

A Real Time Seafloor Seismometer

M. Carbonell⁽¹⁾, I. Massana⁽²⁾, J. Prat⁽²⁾, J. del Río⁽³⁾, E. Trullols⁽²⁾

⁽¹⁾ Dept. Mecànica de Fluids, SARTI-EPSEVG, Universitat Politècnica de Catalunya, Vilanova i la Geltrú, 08800, Spain

⁽²⁾ Dept. Matemàtica Aplicada 4, SARTI-EPSEVG, Universitat Politècnica de Catalunya, Vilanova i la Geltrú, 08800, Spain

⁽³⁾ SARTI-EPSEVG, Universitat Politècnica de Catalunya, Vilanova i la Geltrú, 08800, Spain

Abstract - In this paper we present a new compact design of marine seismometer in the frame of INTMARSIS project (CGL2013-42557-R). The design pretends to be an alternative to OBS (Ocean Bottom Seismometers) in shallow waters (depth < 500m) to be deployed near de coast. In contrast to OBS, a physical connection between the seafloor unit and the surface buoy allows real time data processing and satellite communication.

Even though an umbilical cable seems to be the more obvious alternative, the low energetic consumption of the seafloor unit and the recent improvements in inductive communications open a very interesting new possibility, the connection with steel cables. Steel cables are cheaper and not so heavy as the umbilical ones. Bandwidth inductive communications supports at least 100Hz sampling in real time.

I INTRODUCTION

The Ocean Bottom Seismometers (OBS) is a well know technology to measure underwater earthquakes. Standard OBS design consist of a seismometer itself (with the associate electronics, data logger and batteries), a weight to sink it to the sea floor, a flotation to bring the instrument back to the surface and a remote acoustic release. An important aspect of the OBS is that it can be deployed and recovered from almost any research vessel.

Monitoring high frequencies produces large amounts of data, so that, storage capacity could be a critical point in the OBS design. Other critical points are the live of the batteries and the time synchronization with other devices. Because of the lack of physical or logical connection with ground stations, OBS do not allow real time measurements.

In this paper we present a new ocean seismometer that pretends to be an alternative to OBS in shallow waters to be deployed in the Alboran Sea (western Mediterranean). In contrast to OBS, in our design a physical link connects the seafloor seismometer with a

surface buoy allowing real data measurement and time synchronization. Surface unit (the buoy), bottom unit (seafloor seismometer) and link have been modelled in order to minimize forces and tensions between them. Simulations were performed using Orcaflex 9.3c under educational license N1594 [1].

As an alternative to inverse catenary we also present a system containing an intermediate buoy connected to surface buoy with an elastomer. Numerical simulations, including different wind and wave conditions, show that the elastomer absorbs an important part of wave's movement. Tidal elevation is not taken into account. Intermediate buoy and the seafloor unit are connected with a steel cable that allows data transfer using inductive communications.

The structure of this paper is the following: section II is devoted to Material and Methods where the Orcaflex model is given. Results and Discussion are collected in section III and Conclusions and further work are presented in section IV.

II MATERIAL AND METHODS

In this paper we present the project requirements and possible solutions related to one specific deployment in 250-350 m water depths for recording natural seismic events. The purpose of this project is to design a marine seismometer allowing real time access to the data. The system was intended to be connected with a buoy at the surface transmitting continuous data to shore, and communication from the subsea unit via induction coupled commutation though a steel mooring wire. The data is to be continuous vertical data, with a triggering algorithm to switch to 3 components data for events and with enough latency in the transmission for it to be possible to catch up in a reasonable time. This will be especially relevant

to equipment located near the coast or in wired network observatory. This system should allow seismic measurements in real time of passive seismicity produced by near faults or active volcano in a range of 200 km. The purpose of these stations is to provide good azimuth observations in relation to the hypocentre. The data will be used for hypocentric location and magnitude determination. The seismic station should be capable to capture moderate seismicity ($1.5 < M < 5$), rarely exceeding depths of 20 km and always at depths less than 100 km, being the natural period of 1 second nominal, short period of 1 Hz. Needed bandwidth will be from 0.5 up to 30 Hz (seismic LP events) with a 18 bit resolution. SNR should be above 60 dB and data loss less than 10%. The seismic data transfer assumes that short-term packet loss will occur and assumes that degraded seismic data is better than no seismic data.

