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A simplified computational method for random seismic responses of a jacket platform

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ABSTRACT

A simplified method for modeling Jacket Offshore Platform was developed and numerical examples were presented to demonstrate the validity of the proposed method. In this method, a jacket platform was described as a cantilever beam subjected to an axial compressive load acting at the top-end centre of the jacket. The random seismic responses of the model were derived by using both the pseudo-excitation method and the classical Ritz method. The authors found and demonstrated in this paper that this proposed method may be used to calculate the random responses accurately and efficiently. In particular, the responses of a non-uniform beam, in the form of an auto-PSD function, cross-PSD or higher spectral moments could be solved directly without the need to determine the normal modes. The writers included an example in which the solution was obtained using the proposed method with a selected Ritz function. The results were compared with that obtained using the conventional finite element method (FEM). The findings of the study showed that the proposed method was effective, practical and useful in the seismic design of platforms.

1. Introduction

Although vibration of jacket platforms under seismic excitation has been studied extensively, the subject is still being investigated today (Zhou, 2004; Han et al., 2006, 2008; Bargi et al., 2011; Park et al., 2011). With the wide-spread use of the finite element software, the research focus has been set on three-dimensional modeling of the seismic response of the platform. Ideally the more comprehensive and more inclusive are the models, the more accurate the computation results are expected. However, these comprehensive models are not easily accomplished and acceptable in engineering practice because of their low computational efficiency and model complexity. Therefore, the current engineering practice still prefers simplified structural calculation model in which a reasonable degree of precisions could be achieved. This paper deals with such a simplified model and method of computation.

In a conventional random vibration methods, such as the Square Root of the Sum of Squares (SRSS) and Complete Quadratic Combination (CQC) methods, the combination of modes are either ignored or they are too complicated if not outright difficult to be applied. An accurate and efficient method for computing the random vibration, known as the Pseudo-Excitation Method (PEM), has been developed since early 1980s. PEM could be applied with ease because by using this method, the structural stationary random response analysis may be reduced to the analysis of structural harmonic response, while non-stationary random response may be calculated by using a step-by-step integration scheme, see Lin et al. (1995). PEM is an accurate Complete Quadratic Combination (CQC) method as the cross-correlation quadratic terms between the participant modes and that between the excitations have both been considered. In general, the random responses of a continuous structure may be obtained by using the orthogonal property of natural modes to reduce the number of degrees of freedom, see Chopra (2005). Thus some normal modes of the continuous structure have to be computed, which may present certain degree of challenge in the analysis of the non-uniform beam whose normal modes may not be determined readily.

In this study, the PEM associated with the classical Ritz method was used to analyze the random seismic responses of jacket platforms, such as auto-PSD function, cross-PSD and higher spectral moments, etc., without the need to compute the normal modes. A simplified method of modeling jacket platform was studied first, and a simplified calculation model based on beam theory was presented for the analysis of random seismic responses. Numerical examples were conducted to demonstrate the validity of the methodology. Then the classical Ritz method and the pseudo-excitation method were combined to prescribe the problem: the pseudo governing differential equation was developed by specifying the pseudo-ground acceleration, and the

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Ritz approach was used to study the transverse vibration of platforms by expanding the displacement in a series of approximate functions that could satisfy the boundary conditions. A numerical experiment was conducted using the method proposed and the findings using this method were compared with those obtained from FEM. The reliability and robustness of the proposed technique were demonstrated and presented herein.

2. Analysis of simplified modeling method

A real structure is always complex and has to be simplified to various degree to fit into the framework of the numerical model for dynamic analysis. Many research works on three-dimensional (3-D) analysis have been conducted with the understanding that high-precision results could be obtained by using more complex computational model (Fan and Xiao, 1997; Xiao, 1997; Wilson, 2000; Kim et al., 2005; Han, 2008; Park et al., 2011). Often than not, the objective may not be achievable due to the low-efficiency in the computation and the precision of the simulation results. In fact, it turns out that a simplified analytical method, with appropriate simplification, could well satisfy the requirements of analytical fidelity and precision required by the engineering profession has an important practical significant.

