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SEA SEISMOMETER COUPLING ON THE SEDIMENT

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Abstract – We can obtain the performance of the marine seismometer upon the sediment to know its coupling in the bottom sea. This paper deals with the coupling parameters in order to obtain the geophone response through the frequency. The use of the shake table and vibration calibrator allows to deduce the coupling transfer function between the geophone and the sediment sea without using a detailed model of interaction sensor/seabed.

Keywords: Seismometer, coupling, sensitivity.

1. INTRODUCTION

The OBS (Ocean Bottom Seismometer) measures the vibrations refracted of the seabed with geophones in three orthogonal axis and frequency range from 0.1 to 100 Hz, in order to investigate the composition and stratification of oceanic subsoil by seismic prospecting.

The main problem when someone presents a marine geophone design is to know the performance of the geophone in the bottom sea in order to obtain a good response to vibrations of seabed. This interaction between the OBS and the sediment or rocks is not usually good because the geophone is deployed only by surface contact, without penetration into the bottom sea. The response to forced oscillations of OBS with the seabed is the coupling ratio.

Suppose an OBS of mass m suspended in water moving in response to a sinusoidal force **F** [1]. The relation between this force and the resulting velocity $\mathbf{v_{sus}}$ follows from Newton's law:

$$j\omega(m+m_{sus})v_{sus} = F \quad (1)$$

Where $\mathbf{m_{sus}}$ is the hydrodynamic added mass. If we now consider the OBS on the seabed the equation of motion for the bottomed OBS is:

$$j\omega(m+m_{bot})v_{bot} = -Z\cdot v_{bot} + F \qquad (2)$$

where $\mathbf{m_{bot}}$ denotes the bottomed added mass to account for changes in flow patterns around mass effects associated with the seabed sediments themselves. The $\mathbf{v_{bot}}$ is the bottomed velocity and ***Z*** is the interaction impedance between an OBS and the seabed which accounts for the seabed stiffness ***k*** and damping ***R*** according to equation (3) by Olser and Chapman reference [1]. This impedance is function of the frequency and characterizes the coupling instrument-sediment totally.

$$Z = \frac{k}{j\omega} + R \qquad (3)$$

Coupling ratio

The coupling ratio, *r*, between bottomed and suspended velocities follows Osler and Chapman equation [1].

$$r = \frac{v_{bot}}{v_{sus}} = \frac{j\omega(m+m_{sus})}{j\omega(m+m_{bot})+Z} \cong \frac{m+m_{sus}}{m+m_{bot}} \quad (4)$$

When Z/ω approaches zero as frequency increases, the high-frequency limit of the coupling ratio is simply a ratio of masses (4).

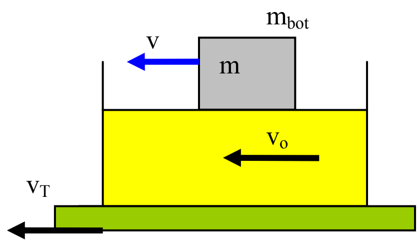

Fig. 1. Response of bottomed OBS to horizontal seabed motion

As shown in Fig. 1, if the seabed moves with horizontal velocity v_o and the OBS responds by moving with horizontal velocity ***v*** while the water remains at rest, (considering **Z**, $\mathbf{m_{sus}}$, $\mathbf{m_{bot}}$ and ***r*** not distinguished between vertical and horizontal motion) the coupling transfer function $\mathbf{T_h}$ for horizontal seabed motion is shown in equation (5). If the coupling ratio can be measured, the T_h can be inferred, without recourse to detailed model of the OBS/sediment interaction. Substituting the Z value expressed in equation (3) at the T_h expression we can obtain:

$$T_h = \frac{v}{v_o} = \frac{\frac{R}{m+m_{bot}}\left(s+\frac{k}{R}\right)}{s^2 + s\frac{R}{m+m_{bot}} + \frac{k}{m+m_{bot}}} = 1 - \frac{r}{r_\infty} \qquad (5)$$

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In the expression (5) the resonance frequency ω_o and the quality factor Q are identifying parameters showed in a equation (6).

$$\omega_o = \sqrt{\frac{k}{m + m_{bot}}} \quad ; \quad Q = \frac{\sqrt{k(m + m_{bot})}}{R} \qquad (6)$$

2. MEASURES IN THE LAB

2.1. Material of the bottom seabed

The geophone was placed on a clayed sediment of density 2005 kg/m^3 and dampness 29 %. It is characterized by a liquidity limit w_L (41 %) and a plastic index I_P (18%).

