Quasi-static and dynamic monitoring of SPM

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ABSTRACT: The Single Point Mooring system moored to ship tanker nearby the production platform Vega A, operating from 1988 in Sicily channel. This paper involves the monitoring of yoke, the collection and statistical interpretation of structural response data, recorded from October 2009. Strain optical fiber sensors and inclinometers are installed to know the behavior of the articulated structures: column-yoke-vessel, named FSO Leonis. The optical fiber data are processed, the temperature compensation of the strain data are performed in order to determine the forces on the column. The inclinometers sensor data are analyzed to identify the dynamic response of the SPM system and to count the number of fatigue cycles. The acquired data are computed in order to establish their representativeness in relation to the design assumptions and to allow the control of the column, yoke itself and the ship structures.

1 INTRODUCTION

The VEGA field is located approximately 12 miles south of the southern coast of Sicily, off the coast of Pozzallo. It includes a platform called VEGA-A for the exploitation of the oil field and a 110,000 ton floating deposit obtained from the transformation of the former oil tanker Leonis in FSO (Floating - Storage - Offloading). The float is moored at SPM (single point mooring) located about 1.5 miles from the platform and connected to it via pipelines. In Figure 1 the ship Leonis and the SPM (column and yoke) are shown.

Figure 1. VEGA field, ship Leonis and the mooring system.

2 THE MONITORED SYSTEM

Both VEGA-A platform and the tanker ship Leonis are monitored. VEGA-A platform is monitored by means of 9 linear accelerometers, a current meter, a depth gauge and sensors for detecting speed and direction of wind; therefore the monitoring system installed is able to reconstruct the actions of the sea states and the wind.

The SPM is constituted by a column that is bound to the seabed by means of a universal joint which allows rotations in two orthogonal vertical planes, and a reticular arm (Yoke) that is bound to the column via coupling tri-axial joint allowing rotations around all three axes, and to the ship by two aligned cylindrical hinges.

The data acquisition of the system is installed and is running from October '09 on the ship Leonis in order to monitor and collect all the structural data. The system performs the structural monitoring through a series of optical strain gauges, produced by SMARTEC SA and installed on the ship (# 25 strain gauge sensors, Fiber Bragg Gratings (FBG)) and on the Yoke (# 12 strain gauge sensors, Fiber Bragg Gratings (FBG)). Two biaxial inclinometers were also installed on SPM (# 2x2 inclinometer sensors).

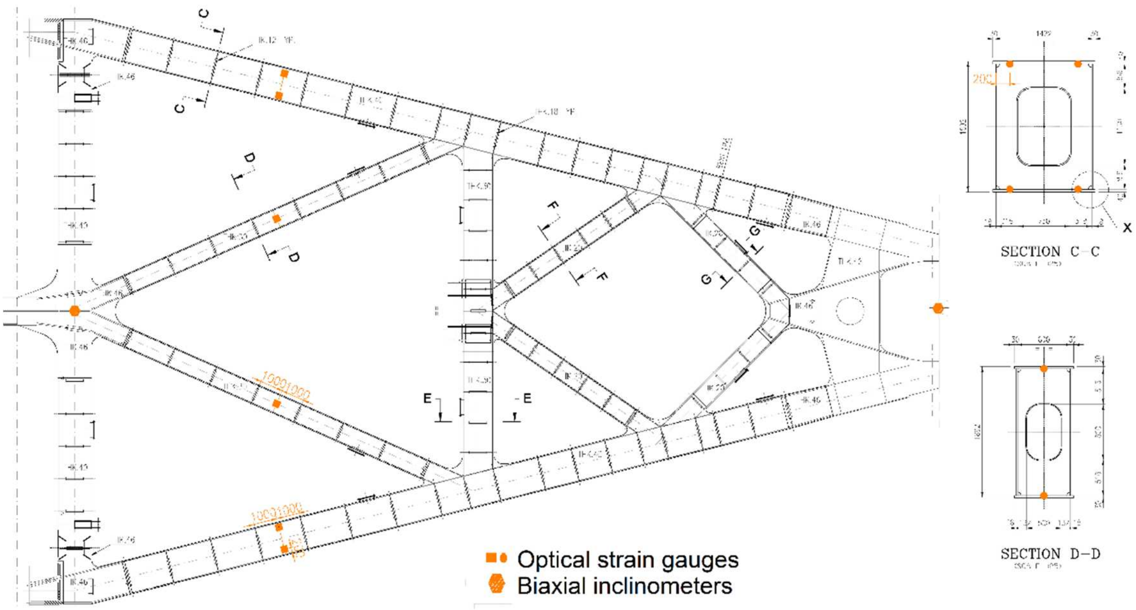

Figure 2. VEGA field, SPM monitoring system.

