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Monitoring of a single point mooring in the VEGA field

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ABSTRACT: In Sicily channel is operating from 1988 the offshore platform VEGA; in addition, the ship tanker Leonis is moored nearby the platform and coupled to a system tower-tanker. This work involves the collection and statistical interpretation of structural response data recorded, from October 2009 so far, on the link column-yoke-vessel FSO. The acquired data are processed on the ship in order to establish their representativeness in relation to the structural control of the yoke itself and the ship Leonis. The present work presents the results of data processing provided by the monitoring system, which performs the spectral analysis and dynamic identifications. These results are then compared with data from the project in accordance with the storms that have affected the structural system.

1 INTRODUCTION

VEGA is the largest off-shore oil platform built in Italy. Oil production in Sicily began with the discovery of deposits in the areas of Ragusa in 1950 and Gela in 1956. The offshore exploration, from 1959, found some minor deposits, but only in the period 1978-80 through the acquisition of 3D seismic data the interpretation of the results and identification of the structure of Vega and its extension became possible. 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 field, ship Leonis and the mooring system.

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. The platform, in February 1987, was endorsed at a depth of about 122 meters under sea level using a jacket and a steel lattice structure with eight pillars anchored to the seabed by means of 20 piles; on top of these the remaining structural modules hosting production and services plants were subsequently placed. In Figure 1 the VEGA platform, the ship Leonis and the single point of mooring (yoke and column) are shown.

2 FEATURES OF THE SYSTEM AND THE MONITORING

Monitoring systems are present on both the VEGA 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 is in charge of the monitoring and data analysis for the VEGA platform since 1988, when the system was first operated.

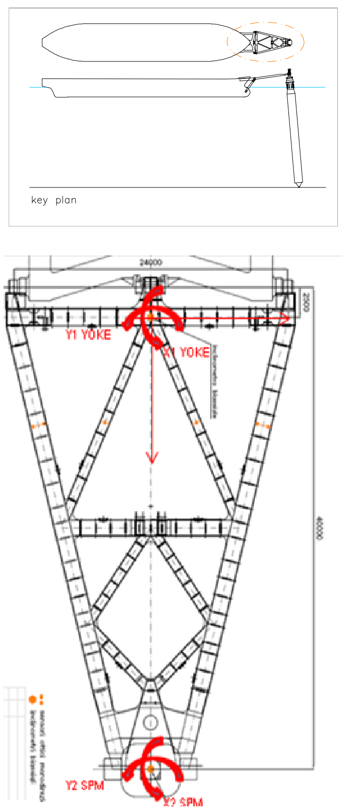

Figure 2. Yoke and locations of the inclinometers.

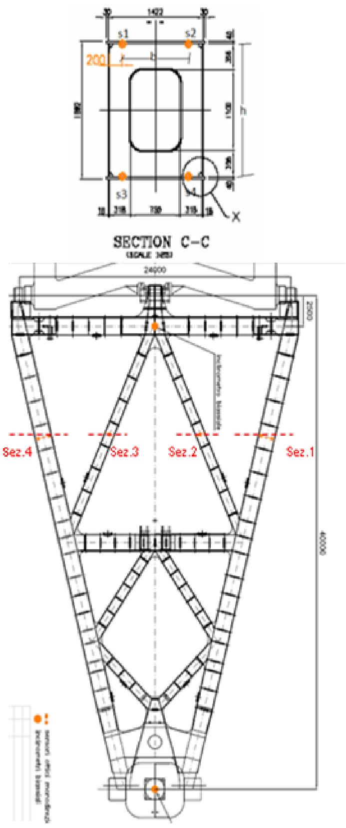

Figure 3. Yoke and locations of the strain gauges.

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 installed by Edison is running from October 2009 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 installed on the ship (# 25) and on the Yoke (# 12); two biaxial inclinometers were also installed on SPM (# 2x2). Therefore the following items are monitored: strain in the frames 62, 74 and 86, within the ballast tanks; strain in the structure of the yoke; tilt angles of Yoke and SPM. In Figures 2 and 3 the location of sensors on the Yoke are shown. Strain data are then converted in corresponding stresses. The monitoring procedure includes the acquisition of data in the initial phase and thus allows to detect the geometry of the system and the deformations of the beams due to the current calm sea conditions. The time data acquisition for stress is 60 minutes with a sampling frequency f_c=0.5Hz, while tilt angles are recorded with a sampling frequency f_c=1 Hz. The direction of the ship is detected and recorded by the Captain of Leonis. The conditions of sea and wind conditions is detected by the monitoring system on the platform.

