Dynamic Monitoring of Steel and Concrete Offshore Structures

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ABSTRACT: Steel jacket platform and gravity based structure located and operating in Italian offshore sea are monitored with a continuous dynamic system to investigate the structural response to the sea storms and earthquakes. In order to make a long-term dynamic monitoring, are located on the structures some acceleration units positioned at different elevations, each unit can contains linear or angular accelerometers.

The numerical elaborations are performed through the experience gained over 10 years of continuous dynamic monitoring, and compared the behavior of one steel structure, tubular jacket type with pile foundation, and one gravity reinforced concrete structure.

The paper deals with data collection and the statistical analysis of the structural dynamic response data recorded during the normal work, during the storms and seismic events; the accelerometer data are used to compare design accelerations of the structures, and to determine the natural frequencies and relevant modal shapes after the events.

For this purpose, methods of Operational Modal Analysis (OPA) and methods of the principal components (PCA) can be used to highlight structural damage states. The identification methods are applied to two offshore structures that have different frequencies and different dynamic behaviors.

1 INTRODUCTION

The certification of offshore structures for their use beyond their initial life requires a design of inspection aimed to check-up constantly the structural element; the inspections, their typology and their frequency are a critical issue and inspection planning, were based mainly on probabilistic analysis (Risk Based Inspection, RBI). The check of structural damage is in usually hard to perform, taking in account both the water depth, foundations and marine growth that hide the structural member. To overcome these problems the monitoring techniques for damage identification through the analysis of the changes in the modal properties of offshore structures have been developed and the results of previous researches showed indexes capable to detect both offshore damages and mass changes, Betti et al. (2015). This research investigates the capacity of monitoring systems to assess possible structural damage in presence of environmental and operational variations, the Principal Components Analysis (PCA) and Novelty Detection can be used for this scope. This output-only black box technique, has been applied for eliminating environmental influences on features such as natural frequencies, which boils down to estimating a relationship between the observed features and unknown environmental factors, Rizzo et al. (2015). An effective method for Structural Health Monitoring (SHM) in changing environmental conditions is the kernel PCA, Reynders et al. (2014). In this work we monitored the status of some offshore structures, using the frequencies as parameters. As a reference case study was considered the VEGA-A offshore platform, an eight-leg steel fixed jacket platform operating in the Sicily Channel, 25 km offshore and compared to a gravity concrete structure, designed to operate in the Adriatic sea.

2   DYNAMIC IDENTIFICATION

2.1   The Stochastic systems

Next are shown the basic steps of the Stochastic Subspace Identification algorithm (SSI) that compute state space models from given output data as shown in Peeters et al. (1999). The used form is the covariance-driven version of the algorithm;

the output $y_\kappa \in \Re^1$ is supposed to be generated by the unknown stochastic system of order n:

$$x_{\kappa+1}^S = A\, x_{\kappa+1}^S + w_\kappa$$
$$y_\kappa = C\, x_{\kappa+1}^S + v_\kappa$$

(1)

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

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

(2)

as is known, 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 main 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 the work of Van Overschee et al. (1996).

In addition, the stabilization diagram can be used to define the probability density of structural resonance. The Probability Density Function (PDF) 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

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

where,

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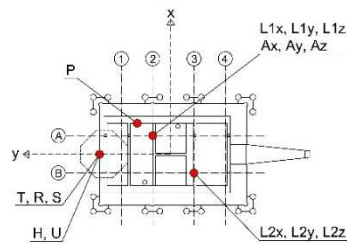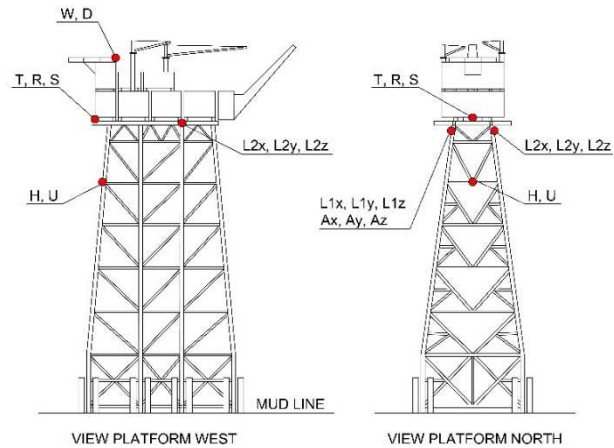
(3)

Once the eigenfrequencies were estimated, the corresponding mode shapes are retrieved by means of the Singular Value Decomposition (SVD).

