Journal of Sound and Vibration 416 (2018) 224–243

Contents lists available at ScienceDirect

Journal of Sound and Vibration

journal homepage: www.elsevier.com/locate/jsvi

Stochastic dynamic analysis of marine risers considering Gaussian system uncertainties

Pinghe Ni [a,b], Jun Li [a,*], Hong Hao [a], Yong Xia [b]

[a] Centre for Infrastructural Monitoring and Protection, School of Civil and Mechanical Engineering, Curtin University, Kent Street, Bentley, WA 6102, Australia

[b] Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

ARTICLE INFO

Article history:
Received 19 June 2017
Received in revised form 15 November 2017
Accepted 24 November 2017

Keywords:
Karhunen–Loève expansion
Polynomial Chaos expansion
Monte Carlo Simulation
Stochastic Finite Element Method
Model reduction

ABSTRACT

This paper performs the stochastic dynamic response analysis of marine risers with material uncertainties, i.e. in the mass density and elastic modulus, by using Stochastic Finite Element Method (SFEM) and model reduction technique. These uncertainties are assumed having Gaussian distributions. The random mass density and elastic modulus are represented by using the Karhunen–Loève (KL) expansion. The Polynomial Chaos (PC) expansion is adopted to represent the vibration response because the covariance of the output is unknown. Model reduction based on the Iterated Improved Reduced System (IIRS) technique is applied to eliminate the PC coefficients of the slave degrees of freedom to reduce the dimension of the stochastic system. Monte Carlo Simulation (MCS) is conducted to obtain the reference response statistics. Two numerical examples are studied in this paper. The response statistics from the proposed approach are compared with those from MCS. It is noted that the computational time is significantly reduced while the accuracy is kept. The results demonstrate the efficiency of the proposed approach for stochastic dynamic response analysis of marine risers.

1. Introduction

Marine risers are used to connect the offshore platforms on the water surface to the well head at the sea floor, ensuring the safe operations of offshore platforms in the oil and gas industry. Excess vibration of risers is considered as the main cause of the fatigue induced degradation and failure [1], which could lead to catastrophic infrastructure damage and environmental consequence. Significant attention has been drawn to investigate the dynamic vibration analysis of marine risers. A comprehensive review of flexible riser modelling and analysis techniques can be found in Ref. [2]. Lei et al. [3] proposed a frequency domain method to investigate the effect of time-dependent tension force on the lateral deflection of marine risers. Tsukada and Morooka [4] developed a numerical method to estimate the vortex-induced vibration forces of a catenary riser. Han et al. [5] carried out experimental tests to investigate the dynamic characteristics of vortex-induced vibrations of a riser. The dynamic response characteristics were obtained from the analysis of strain responses, displacement amplitudes, dominant modes, response frequencies and drag force coefficients. Rivero-Angeles et al. [6] presented a comparison study on the modal identification of offshore risers by using two methods, namely, the Frequency Domain

* Corresponding author.
E-mail addresses: junli@curtin.edu.au, LI.Jun@connect.polyu.hk (J. Li).

https://doi.org/10.1016/j.jsv.2017.11.049

Decomposition Method and the Conventional Spectral Analysis Method, with numerical simulation data. Gao et al. [7] proposed a method to study riser's fatigue damage induced by the vortex-induced vibrations. The riser was defined as a pinned-pinned cable model and the fatigue damage of the riser can be predicted by applying the modal superposition method combined with the *S* - *N* curve.

In the above-reviewed studies on the dynamic analysis, modal identification and damage detection of marine risers, deterministic analyses are conducted by assuming the system parameters with specific constant values. However, in reality, the inevitable random fluctuations in the structural system, i.e., random variations of the material properties including mass and stiffness, affect the structural responses, which have not been well considered. For example, the growing marine organisms have a number of adverse effects on offshore structures, one of which is that it may change the mass density of the risers significantly. Moreover, the long term corrosion in aggressive sea environment may also significantly affect the stiffness of risers. These uncertainty effects should be properly considered for a better understanding of the lifetime performance of marine structures.