In Figures 2 the location of sensors on the Yoke are shown. The time data acquisition for stress is 60 minutes with a sampling frequency fc=0.5Hz, while tilt angles are recorded with a sampling frequency fc=1 Hz. The direction of the ship is recorded by the Captain of Leonis. The conditions of sea and wind conditions are available by the monitoring system on the platform.

FBG sensors are a multiplexed strain and temperature monitoring system based on Fiber Bragg Gratings. In figure 3 and 4 we can see the sensors and the multiplexed system. The multiplexed acquisition system of the optical strain gauges is composed of a control unit that acquires through 16 channels the signals from the sensors; the sensors are installed both on the ship that yoke (63 sensors, strain and temperature). The figures 5-6 shows the graph of some yoke's spectrum signals (channels # 13-14).

Figure 3. Sensors (by SMARTEC).

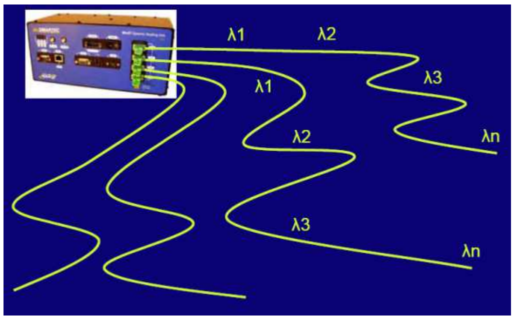

Figure 4. Multiplexed sensing (by SMARTEC).

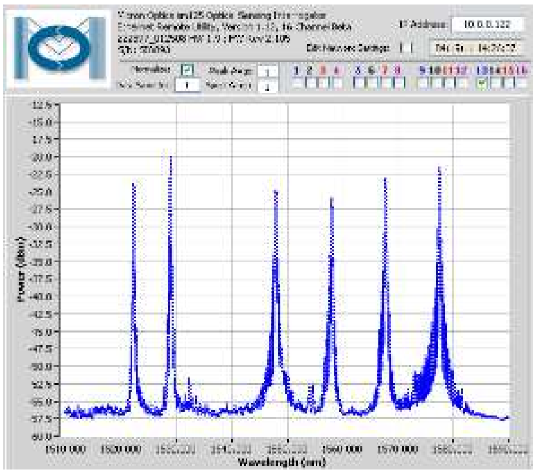

Figure 5. Spectra Control unit channel #13; 1519_T_7_3, 1526_T_7_6, 1542_S_7_1, 1552_S_7_2, 1562_S_7_4, 1572_S_7_5.

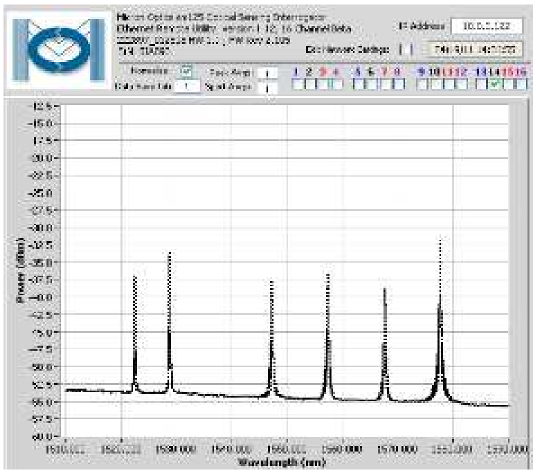

Figure 6. Control unit channel #14; 1519_T_8_3, 1526_T_8_6, 1542_S_8_1, 1552_S_8_2, 1562_S_8_4, 1572_S_8_5.

3 DATA ANALYSIS

Below in Table 1, the main features of the two sea states are summarized. The first with 6.7 m of height significant while the second with 0.2 m. The data have been acquired by means of the monitoring system installed on VEGA platform.

Table 1. Characteristics of the sea states (from monitoring system on VEGA platform).

day: h	H_s(m)	H_{max}(m)	T_z(s)	T_s(s)	T_{hmax}(s)	D_{seas}(°)
2013/03/14: 22	6.7	9.9	9.0	9.8	9.3	307
2013/07/21: 13	0.2	0.4	4.5	4.6	4.4	242

In the wide monitored sections (C-C) are placed 6 sensors: 4 bound to the structure (strain sensors 1572_S_7_5, 1562_S_7_4, 1542_S_7_1 and 1552_S_7_2) in the 4 vertices of the structural section, and 2 non-bound to the structure (temperature sensors 1526_T_7_6 and 1519_T_7_3) that are found in the mid-lower and the mid-top position.

