Simulations of a moored power cable at OBSEA platform

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***Abstract*— New green energy sources deployed at sea in mobile platforms use power cables in order to transport green energy at sea surface to the bottom. Theses power cables are exposed to the dynamic behaviour of the platform movements due to waves, currents and wind. OBSEA is a seafloor cabled observatory at 20 m depth in front of Vilanova, in Catalan coast. OBSEA captures data in real time like current, waves and wind among others. In this paper, a model of a moored power cable installed at OBSEA is studied. The study is focused on the trajectory, tensions and deformation or curvature of cables about 0.1 m diameter and under real conditions collected from OBSEA sensors. Simulations are done with OrcaFlex 9.3 software (license N1594). This software allows to model underwater structures and cables.**

***Index Terms*— Model, Simulation, Sea Mooring, Power Cable, Data Acquisition, OBSEA.**

I. INTRODUCTION

Simulation of the static and dynamic power cable behavior due to marine conditions is useful to be done before the design and deployment of the cable by a manufacturer, in order to identify critical parameters like forces, effort, elongations and curvature that cable suffers. It is also important to identify the trajectory of the top end of cable in order to design cable and connector to buoy.

Many bibliography can be found about underwater cables, moorings, buoys, and many simulations exists that study dynamic cables, some of them umbilical cables, in several types of moorings [2, 3, 5, 7]. But little information is found with respect to power cables [6]. It is not easy to get some physic characteristics of power cables like the bending stiffness, because of different layers of cables fitted inside the cable.

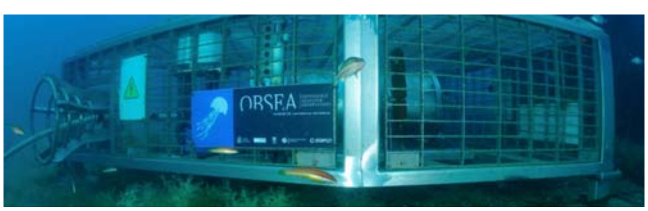

Fig. 1. Underwater OBSEA laboratory in Vilanova coast, Catalunya, Spain.

OBSEA is a cabled seafloor observatory located 4 km off the Vilanova i la Geltrú coast in a fishing protected area of Catalan coast. It is connected to a station on the coast by a power and communication mixed cable (see Fig. 1). The station located on shore provides the power supply and a fiber optics communication link and at the same time carries out alarm management tasks and stores data in real time. This marine observatory is located 20 m depth. In addition, there is a buoy moored with three chains that captures data of waves, current, pressure among others (see Fig.2). All details of OBSEA are summarized in web site www.obsea.es.

In present paper the OBSEA's buoy is modeled. Moreover a fictitious power cabled is added to the structure, it is moored from the buoy to the seafloor. The numerical simulations of this model are carried out with the help of OrcaFlex software, version 9.3c, under an educational license (N1594) [4]. 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 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.

Fig. 2. Buoy at OBSEA platform.

The goal of this paper is to show the behavior of an offshore structure under real conditions. As a preliminary work the OBSEA's buoy is modeled using OrcaFlex software. To be precise, the study is focused on the trajectory of buoy, tensions and deformation or curvature of cable and chains.

The structure of this paper is the following: details of real data used in simulations are explained in chapter II. OrcaFlex models are given in chapter III. OrcaFlex simulations and results are collected in chapter IV. Finally, conclusions and further work are given in chapter V.

II. OBSEA'S DATA

In this section we analyze specific OBSEA's data collected during 16th December of 2011. This day is chosen to represent a typical behavior of windy conditions on Vilanova coast, Catalunya (Spain). The reason to consider a fixed day instead of averaged values between long periods is to be more realistic with external conditions of OBSEA platform.

The wind, waves and current temporal series are studied. Different values are summarized: averaged values, maximum waves and maximum peaks of wind speed. Results of present analysis will be used in chapter III. These values will be used as an input of external conditions of OBSEA's buoy models in OrcaFlex environment.

One of the instruments installed at OBSEA Cabled Observatory is an AWAC (Acoustic Wave And Current profiler) that collect time series data every hour during eight minutes and then averaged values for sea waves (significant height, direction and period) and current (magnitude and direction) are calculated. Undersea current speed and velocity to the North and to the East (if negative values this means a velocity to the South and West respectively), are collected every meter and every ten minutes. The direction of current is easily calculated using velocity components. To get mean values of current it is important to calculate firstly the average of velocity components and then calculate the current direction, otherwise the average using degrees/radians could be done wrongly. Temperature, sound speed, pressure, chlorophyll and turbidity are also collected.

Wind data is taken every 25 minutes by a weather station located at on shore, 14 m above sea level (see http://meteoclimatic.com).

Series of wind data along all day of 16th December of 2011 are collected. As can be shown in Fig. 3, this corresponds to a windy day, with an average of 11.53 kn (5.93 m/s) with direction 272.6º, this is a direction of advance of 92º with respect to N.

