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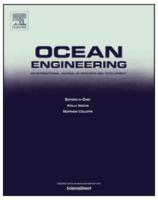

Review

A review of the state-of-the-art developments in the field monitoring of offshore structures

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ABSTRACT

This paper presents a comprehensive review of the state-of-the-art developments in the field monitoring of offshore structures. The field monitoring of offshore structures plays a vital role in reducing the risk of structural failure and guaranteeing the success of offshore operations, which is also considered as an important part of the offshore platform integrity management. The typical monitoring scopes including the metocean, structural motions and operation status are introduced respectively. Moreover, the related sensor technologies are also summarized. The design aspects of monitoring systems are introduced, and the applications of offshore structures field monitoring are discussed. The field monitoring in other ocean-related fields, such as the health monitoring of submarine pipelines and ocean ecological environment monitoring, are briefly described in this paper. Finally, conclusions and future development directions are addressed.

1. Introduction

Since the first full-scale measurement system for offshore platforms was put into practice by the BMT company in 1987 (Peters et al., 1990), field monitoring has been widely developed in the Gulf of Mexico, the North Sea, the ocean adjacent to Brazil and West African waters to record the environmental parameters, structural responses, riser tension, tendon tension, shapes of mooring systems, etc (Peng and Zhi, 2012). Prototype measurements of offshore platforms in the South China Sea and the Bohai Sea have been conducted since the 1990s by Shanghai Jiao Tong University (Hu et al., 2011) and Dalian University of Technology (Du et al., 2014), respectively. To date, many platforms worldwide have been synchronously equipped with monitoring systems during the construction of the platforms. A significant number of field monitoring projects for offshore platforms have been developed by oil and gas companies and institutions all over the world. Table 1 shows the typical monitoring projects of offshore platforms since 1996.

As the exploitation of marine resources moves into deeper water, floating platforms for drilling or production may be subjected to an extreme environmental condition, and the safety of personals and platforms is a priority position in platform design and operation. Compared with the assumptions and simplification in numerical analysis and the limitations in physical model tests, field monitoring of offshore structures can directly obtain raw data in real time, enabling the timely detection of structural failures, safety assessments, and predictions of performance changes and the remaining structural life (Du et al., 2014). Moreover, field monitoring can verify the design parameters and provide a database for post project analysis (Peters et al., 1990). Due to the complex environment loads and complicated failure mechanisms of the riser and mooring systems, field monitoring has become an effective method for obtaining real-time tracking and feedback information based on a specialized monitoring system to reduce failure risk. During installation operations at sea, field monitoring can provide necessary operational support. These factors all contribute to the popularity of research on field monitoring.

This paper provides a comprehensive review of the recent developments in field monitoring for offshore structures. Noteworthy monitoring scopes and related sensing technologies, including sensing the metocean, structural motions, and structural operational status, are discussed in Section 2. Then, the designs of the monitoring systems are described with respect to optimization of sensor placement, integrated marine monitoring systems (IMMSs), and independent remote monitoring systems (IRMSs) in Section 3. Next, the applications of offshore structures field monitoring are discussed in Section 4; these applications can be divided into four parts: construction of the database, safety evaluation and early warning, safeguarding of offshore construction

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Table 1
The typical field monitoring projects of offshore platforms.

Year	Project	Main monitoring contents
2017	Two platforms in Malaysia	The metocean and the motions of topsides were monitored during the floatover installations (SJTU, 2017)
2015	Berkut oil platform	An integrated system was provided to monitor the seismic response of the platform
2015	Wellhead	The BOP stack motions were measured and wellhead fatigue was calculated during a deployment in the Gulf of Mexico.(Fugro, 2015)
2014	LF 7-2 jacket platform	Stress response of the jacket legs was monitored by mounting fiber grating strain sensors to calculate the collision force (Ge et al., 2016a)
2013	PY 34-1 jacket platform	The stress of barge rocker was monitored during the jacket lunch operation (Chen, 2014)
2012	LW 3-1 jacket platform	The process of jacket launch was monitored with integrated GPS/INS system (Chen, 2014)
2011	LH11-1 FPS	Both the metocean data and responses of the platform were recorded in one typical typhoon event (Qu et al., 2013)
2010	HYSY 981 drilling platform	The air gap performance and structural strain characteristics of the platform were monitored
2009	Chevron Tahiti spar	The dynamic response of the catenary was monitored
2009	Espirito-Santo FPSO	The tension of the anchor line was monitored by an inclination sensor and an underwater acoustic signal transmission system
2007	Marlin FPSO	The flexible risers were monitored for ring leakage, internal and external pressure
2006	Schiehallion FPSO	The bending moments of the flexible risers hang-off position were measured using an optical fiber sensor
2005	A spar platform in Gulf of Mexico	Fatigue damage of two top tension risers was monitored
2004	Marco Polo TLP	The environment, position and attitude of the riser were monitored to verify the TLP design method
1998	Alliance drilling platform	The VIV of the drilling riser was monitored using 5 acceleration sensors
1997	Neptune spar	The dynamic response of the platform was monitored under hurricane sea conditions
1996	17 deepwater floating platform in Gulf of Mexico	The integrated marine monitoring system was established and gradually improved