The conversion and compensation of the raw data λ (bound data) and λ_T (non-bound data) in data strain takes place according to the following procedure:

$$\Delta\varepsilon = C_\varepsilon \Delta\lambda - \frac{C_\varepsilon}{C_t}\Delta \mathrm{T} - C_\varepsilon \Delta\lambda_T \quad (1)$$

with C_ε =830*μs/nm* and C_T =*96°C/nm* are constant; T the data temperature calculated below:

$$\mathrm{T(t)} = \mathrm{S}_2\,(\lambda(t) - \lambda_0)^2 + \mathrm{S}_1\,(\lambda(t) - \lambda_0) + \mathrm{S}_0 \quad (2)$$

where λ is the current wavelength of the strain gauge, λ_0 the wavelength of the strain gauge at the measurement start and S_2, S_1 and S_0 are temperature sensitivity constants. The first expression in the equation 1 describes the strain impact caused by force and temperature, while the second part describes the change of the glass refraction index caused only by temperature. Because the temperature has a very strong impact on FBG signals, precise strain measuring results can only be achieved with proper temperature compensation. In our case an additional temperature-measuring FBG is used and the signal of strain-measuring FBG is corrected by the third part of equation 1. The figures 7 and 8 shows the relation between the values compensated and uncompensated for the events in question.

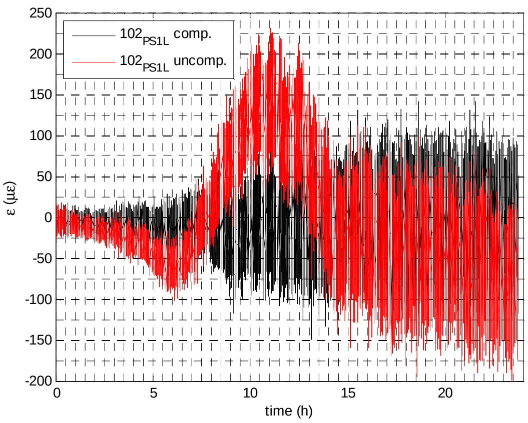

Figure 7. Temperature compensation of raw data, sea state of 2013/03/14, h22.

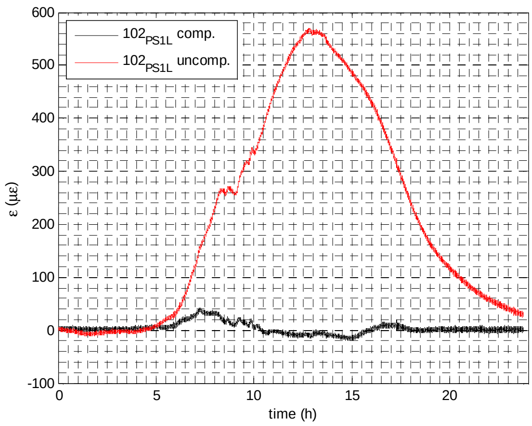

Figure 8. Temperature compensation of raw data, sea state of 2013/07/21, h13.

In figures 9-12 are shown the spectra of the signals about the raw sensors at the top of the section of the yoke (small section).

The spectra show that the signals related to the bound strain gauge contain the frequencies of sea waves as well as the SPM frequencies. While the spectrum of the free sensor only shows the typical frequency of temperature trend. In addition, the graphs in the figures 10 and 12 show that the strain signals are in antiphase with the signal relating to temperature and are exactly in phase between them.