The averaged values from waves data are: 1.37 m of significant height with a mean period of 3.64 s and mean direction of advance of 200º (see Fig. 4, rigid line).

Wind direction and speed are variable in time: during night the intensity is smaller and these values are not characteristic of behaviour of that day. For this reason we also consider data related with maximum wind intensity as well as data with maximum waves height.

At 21 p.m., a maximum wind speed is found with 11.27 m/s (21.9 kn) and direction of advance about 117º . The significant height of wave is 3.05 m with period about 7.52s and direction of advance of 17º.

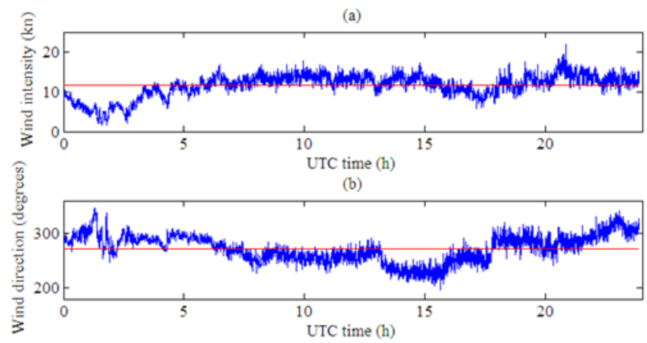

Fig. 3. Wind data series of 16-12-2011 from 0 a.m. to 24 p.m, UTC time. (a) Wind intensity (kn) and (b) wind direction (degrees) as a function of UTC time (h) in the horizontal axis. Red line denotes the corresponding averaged value.

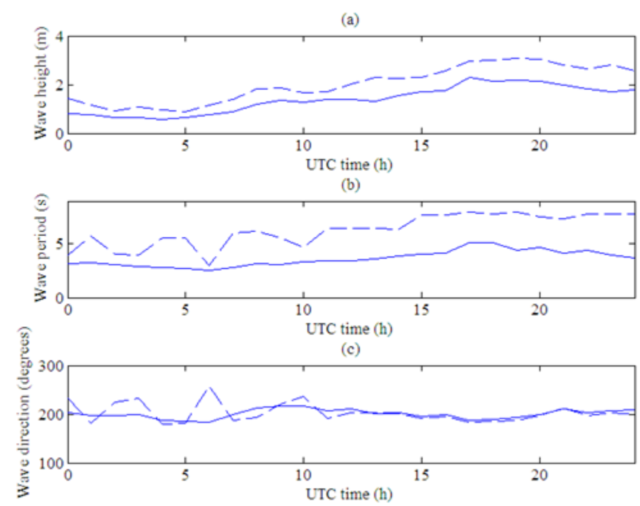

Fig. 4. Wave data series of 16-12-2011 from 0 a.m. to 24 p.m, as a function of UTC time (h) in the horizontal axis. (a) Significant height and maximum height (m), (b) Mean period and peak period (s) and (c) Mean direction and peak direction of advance (degrees), plotted with rigid and dashed lines respectively.

The current intensity and direction of advance are shown in Fig. 5. The profile of current is divided into three layers: on the top a linear boundary layer of three meters is found, with a maximum of 0.92 ms^{-1} on the top (depth value equal to zero) and direction of advance of about 87º. Another middle layer is observed, from 3 to 13 m depth, where current intensity keeps quite constant at about 0.55 m/s. And finally another boundary layer is found, 7 meters above the seabed, with intensity decreasing linearly to zero. The direction of advance of current varies in a narrow sector, less than 30º contained in 1^{st} quadrant (see Fig. 6). So the current direction is smoothly dependent on depth.

At 19:20 p.m., a maximum peak of wave is found: 3.08 m with period about 7.99 s and direction of advance of 7º. The wind speed was 7.5 m/s (14.6 kn) and direction of advance about 108º .

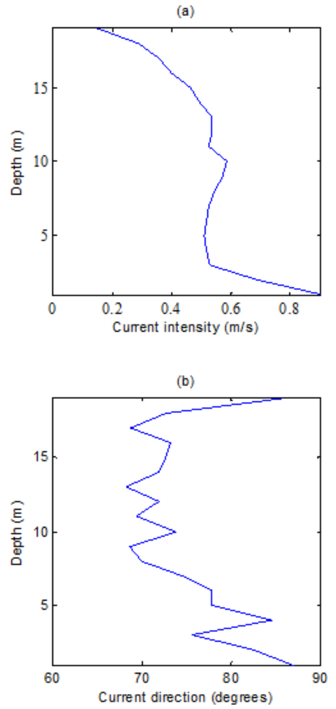

Fig. 5. Current data at 21 p.m. (UTC time), 16-12-2011. (a) Current intensity (m/s) and (b) Current direction of advance (degrees) as a function of depth in the vertical axis.