Note: The cases before 2009 were presented by Peng and Zhi (2012).

operations and integrity management. Field monitoring in other ocean-related fields, such as the health monitoring of submarine pipelines and ocean ecological environment monitoring, are briefly described in Section 5. Conclusions and further research directions are noted at the end.

2. Monitoring scopes and sensing technologies

An integrated field monitoring system of an offshore structures should provide tracking and feedback information on the metocean, structural motions and operational status, to obtain a comprehensive understanding of structural dynamic behavior, to calculate the accumulated damage and to assess the overall safety status. As the fundamental elements of the monitoring system, sensors with satisfactory performance are essential to ensure the reliability of monitoring systems. Thus, the precision, durability and stability aspects of sensors are discussed in this section.

2.1. Metocean

Metocean factors are complicated when combined with wind, waves, currents and sometimes internal waves and ice. Structural responses can be significant when a platform is subjected to extreme environmental conditions, which will result in serious consequences such as ecocatastrophes or even deaths. Therefore, it is essential to conduct the matocean monitoring.

2.1.1. Wind

Wind speed and direction are primary inputs for evaluating floating system responses (Qu and Shi, 2013), as crane operations and helicopters are susceptible to wind loads. A vane anemometer is widely used to detect the speed and direction of the wind, while an acoustic anemometer with high reliability is preferable in hurricane (Qu et al., 2013). Different types of anemometers are listed in Table 2.

2.1.2. Waves

The significant height and peak period of waves are the primary factors that influence platform responses, and can be easily measured by a wave buoy (Edwards et al., 2005). Two wave buoys, the Motion Reference Unit (MRU) and the differential Global Positioning System (DGPS) used in the Smart-800 buoy, are described by Krogstad et al. (1999). In addition, X-band radar is also available to measure wave parameters (Borge and Soares, 2000; Reichert et al., 2006). It is possible to install the X-band radar even on a movable platform and from there to scan the sea surface with high temporal and spatial resolutions. It estimates the directional wave spectra with a range of several kilometers based on the characteristics of the site where it is installed. By analyzing the spatial and temporal changes of the radar backscatter from the sea surface, it can determine the directional wave and even surface current information. In 1994, the X-band WaMos II radar was installed on the 2/4 k spar platform in the North Sea to measure wave characteristics with high precision (Irani et al., 2007). Additionally, air gap sensors were used to measure the air gap between the lower deck and the sea level and the wave height information can also derived from the measured data. The configuration and number of air gap sensors are recommended by Edwards et al. (2005). The wave buoy, microwave radar air gap sensor and X-band radar are shown in Fig. 1. Comparisons between the different wave measurement sensors are listed in Table 3.

2.1.3. Current

Long, slender structures are susceptible to current in deep water, and the response of risers and mooring systems to currents can sometimes be destructive. Deepwater current observation around platforms is essential and feasible through the installation of acoustic Doppler current profilers (ADCPs) (Govea et al., 2006). There are three types of ADCPs: the 38 kHz Ocean Surveyor(OS) ADCP, 75 kHz Long Ranger(LR) ADCP and the 300 kHz Horizontal(H) ADCP, as shown in Fig. 2. The 38 kHz OS-ADCP provides the deepest penetration with a range of up to 1100 m and is widely installed in deep water. The H-ADCP is always installed on the platforms to measure the current profile with a small tilt. The LR-ADCP is deployed looking downward from a heave plate with a range of up to 750 m. Current monitoring with these three types of ADCP packages can achieve an overall view of the current within a 4000-foot water depth

Table 2
Properties of the parameters of different types of anemometers.

Type	Working principle	Wind speed (m/s)	Accuracy (%)	Remarks
Vane	Based on the rotational speed of the vane	≥3	1.5	Low cost and less maintenance
Hot wire	Based on the measured current and resistance	1–9	5	Low accuracy and need to adjust the temperature
Ultrasonic	Based on the frequency of a vortex	1–25	1.5	High reliability and stability
Hall effect	Based on the change in voltage	0–20	1.1	High precision and widely application range