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Damage detection in dolphin platform of a wharf by finite element model updating

M. Pedram[1], M. R. Khedmati*[1] , A. Esfandiari[1], H. Kazem[2]

[1]Department of Maritime Engineering, Amirkabir University of Technology, Tehran, Iran
[2]National Iranian Oil Engineering and Construction Company, Tehran, Iran

ABSTRACT: In this paper, the performance of a damage detection method based on power spectral density (PSD) is numerically investigated on the dolphin platform of a wharf used for the unloading of merchant ships. In this numerical investigation damage is modeled as a percent reduction in stiffness of the elements. For this purpose, the finite-element model of the dolphin is made in the MATLAB software and the effect of surrounding water is considered as the added mass on the elements. To realise the performance of the method on the dolphin model, several assumed damage scenarios with different levels of damage in the structure, are considered. Furthermore, an approach for calculation of the spectral density of excitation using an approximate FRF is introduced. Results prove the success of the method in the identification of the parameters of a stiff coastal structure like a dolphin. Besides, the results from these investigations prove that the added mass significantly affects the damage detection results. The quality and accuracy of the numerical results prove the merits of damage detection by finite-element model updating in the frequency domain. The results of the present study urge the practical assessment of the performance of the method in the future.

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1-Introduction

The structures and facilities operating in marine environment face harsh operational condition, thus the occurrence and accumulation of damage might cause catastrophic failure in long-term service life. Hence, damage detection at early stage is very crucial for these structures. Continued research efforts have been devoted to this area and it is expanding nowadays. In this regard, reference is made to Vandiver [1], Salawu [2], Li et al. [3] who applied a cross model-cross mode (CM-CM) model updating method to a jacket platform as did Asgarian et al. [4]. Liu et al. [5] conducted data-based damage detection on the model of a marine turbine foundation. They also used a modal energy-based approach to detect damage in jacket platforms [6]. Signal processing of vibration response is also used in damage detection of marine structures. In this regard, reference is made to Elshafi et al. [7] and Asgarian et al. [8] in the use of signal energy rate for damage localization.

Implementation of frequency domain data in a way that leads to the identification, localization and quantification of damage in the dolphin platform of a wharf is the purpose of present study. In this regard, a method previously introduced by the authors [9, 10] is adopted. Until now, few studies have concentrated on the model updating of the marine structures [11]. In this study, a finite element model of the dolphin platform is introduced and detection of damage in several scenarios is numerically investigated. In these investigations, the effect of measurement error and added mass of water around the piles are studied. It is understood that the later has significant effect on the parameter identification results. Furthermore, based on the substitution of approximate transfer function an approach for estimation of the PSD of excitation was introduced. The results proved the viability of damage detection in the dolphin platform by perfect accuracy and urges further future practical research.

Corresponding Author: kilanehei@eng.ikiu.ac.ir

2-Methodology

For the purpose of damage detection, the model updating method previously introduced by authors [9], is adopted. Since, the strain data is more susceptible to changes; its sensitivity is adopted for model updating. Approximate transfer function by Equation 1 is used to overcome the adverse effects of incomplete measurement.

$$\mathbf{H}_{\mathrm{d}}^{approx.}(\omega) = \sum_{j=1}^{m} \frac{\phi_j \phi_j^T}{\Omega_{jd}^2 - \omega^2 + 2i\xi_{jd}\Omega_{jd}\omega} + \sum_{j=m+1}^{nd} \frac{\phi_j \phi_j^T}{\Omega_j^2 - \omega^2 + 2i\xi_j\Omega_j\omega} \tag{1}$$

This equation consists of measured natural frequencies of the damaged model in first few modes and natural frequencies and mode shapes of analytical structure in other modes. Assuming that the mass is not altered by the damage, the sensitivity of PSD with respect to stiffness parameters is given in Equation 2.

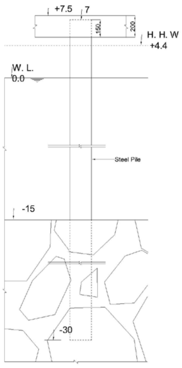
$$\mathbf{S}^{S} = -\mathbf{B}\mathbf{H}_{\mathbf{d}}^{*}(\omega)\mathbf{S}_{\mathbf{FF}}(\omega)\mathbf{H}\ (\omega)\mathbf{K}_{\mathbf{n}}\mathbf{H}_{\mathbf{d}}(\omega)\mathbf{B}^{\mathrm{T}} - \mathbf{B}\mathbf{H}^{*}\ (\omega)\mathbf{K}_{\mathbf{n}}\mathbf{H}(\omega)\mathbf{S}_{\mathbf{FF}}(\omega)\mathbf{H}_{d}(\omega)\mathbf{B}^{\mathrm{T}} \tag{2}$$

The solution to this equation is achieved by least-squares error minimization method and applying unbiased bounds on the stiffness variables as given in Equation 3.

$$\min_{\Delta p} \left\| \mathbf{S}^S \Delta p^S - \Delta \mathbf{S}_{\varepsilon\varepsilon} \right\|_2 \quad \text{Subject to } -1 \leq \Delta p \leq 1 . \tag{2}$$

The effect of added mass is also considered on the submerged elements of piles and is calculated using Morrison's equation [12]. The flexible dolphin [13] considered in this study is located besides a wharf and it consists of six piles and a concrete pile cap. The dolphin structure and full view of a pile is given in the Figure 1 a and b, respectively.

a)The studied dolphin platform



b) Full view of one dolphin pile

Figure 1. View of dolphin and its pile

The FE model has 60 elements (ten elements on each pile), and 3D frame elements are used to form the numerical model. This model has 66 nodes and 360 active DOFs. The top elements on each pile are a dry element, and the other elements are wet elements.

3-Results and Discussion

Several damage scenarios are considered with different location and extent of damage. Twenty-four out of sixty elements are considered as measurement elements. One excitation on a DOF in the birthing direction of the vessel is considered. The frequency ranges for model updating are selected around the first few natural frequencies based on the instructions given in [9]. In each case random error is added to the response of damaged model and Monte-Carlo simulation is performed. The mean and coefficient of variation (COV) of the estimated parameters are used as the results indicator. The results of a damage scenario when considering all elements as dry elements and when considering the top elements as dry elements and the other elements as wet elements are compared to highlight the effect of added mass on the results. The results proved the accuracy of the method in parameter estimation in presence of measurement error and added mass effect. Considering the importance of input quantification in SHM [14], by taking advantage from the accuracy of approximate Equation 1 [10, 15], an approach is introduced and examined to quantify the PSD of a single excitation in certain frequency points.

4-Conclusions

In this paper, the PSD of structural response is adopted to investigate damage detection of the dolphin platform of a wharf, numerically. Different damage scenarios regarding the location and extent are investigated, and the effect of added mass is also considered on the submerged elements of piles. The results demonstrate the significant effect of added mass on the damage detection results. The results also certify the success of method in identification of damage of different level and location, in presence of measurement error. The paper also introduces an approach for single input spectrum quantification using the approximate FRF that is highly accurate. The results inspire the practical implementation and further investigation of model updating method in the future.

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