Deployment will be from vessels that are not fully equipped for research and will likely be done by Scientifics not familiar with the deployment of this type of equipment.

Prior to the deployment of the seismometer a model of the structure is done and its dynamics is studied. The simulations are carried out with OrcaFlex software, version 9.3c [1]. OrcaFlex is a marine dynamics program developed by Orcina for static and dynamic analysis of a wide range of offshore systems. OrcaFlex provides fast and accurate analysis of umbilical and power cables under wave and current loads and externally imposed motions. It is a fully 3D non-linear time domain finite element program capable of dealing with arbitrarily large deflections of the flexible from the initial configuration [2,4]. We assume for the model a spar buoy on the top linked with an elastomer to an intermediate underwater buoy linked to the bottom with steel cable in 300 m depth (see Figure 1). The steel cable will support the inductive mode until intermediate buoy, from this one to the top data is conducted by a power cable rolled along elastomer, but model do not includes the power cable as we assume it will not affect significantly the dynamics of the structure.

We want to keep the seabed anchorage as stable as possible with minimum oscillations and tensions on it due to sea conditions. The elastomer could absorb the vertical and horizontal movements of top buoy.

In this first approximation buoys are considered cylinders, the surface buoy is small enough to

be easily loaded by a person: 0.5 m diameter, 1 m high and 50 kg weight with a centre of mass

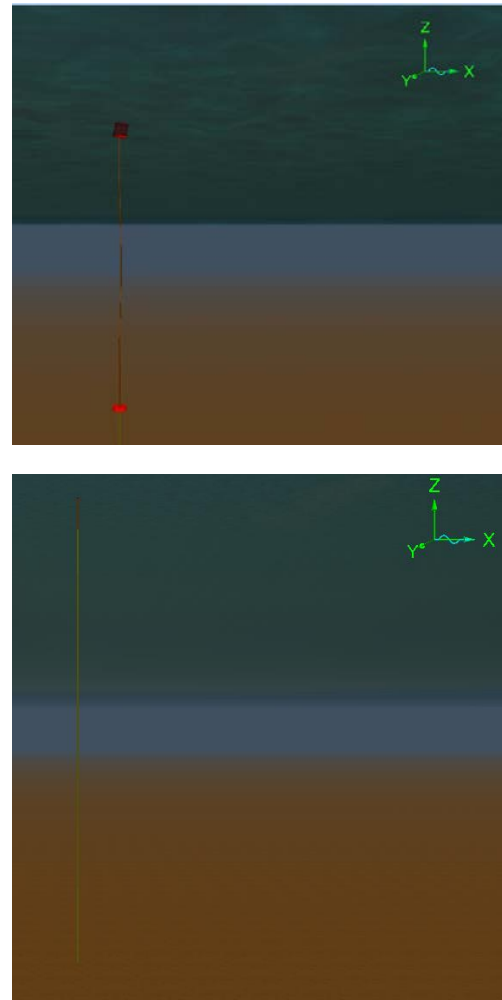


Figure 1. OrcaFlex vertical views of the model.

located on the vertical axis and 0.2 m above the bottom basis to have correct buoyancy. The elastomer is chosen to be made by natural rubber with a cord 0.035 m diameter, hardness 45 or 60 Shore A with an elongation of 300% [5,6]. The choice of the length of the elastomer is related with the bad sea conditions. We have tested with 19.5m length, approximately 4 times the worst significant height waves measured during years in the region, 5 m. The steel cable is chosen as thin as possible to minimize the deployment, being 6mm the minimum diameter that can support the inductive modem, the cable chosen is 6x19 with wire core, 280 m length. Some other specific properties of cables are needed to run correctly OrcaFlex (see Table 1) [5,6]. The OrcaFlex software simulates the cable like a union of cylindrical segments, for this reason, and due to the real geometry of steel cable (a section is not circular), a nominal

diameter smaller is used to have same section area of a cylinder.

Table 1. Properties of the rubber cord and the steel cable.