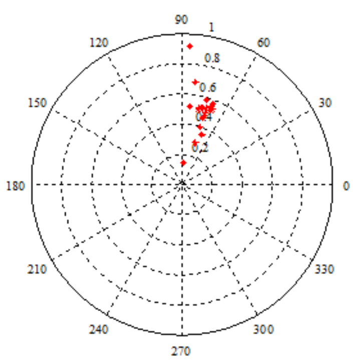

Fig. 6. Current data at 21 p.m. (UTC time), 16-12-2011. Current intensity (m/s) and current direction (degrees) on a polar diagram.

Comparing both peak data, it is clear that at 21 p.m. the worst case it is found, as the wind is higher and the significant wave height is almost as large as at 19:20 p.m.

III. OrcaFlex Model

The location of OBSEA buoy is: 41º10.91'N, 1º45.15'E. It is moored with three chains of 30 m length each one. Chains are moored on seabed on a circle of 20 m of radius centered on the static buoy position. Chains are equally spaced 120º. The 'first' chain is moored 10º clockwise with respect to the North.

The buoy consists of one cylinder of 4 m length and 0.8 m of diameter and another small cylinder on the bottom of 0.9 m length and 0.05 m of diameter. Its mass is 650 kg in air. On the

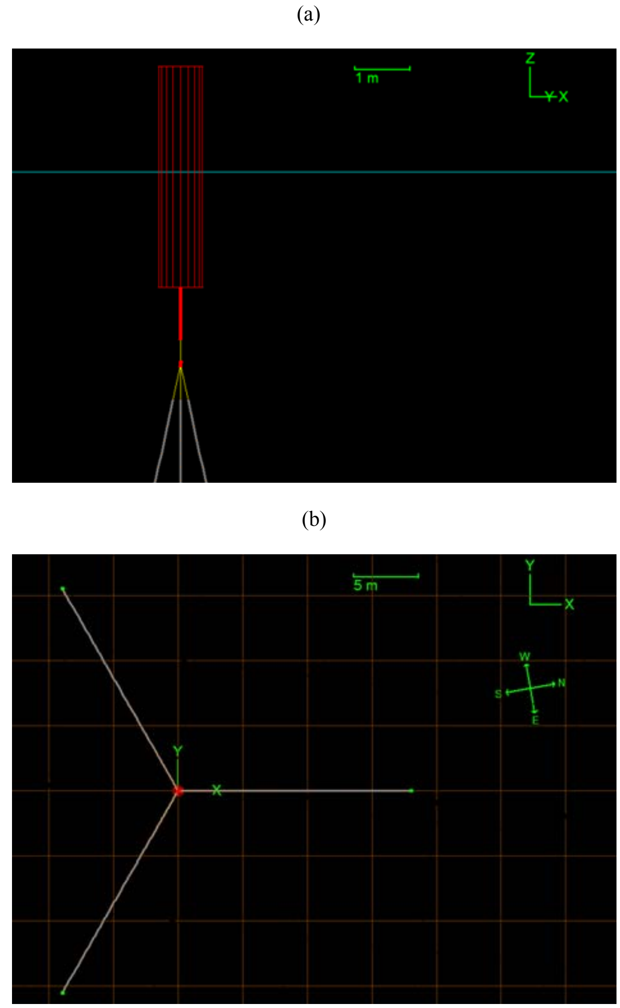

Fig. 7. OBSEA's buoy model without cable on OrcaFlex environment. (a) Vertical view of Spar Buoy type on OrcaFlex environment and links to chains and cable. (b) OrcaFlex plan view of buoy model after the static simulation.

bottom there is a free link to the chains with three branches of 0.65 m length, 0.03 m diameter and 130º of declination, equally distributed around (see Fig. 7 (a)).

A first model with OrcaFlex environment is done (hereafter Buoy model). This model simulates the real buoy with three chains. As can be observed in Fig. 7 (b), 'First' chain is located on x axis, hereafter named Chain 1. In this local axis, North is located 10º anticlockwise from x axis.

Another model is build (hereafter Buoy model with cable): it is added to latest configuration a fictitious power cable of 0.1 m diameter and 45 m length, moored at the steady state position, 35 m layback from buoy position [6]. Different moorings of cable are tested (NE, S and NW). The cable is attached to the link to buoy with a vertical branch of 0.65 m length, 0.12 m diameter, 60 kg/m, bending stiffness of 70x10^3 kN/m^2. Details of parameters used in both OrcaFlex models are summarized in Table I.

The unit segment length used to simulate numerically chains and cable are 0.25 m and 0.1 m respectively.

OrcaFlex inputs of directions of waves, wind and current are directions of advance. In chapter II we found directions of advance with respect to N, $\alpha \in [0^{o},360^{o})$. In local axis of OrcaFlex model this means a translation of α to a new angle $360^{o} - \alpha + 10^{o}$.

Real data of meteorological conditions from 16th of December of 2011 (see chapter II) are used into OrcaFlex models, however some restrictions are imposed. A periodic sea wave, a constant wind and a time-constant profile of current are considered. All these values are summarized in Table II.

Figure 8 summarizes the chains location of buoy in a NE plan and the external conditions used in OrcaFlex models of 16-12-2011, i.e., directions of advance of wind, waves and current at the top (see chapter II).