3   REFERENCE SYSTEMS

3.1   A steel jacket platform

In February 1987, the VEGA-A platform was installed by Edison 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-A platform is shown in the dockyard and in the actual position. The platform is monitored by means of 9 linear accelerometers, 6 linear and 3 rotational, a depth gauge, a marine current meter and systems for

detecting speed and direction of wind. First in 2001, the monitoring system has been changed, principally with the addition of new accelerometers and a new wave-meter (depth gauge and current meter) and in September 2015, in addition to a second microwave wave-meter.

Figure 1. VEGA-A platform, in the dockyard, in service and actual sensor position.

The meteocean and accelerometer signals of the sensors are acquired by an acquisition unit which transmits the data to the control system. The acquisition unit provides to send (email or sms) alarms on the basis of pre-set threshold values. Actually, the acceleration data are acquired with a sampling frequency of 16 Hz, while all the meteocean data are acquired with a sampling of 2 Hz.

3.1.1 Dynamic Identification of the steel jacket platform

The modal parameters are obtained through an automated processing implemented on Matlab code; the record used to extract the modal parameters from year 2001 to year 2015 have a duration of 20min at the midnight of every day and the sampling frequency is 10 Hz. One of the objectives of the analysis is to capture the environmental effects, therefore it is considered sufficient that the analyzed time series report an estimation per day. For example in Figure 2 are shown the time history of the 9 accelerations for a storm that happened in 2014.
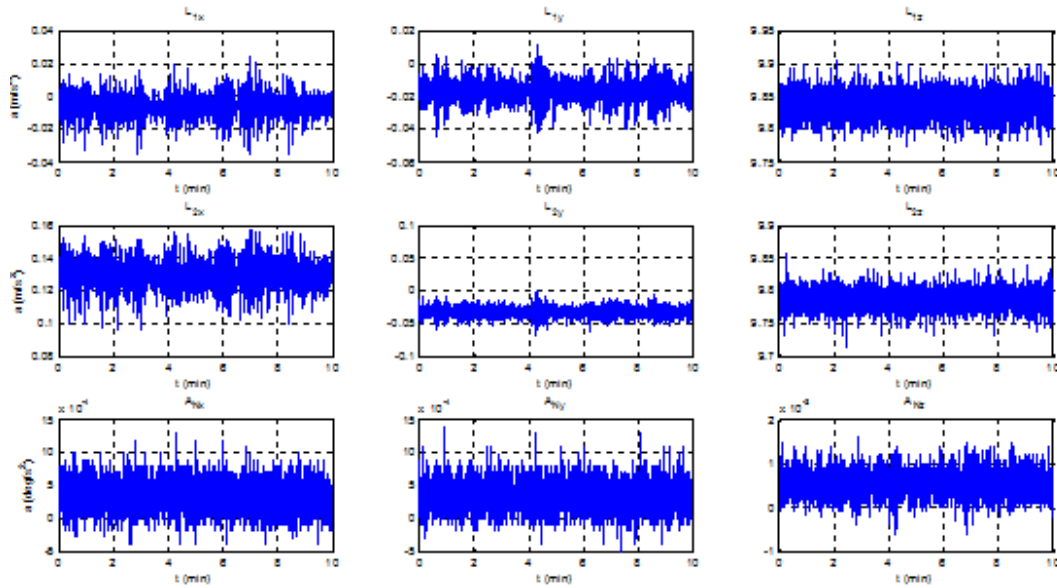
Figure 2. Time history of accelerometers, storm of 2014/01/25; units m/sec^2 and rad/sec^2.