Propertie	Object	Value	Unit
Nominal diameter	Rubber cord	0.035	m
	Steel cable	0.0048	
Young Modulus	Rubber cord	2613	kPa
	Steel cable	2100	
Poisson ratio	Rubber cord	0.48	
	Steel cable	0.5	
Kilograms meter (in air)	Rubber cord	1.5	kg/m
	Steel cable	0.14	
Bending stiffness	Rubber cord	0.00019	kNm ²
	Steel cable	2	
Axial stiffness	Rubber cord	2.1514	kN
	Steel cable	1454.4	

The dimensions of intermediate buoy, also cylindrical, are chosen in order to equilibrate the weight of cable at rest, to have minimum tension at the seabed anchorage. The buoyancy is determined by the ratio

$$\rho = \frac{M_{buoy} + M_{cable}}{V_{buoy} \rho_{water}}$$

where M_{buoy} and M_{cable} are the mass of the buoy and cable respectively and V_{buoy} is the volum of the buoy and $\rho_{water}=1025 \text{ kg/m}^3$ the sea water density assumed. We consider a buoy of 25 kg weight and 0.5 m diameter, then a length of 0.32 m is necessary to reach neutral buoyancy.

The hydrodynamic drag and inertia coefficients associated with the surface and intermediate buoys and the cable are approximate to those for circular cylinders [7]: A drag of 1.2 in the normal direction and 0.8 in the axial and an inertia coefficient of 2. These values are assumed to be constant.

Wave simulation was carried out by Dean stream function theory. This theory is very robust presenting an optimum numerical fit that it does not suffer from the truncation problems of the Stokes' 5th and cnoidal theories.

Dynamic simulations are done with fixed step size of an implicit integration method. The step size is small enough to generate results that do not change when the step size is decreased. To study temporal behaviour, simulations are done during a time long enough to avoid the transient.

III RESULTS AND DISCUSSION

The simulations of the OrcaFlex model were performed for a sea-state with periodic waves 3.5 m height and with a period of 10 s. The

waves are imposed in the x axis to keep 2D state (coordinates x, z).

Firstly we study the buoys oscillations (Buoy 1 and Buoy 2, hereafter for the top buoy and intermediate respectively). To be precise we study the relative position (x,z) of buoys at the link with rubber cord/steel cable, where x is the horizontal component (wave direction). The coordinates are measured in meters at the basis of small cylinder of buoy. The origin of axis is on the sea surface without current, wind and waves and z coordinate is negative downwards. A long transient about 2000 s was found, and simulations were done longer enough to avoid that transient, 3250 s. A step size of 0.5 s is found to be enough for the proposals of present paper. See Figure 2 for the evolution of Buoy 2 coordinates.

Tables 2 and 3 collect a number of significant outputs of buoys orbit from the simulations that are helpful to understand the behaviour of the buoys like the maximum, minimum and range of oscillations of buoy coordinates and effective tensions of the cables at the top and the bottom (hereafter EndA and EndB respectively). Effective tension is the tension in the longitudinal axis of last segment of cable or link.

The equilibrium state, with no waves (no wind, no current), is a stationary state that shows a tension of 0.012 kN at the anchorage, 0.38 kN at EndA of steel cable (this is 0.012 kN plus the weight of cable in water). The intermediate buoy absorbs part of that tension as it is build with neutral buoyance. The dynamic simulation with periodic sea waves shows promising results where the anchorage (EndB, steel cable) only suffers a maximum of 0.2 kN, with oscillations of about a range of 0.17 kN. The rubber cord do not absorbs the tension of top buoy as we expected, is an elastic object.

The most important effect of the elastomer is the reduction of the amplitude of horizontal oscillations by a factor of about 1.7 and the reduction of the vertical movement to 40 cm (see Table 2). Another effect is that the elastomer displaces horizontally the top buoy from 8 to 13 m from the original position (equilibrium state), and the intermediate buoy 7 to 10 m. This displacement compared with the 300 m of depth is small enough to guarantee small tensions at the anchorage.

Table 2: Minimum, maximum and variation range of relative position (m) of buoys from simulations of OrcaFlex model.