IV. OrcaFlex Simulations And Results

Dynamic simulations are done with fixed step size of an implicit integration method. The step size is small enough to have stable results and that do not change when the step size is decreased. A step size of 0.05 s is enough with the Buoy model, but a step size of 0.025 s is needed when a cable is added. Long time simulations are done in order to get conclusions from temporal behaviour. Simulations are carried out from time -20 s to 600 s.

TABLE I. Parameters Used In OrcaFlex Simulations

Parameter	Object	Value	Units
Sea density	sea	1025	kg/m^3
Kinematic viscosity	sea	$1.35x10^{-6}$	m^2/s
Seabed friction coefficient	cable	0.25	
	chain	0.74	
Length	cable	45	m
	chain	30	
Diameter	cable	0.1	m
	chain	0.026	
Weight per meter	cable	22	kg/m
	chain	4.3	
Bending stiffness	cable	7	kN/m^2
	chain	0	
Axial stiffness	cable	$700x10^3$	kN
	chain	19796	
Drag coefficient (x)	cable	1.2	
	chain	1	
Drag coefficient (z)	cable	0.008	
	chain	0.4	

TABLE II. External Conditions Of Wind And Waves (16-12-2011) used in simulations of OrcaFlex models. Waves are considered periodic and wind constant. All directions are of advance

Wind and waves	Parameter	Value	Units
Wind	Intensity	11.27	m/s
	Direction	117	degrees
Waves	Height	3.05	m
	Period	7.52	s
	Direction	17	degrees

Results are only shown from 0 s to 600 s, i.e., during last 10 minutes, as the first transient period of 20 s is not considered, sometimes a bigger transient is needed to be considered .

A 3D-view of cable model after a dynamic simulation is given in Fig. 9.

Under OrcaFlex environment, simulations of both models are performed using data of 16-12-2011 (see Table II). The models considered in this section are: Buoy model (without cable) and Buoy model with cable at three different moorings: NE, S and NW. Different results are shown: tensions, positions and range graphics. Behaviour of buoy and the impact of such a structure when a cable is added it is shown.

Firstly the results of buoy model are analyzed.

A. Results of Buoy model

The relative position (x,y,z) of buoy at the top end of chains/cable (hereafter called EndA) are studied. The coordinates (m) are measured at the basis of small cylinder of buoy. The origin of axis is on the sea surface without current, wind and waves. In this case the initial position of buoy is (0,0,-3), i.e.., at 3 m depth. Fig. 10 shows the evolution of relative positions of buoy. The vertical coordinate z oscillates according to the height of waves but the horizontal coordinates translate a median of about 2 meters with respect to the initial position.

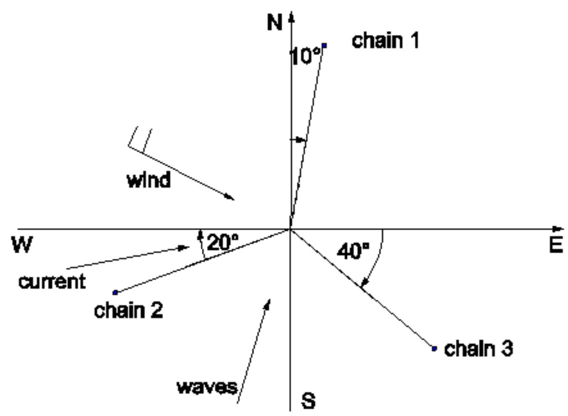

Fig. 8. Schematic plan view (in a NE plan) of Buoy model: chains location and directions of advance of wind, waves and current, 21 p.m. (UTC time), 16-12-2011

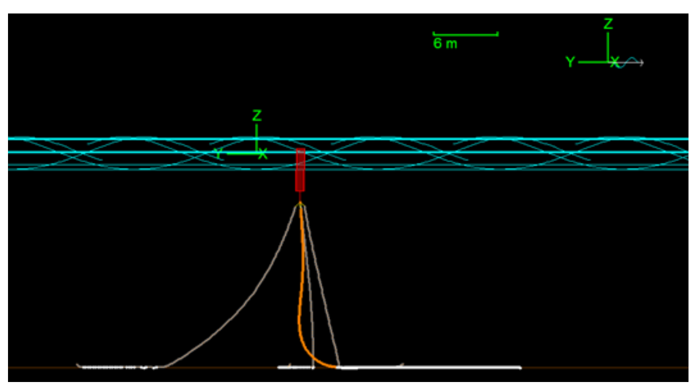

Fig. 9. OrcaFlex 3D-view of Buoy model with cable in a dynamic simulation.

