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MONITORING OF A SINGLE POINT MOORED SHIP

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ABSTRACT

The offshore platform VEGA is operating since 1988 in Sicily channel with a Single Point Moored tanker ship,. This work shows the overall features of the system and the collection and analysis of the data concerning the structural response of column-yoke-vessel FSO recorded since 2009. The structural monitoring is performed through a series of 37 optical strain gauges installed on the ship and on the yoke, and two biaxial inclinometers installed on SPM. Therefore the following items are monitored: three frames within the ballast tanks, the main structure of the yoke and tilt angles of yoke and mooring column. The acquired data are processed in order to establish their representativeness in relation to the structural control of the yoke/column and the tanker ship. The moored ship is free to rotate and to assume a favorable alignment to the prevailing current, wind or waves, reducing the actions on the mooring column if the loads are collinear. The results of data processing, the spectral analysis and dynamic identifications are presented. The characteristics of the monitoring system installed in the SPM and in the ship allow the dynamic identifications of system.

KEYWORDS

Offshore structures; Structural monitoring; Dynamic identification.

INTRODUCTION

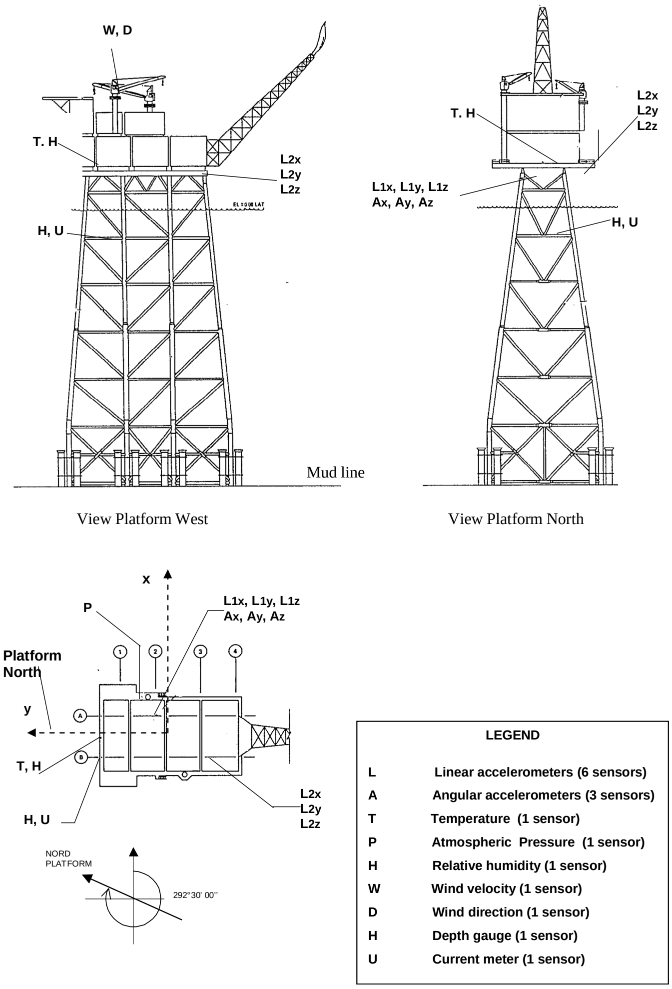
The platform VEGA-A is the largest offshore oil platform built in Italy and its oil production in Sicily began with the discovery of deposits in the areas of Ragusa in 1950 and Gela in 1956. The reservoir is located at a depth variable from 2400 to 2800 meters below the sea level, and extends over an area of about 28 square kilometers. The production started in August 1987, 20 wells are currently in production.

Figure 1. VEGA-A platform and FSO Leonis.

The VEGA field includes the platform 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 ship is moored at SPM (single point mooring) located about 1.5 miles from the platform and connected to it via submarine pipelines. The platform, in February 1987, was installed at a depth of about 122 meters under sea level using a jacket and a steel structure with eight columns anchored to the seabed by means of 20 piles; on top of the structural modules, hosting production and services plants were subsequently placed.