The observation of the evolution of the first three natural frequencies identified in the frequency range 0.4÷0.8 Hz on the basis of the SSI method in the period 01/01/2001 to 31/08/2015, suggest that these frequency estimated are stable; except for the period 2001-2002 in which the derrick on the platform were removed and in the first months of 2015 where in the platform were performed heavy maintenance work of the wells. In Figure 3 is shown the frequency trend.
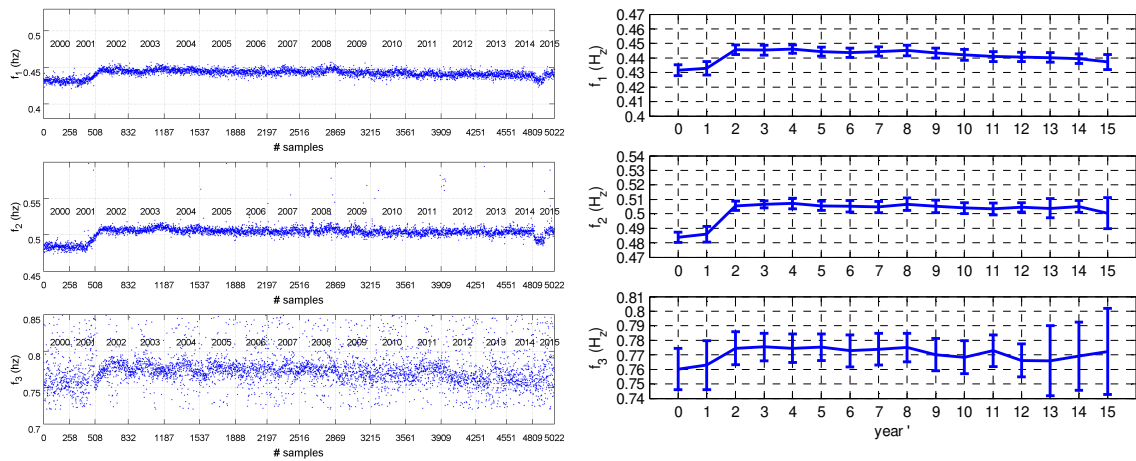

Figure 3. Variation of f_1, f_2 and f_3, mean and standard deviation rapresentation, years 2000-2015.

In Figure 4 we can see, the first three modes identified from the analysis; the first two modes of vibration are characterized by a horizontal translation while the third is a torsional mode shape around the z axis.
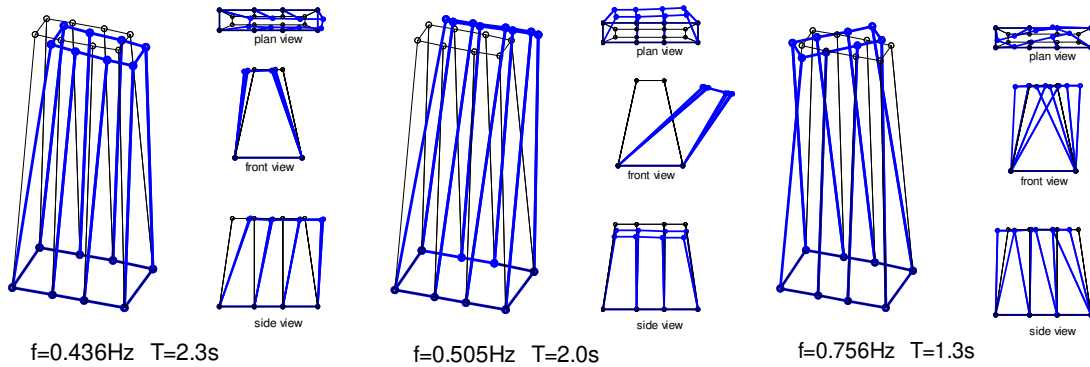
f=0.436Hz T=2.3s   f=0.505Hz T=2.0s   f=0.756Hz T=1.3s

Figure 4. Identified mode shapes of platform, f_1=0.436, f_2=0.505 and f_3=0.756 (Hz).

It can be observed, in addition to the change of mean value due to the removal of derrick in the year 2000-2001 and the variation of 2015 for the work of maintenance, also in that the standard deviation of the third frequency is very large when compared to the other two.