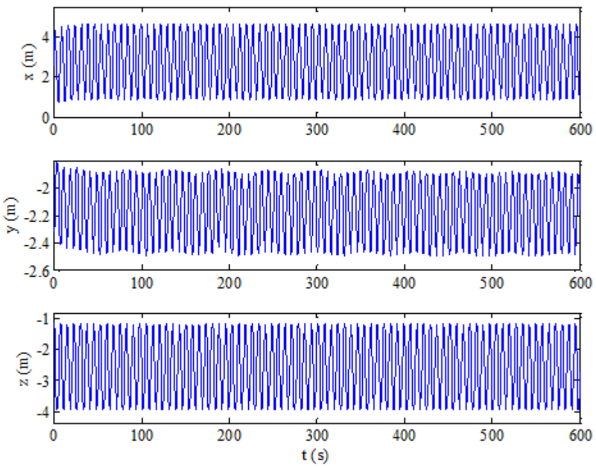

Fig. 10. Buoy model. Temporal evolution (s) of relative positions (x,y,z) of buoy (measured in meters).

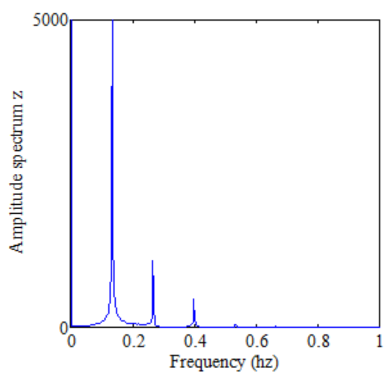

Fig. 11. Buoy model. FFT of relative vertical position z of buoy, i.e., the amplitude spectrum as a function of frequency (hz).

Temporal behaviour can be interpreted by means of the amplitude spectrum, using a FFT: the vertical movement inherits the periodicity of waves (7.52 s), its spectrum shows a main frequency f_1= 0.1329 = 1/7.52 hz and the corresponding multiples as can be deduced from Fig. 11. However, when the spectrum analysis is performed with the y coordinate, a new small frequency appears, at f_2 = 0.0166 = 1/60 hz (see Fig. 12), that describes the modulation of 60 s observed in Fig. 10. This frequency is incommensurable with the waves periodicity, this implies that the orbit of the buoy is quasi periodic, i.e., it is topological equivalent to a torus. Moreover, the buoy trajectory is regular and circular at every wave period (see Fig. 13).

Figure 14 shows tension series (kN) of Buoy model: Effective tension at the top end of chains (EndA), force of buoy and total effective tension supported at the link chains - buoy. Effective tension is the tension in the longitudinal axis of last segment of chains or link. The force of buoy is the weight in water and the inertial forces due to waves, wind and current. If we focus on chains, clearly, the working chain is

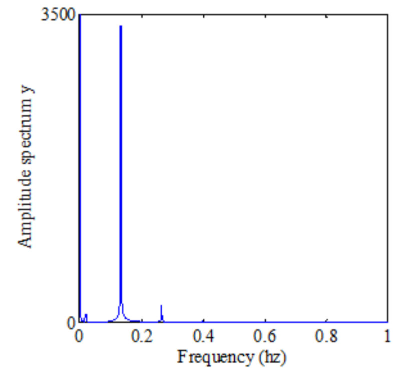

Fig. 12. Buoy model. FFT of relative horizontal position y of buoy, i.e., the amplitude spectrum as a function of frequency (hz).

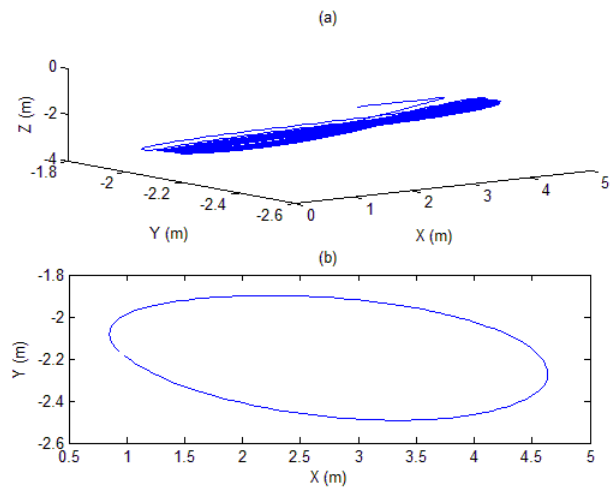

Fig. 13. Buoy model. Orbit of buoy, in m, (a) from 20 s to 600 s and (b) horizontal projection orbit during 1 wave period (7.52 s).

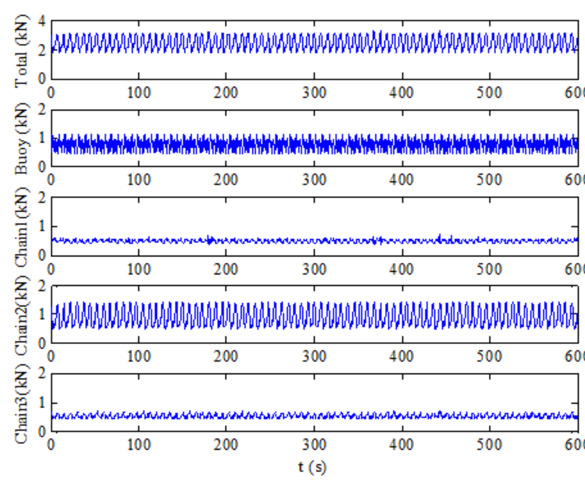

Fig. 14. Buoy model. Temporal evolution (s) of tensions (kN) at EndA. Total effective tension, force of buoy and effective tensions of chains.