Probabilistic structural response analysis gains more attention in the last decades [8]. In the probabilistic structural response analysis, various methods have been developed to represent the random input parameters and evaluate the random output statistics. Karhunen–Loève (KL) expansion method [9], orthogonal series expansions [10] and optimal linear estimation method [11] have been developed and used to simulate random system parameters. Neumann series expansion [12] and Polynomial Chaos (PC) expansion [13] can be used to represent the random output responses. KL and PC expansion methods have been used for modelling the uncertainties in the dynamic systems [13–18]. Stochastic Finite Element Method (SFEM) [13] has been successfully applied in many engineering areas, for example, structural response analysis with uncertain system parameters [8], bridge–vehicle interaction analysis [14] and reliability analysis [15], etc.

Some studies have been conducted to perform the stochastic dynamic analysis of offshore structures. Bi et al. [19] carried out the stochastic seismic response analysis of offshore pipelines subjected to spatially varying ground motions. The mean peak seismic responses of pipelines in the axial and lateral directions were stochastically formulated in the frequency domain. Foo et al. [20] performed the stochastic simulations of riser sections. Three-dimensional riser-sections undergoing elastic deformations due to random pressure loads were considered. The riser's deformations with the stochastic elastic modulus and deterministic loading were also studied. He and Low [21] predicted the probability of riser collision under stochastic excitations and various uncertainties. The considered random variables included the current, drag coefficient, vessel motions and riser mass, and the likelihood of collision was obtained. Mousavi et al. [22] estimated the probability of fatigue or strength failure of steel catenary risers. The uncertainties in the yield strength and fatigue capacities, as well as the environmental conditions, were considered. The proposed method was combined with the integrity based optimal design to improve the safety of steel catenary risers. Qiu et al. [23] discussed the uncertainties related to the prediction of loads and responses of ocean and offshore structures, particularly in the model tests. Uncertain parameters included the physical properties of the fluid, initial conditions, model definition, environment, scaling, instrumentation and human factors. Uncertainty effect on the dynamic response of offshore structural risers have not been well investigated yet.

This paper investigates the effect of uncertainties in the structural parameters, i.e. mass density and elastic modulus, on the dynamic responses of the marine risers under sea wave loads. The stochastic mass density and elastic modulus are represented by using KL expansion. The mean value and standard deviation are assumed based on design and available information, and the probability function of random parameters is assumed to follow the Gaussian distribution. PC expansion is adopted to represent the stochastic output response, in which the covariance matrix of the output response is unknown. Two numerical examples are studied in this paper. In the first example, the marine riser is simulated as a beam structure. Then a more complicated cylinder model with shell elements is studied in the second example. Model reduction based on the Iterated Improved Reduced System (IIRS) technique is applied to reduce the dimensions of stochastci system matrices and improve the computational efficiency. The response statistics of the modeled riser with and without using the model reduction technique are compared with those from Monte Carlo Simulation (MCS). Results demonstrate the accuracy and efficiency of the proposed approach. It should be noted that in reality the offshore environmental and loading conditions usually experience, if not more significant, the same random fluctuations as the structural parameters. They are, however, not considered in the present study because the primary objective of the present study is to introduce and demonstrate the accuracy and efficiency of the reduction method in stochastic analysis of dynamic structural responses. Without loss of generality, only the random variations of structural parameters are considered.

This paper is organized as follows. In Section 2, the theoretical background of KL expansion and PC expansion for representing the random processes is briefly reviewed. KL expansion can be used to represent the known stochastic fields (i.e., the stochastic inputs) efficiently. PC expansion is adopted to represent the stochastic outputs since the covariance matrix of the random output is unknown. In Section 3, the deterministic equation of motion of an offshore riser is introduced first. The random fields of the mass density and elastic modulus are generated by using KL expansions, and random output responses are represented with PC expansions. The stochastic dynamic system is formulated in Section 3.3. Model reduction technique is then used to reduce the dimensions of the stochastic dynamic system in the response analysis by eliminating the