3.2   A gravity concrete structure

In this type of structure a structural monitoring system is installed in order to monitor dynamic response during normal conditions and during exceptional events, witch seismic activity, high loads from wind, waves and marine currents. The structural monitoring system consists of inclinometers installed at the top of structure and accelerometer at the bottom and top slabs of the structure, Belloni et al (2013). The static sensors: inclinometers have acquisition frequencies of 1 Hz or less and allow to check the deformations; the accelerometers with acquisition frequency of 16 Hz allow to detect the dynamic response of the structure during the time variable actions and specifically the response during an earthquake and allow to determine the shapes and frequencies of vibration (see Figure 5).
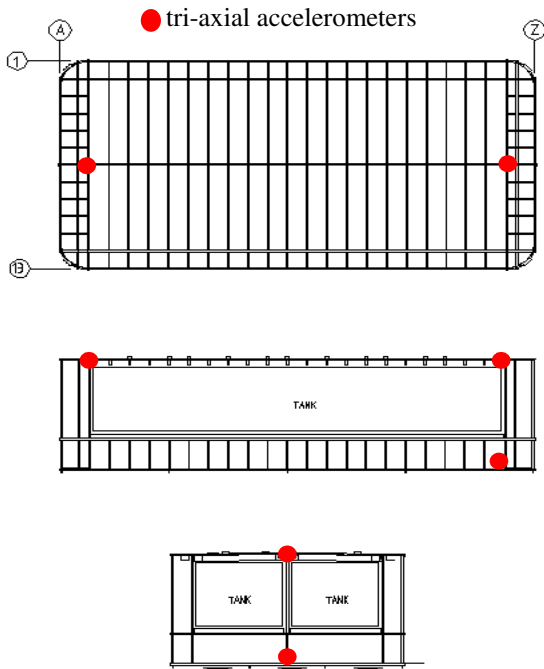

Figure 5. Position of the three tri-axial accelerometers.

3.2.1   Dynamic Identification of the gravity-based structure (GBS)

This section provides primary results of the structural analysis of the raw accelerometer data which was recorded during the seismic events occurring on May, 20th 2012 (see Figures 6 and 7).
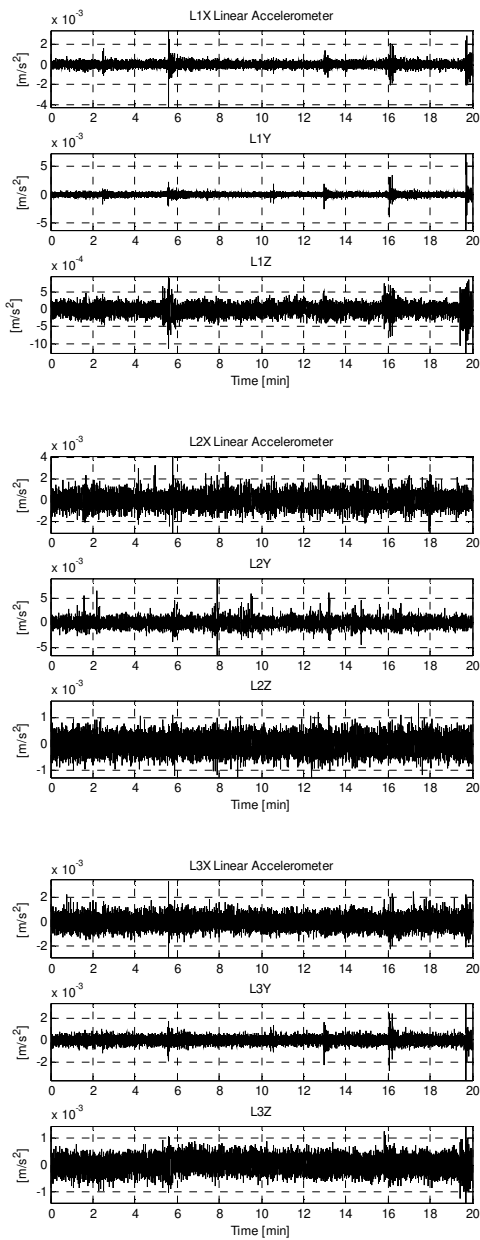
Figure 6. Nine accelerograms for Earthquake of 2012/05/20; units m/sec².
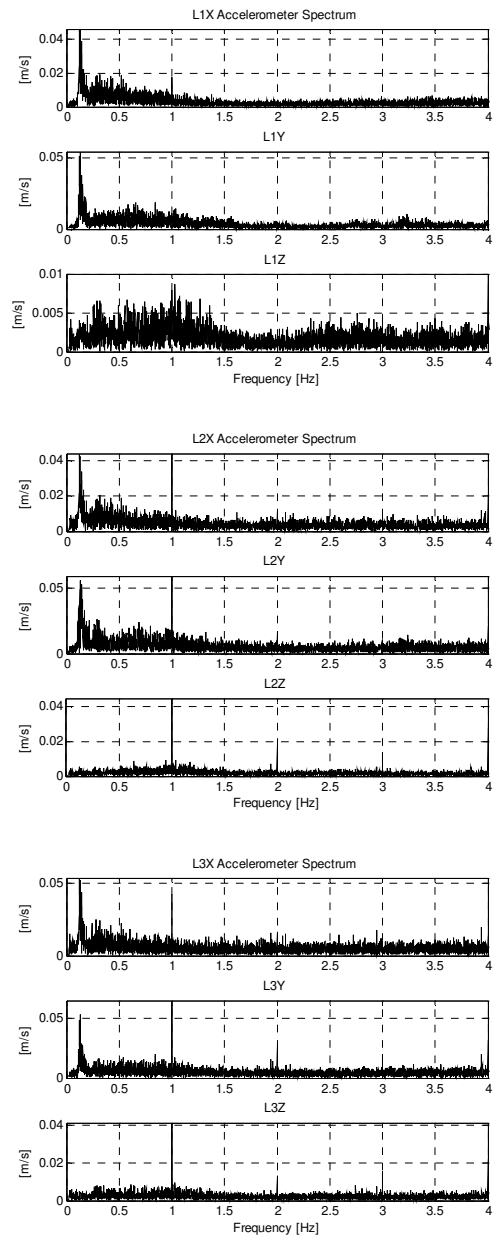