FEATURES OF THE SYSTEM AND THE MONITORING

A monitoring system is installed on both the VEGA-A platform and the mooring of the tanker ship. VEGA platform is monitored by means of 9 linear accelerometers, a current meter, a depth gauge and systems for detecting speed and direction of wind. Therefore, the action of sea and wind on the VEGA platform are recorded as well as its structural response. The Department of Civil and Environmental Engineering of the University of Florence has the task of collecting and processing the monitoring data analysis for the VEGA platform since 1988, when the system was first operated.



View Platform West

View Platform North

LEGEND

L	Linear accelerometers (6 sensors)
A	Angular accelerometers (3 sensors)
T	Temperature (1 sensor)
P	Atmospheric Pressure (1 sensor)
H	Relative humidity (1 sensor)
W	Wind velocity (1 sensor)
D	Wind direction (1 sensor)
H	Depth gauge (1 sensor)
U	Current meter (1 sensor)

Figure 2. Features of VEGA-A monitoring system.

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; the reticular arm (Yoke) is bound to the column via a coupling tri-axial joint allowing rotations around all three axes and to the ship by three aligned cylindrical hinges.

A data acquisition system on the ship Leonis is running since October 2009 in order to monitor and collect all the structural data. The system performs the structural monitoring by means of 25 optical strain gauges installed on the ship and 12 strain gauges on the yoke; two biaxial inclinometers were also installed on SPM. Therefore, the following items are monitored: strain in the ship frames #62, 74 and 86, within the ballast tanks; strain in the structure of the yoke; tilt angles of yoke and SPM. In Figures 3 and 4 the location of sensors on the yoke are shown. The duration of acquisition of strain data 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 detected and recorded on board of Leonis. In the Figure 5 the monitored sections of the ship are shown. All data are available in real-time on board.

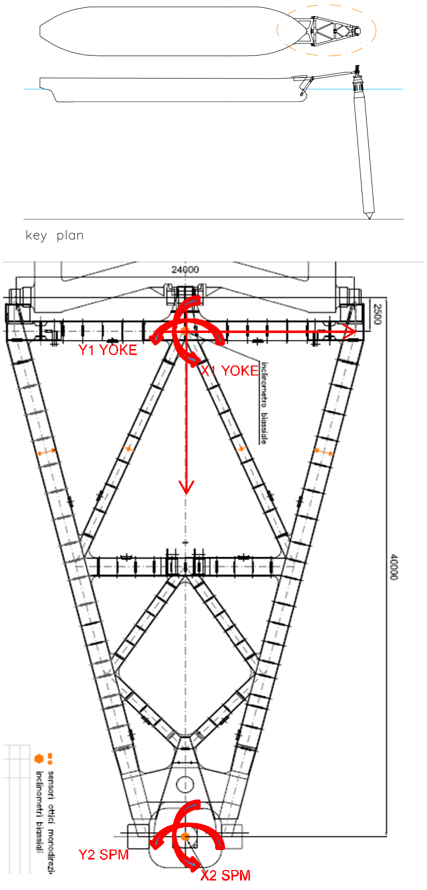


Figure 3. Yoke and locations of inclinometers.

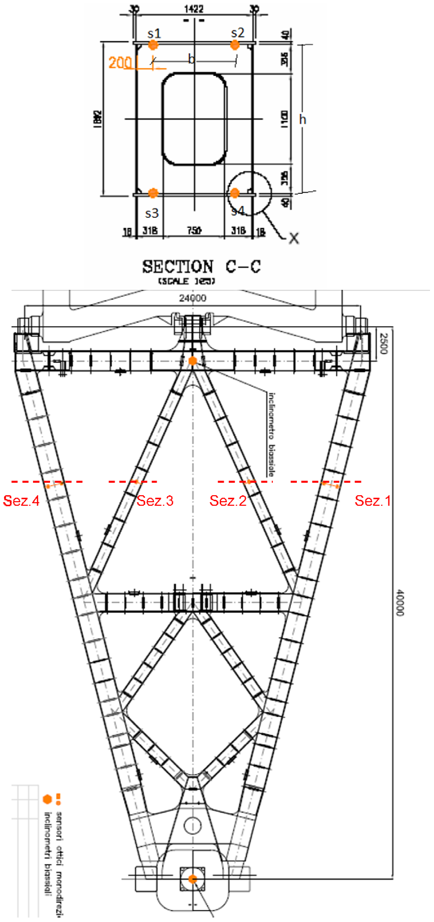


Figure 4. Yoke and locations of strain gauges.

