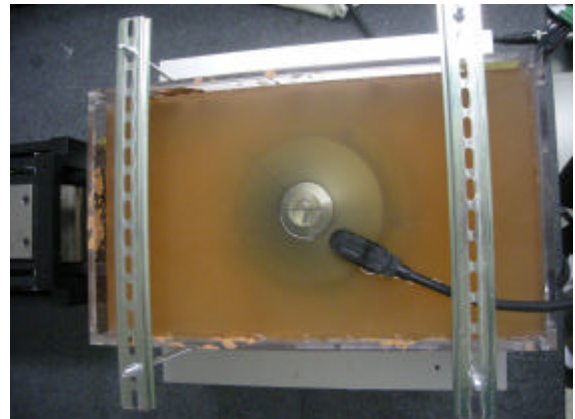


Fig. 7 Sediment box and geophone underwater in a shaker table

The next process is to put the sediment box and the geophone inside the hyperbaric chamber (figures 8 and 10) at 20 atmospheres of water pressure to measure the output of the geophone sensors to know its performance, changes and response underwater at depth of 200 meters. The test consists of several cycles of pressure and maintenance of 20 hours at 15 atmospheres.



Fig. 8 Sediment box and geophone inside the hyperbaric chamber

The last process is to calibrate once more the sensors of the geophone through the sediment and compare it with the first calibrations under the water and without water, in the exactly same conditions of the initial tests.

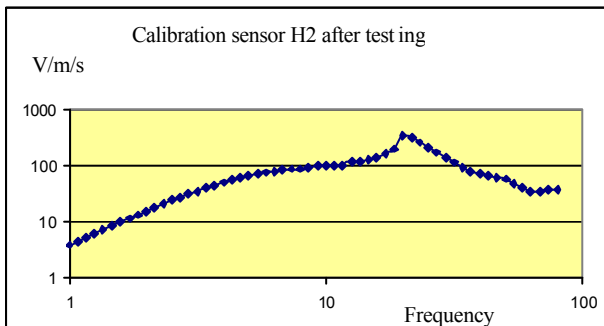


Fig. 9 Calibration H2 channel second calibration after the underwater test of geophone



Fig.10 Sediment box and geophone inside the hyperbaric chamber

The results of the second calibration in the channels of geophone get the similar transfer functions of sensibility (figure 9), which are compared in a figure 11 and we observe the same values and some change of frequency of maximum in the H2 channel sensibility.

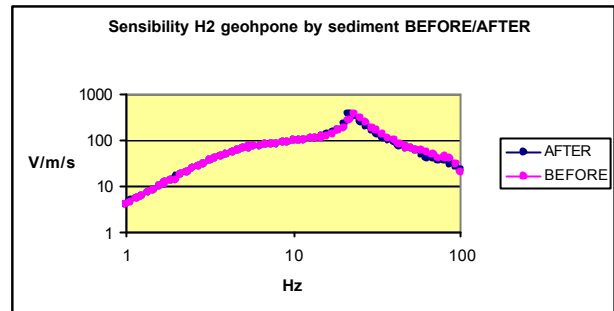


Figure 11 Compared sensibility H2 channel geophone by sediment

#### IV. RESULTS AND DISCUSSION

We can observe that the geophone supported the water pressure and worked correctly underwater thanks to airtight structure and its sensibility is the same after the underwater test. In figure 12 we observe that the sensibility is practically the same ( $\pm 3\%$ ) of the first calibration when testing the sensor geophone "in dry", except at highest frequency due to a resonant effect in the shake table and its support structure.

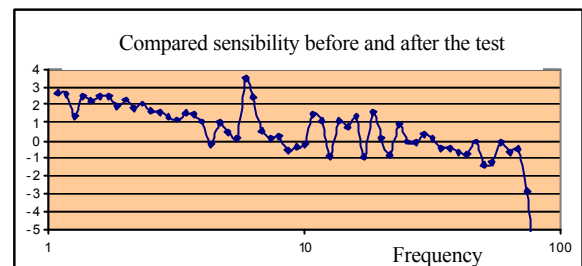


Figure 12 Compared sensibility of H2 sensor without sediment in percentage respect to the frequency

When we compare the sensibility of the channel H1 of geophone in 90 degrees or transversal response before and after the test inside the hyperbaric chamber we can observe more changes than H2 channel seen in figure 13.

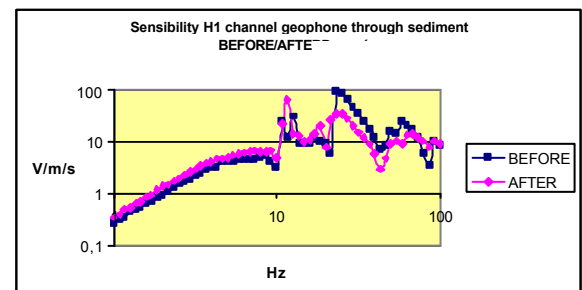


Fig. 13 Compared sensibility H1 channel geophone by sediment

The figure 14 shows the differences in % when calibrating the geophone in the sediment box. In this case the calibration is the same except for the typical maximum when there is a change of sensibility, and except at highest frequency due to better coupling after chamber test.

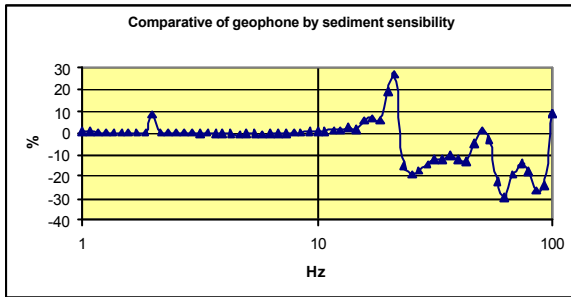


Fig. 14 Compared sensibility of H2 sensor with sediment in percentage respect to the frequency

The results showed the good behaviour of the geophone designed structure and validates the design in the real test in underwater conditions that do not change the sensibility of the geophone and the coupling sensibility after extreme pressures such as oceanic trenches of 6000m.

#### ACKNOWLEDGMENTS

The development of the Ocean Bottom Seismometer has been possible thanks to the project Signal Transmission in light and Autonomous Underwater Sensors (CTM2004-04510-C03-00) funded by the Spanish Research and Technology Management Unit (DGICYT), as a continuation of the project New Generation of Light and Autonomous Underwater Sensors-SENSUAL (Ref:REN2000-1016-C02-01/02) which is a joint work between Technical University of Catalonia (UPC), Marine Technology Unit (UTM) and Technical University of Navarra (UPN) Tecnoterra Associated Unit.

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