Figure 7. Fourier spectra (FFT analysis) for Earthquake of 2012/05/20.

Through the SSI analysis, it is possible to obtain and superimpose the spectra for January 2009 and January 2018. In Figure 10 and 11 the spectra graphs are shown. The Figure 12 shows the trend of the frequencies identified throughout the life of the structure, from January 2009 to June 2018.
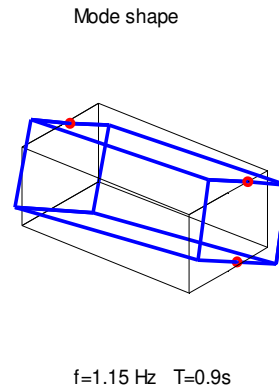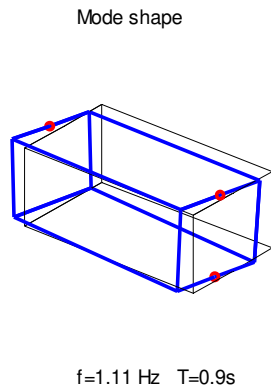
f=1.11 Hz   T=0.9s

f=1.15 Hz   T=0.9s

Figure 8. SSI analysis, earthquake 2012/05/20, mode at 1.11 Hz; combined sliding and rocking mode.

Figure 9. SSI analysis, sea storm 2011/12/19, mode at 1.15 Hz; rocking mode.

The dynamic identification with the SSI method allows to find also the GBS modal forms that was shown in Figure 8 and 9.
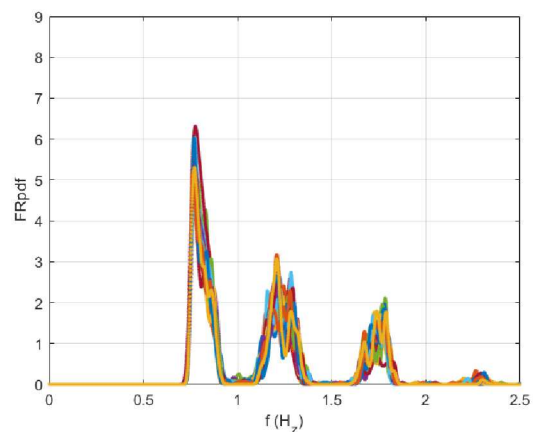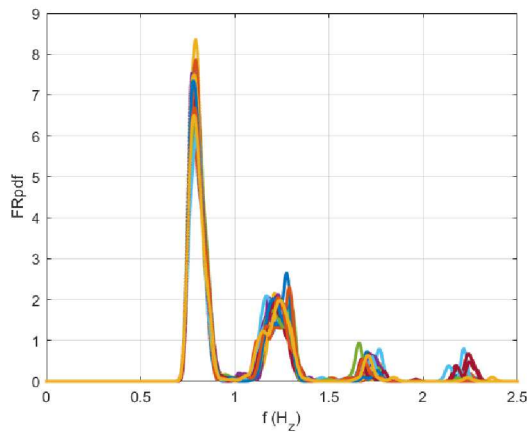

Figure 10. Spectra (SSI analysis) of January 2009.