Figure 5. FSO Leonis and locations of strain gauges.

ANALYSIS OF INCLINOMETER AND STRAIN GAUGES DATA

Below are summarized, in Table 1, the main features of the storm occurred on 2012/01/06 in the VEGA field. The data have been acquired by means of the monitoring system installed on VEGA platform.

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

Mount	day:h	Hs (m)	Hmax (m)	Tz (s)	Ts (s)	Thmax (s)	Dseas (degN)	Wwind (m/s)	Wwind (m/s)
January	2012/01/06:10	6.7	9.8	8.3	10.1	9.3	290	24.05	24.05

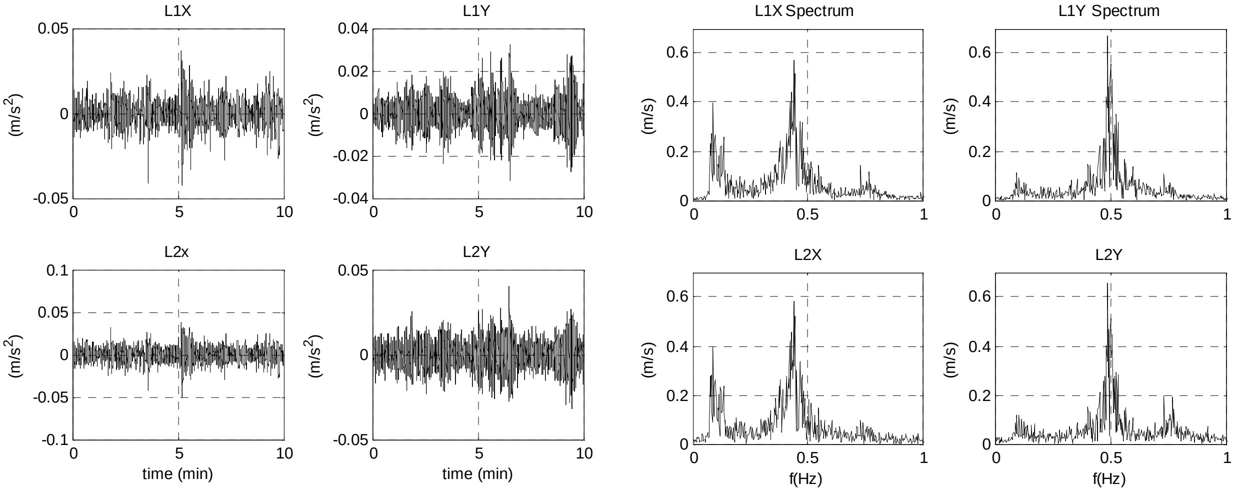


Figure 6. VEGA-A accelerometer and spectra, storm of 2012/01/06.

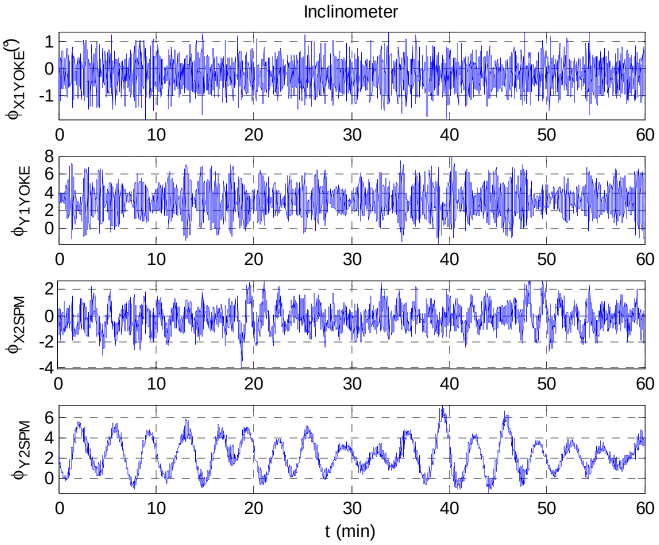


Figure 7. Yoke's inclinometers, storm of 2012/01/06.

In the figure 6, 7, 8 and 9 are presented the registered data from VEGA-A accelerometer, yoke's inclinometer sensors, yoke's strain gauges sensors and ship's frame strain gauges sensors.