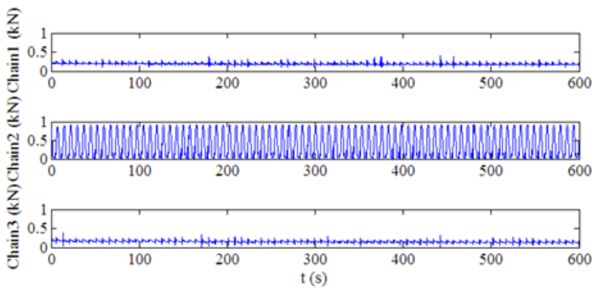

Fig. 15. Buoy model. Temporal evolution (s) of chains' tension (kN) at the anchorage.

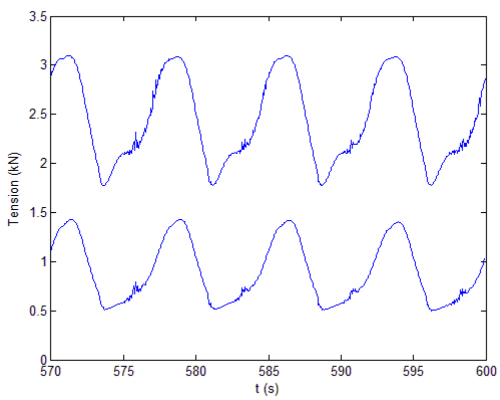

Fig. 16. Buoy model. Detail of instabilities of total (top) and Chain 2 effective tension at EndA at every main period of the series (s).

Chain 2, this is coherent with the external conditions of current and waves (see Fig. 8). Effort of Chain 2 is important, it loses contact with seabed following the quasi periodicity pattern, and then the anchorage is exposed to significant tension (see Fig. 15).

The spectrum analysis of chain tension (at EndA) shows the same quasi periodic patron as the horizontal coordinates one explained above. A detailed study of tension series of chains shows an instability effect that is repeated every wave period (see Fig. 16 to see this short time instability with the Chain 2 tension at the top end). Such a instability is inherited by total tension, doesn't decrease when the step size decreases and appears when the orbit of buoy is about the maximum depth and minimum value of y, i.e., at the bottom turning point (see Fig. 13 (a)).

B. Results of Buoy model with cable

OrcaFlex simulations of buoy model with a cable are also carried out. Cable is moored at three different moorings (NE, S and NW). Results of simulations show an oscillatory pattern in time, even though it is difficult to study the exact behaviour (periodicity, quasi periodicity, length of transient...) some significant results are collected: maximum, minimum and range of oscillations of the tensions and coordinates at the top (see Tables III and IV respectively).

TABLE III. MINIMUM, MAXIMUM AND RANGE OF VARIATION OF TENSIONS (KN) AT ENDA FROM SIMULATIONS OF DIFFERENT ORCAFLEX MODELS.

Measured parameter (kN)		**Buoy model**	**Buoy model with cable**		
			NE	**S**	**NW**
Total tension	Minimum	1.77	3.23	3.07	3.39
	Maximum	3.31	6.13	7.60	7.26
	Range	1.54	2.90	4.53	3.87
Chain 2 tension	Minimum	0.49	0.54	0.48	0.50
	Maximum	1.43	1.99	1.66	2.94
	Range	0.94	1.45	1.18	2.44
Cable tension	Minimum	--	1.53	1.37	1.64
	Maximum	--	2.82	4.61	3.32
	Range	--	1.29	3.24	1.68

TABLE IV. MINIMUM, MAXIMUM AND RANGE OF VARIATION OF RELATIVE POSITION (M) OF BUOY FROM SIMULATIONS OF DIFFERENT ORCAFLEX MODELS.

Measured parameter (m)		**Buoy model**	**Buoy model with cable**		
			NE	**S**	**NW**
X	Minimum	0.81	2.77	-2.24	4.98
	Maximum	4.65	5.44	1.26	7.98
	Range	3.84	2.67	3.50	3.00
Y	Minimum	-2.50	-3.60	-6.09	-3.52
	Maximum	-1.86	-3.13	-5.30	-1.49
	Range	0.64	0.47	0.79	2.03
Z	Minimum	-3.95	-4.43	-4.56	-4.53
	Maximum	-1.17	-1.68	-2.06	-1.89
	Range	2.78	2.75	2.50	2.64

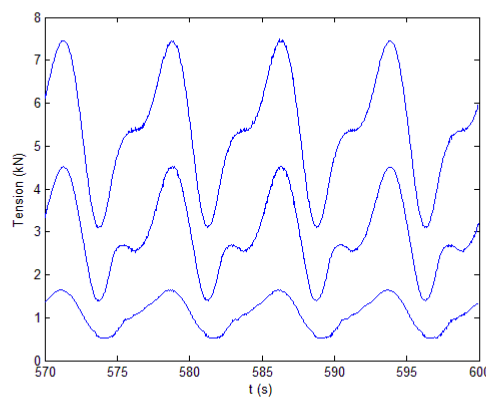

Fig. 17. Buoy model with cable. Detail of temporal evolution (s) of tensions (kN) at EndA. Total, cable and chain 2 effective tension.