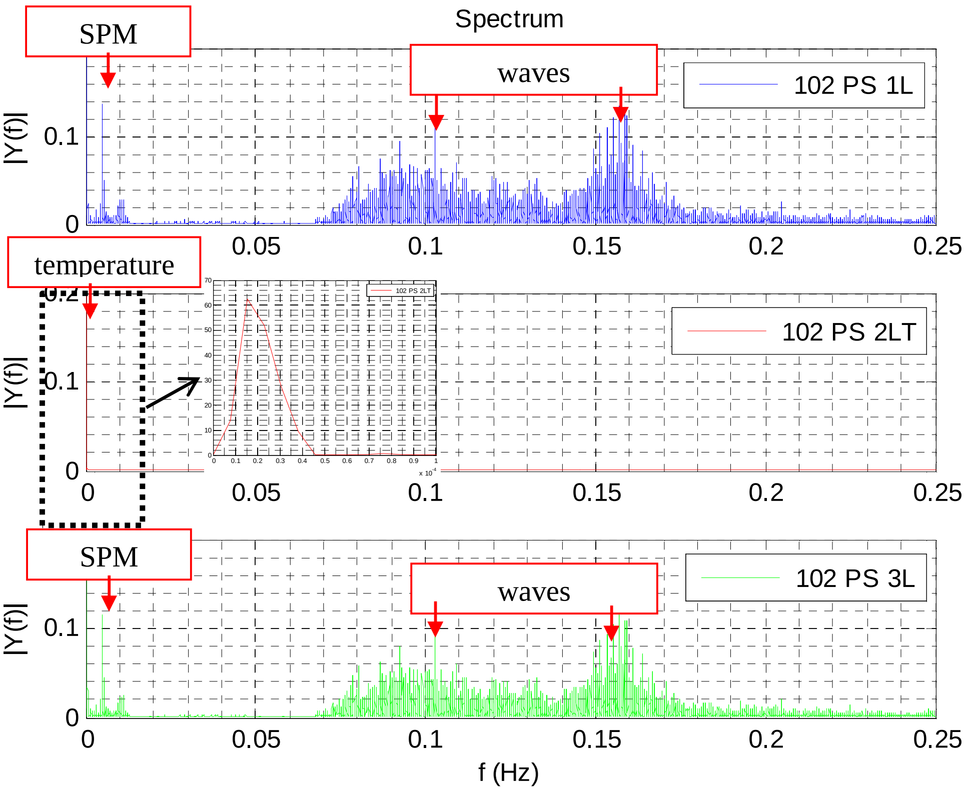

Figure 9. Raw data spectra, sea state of 2013/03/14, h22.

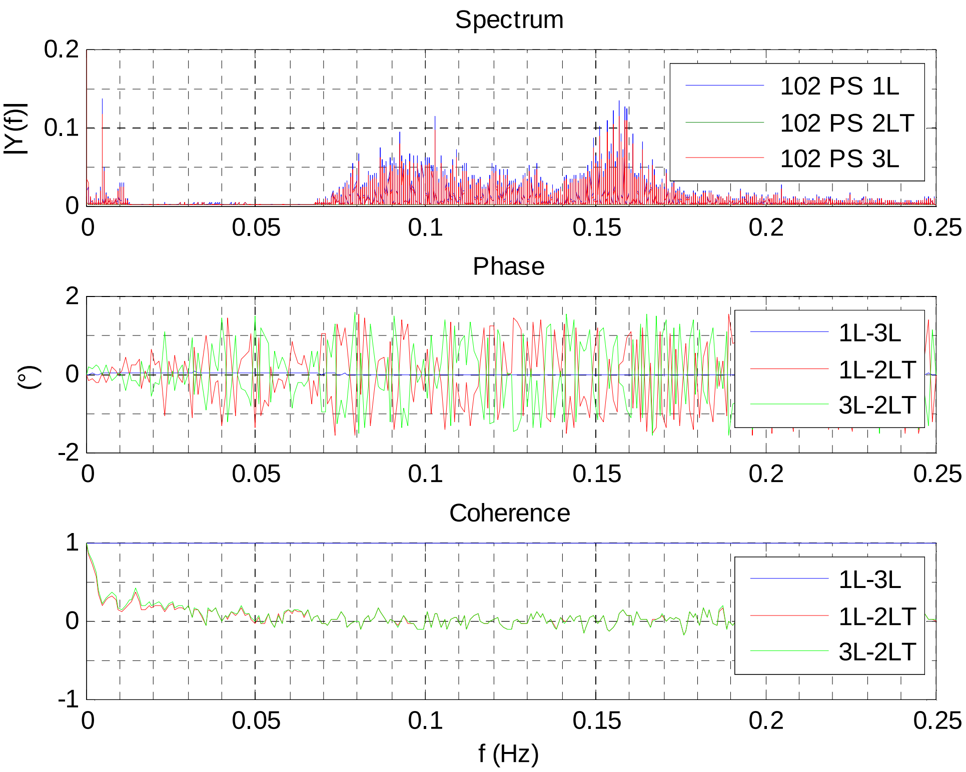

Figure 10. Raw data spectra, phase angle and coherence, sea state of 2013/03/14, h22.

