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Review

A review of vibration control methods for marine offshore structures

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ABSTRACT

Vibrations in marine offshore marine structures, due to various environmental loads, can reduce platform productivity, endanger safety, affect serviceability of the structure and have been attributing factors in several major accidents and failures in the marine and offshore industry over the last few decades. Controlling the vibrations in marine offshore structures potentially due to self-excited nonlinear hydrodynamic forces, large deformations and highly nonlinear responses, is challenging. While general vibration control strategies have been investigated and demonstrated to be effective for structural vibration mitigation, there currently is limited research highlighting the specific methods available for design engineers and researchers concerned with vibrations of marine offshore structures.

This paper provides a review of vibration control techniques and their application for marine offshore structures. Initially, a review of the general approaches following the conventional categorization of passive, active, semi-active and hybrid is presented. This is then followed by a review of the specific marine offshore vibration control methods and a comparison of the approaches. The marine offshore structures considered in this review include jacket structures, tension leg platforms (TLPs), spar structures, floating production storage and offloading vessels (FPSOs) and riser structures. It can be found that the general trend is progressing towards semi-active and hybrid vibration control from passive or active control, as they provide more practical approaches for implementation, possessing the advantages of passive and active control systems.

1. Introduction

In general, vibration is undesirable in most engineering systems. Mechanical vibrations lead to excessive wear of bearings; loosening of fasteners; structural and mechanical failures; discomfort and reduced efficiency. Hence it is necessary to eliminate or reduce vibration (Rao, 2011). Vibration reduction can be achieved in many different ways, depending on the problem; the most common are stiffening, damping and isolation. Stiffening involve a sort of shifting the resonance frequency of the structure beyond the frequency band of excitation. Damping consists of reducing the resonance peaks by dissipating the vibration energy. Isolation is a method that can be used to prevent the propagation of disturbances to sensitive parts of the systems (Preumont et al., 2011). When it comes to marine and offshore engineering, it is really challenging to understand various vibration behaviorss, as they are usually subjected to various loads, with large deformations and highly nonlinear responses.

The environmental loads could contribute the complexity of marine offshore structural vibration control. As summarized in Table 1, marine offshore structures are often subjected to several types of environmental loads during their lifetime. These loads are dynamic in nature and can cause vibration failure in structural components (Wang and Li, 2013). Vibrations in these structures due to dynamic wave (Li et al., 2003; Chen et al., 2013), wind (Haritos, 2007), current (Mostafa and El Naggar, 2004), ice (Yue and Bi, 2000; Bjerkås, 2006; Wang et al., 2013) and earthquake (Ou et al., 2007; Bargi et al., 2011) loads can reduce platform productivity, endanger safety, affect serviceability of the structure and have been attributing factors in several major accidents and failures in the marine and offshore industry over the last few decades. For example severe ice-induced vibrations have been observed from field data on several jacket platforms in the Bohai sea (Yue and Bi, 2000; Yue et al., 2008; Liu et al., 2009). Four platforms have collapsed due to ice [two in China in 1969, 1979 (Liu et al., 2009) and two in USA in 1964 (Bjerkås, 2006)] and recently it was reported that ice-induced vibrations threatened the structural performance and production facility of JZ20-2MUQ jacket platform in the Bohai Sea (Wang et al., 2013). These vibrations, induced when ice sheet breaking frequencies (as the ice sheets pass and break through the legs of the structure)

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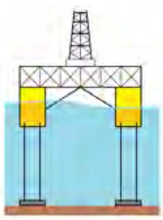
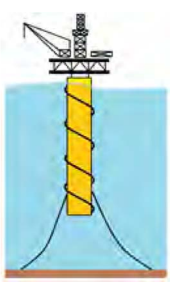
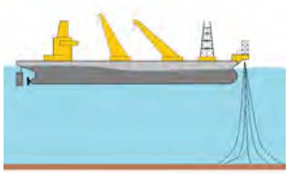
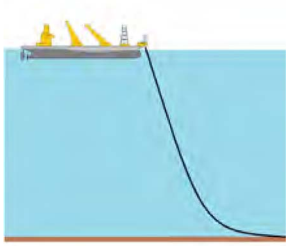
Table 1
Offshore marine structures.