3 DATA ANALYSIS: INCLINOMETER AND STRAIN GAUGES

Below are summarized, in Table 1 and in Figures 4 and 5, the main features of the storm occurred on 2012/01/06 in the area of 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	H_s (m)	H_{max} (m)	T_z (s)	T_s (s)	T_{hmax} (s)	D_{seas} (degN)	W_{wind} (m/s)	D_{wind} (degN)
January	2012/01/06:10	6.7	9.8	8.3	10.1	9.3	290	24.05	282

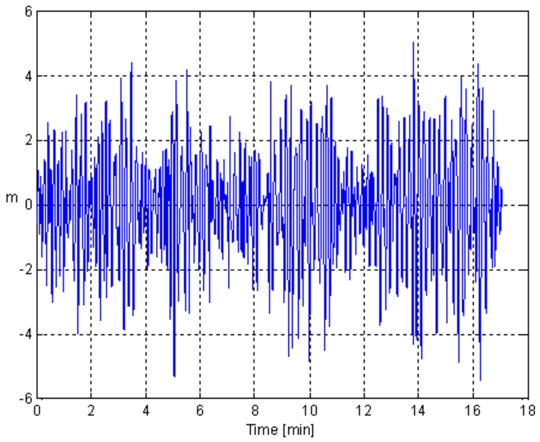

Figure 4. Environmental data: wave plot elevation H, storm of 2012/01/06.

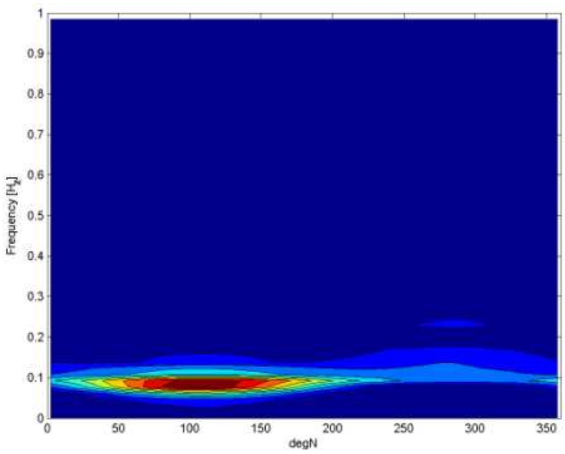

Figure 5. Environmental data: wave energy spectrum vs direction, storm of 2012/01/06.

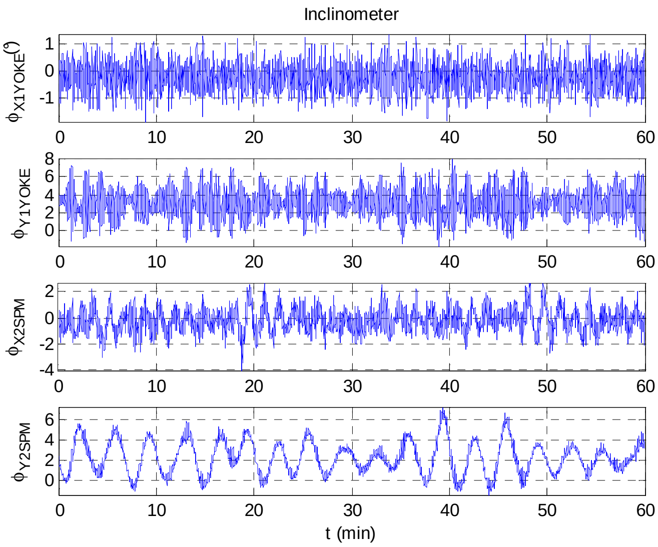

Figure 6. Time history of Yoke's inclinometers, storm of 2012/01/06.

In Figure 6 are shown, with reference also to Figure 2, the relative rotations of two biaxial inclinometers installed on the yoke about the event 2012-01-06 in the hour of the examination.

4 DYNAMIC IDENTIFICATION

4.1 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 $y_\kappa \in \Re^l$ is supposed to be generated by the unknown stochastic system of order *n*:

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

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

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

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).

4.2 System identification: storm of 2012/01/06

Below are shown the results of the Subspace Stochastic Identification (SSI). The eigenfrequencies estimated can be used to evaluate the corresponding modal shapes by means of the Singular Value Decomposition (SVD). The estimated mode shape is reported in Figure 8, for the event of 2012/01/06. The Probability Density Function (PDF) in Figure 7 could be built by means of a Gaussian base according to Eq. (3) where O_{min} and O_{max} represent the minimum and maximum order of the SSI model and N_f is the number of identified main frequencies. In Figure 7 are shown also the stabilization diagram and the PDF of structural resonance.

$$p(f) = K \sum_{h=O\min}^{O\max} \sum_{k=1}^{Nf} \exp\left(-\frac{(f - f_{hk})^2}{2\sigma_h^2} \right)$$

where,

$$K = \left[\int_{-\infty}^{+\infty} \sum_{h=O\min}^{O\max} \sum_{k=1}^{Nf} \exp\left(-\frac{(f - f_{hk})^2}{2\sigma_h^h} \right) df \right]^{-1} \quad (3)$$

The analysis shows, in Figure 8, 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.