Measured parameter (m)	Equilibrium State (no waves)	Dynamic State (waves)
Buoy 1		
x	minimum	0
	maximum	--
	range	5
z	minimum	-0.3
	maximum	--
	range	3.5
Buoy 2		
x	minimum	0
	maximum	--
	range	3
z	minimum	-20
	maximum	--
	range	0.040

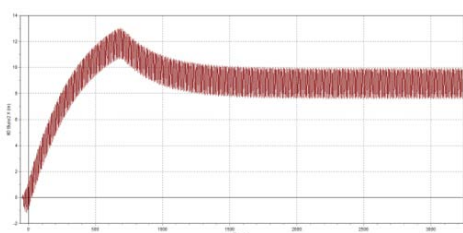
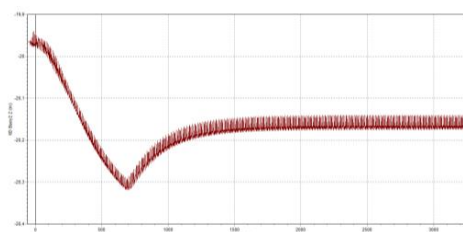


Figure 2. Temporal evolution of relative buoy coordinates of intermediate (Buoy 2). (top) z, (bottom) x.

Table 3: Minimum, maximum and range of variation of tensions (kN) from simulations of OrcaFlex model

Measured parameter (kN)	Equilibrium State (no waves)	Dynamic State (waves)
Rubber cord		
EndA	minimum	0.1
	maximum	--
	range	0.26
EndB	minimum	0.08
	maximum	--
	range	0.23
Steel cable		
EndA	minimum	0.348
	maximum	--
	range	0.21
EndB	minimum	0.012
	maximum	--
	range	0.17

IV CONCLUSIONS

Preliminary results of a new design for a mooring system of an undersea seismometer have been presented. A marine moored buoy has been proposed as alternative to classical OBS in shallow waters. Physical connection with a surface unit allows real time data communications with enough bandwidth to analyse seismic activity. In order to minimized weigh and cost (including the cost of deployment), a steel cable and inductive communication have been chosen as alternative to umbilical cable connection. A third unit (an intermediate buoy) has been added in order to minimize displacements and tensions in the system. An elastomer between the surface buoy and the intermediate buoy has been proved as a good option to minimize displacements and tensions. Numerical simulations have carried out using Orcaflex 9.3c

Next phase of work should take into account different sea conditions (waves, winds, currents, tides,..) and final design of the buoys, sea unit, electronics and communication.

ACKNOWLEDGMENTS

We acknowledge the financial support from Spanish Ministerio de Economía y Competitividad under contract CGL2013-42557-R (Interoperabilidad e instrumentación de plataformas autónomas marinas para la monitorización sísmica, INTMARSIS project). The authors extend their thanks to Orcina for their kind support and offer of the academic license N1594 (2015) to Universitat Politècnica de Catalunya.

REFERENCES

- [1] Orcaflex Manual: 2012, Online at <http://www.orcina.com/SoftwareProducts/OrcaFlex/Documentation/OrcaFlex.pdf>
- [2] Prat, J., del Rio, J., Arbos, A. Preliminary study of moored power cables. *Oceans'11 IEEE/OES Santander: Oceans of energy for sustainable future*, 2011; ISBN 1-61284-4577-0088-0.
- [3] Prat, J., Massana, I., del Rio, J. Simulations of a moored power cable at OBSEA platform. *Oceans'13 IEEE/OES Bergen: The Northern dimension and Challenges 2013*; ISBN 978-1-4799-0000-8.
- [4] Prat, J., Zaragoza, M., del Rio, J. Simulation of Cable Dynamics for moored Ocean Platforms. Modeling Aids Design of Large, Underwater Power Cable. *Sea Technology* 2014; **55** (7): 39-42.
- [5] 2015, Online at <http://www.rubber-foundation.org>
- [6] 2015, Online at <http://www.engineeringtoolbox.com>
- [7] DNV-RP-C20: Environmental conditions and environmental loads, October 2010. 2015, Online at <http://www.dnv.com>