The cable suffers the worst effective tension at the S mooring, with a maximum of about 4.6 kN with oscillation range of 3.2 kN (see Table III). We will focus in this case from now. The total tension of structure is also the biggest in this particular case. In this case, the effect of cable to the total effective tension is the following: the amplitude of oscillations with the cable is 3 times bigger than without, and the maximum value is about 2.3 times bigger. Figure 17 shows total, cable and Chain 2 effective tension during a short time. Total tension evolution is similar to the cable tension one. The instability of Chain 2 - at every main period - is translated to the cable and to the total tension too. With respect to the spectrum of tension series, a comparison between total effective tension of Buoy model and Buoy model with cable is done (see Fig. 18).

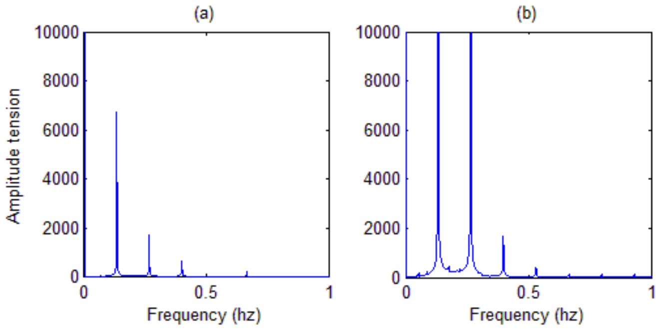

Fig. 18. Amplitude spectrum as a function of frequency (hz) of total effective tension in Buoy model (a) without cable and (b) with cable.

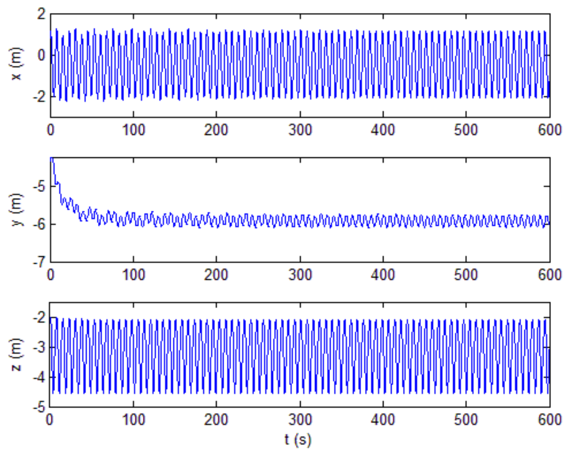

Fig. 19. Buoy model with cable. Temporal evolution (s) of relative positions (x,y,z) of buoy (measured in meters).

The model with cable shows a more complex tension behaviour than without. A carefully study of spectrum of tensions when the cable is added shows traces of a quasi-periodic pattern meanwhile the model without cable doesn't .

The results of buoy orbit are summarized in Table IV and Figs. 19, 20 and 21 for the case S. Clearly, when the cable is added to the structure, the position of buoy is modified, and this results in a bigger translation of buoy from the origin (see Table III). However the range of movement of buoy is similar in all cases studied. With the cable (S case), a bigger transient is found until 'stabilizes' to some oscillatory patron (see Fig. 19). Amplitude spectrum of positions are done from 60 s to 600 s, in order to avoid the transient and keep as much modulations as possible (see Fig. 20). In this case, the quasi periodicity is broken but there are still traces of it, in the horizontal components, like tension spectrum. The orbit of buoy has a more complex temporal behaviour but still keeps the regular and circular movement at every wave as can be observed in Fig. 21.

Figure 22 shows the range of variation of curvature and vertical component of cable along the cable. The figures are a direct output of OrcaFlex software. The mean value and variation of curvature is bigger when the arc length is in between 10 m and 20 m. Moreover, from 18 m to 20 m arc length the cable has interaction with seabed (see Fig. 22 (b)).

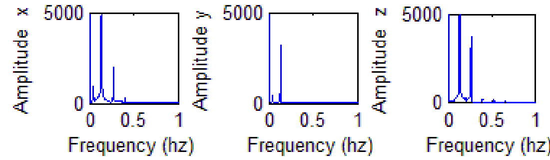

Fig. 20. Buoy model with cable. FFT of relative position of buoy, i.e., the amplitude spectrum as a function of frequency (hz).