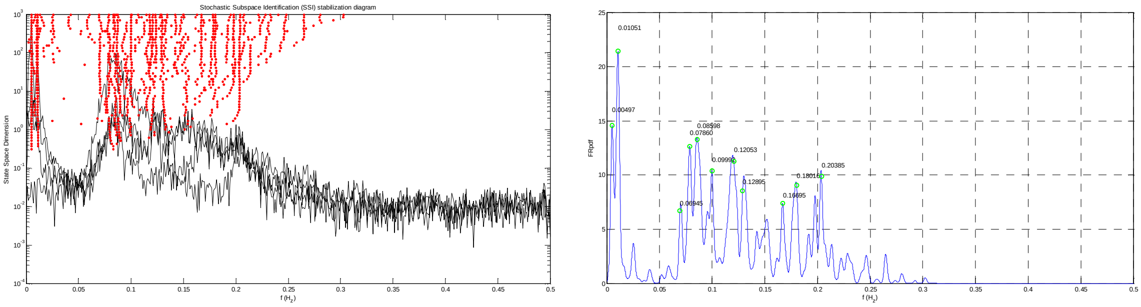

Figure 7. Stochastic subspace identification analysis: stabilization diagram and PDF for storm of 2012/01/06.

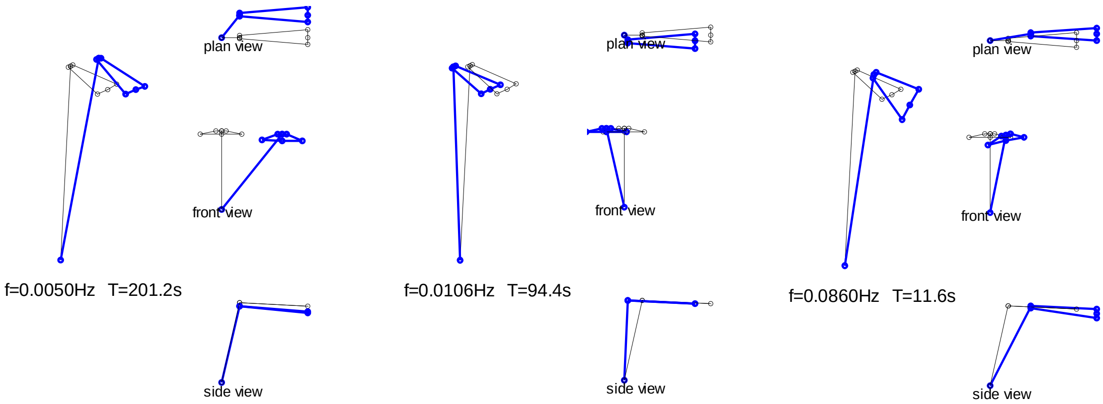

Figure 8. Identified mode shapes of mooring system, f_1=0.0050Hz, f_2=0.0106Hz, f_3=0.0860Hz .

4.3 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 the procedure will be presented for reconstruction of global actions on column, using data provided by the monitoring system. 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. In Table 2 are shown the SPM design environmental load cases. In Figure 9 are reported the references for the direction of the waves/winds/currents.

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

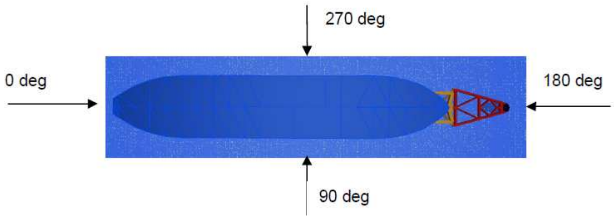

Figure 9. Environmental reference system..

The design analysis has been carried out using the well known MOSES software (Multi-Operational Structural Engineering Simulator). MOSES is a general-purpose program for computation of hydrostatic and hydrodynamic characteristics of systems of connected floating structures subjected to a combination of environmental conditions.

Table 3 summarizes an extract of the design forces in the triaxial 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		
		Fx (tonn)	Fy (tonn)	Fz (tonn)	Fx (tonn)	Fy (tonn)	Fz (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 rods of the yoke, mediating the actions on the 4 strain gauges, then the acting forces were obtained using the 4 actions and decomposing them according to the relative position of the column-yoke systems.