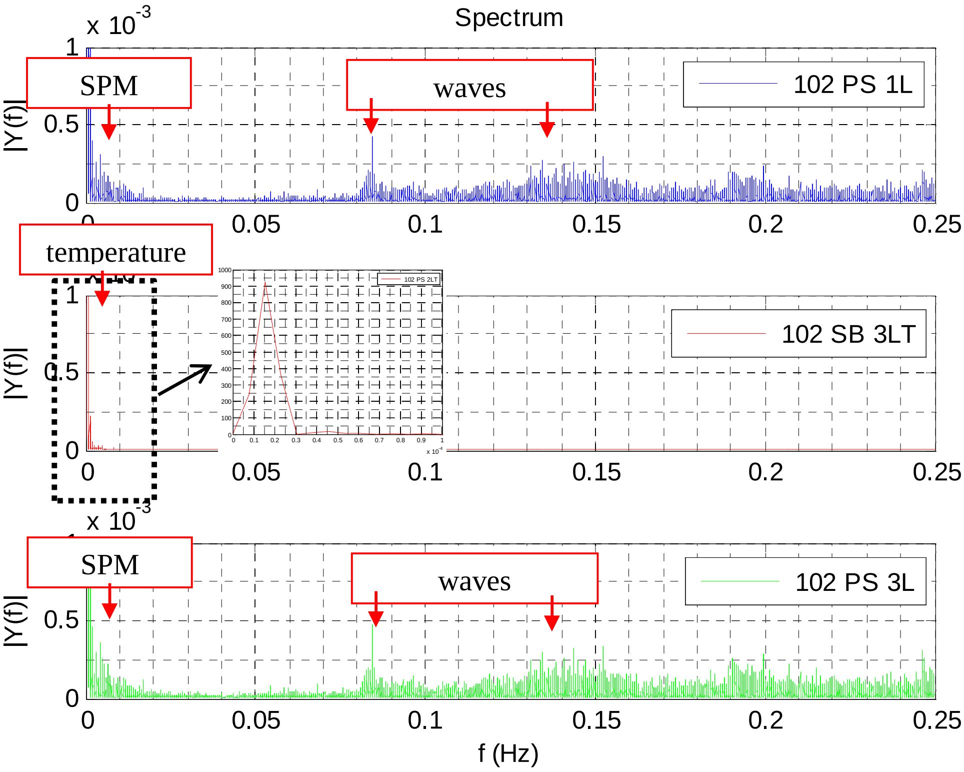

Figure 11. Raw data spectra, sea state of 2013/07/21, h13.

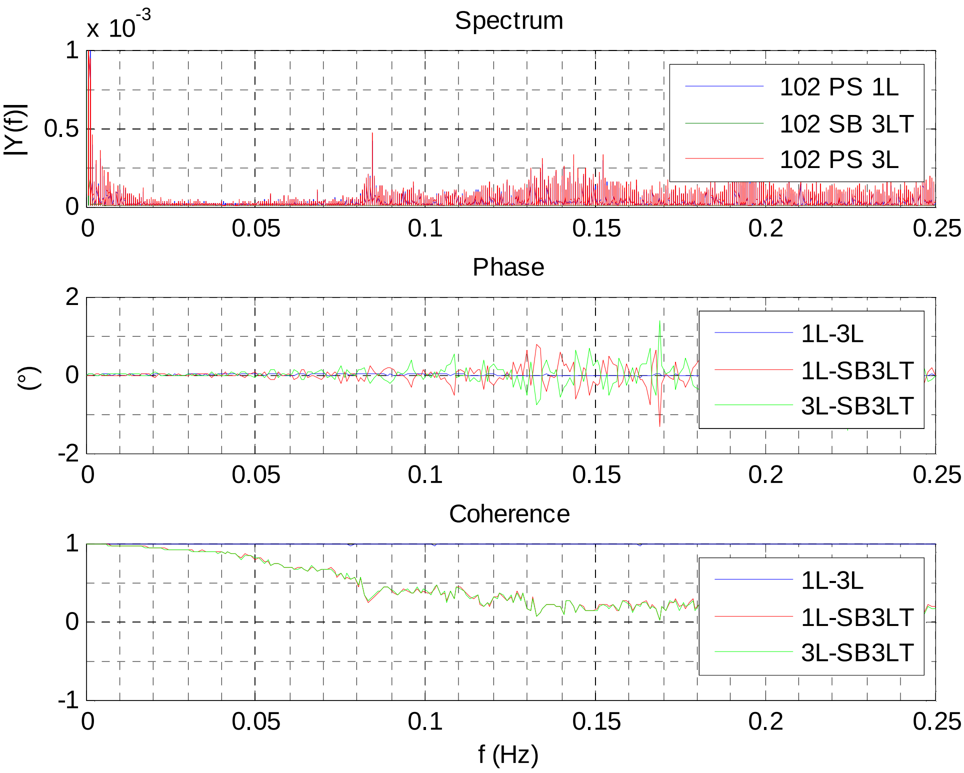

Figure 12. Raw data spectra, phase angle and coherence, sea state of 2013/07/21, h13.

