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Research paper

# Cointegration strategy for damage assessment of offshore platforms subject to wind and wave forces

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ABSTRACT

In structural engineering, offshore structures are undoubtedly among the most exposed to the effects of harsh environmental conditions. The external conditions of these semi-immersed systems involve complex combinations of wave and wind loads. The operating conditions are also unique because oil production platforms are subjected to repeated loading and unloading cycles of the extracted material, which continuously alter their mass. These characteristics make the definition of a structural health monitoring (SHM) protocol highly challenging but necessary to avoid environmental disasters. In this regard, this study discusses an SHM method that can be applied to offshore structures under realistic wave and wind loads. This approach combines anomaly detection, frequency domain decomposition, and a cointegration strategy. Two machine learning regression algorithms were tested to define a cointegration relationship: the support vector machine and the relevance vector machine. The effectiveness of the overall method was evaluated on time-domain signals generated from a finite-element model of a fixed steel platform, on which the Davenport and JONSWAP spectra were used to simulate wind and wave forces. The results show that this damage detection strategy is effective in supervising the health conditions in the analyzed scenario.

## 1. Introduction

Owing to their particular location, offshore platforms are exposed to extreme weather conditions such as downbursts and strong thunderstorms. These factors and others such as earthquakes, subsidence, and accidental collisions with ships, can cause structural damage, which can endanger the lives of operators and irreparably damage the ecosystems in which these platforms exist. For example, a downburst can cause a floating system to oscillate significantly, possibly causing damage (Nichol et al., 2021). Generally, structural damage arises from an accumulation of fatigue damage or sudden local collapse, which could impact the global static and dynamic behavior. For instance, in 1980, a storm hit the Norwegian North Sea, tearing five legs of the semi-submersible platform Alexander L. Kielland, resulting in the loss of 123 people. The accident investigation revealed that one bracing of the platform developed fatigue cracks before this extreme weather phenomenon, and the failure catastrophe began at this weak point (Almar-Naess et al., 1984).

Therefore, periodic inspections and/or continuous surveillance is required for all platform types. Consequently, structural health monitoring (SHM) and anomaly detection have received increasing attention for this type of structure (Ruotolo et al., 2000; Surace and Worden, 1998, 2010). SHM uses an automatic monitoring system, including sensors, data processors, and analysis terminals, to assess the health of platforms over time (Chen and Ni, 2018). This practice is quite different from nondestructive technologies (NDTs), such as X-ray, acoustic, or eddy currents, which can generally detect damage locally (Civera and Surace, 2022a). If global detection is required, using these techniques can take a long time and can be economically impractical. SHM techniques, particularly vibration-based inspection (VBI) (Rytter, 1993), are often used to obtain information on the global health status of structures. VBI detects changes in dynamic properties and analyzes the relationship between them and the occurrence of structural damage. This is generally performed using data processing techniques and damage-related features, ranging from the most basic (e.g., natural frequencies and mode shapes) to more refined parameters such as entropy (Civera and Surace, 2022b) or signal bicoherence (Civera et al., 2017), which quantify phase coupling within the signal (Hillis and Courtney, 2011).

For offshore platforms, recent methodologies reported in the

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