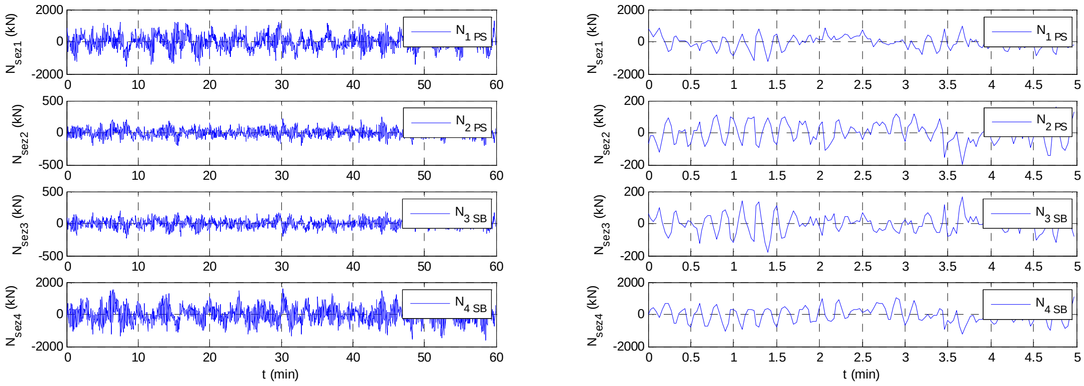

Figure 10. Time history of the axial action on the yoke's frames, 0-60min, 0-5min.

In Figure 10 we can see the normal action obtained while in Figure 6 the position of the bodies Yoke and Column.

Finally, in Figures 11 and 12 the forces on the column are shown. The extreme values, relating to storm of 2012/01/06, are lower than the design ones and assume the following values: N = 10 t, Tx=176 t and Ty = 84 t. The charachteristics of storm are summarized in Table 1 (H_s = 6.7 m).

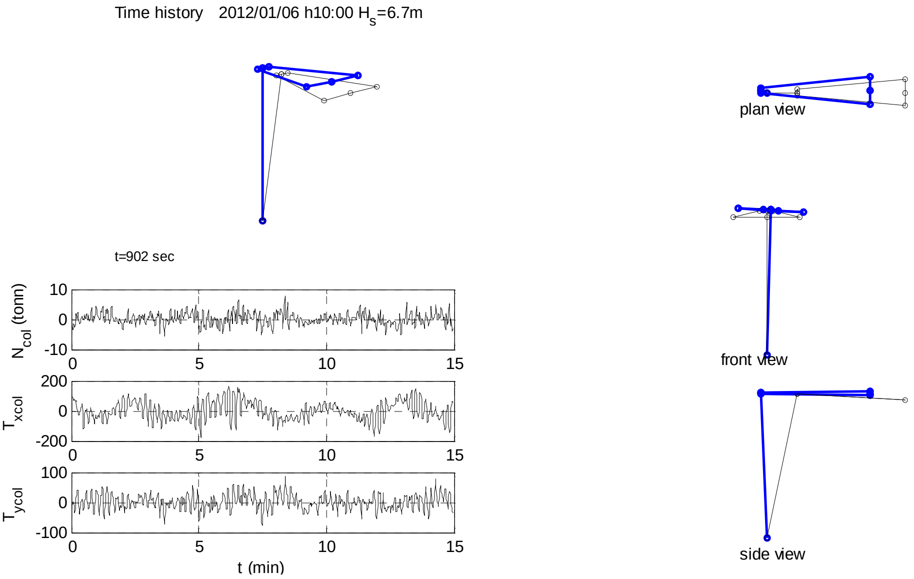

Figure 11. Time history of the action on the column Tx, Ty, N and position of the system.

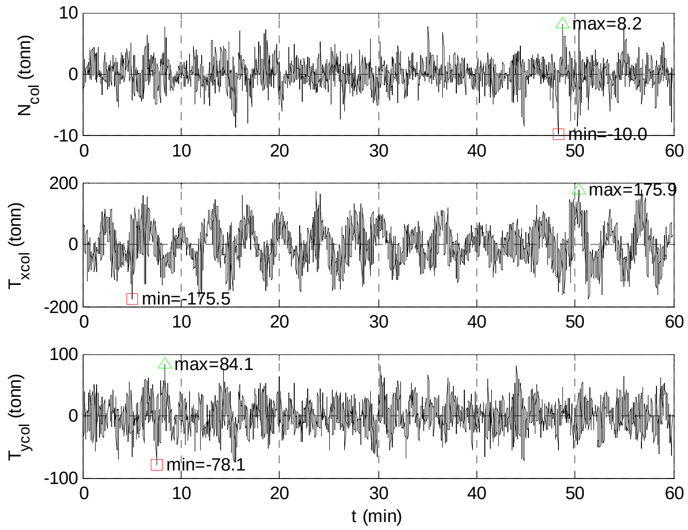

Figure 12. Action on the column, Tx, Ty, N.

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 the dynamic identifications of connected systems, also it is possible to reconstruct the global actions on the column in order to compare these values with the project ones. Finally, the results of the monitoring system are a valuable tool for evaluation the structural response during the life of the SPM and a useful support in the risk based inspections.

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