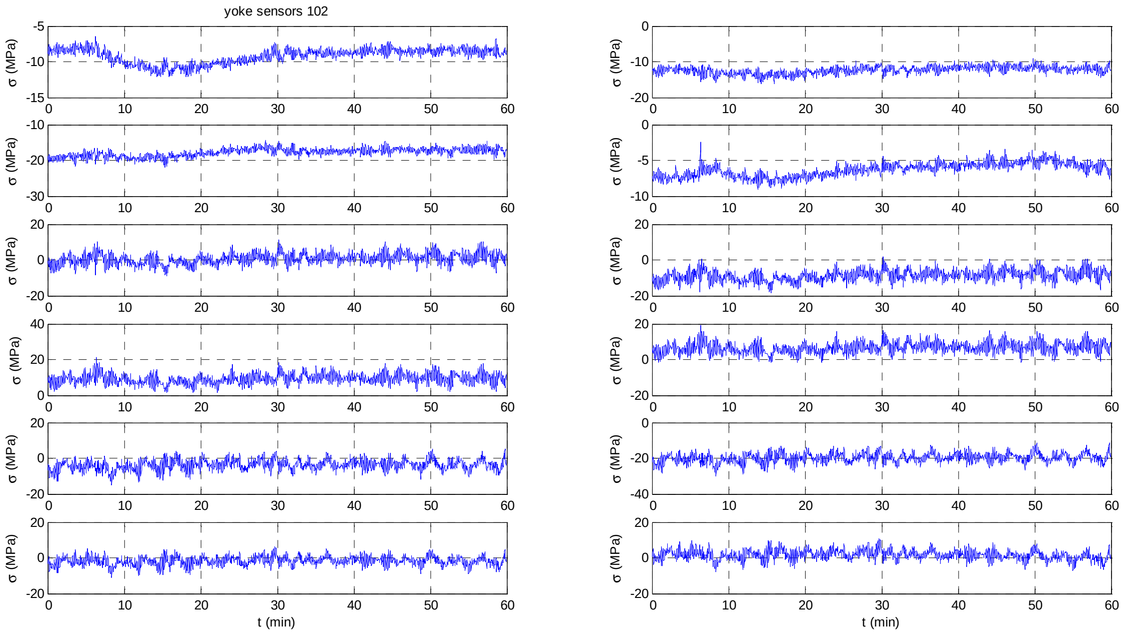


Figure 8. Yoke's strain (stress) gauges, storm of 2012/01/06.

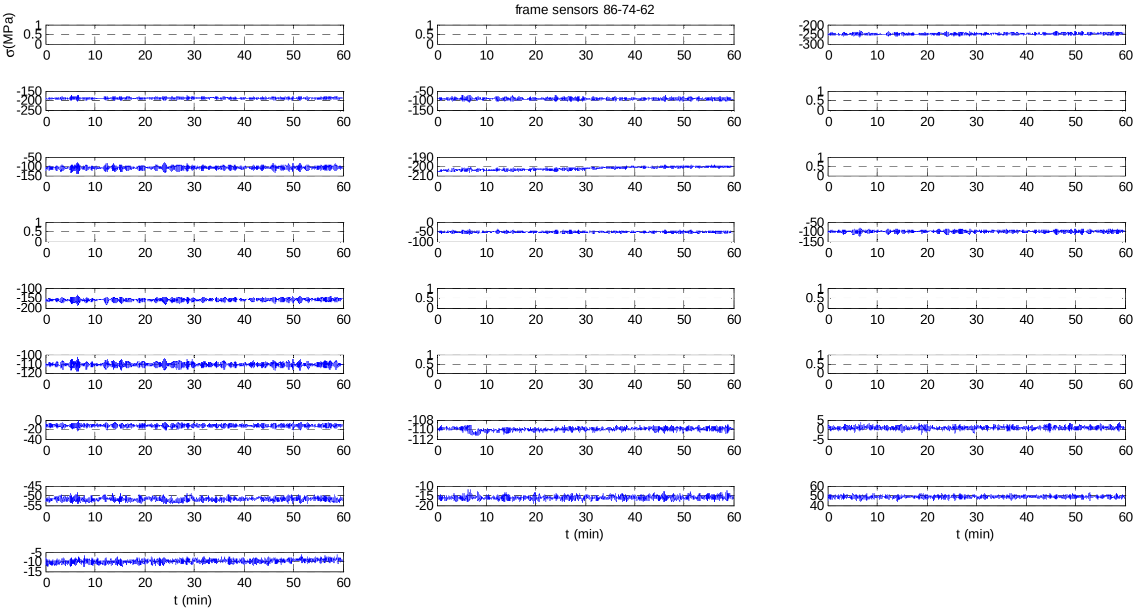


Figure 9. Ship's strain (stress) gauges, storm of 2012/01/06.

