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Investigation of the condition and the behavior of a modular floating structure by harnessing monitoring data

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ABSTRACT

In this paper, the condition and the behavior of an installed and operating Modular Floating Structure (MFS) is investigated and assessed by harnessing field monitoring data and using collectively multiple Correlation Coefficients (CCs) between measured quantities. The examined MFS consists of five pairs of interconnected floating concrete modules and it functions as a floating breakwater. The field monitoring data are acquired through a sensor network deployed on one pair of modules (connected through two groups of connectors) of the MFS. A methodological data processing framework for data organization, manipulation and post-processing is developed and presented. This framework enables the quantification of the structure's condition at different time periods through the calculation of CCs: (a) between the incident wave height and the tensions of the mooring lines and (b) between the tensions of the mooring lines, considering various wave directions. Recorded data at three characteristic time periods during the structure's lifetime are used, namely: (i) before any failure (structure's initial condition), (ii) after the failure of the first connectors' group and (iii) after the failure of the second connectors' group. The data processing framework developed in the present paper is applied to the above recorded data in order to calculate CCs and, therefore, quantify the structure's condition, at the three aforementioned time periods. The quantification of the structure's initial condition resulted to conclusions that were consistent from a physical point of view with the most recently documented, available in-situ mapping of the mooring lines' configuration in the horizontal plane. By considering the structure's initial condition as a reference base for comparison, the effect of the connectors' failure on the CCs, used to quantify this condition, was also investigated and efficiently assessed. Specifically, the significant changes observed in the variation patterns of all examined CCs, when compared with their respective patterns corresponding to the structure's initial condition, demonstrated and confirmed the existence of significant reformation of the examined structural system resulting from the connectors' failure. In this way, the effectiveness of the joint utilization of CCs to assess the structure's condition was proved.

1. Introduction

The world's oceans are being constantly populated by offshore structures that serve a variety of purposes: from oil and gas production to energy generation and coastal protection. However, many of the offshore structures are reaching or have already reached their design lives. At that point, the entities or authorities responsible of or associated with an offshore

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structure are faced with the decision of removal/decommissioning or life extension. To support this decision, they rely on an integrity management process that has accompanied the structure during its lifetime up to that point. Fundamental elements of an integrity management process are inspection and maintenance of the structure.

Today, the maintenance of structures, both onshore and, especially, offshore, is a combination of preventive (schedule-based maintenance) and reactive/corrective (in the case of damage) measures [1]. Schedule-based maintenance is carried out at prescribed intervals, most usually without the structure's actual condition being taken into account. The frequency of the schedule-based maintenance is determined through a compromise between the cost of maintenance and the risk of a potential damage. Contrary to the above, i.e. combination of schedule-based maintenance and reactive/corrective measures, condition-based maintenance is gaining appreciation for its merit. Condition based maintenance relies on the structure's actual condition, assessed by proper inspection, to determine the required maintenance of the structure. When applied, it can dramatically reduce the lifecycle cost of a structure, whilst increasing its reliability and safety [1]. Structural Health Monitoring (SHM) systems can support the condition-based maintenance. They are defined as "*autonomous systems for the continuous monitoring, inspection and damage detection of a structure with minimum labor involvement*" [2]. SHM is based on the fundamental principle that damage affects the stiffness, mass or damping of a structure, which in turn alters the structure's dynamic behavior and performance. The presence, type, location and severity of damages in combination with an estimation of its remaining useful lifetime can be used to determine a structure's health state [1]. A significant amount of research exists on SHM and its application on marine structures, with an overview presented in the following paragraphs. SHM uses monitoring data in conjunction with mathematical models to detect subtle changes in the system and predict potential failures. A different approach than SHM is presented in the present paper. Based purely on sensor data (data-driven), a methodology using Correlation Coefficients (CCs) to assess the condition of a structure and identify changes to that condition is proposed.

Damage detection methods were for the first time developed by the oil and gas industry in the 70's and 80's of the last century and they were mainly based on the calculation of the structure's natural frequency through vibration detection techniques [3]. Begg et al. [4] were among the first, who investigated the application of SHM in fixed-bottom offshore structures. Their efforts were based on experimental measurements on a scale model and focused on the identification of the structural integrity of a jacket-type structure through recording its vibrations. Until today, various techniques for monitoring a fixed-bottom offshore structure have been developed (e.g. Ref. [5]~ [13]). Duncan [5] developed a technique to estimate the actual stiffness and damping characteristics of a gravity platform considering simulation-based numerical data related to appropriate physical quantities describing the behavior of the platform. Several other investigators focused on damage detection in jacket-type structures using different methods/techniques: Mangal et al. [6] and Elshafey et al. [7] used neural networks, Mojtahedi et al. [8] used fuzzy logic systems, Hillis and Courtney [9] performed a bicoherence analysis of ambient vibration measurements, Malekzehtab and Golafshani [10] used genetic algorithms, while Asgarian et al. [11] applied a wavelet packet analysis. Wang [12] developed an iterative modal strain energy method for damage detection in fixed-bottom offshore structures, whereas Wang et al. [13] used genetic algorithms for damage detection in a jack-up platform. In Mangal et al. [6], Elshafey et al. [7], Mojtahedi et al. [8], Malekzehtab and Golafshani [10] and Asgarian et al. [11] the data required for developing the corresponding damage detection methods were obtained through the implementation of laboratory experiments. On the other hand, Hillis and Courtney [9] and Wang [12] generated data from finite element models, while Wang et al. [13] obtained the required data from appropriate numerical models combined with laboratory experiments. Although damage detection methods have been extensively developed, there appears to be lack of published material on the use of full-scale measurements to develop and validate these methods.

With regards to Floating Structures (FSs), the first application of a SHM is traced back to the Joliet TLWP in 1987 [14], where a system measuring the platform's weight characteristics (distribution and center of gravity) was installed and its measurements were used for load management and ballast control purposes. The above system, supplemented by the recorded oceanographic conditions, was, then, used to verify laboratory model tests and numerical results employed for TLP design. Furthermore, a SHM system was installed on Auger TLP [15] and its measurements were used: (a) for calibrating numerical models and (b) as a means for assessing the tendons' fatigue damage, making it one of the first research efforts towards the quantification of damage of a FS through the utilization of measured field data. Monitoring the behavior, the position and the geometry of mooring lines and of riser systems of floating installations using acoustic transponders, strain meters, sonars, etc. is quite common in the oil and gas industry. In addition to mooring lines and risers, operators may choose to monitor the response of the FSs themselves by using e.g. GPS and accelerometers [16–19]. More specifically, Liagre et al. [16] compared inertial navigation and DGPS systems as data sources to determine the motions of a FS during a storm. Gkaras et al. [17] presented a methodology for deriving the motions of a spar by using DGPS data recorded during two hurricanes, while Gerner et al. [18] elaborate on data acquisition, archiving and transmission from monitoring systems installed on floating installations in the Gulf of Mexico. Finally, in Michailides et al. [20] a recently installed Sensor Network for Monitoring the Response (SNMR) of a Modular FS (MFS) was presented and characteristic examples of time series of the measured quantities obtained during the operation of the SNMR were shown in order to highlight the SNMR's capabilities.

Based on the above, it is clear that there exists a quite extensive research related to the characteristics of SHM systems installed on FSs (e.g. sensor types/locations, measured quantities) as well as to data acquisition methods. However, gathering, processing and interpreting field data of an FS for the purpose of the quantification, investigation and assessment of the structure's condition during its lifetime using purely data-driven methods appears to lack so far of considerable published research support.