Through the compensation data is possible to reconstruct the stress history of all monitored points, in figures 13 and 14 are shown the stress data of section c-c:

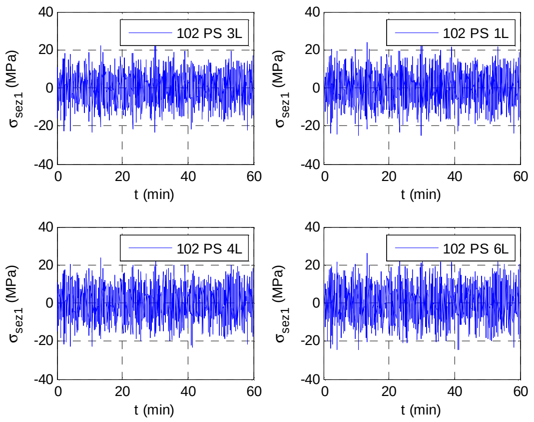

Figure 13. Stress data, sea state of 2013/03/14, h22.

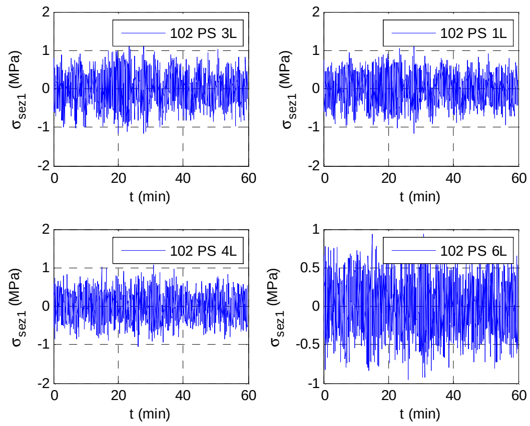

Figure 14. Stress data, sea state of 2013/07/21, h13.

4 DYNAMIC RESPONSE

To compare the design strength of SPM system with the forces that are generated by the storms, the following procedure will be presented for reconstruction of global actions on column.

The design environmental conditions and the maximum forces at the yoke-vessel and yoke-column articulation nodes and the maximum slamming velocities on the yoke beams have been determined for a set of significant extreme environmental conditions.

Table 2. SPM design environmental load cases.

	wave 1			wave 2			wind		current	
	Dir. (deg)	H_s (m)	T_p (s)	Dir. (deg)	H_s (m)	T_p (s)	Dir. (deg)	Speed (kts)	Dir. (deg)	Speed (m/s)
Case 1	180,0	9,0	13,1	-	-	-	180,0	62,6	180,0	0,95
Case 2	180,0	9,0	13,1	-	-	-	170,0	62,6	180,0	0,95
Case 3	180,0	5,9	10,6	120,0	3,5	8,2	120,0	41,5	180,0	0,65
Case 4	180,0	3,5	8,2	-	-	-	180,0	45,6	90,0	0,50
Case 5	180,0	9,0	13,1	-	-	-	150,0	50,5	135,0	0,57

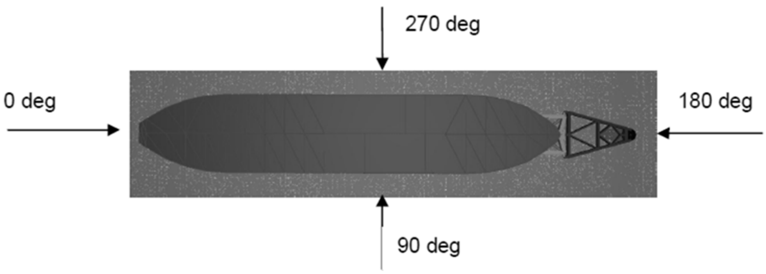

Figure 15. Environmental reference system.

Table 3 summarizes an extract of the design forces in the tri-axial joint that links the Yoke and Column. Reference system is at yoke tip (articulation node); X positive axis towards lateral abutment node, Z positive axis upwards and Y axis accordingly (positive to starboard).

Table 3. SPM extract of the design forces.

		load condition ship: Full Load			load condition ship: Ballast		
		Tx (tonn)	Ty (tonn)	N (tonn)	Tx (tonn)	Ty (tonn)	N (tonn)
Case 2	max	318	39	**161**	315	**367**	**161**
	min	**-1388**	-75	-73	**-1582**	-8	-65

The actions on the column were obtained using the 4 axial forces on the members of the yoke, mediating the forces on the 4 strain gauges, then the actions were obtained using the 4 forces and decomposing them according to the relative position of the column-yoke systems.