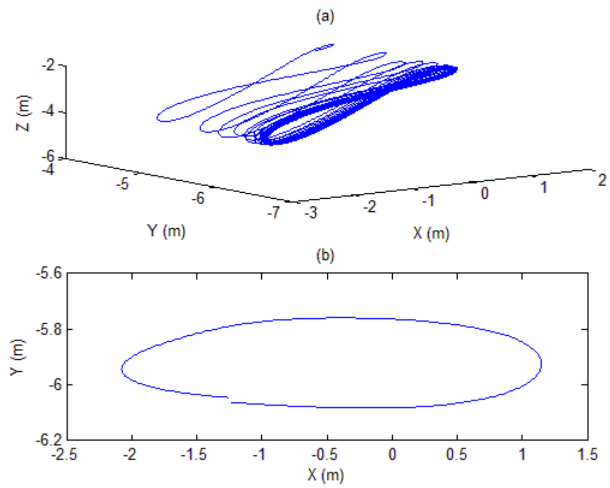

Fig. 21. Buoy model with cable. Orbit of buoy, in m, (a) from 20 s to 600 s and (b) horizontal projection orbit during 1 wave period (7.52 s).

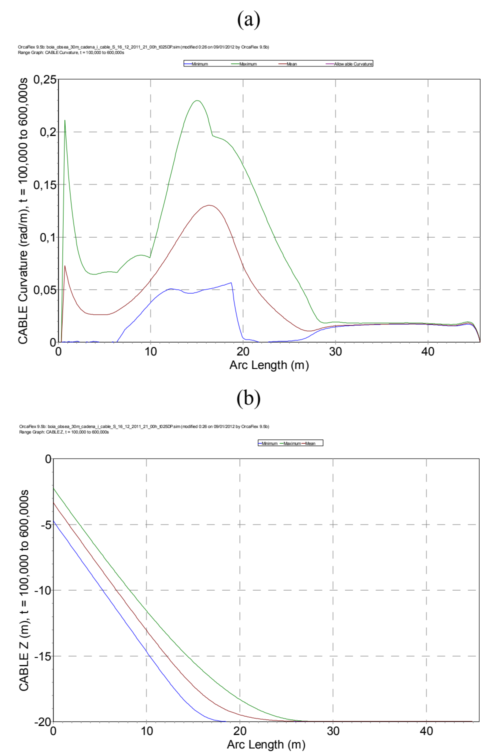

Fig. 22. Buoy model with cable. Results of dynamic simulation of cable as a function of the arc length (m). (a) Range of curvature (rad/m). (b) Range of vertical component z (m).

V. Conclusions

From this study of OBSEA's Buoy model, without and with a fictitious power cable (moored at different locations), we can conclude some important topics, not only the effect of the addition of a power cable to the buoy as well as some rules to the power cable deployment.

As we have explained above, real data of meteorological conditions are used into OrcaFlex models to represent a typical behavior of windy conditions where OBSEA's buoy is located. However some restrictions are imposed: A periodic sea wave, a constant wind and a time-constant profile of current. Even though we consider the pick of wind (this is instantaneous) we carry out the simulations during a long time (20 seconds of transient and 10 minutes).

Firstly, we observe that numerical simulations are more unstable with a power cable, have bigger transients and need smaller step size in time. This is because the pattern found is more complex than without a cable.

The orbit of buoy is found to be regular and circular in both cases. To be precise, the buoy model orbit shows a quasi periodic modulation with main frequency inherited by sea waves period. We think that the quasi periodicity appears because of the attachment of buoy. When a power cable is added, more complex oscillations appear but still there are traces of the quasi periodicity. In all cases the vertical movement is mainly periodic, following the sea waves frequency. Even though the buoy model with a power cable has bigger translations from static position, the range of oscillations are similar with and without cable.

The regularity of buoy orbit contrast with tension instabilities at every wave period, that appear at the bottom turning point of the buoy trajectory, and must probably appear because of the unstable chains movement. Not only the oscillations of total tension are bigger but the range of them are much bigger when a cable is added. Total effective tension at the buoy model with cable has similar behaviour than cable one and the temporal pattern is more complex than a quasi periodic one.

The study of the range of curvature variation along the dynamic cable gives information about the more unstable cable segments. The range of variation of vertical movement along cable give information of the seabed contact of cable. In present study, in a particular case, we find a big variability between 10 m and 20 m arc length (of 45 m length), and a seabed contact between 18 and 20 m of arc length.

The design of this cable-structure could consider the range information, one could try to reinforce with other material or help with local buoys the more unstable part of dynamic cable or change components of structure. On the other hand the trajectory of buoy should help to the design of connectors of the cable to the offshore structure.

We also conclude that is important to study the dynamics of the structure (buoy, in this case) without a cable, where will be added the power cable. For example, simulations of Buoy model show that the chains of OBSEA's buoy should be increased in length, in order to decrease the effort at the anchorage point. When a power cable is added, the dynamics of buoy is more complex but still has important traces of the original structure dynamics. Moreover, when a power cable is added at different anchorages, in a particular case one of the chains is doing the main effort under the external conditions; to avoid this case we think a better attachment for the buoy will be four chains.

Future work will focus on a comparison between real measurements and results of these models. A bigger depth will be also tested.

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