Laboratory studies have been carried out using co-axial cylindrical reometer *"Haake"*, which indicate this material performs reologically as a non-Newtonian substance. Under low to intermediate shear stresses (2 - 121 Pa) and shear rates (0.46 – 500.2 s^{-1}) it performs as shear thinning (pseudo plastic), the apparent viscosity decreases with increasing rate of shear stresses. The relationships have been defined as equation (7).

$$\tau = 35.918 \cdot \gamma^{0,1955} \qquad (7)$$

where τ is the shear stress in Pa and γ is the rate of shear strain in s^{-1}.

It has also been carried out a test of oscillation together with a frequential sweep by means of a rotary-oscillatory reometer *"Haake"* from which we obtained a lineal viscous elastic behaviour by stress below 10 Pa with a 1 Hz frequency (Fig 2). It shows how the elastic and viscous modules evolve at a 1 Hz frequency when changing the applied effort. Therefore the elastic module G is constant and independent of the stress at rates below 10 Pa.

By doing a frequency sweep (Fig.3) at a 1 Pascal stress, it resulted that the elastic module component G' is always higher than the viscous module G''.

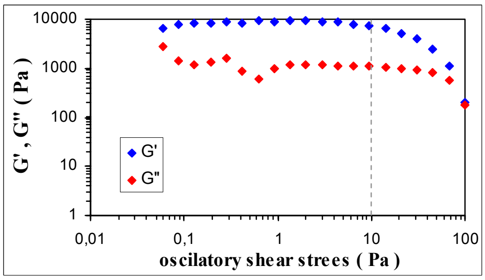

Fig. 2. Test of values G' i G" for frequency 1Hz varying the shear stress.

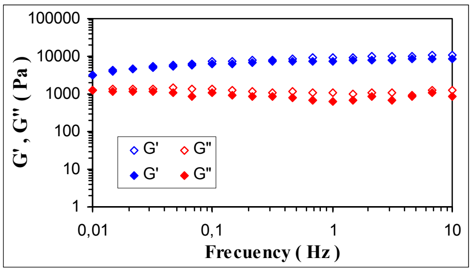

Fig. 3. Spring and viscous modules by frequency.

During the test shown in figure 3, the tested sediment has an elastic behavior at 1 Pa since G'>G''. However, when experimenting at the vibration laboratory it became more fluid when increasing the stress and/or the frequency value.

2.2. Shake table measurements

The experimental set-up to measure in the shaker table (APS Model 129, 0.1 to 100 Hz) with transducer vibration calibrator *"BERAN 455"* in the SARTI lab are showed in the Fig.4. The accelerometer type PCB Piezotronics (model 393B31) is the reference sensor vibration on shaker table.

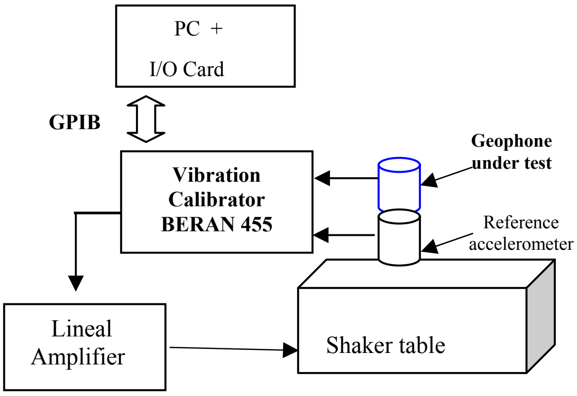

Fig. 4 Block diagram of the measurement system

The geophone has been designed from triaxial magnetic sensors (GS11 from Geo-Space with 32 V/m/s). This sensor contains a seismic mass and its movements produce a change in the magnetic field, which will transform into an electric current through the coil. The signal will be proportional to the movement of the surface where the geophone is placed. This container of geophone would be able to work under the elastic limit at 600atm.

When we leave the geophone upon the sediment basin and the box containing the sediment and geophone upon the shaker table according to Fig. 5 and Fig. 6, we can obtain the sensitivity of the sensor under test, related to a reference accelerometer.

Fig. 5. Coupling of geophone on the sediment.

This function is the output voltage of the geophone regarding the velocity vibration of the table (8), and is equal to the sensitivity of the geophone by the ratio of velocities of the geophone regarding the sediment and the ratio of velocities to the sediment regarding the table motion.