2.1. Equivalent pile model

As a case in example, when there is a lack of soil data, an equivalent pile model has been found to be a good model for describing the characteristics of soil-structure interactions when the foundation moves under certain environmental excitation such as wave, current or earthquake. In this model, a pile driven into the soil is assumed to be equivalent to a fixed-end pile. The stiffness characteristics of the equivalent pile is maintained the same to correctly model the performance of the pile foundation. This is an acceptable approach for the preliminary design, as shown in Classification and construction specification for fixed offshore platforms (1992). Here, T is the depth of the rigid fixed end below the soil surface, and can be determined using the following empirical formula:For foundation in sludge,

$T = (7\text{–}8.5)D$

For foundation in hard clay,

$T = (3.5\text{–}4.5)D$

and for soil information is missing,

$T = 6D$

where D is the outer diameter of pile (m).

2.2. Added mass

There will be a certain amount of water moving as a result of the vibration of the offshore platform. The amount and movement of water should also be considered for proper dynamic response analysis of an offshore platform. This amount of water is treated as the added mass to the platform leg during the excitation. The kinetic energy associated with the fluid movement per unit length of a pile is

$$T = \frac{1}{2}\rho\pi b^2 v^2 \tag{1}$$

where ρ is the mass density of the liquid (kg/m^3), b is the radius of the cylinder perpendicular to the direction of motion (m), as shown in Fig. 1; and v is the velocity (m/s). The added mass m_a of water moving with the vibrating offshore platforms per unit length is

$$m_a = \rho\pi b^2 \tag{2}$$

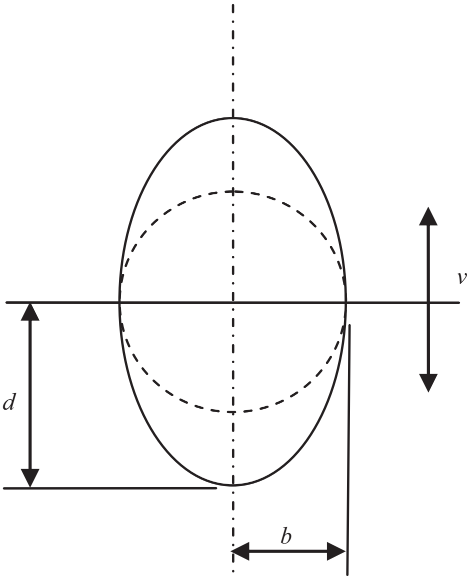

Fig. 1. Vibration of elliptic section in unbounded flow.

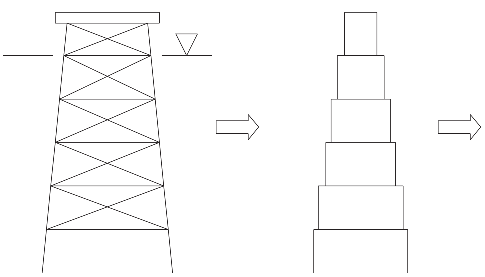

Fig. 2. A diagrammatic sketch for deriving a simplified model of a jacket platform.

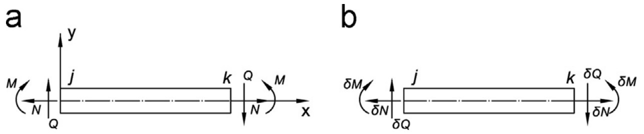

Fig. 3. Equivalent beam element. (a) System of real external load. (b) System of virtual load.

2.3. Characteristic parameter of a simplified model

In terms of dynamic performance jacket platform are complex and different from ordinary buildings, especially in the distribution of the stiffness and mass. The main loads are highly concentrated at the top parts of the structure, and the loads change with the different production stages. Fig. 2 illustrates the simplification process of a typical jacket platform. The complementary virtual work principle is adopted in the derivation of the equivalent stiffness, see Lu et al. (1992) and Han (2008).

In Fig. 3(a), the virtual displacement Δ_i of the beam element *jk* is subject to a generalized force. Based on the principle of virtual work, the generalized virtual external force is

$$\delta W^* = \sum_{i=1}^{n} \delta F_i^* \Delta_i \tag{3}$$