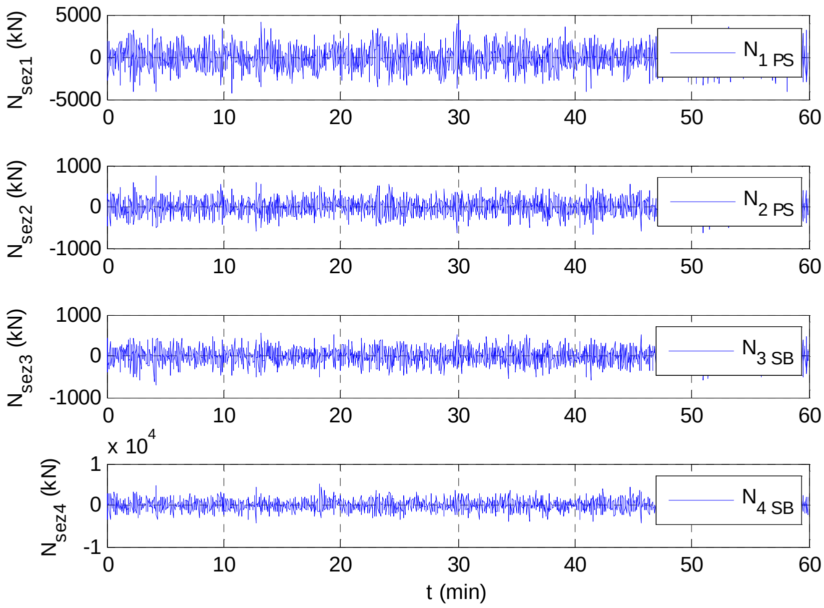

Figure 16. Time history of the axial action on the yoke's frames, storm of 2013/03/14, h22.

In Figure 16 we can see the axial action on the yoke's frames obtained for the storm of 201/03/14 with H_s=6.7 m (see Table 1) while in Figure 17 the position (tilt values) of Yoke and Column during the event.

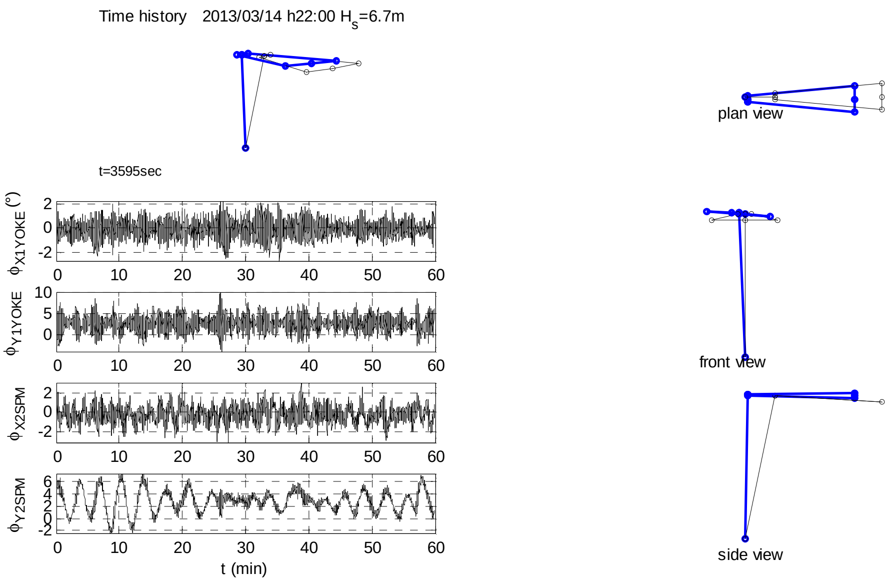

Figure 17. Time history inclinometers and position of the system, storm of 2013/03/14, h22.

In Figures 18 the actions on the column are shown. The extreme values, relating to storm of 2013/03/14, are lower than the design ones and assume the following values: N = 32 t, Tx=555 t and Ty =283 t.