	**Jacket platforms** Fixed offshore platform, tubular (typically welded 1–2 m diameter steel) members interconnected to form a three-dimensional frame (Taghikhany et al., 2013), typically used in water depths from a few meters to more than 100 m (shallow water) (Chakrabarti, 2005).
	**Tension leg platform (TLP)** Vertically moored floating oil or gas production facility, moored to the seafloor by tension legs (buoyancy tensioned steel pipes (tendons) extending from each corner of the structure), typical natural periods of around 3–5 s, used in water depths greater than 300 m (about 1000 ft) and less than 1500 m (Refat and El-gamal, 2014), TLP design is site dependent (high installation risk and cost), as of March 2015, TLPs operating worldwide (Offshore Magazine, 2015a) primarily installed in the Gulf of Mexico, first TLP-Hutton by ConocoPhillips, 1984, 147 m water depth ((Mashhadifarahani, 2015) and (Offshore Magazine, 2015a)), deepest TLP – Big Foot by Chevron, 2015, 1615 m water-depth (Dagang et al., 2013).
	**Spar** Deep-draft floating hollow cylindrical platform (structure), with low centre of gravity (to provide stability), used in deep water applications, strakes often used to reduce vortex induced vibrations (VIV), three types (classic, truss and cell), as of March 2015, 19 operating spars structures (18 of which are in the Gulf of Mexico) (Islam et al., 2012).
	**Floating production storage and offloading vessel (FPSO)** Moored vessel based floating offshore oil and gas production facility, with hydrocarbon processing facility (on the deck) and storage (below the deck), used for remote or deep water locations where seabed pipelines (from an oil well to an onshore terminal) are not cost effective, compared to fixed platforms often more economical (faster development, relocatable, lower abandonment costs), 164 operating FPSOs worldwide (as of March 2015) (Offshore Magazine, 2015a).
	**Riser** A (usually steel) pipe that connects a floating platform such as an oil rig or drill-ship on the ocean surface to the sea floor, used to transport fluid (oil from the seabed to the platform or mud/cement to the seabed), typical diameters range from 2–20 in., water depths 1000–3000 m (Offshore Magazine, 2015b), experience large dynamic responses, susceptible to current induced vibration i.e., VIV.

match the structural natural frequencies, are reportedly prone in slender structures, e.g., jacket platform and wind turbine supports (Yue et al., 2008). Wave-induced vibrations are also reported to lead to dangerous nonlinear dynamic responses of offshore structures (Raheem, 2013), including ringing and springing of monotowers and TLPs (Moan, 2009), whipping of FPSOs (Ledoux et al., 2004). While increased excitation (vibration), including vortex-induced vibrations (VIV) and wave-induced oscillations, are reported to contribute to premature damage (fatigue) and failure of riser structures (Pham et al., 2016; Le Cunff et al., 2002). Vortex-induced motions (VIM), are also reported to cause large motions and large forces to be applied to mooring lines, contributing to premature failure (Oakley et al., 2005). Wind induced vibrations are widely cited in offshore platform surveys as causing damage to deck structures (Gomathinayagam et al., 2000). Lateral wind loads, typically 10% of the total lateral loads for fixed offshore structures and 25% in the case of compliant and floating platforms, are also reported to cause increased dynamic stresses, higher torsional loads and resonant vibrations in structural components (Gomathinayagam et al., 2000). Furthermore, vibrations on FPSOs have been reported to cause discomfort and health problems (Olunloyo and Osheku, 2012).

As a result structural vibration control of offshore structures under environmental loading has drawn much attention from designers and researchers, becoming a very important research subject in ocean engineering. This has led to considerable experimental and theoretical studies on the subject, along with various vibration mitigation methods being proposed for marine offshore structures. To address the growing number of studies and methods, this paper provides a comprehensive review of the literature. First a review of general vibration control methods is presented following the conventional system categorization approach of passive, semi-active, active and hybrid. This is then followed by a detailed review of the literature on marine offshore structure vibration control. Thereafter, a comparison and discussion of the various methods is presented identifying their applications, advantages, disadvantages and remaining research challenges.

2. General vibration control methods

General vibration control methods can be broadly characterized as passive, active, semi-active, and hybrid (Rahman et al., 2015), where;.

- **Passive methods**: A vibration control system is called passive if it uses passive device in which it does not require an external power source for its operation and utilizes the motion of the structure to develop the control forces (Thenozhi and Yu, 2013). It is usually consist of viscoelastic damping layers.
- **Active methods**: A vibration control system is called active if it uses external power to perform its function (Rao, 2011). Active methods generate control forces on the structure to control vibrations (Usually based on a feedback system of sensors and actuators).
- **Semi-active methods**: A semi-active control system typically requires a small external power source for its operation and utilizes the motion of the structure to develop control force, where the magnitude of the force can be adjusted by an external power source (Thenozhi and Yu, 2013). It uses the advantages of both active and passive devices. Semi-active methods or passive tunable systems, control some tunable parameter (e.g. stiffness or damping) to achieve vibration control. Examples include shape memory alloys, pneumatically controlled granules and electro/magneto-rheological fluids.
- **Hybrid methods**: Hybrid methods combine robustness of the passive device and high performance of the active devices (Thenozhi and Yu, 2013). This has resulted in enhanced vibration suppression over a wider frequency and excitation range and has overcome some of the drawbacks of active or passive alone treatments.