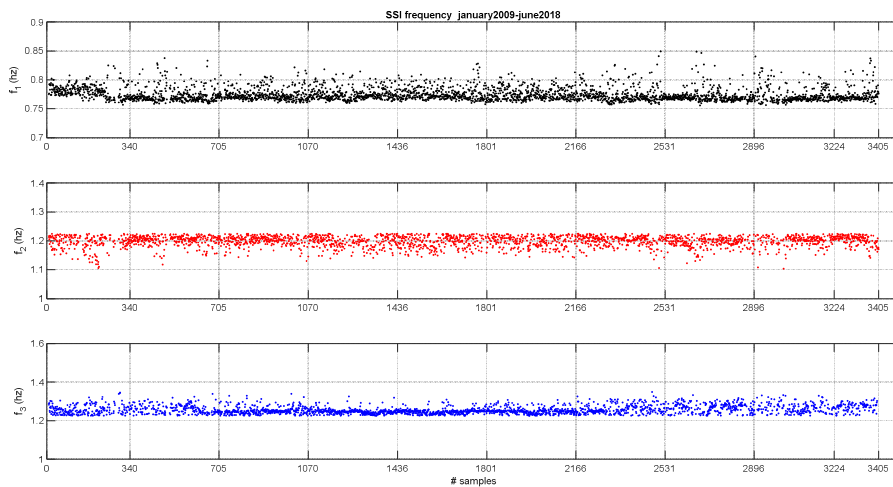Figure 11. Spectra (SSI analysis) of January 2018.

Figure 12. First three frequency (SSI analysis) of January 2009-June 2018.

4   CONCLUSIONS

This paper shows the investigation of the dynamic behaviour of two offshore structure, a concrete and a steel platform, in reference to their first three modal frequency and their variation over time. The method used, SSI (Stochastic Subspace Identification), allows the identification of the structural behaviour. The SSI method proves to be effective in detecting the structural frequencies of two structures with different modal forms, the first, in steel, with a modal form with a cantilevered bracket and the second in box-like concrete with modal forms of rigid body.

A monitoring system of this type can provide important dynamic information and, together with an ad hoc method that allows the seasonal effects on frequencies to be removed, can be a valuable tool for detecting any structural damage. Finally, the application of this type of method, together with the data collected over the long term, will be able to function as an alarm system and the verification of vibration serviceability limits and can be a useful support in the risk based inspections.

References

Belloni F., Rizzo M., Spadaccini O., Vignoli A., 'Dynamic Monitoring of GBS Terminal', *Proceedings of SMAR 2013 the 2nd conference on smart monitoring, assessment and rehabilitation of civil structures*, September 9–11, 2013, Istanbul.

Betti, Spadaccini & Vignoli 2015, 'Offshore Platform Structural Damage Identification Versus Robustness', *Proceedings of the IABSE 2015 Workshop on Safety, Robustness and Condition Assessments of Structures*, Finland, Helsinki, 11-12 February 2015, 86-93.

Peeters, B. & De Roeck, G. 1999. Reference-based stochastic subspace identification for output-only modal analysis, *Mechanical Systems And Signal Processing*, 13 (6): 855-878.

Reynders, Wursten & De Roeck, 2014, 'Output-only structural health monitoring in changing environmental conditions by means of nonlinear system identification', *Structural Health Monitoring*, Vol 13(1) 82–93.

Rizzo & Vignoli, 2015, 'Monitoring and dynamic identification of Vega-A platform', *Proceedings of the ASME 34th International Conference on Ocean, Offshore and Arctic Engineering, OMAE2015*, May 31-June 5, 2015, St. John's, Newfoundland, Canada.

Van Overschee P. and De Moor B. 1996. Subspace Identification for Linear Systems: Theory-Implementation-Applications. Dordrecht, Netherlands: Kluwer Academic Publishers.