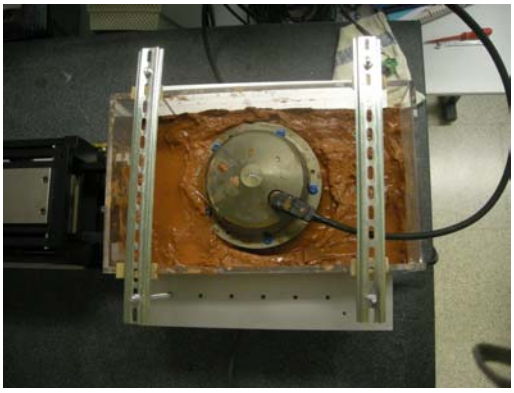

Fig. 6. Vibration test profile with sediment basin up the shake table

Considering that the expression (8), v_o/v_T is near to the unit, the transfer function $T_h = v/v_o$ can be deduced. The T_h function is the sensitivity of the geophone velocity respect to the velocity sediment regarding the shake table.

$$Sens_{BERAN} = \frac{Voltage_{G.S}}{v_T} = H_G \cdot \frac{v}{v_o} \cdot \frac{v_o}{v_T} \qquad (8)$$

3. RESULTS AND DISCUSSION

Following the expression (5) of the transfer function T_h and the drawing figure 1, the graphic of figure 7 shows the sensitivity of the geophone through the frequency obtained from the sediment by calibrator (squares), expressed with v, and the geophone sensitivity from the shaker table directly (triangles), v_o.

The coupling transfer function for horizontal seabed motion $\mathbf{T_h}$ can be obtained from figure 7, by quotient of the geophone response (v) respect to shake table response (v_o), with a zero and a double pole according to the expression (5) and according to the Osler reference [1] showed in figure 8. The performance of this coupling transfer function is a low pass filter and we can identify the parameters that characterize this function as ω_O, quality factor Q or damping factor and zero frequency.

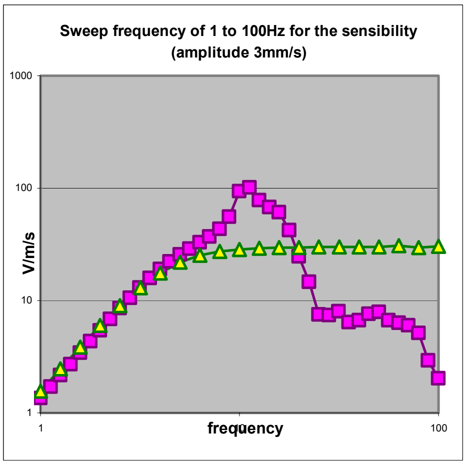

Fig. 7. Sweep frequency of the seismometer sensitivity (square points upon the clay and triangle points upon the shake table)

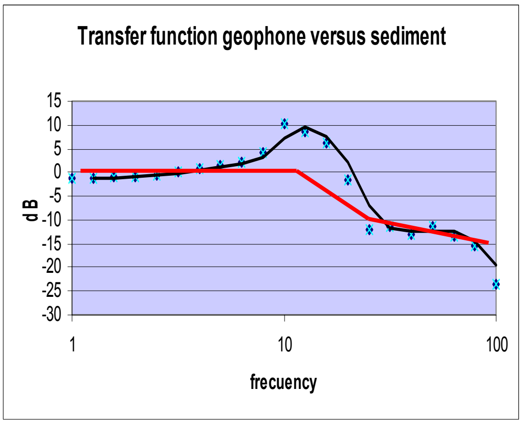

Fig. 8. Coupling transfer function for horizontal seabed motion $\mathbf{T_h}$, and asymptotical associated graph.

Considering the performance of the asymptotic shape in figure 8, we can identify in straight lines the characteristic parameters of the transfer function, the frequency of the double pole is 11.2 Hz, quality factor Q=4 and zero frequency is 44 Hz, in the present case. For low frequencies the function is practically the unity. For frequencies higher than the resonance the slope descends and the material decreases its elasticity (it becomes more fluid). The performance of the coupling is pseudo elastic beyond 20 Hz maybe due to the box walls containing the geophone.

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).

With the above mentioned values we can characterize the interaction impedance between an OBS and the seabed and approach to the value of the seabed stiffness ***k= 19380 Kg/s***^{2} and damping ***R=69.2 Kg/s*** shown in equations (5) and (6).

According to Kimura reference [5] K and R (D) are:

$$k = \frac{4\rho a}{1-\sigma} c_s^2 \qquad R = \frac{4\rho a^2 a_{21}}{1-\sigma} c_s \qquad (9)$$

From the first equation (9) it can be deduced that the value of the shear wave velocity of sediment Cs= 2.97m/s in the case that the Poisson coefficient σ, is 0.49, the geophone radius is 0.1 m and the density of the material in which the geophone is made, ρ is 2830Kg/m^3.

4. CONCLUSIONS

At the present paper we have inferred valuable parameters related to the coupling in the seismometer-sediment interaction and the shear wave velocity of sediment. They have been obtained from a reology and vibration laboratory test. These parameters allow to characterize the coupling transfer function between the sensor and the sediment, and how the geophone performs when recording the ground and seabed vibrations data, what the expected dynamic range is and its accuracy level.

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