DATA ANALYSIS AND DYNAMIC IDENTIFICATION

Stochastic systems: problem description

Stochastic subspace identification algorithms compute state space models from given output data. The following are the basic steps of the method as shown in Peeters and De Roeck (1999) in the covariance-driven version of the algorythm. The output $y_\kappa \in \Re^1$ is supposed to be generated by the unknown stochastic system of order n:

$$\begin{aligned} x_{\kappa+1}^{s} &= \mathrm{A}\, x_{\kappa+1}^{s} + w_\kappa \\ y_\kappa &= \mathrm{C}\, x_{\kappa+1}^{s} + v_\kappa \end{aligned} \qquad (1)$$

with w_κ and v_κ zero mean, white vector sequences with covariance matrices given by

$$E = \left[\begin{pmatrix} w_p \\ v_p \end{pmatrix} \begin{pmatrix} w_q^T & v_q^T \end{pmatrix} \right] = \begin{pmatrix} \mathrm{Q} & \mathrm{S} \\ \mathrm{S}^{\mathrm{T}} & \mathrm{R} \end{pmatrix} \delta_{pq} \qquad (2)$$

The order n of the system is unknown. The system matrices have to be determined $A \in \Re_{nxn}$, $C \in \Re_{lxn}$ up to a similarity transformation as well as $Q \in \Re_{nxn}$, $S \in \Re_{nxl}$, $R \in \Re_{lxl}$ so that the second order statistics of the output of the model and of the given output are equal.

The key step of stochastic subspace identification problem is the projection of the row space of the future outputs into the row space of the past outputs, as shown in Van Overschee and De Moor (1996).

System identification: storm of 2012/01/06

Below the results of the Stochastic Subspace Identification are shown. The analysis shows that it is possible to identify three mode shapes of rigid motion, each distinguished by the frequencies f_1=0.0050Hz, f_2=0.0106Hz, f_3=0.0860Hz. The first mode shape is characterized by a transversal motion (relative to the axis joining the yoke and the ship), the second transverse while the third concerns the rolling motion of the vessel connected.

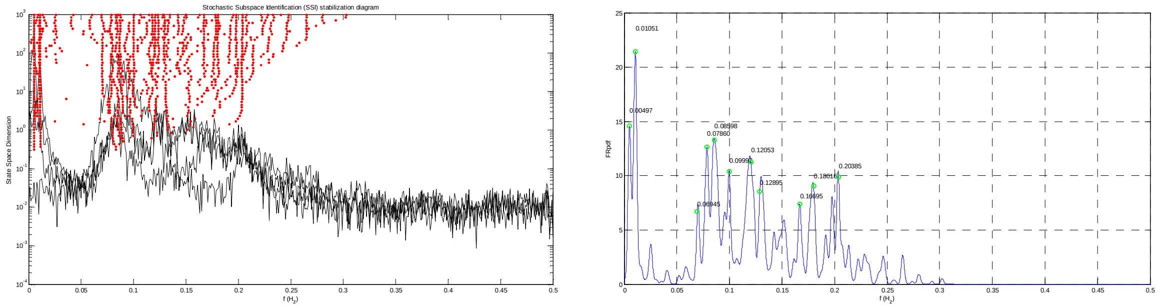


Figure 10. Stochastic subspace identification analysis: stabilization diagram and PDF for storm of 2012/01/06.

Reconstruction of column's action

To compare the design strength of SPM system with the forces that are generated by the storm of 2012/01/06, the following procedure for the reconstruction of global actions on the column will be presented, using data provided by the monitoring system. The environmental design 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.

The actions on the column were obtained using the 4 axial forces on the rods of the yoke, averaging the actions on the 4 strain gauges; subsequently, the acting forces were obtained using the 4 actions and decomposing them according to the relative position of the column-yoke systems.