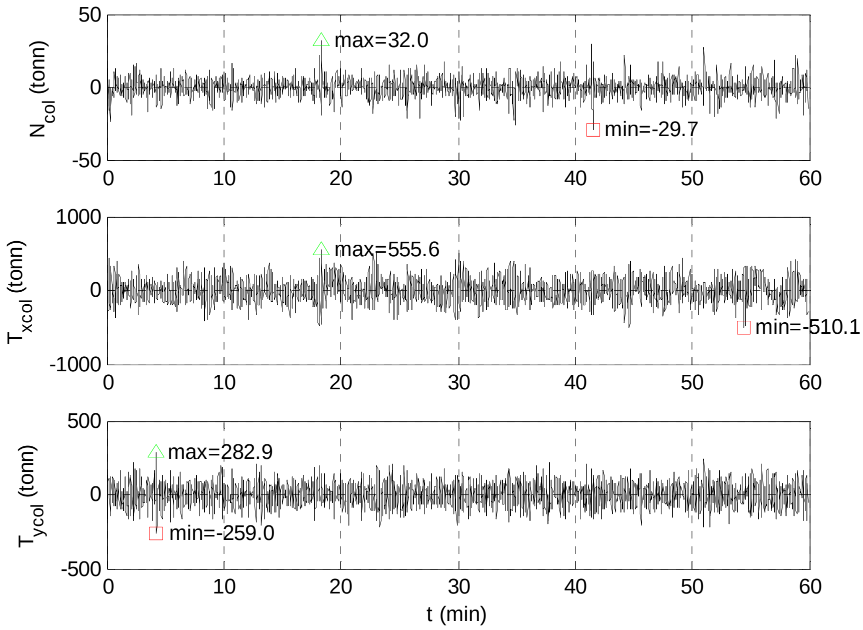

Figure 18. Action on the column, Tx, Ty, N, storm of 2013/03/14, h22.

Finally we report in Figure 19 a wider analysis with waves of a increasing intensity. The analyzes show the evolution of the forces on the column as a function of the significant wave height. The projection of the results shows that, for a wave of 9 m (design data of the system), will have the following actions on the column: N = 53.07 t, Tx=814.35 t and Ty =338.52 t which are lower than the design values shown in Table 3.

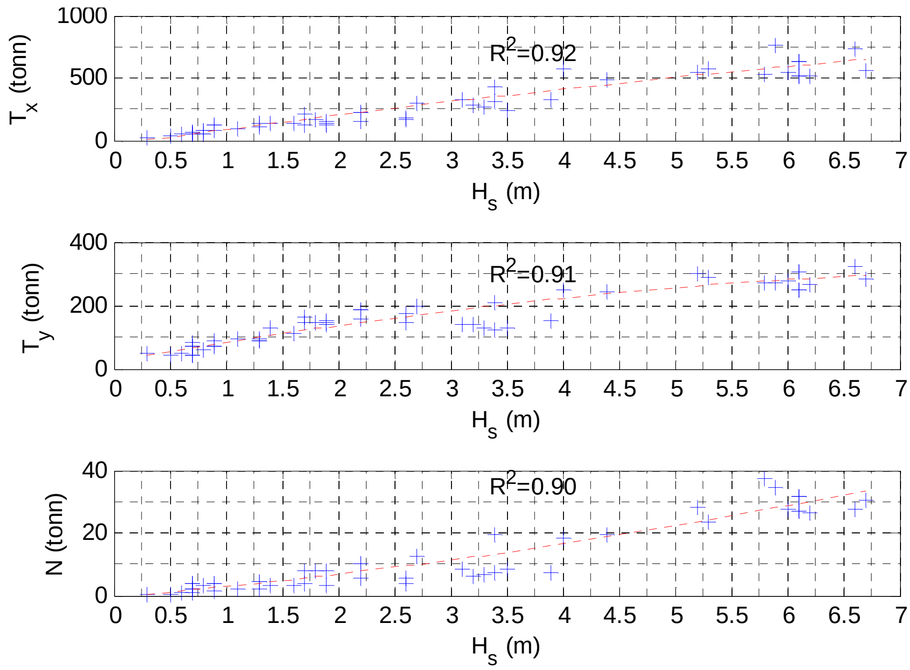

Figure 19. Action on the column, Tx, Ty, N vs Hs. - - quadratic trend line.

5 CONCLUSIONS

The present work shows the characteristics of the monitoring system installed in the SPM in the VEGA field. The monitoring system makes possible to reconstruct the global actions on the column in order to compare these values with the project ones. The future development of the monitoring system provides the increase in the sampling frequency in order to find the structural frequencies of yoke and column. In fact, under the actual system it is possible to reconstruct only the global motion of the SPM system and the resulting global actions on the column. Finally, the results of the monitoring system are a valuable tool for identify the structural response, the fatigue during the life of the SPM and a useful support in the risk based inspections.

Acknowledgements

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