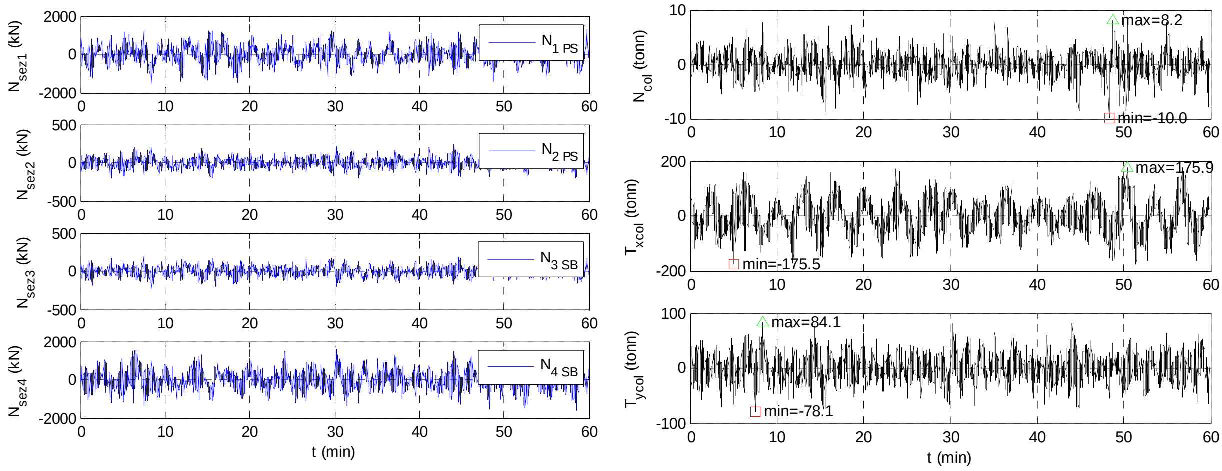


Figure 11. Time history of the axial action on the yoke's frames, 0-60min and action on the column, Tx, Ty, N.

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In Figure 11 the normal action obtained from the analysis and the forces on the column is shown. The extreme values, relating to storm of 2012/01/06, can be compared with the design ones and assume the following values: N = 10 t, Tx=176 t and Ty = 84 t.

Analysis of ship data

To investigate the relationship between the signals acquired on board the ship Leonis, the spectral coherence and phase angle between couples of different signals was estimated; such statistics are commonly used to estimate the power transfer between input and output of a linear system.
The coherence and the phase angle between two signals *x(t)* and *y(t)* are function defined as:

$$C_{xy} = \frac{G_{xy}}{\sqrt{G_{xx} \cdot G_{yy}}}, \tag{3}$$

$$\theta_{xy} = \tan^{-1}\left(\frac{\mathrm{Im}(C_{xy})}{\mathrm{Re}(C_{xy})}\right). \tag{4}$$

where *Gxy* is the cross-spectral density between *x* and *y*, and *Gxx* and *Gyy* the autospectral density of *x* and *y* respectively.

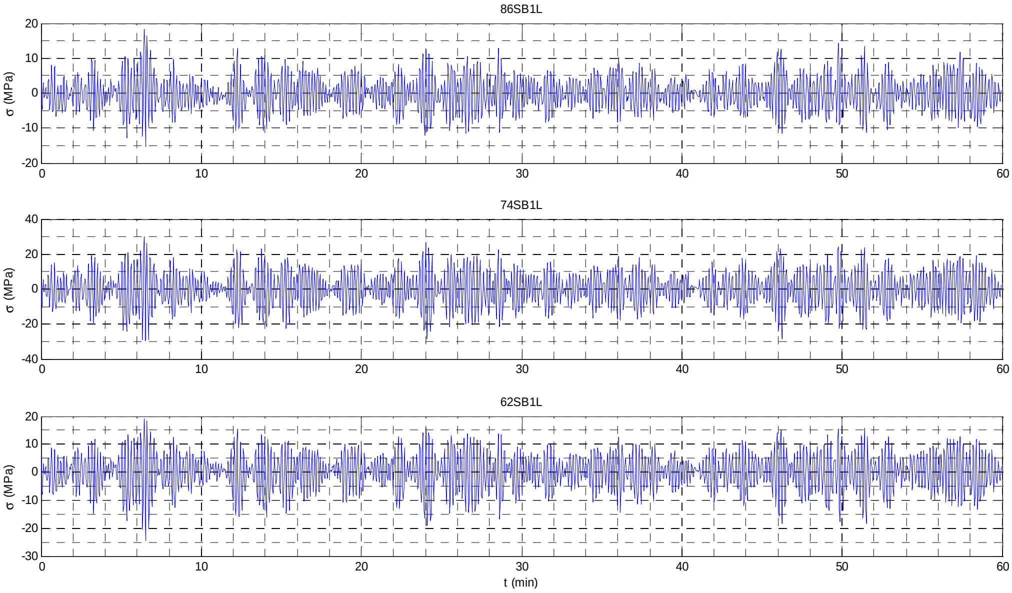

Figure 12. Ship’s strain (stress) gauges 86SB1L, 74SB1L, 62SB1L, storm of 2012/01/06.

In particular, we have analysed the three signals relating to an alignment along the longitudinal axis of the ship, *86SB1L*, *74SB1L* and *62SB1L*.

Estimating the angular coefficient of the straight line interpolating the phase angle (in the interval 0.078-0.086 Hz) is possible to estimate the speed of the wave; in this case is equal to 12.35 m/s and the resulting period of the wave is equal to 7.9s (estimating the period in case of deep water). This result is in agreement with the characteristics of the storm (see Figure 13).

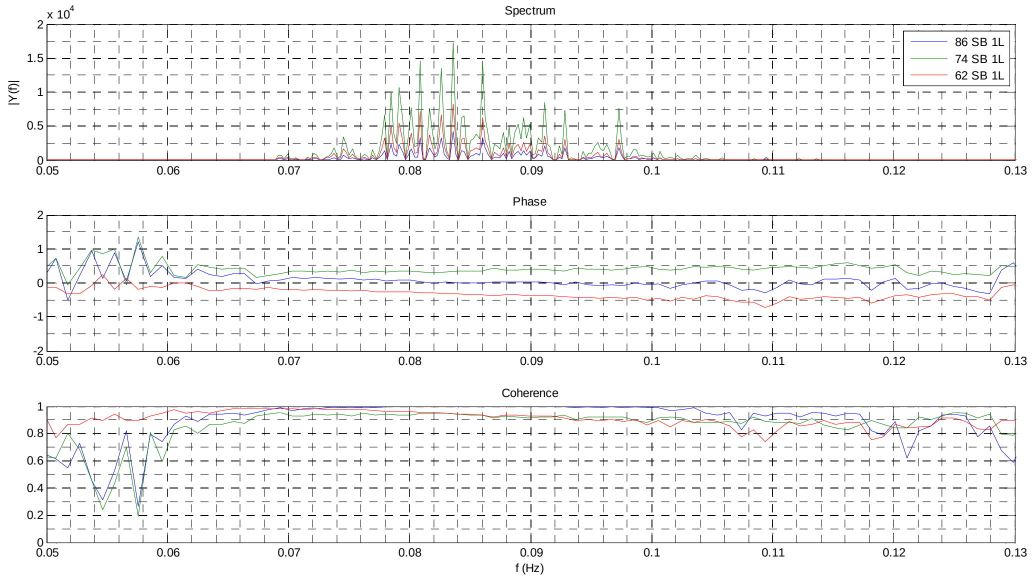

Figure 13. Cross spectra, phase and coherence, storm of 2012/01/06.

CONCLUSIONS

The present work shows the characteristics of the monitoring system installed in the VEGA-A platform and in the SPM placed in the VEGA field. The monitoring system allows the identification of the frequencies of oscillation of the platform VEGA-A and, by means of a process of dynamic identification, it is able to derive the frequencies and the oscillation modes of the SPM and eventually the forces that the latter exchanges with the tanker ship Leonis. Finally, by means of the analysis of the data on the ship, it is possible to check the coherence and the phase of the signals that can be compared with the characteristics of the storm. The monitoring system makes possible the dynamic identifications of the connected systems, also it is possible to reconstruct the global actions on the column in order to compare these values with the design ones. Finally, the results of the monitoring system are a valuable tool for evaluation the structural response during the life of the VEGA-A platform and SPM; this elaborations are a useful support in the risk based inspections.

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