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Damage Detection of Offshore Jacket Structures Using Frequency Domain Selective Measurements

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Abstract: The development of damage detection techniques for offshore jacket structures is vital to prevent catastrophic events. This paper applies a frequency response based method for the purpose of structural health monitoring. In efforts to fulfill this task, concept of the minimum rank perturbation theory has been utilized. The present article introduces a promising methodology to select frequency points effectively. To achieve this goal, modal strain energy ratio of each member was evaluated at different natural frequencies of structure in order to identify the sensitive frequency domain for damage detection. The proposed methodology opens up the possibility of much greater detection efficiency. In addition, the performance of the proposed method was evaluated in relation to multiple damages. The aforementioned points are illustrated using the numerical study of a two dimensional jacket platform, and the results proved to be satisfactory utilizing the proposed methodology.

Keywords: damage detection; structural health monitoring; frequency response function; offshore jacket platform; minimum rank perturbation theory; element modal strain energy ratio

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1 Introduction

Structures face various loadings and confront different circumstances as they are built and used. This situation causes the aging structures to deteriorate, which would lead to a decrease in reliability and safety. In recent decades, the need for systems to assure the integrity of structures in terms of their age, usage and level of safety when experiencing infrequent and extreme forces such as earthquakes, tornados, hurricanes, large waves have deeply been recognized. These systems are often referred to as structural health monitoring (SHM) in the literature. Overall, the field of SHM aims to identify, localize and size any defect in the structure as it happens. The main objective of such a system is to increase reliable operating lifetime.

Generally, structural damage detection can be classified into local damage detection and global damage detection. Local damage detection techniques refer to non-destructive testing (NDT) as X-ray methods, eddy current approaches, thermal imaging and ultrasonic methods, because it is mainly used to detect local damage in structures (Yan *et al*., 2007). Local damage detection is applicable only for small and regular structures, such as pressure vessels and for detecting only the finite suspicious components of large structures. In response to this limitation, a set of more global vibration based approaches have been used. Therefore, global vibration based damage detection is especially essential for large and complicated structures in order to detect the location of damage and then the primary knowledge of the location of defect, the inspection group can trace the damage right to the specified region utilizing one of the local damage detection techniques. In the case of offshore structures, utilizing such global vibration based damage detection techniques is was not only necessary, but also inevitable due to some of its exclusive characteristics., which can be summarized as: (1) offshore structures are so very important, expensive and huge that their failure or collapse would be a catastrophic event. (2) Poor visibility and concealment of damage by marine growth cause other techniques to be accompanied with prohibitive cost. (3) Cyclic wave loading, severe storms, sea quakes and hostile environment could harshly affect the integrity of the structure.

Most of the vibration based damage detection techniques require a significant amount of modal test data. These requirements make the damage detection procedure costly, time consuming, and impractical. Some research studies using modal data have been developed recently. Kaouk and Zimmerman (1994) used eigenvalues, and eigenvectors, which adopted the concept of minimum rank perturbation theory to locate and measure damages in a two-dimensional truss and a cantilevered beam. Li *et al*. (2008) applied the cross-model, cross-mode method for damage detection in offshore jacket structures, and made data available relating to spatially incomplete modal.

However, on the other hand, some literature has concentrated on the use of frequency response function (FRF) directly as opposed to modal data extracted from FRF measurements. There are two main advantages of using FRF data. Firstly, modal data can be contaminated by modal identification errors in addition to measurement errors, because they are derived data sets. Secondly, a complete set of

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modal data cannot be measured in all but the simplest structures. FRF data can provide much more information on damage in a desired frequency range compared to modal data that is extracted from a very limited range around resonances (Carden and Fanning, 2004). Maia *et al.* (2003) discussed some modal based and FRF based damage detection techniques, and compared the results on a simple beam. In addition, they introduced an indicator of damage as FRF based damage index. Hwang and Kim (2004) found the location and amount of damage through computational iterations by matching experimental FRF and analytical FRF.

The objective of this paper is to present a damage detection technique, which applies FRF data in some frequency points to arrive at perturbations to stiffness matrix due to some defects in the structure. This paper develops a favorable methodology to select frequency points wisely. By using this methodology, damage detection efficiency will improve significantly.

The method is demonstrated numerically on a spring mass system (shear building) and then applied to an offshore jacket platform. The authors' effort was to consider a set of more probable and realistic damages in the jacket platforms relative to other similar works.

2 Damage detection formulation

2.1 Basic theory

The basic theory of this type of damage detection initiate with the second order structural equation of motion by considering an n degree of freedom system

$$\boldsymbol{M}_{n\times n}\ddot{\boldsymbol{x}}_{n\times 1}+\boldsymbol{C}_{n\times n}\dot{\boldsymbol{x}}_{n\times 1}+\boldsymbol{K}_{n\times n}\boldsymbol{x}_{n\times 1}=\boldsymbol{f}_{n\times 1}\boldsymbol{1} \tag{1}$$

where $\boldsymbol{M}$, $\boldsymbol{C}$ and $\boldsymbol{K}$ are undamaged mass, damping and stiffness matrices, respectively, $\boldsymbol{x}$ is the vector of positions, $\boldsymbol{f}$ is the vector of applied forces, and the over dots represent differentiation with respect to time. If the structure is excited by a set of forces all at the same frequency, ω, but with individual amplitudes and phases, then

$$\boldsymbol{f}(t)=\boldsymbol{F}(\omega)\mathrm{e}^{\mathrm{i}\omega t} \tag{2}$$

by neglecting the transient response and concerning the steady state

$$\boldsymbol{x}(t)=\boldsymbol{X}(\omega)\mathrm{e}^{\mathrm{i}\omega t} \tag{3}$$

where $\boldsymbol{F}$ and $\boldsymbol{X}$ are vectors of time-independent amplitudes. The equation of motion then becomes

$$\boldsymbol{X}(\omega)=(\boldsymbol{K}+\mathrm{i}\omega\boldsymbol{C}-\omega^2\boldsymbol{M})^{-1}\boldsymbol{F}(\omega)\mathrm{i}=\sqrt{-1} \tag{4}$$

$$\boldsymbol{F}(\omega)=(\boldsymbol{K}+\mathrm{i}\omega\boldsymbol{C}-\omega^2\boldsymbol{M})\boldsymbol{X}(\omega) \tag{5}$$

$$\boldsymbol{H}(\omega)=(\boldsymbol{K}+\mathrm{i}\omega\boldsymbol{C}-\omega^2\boldsymbol{M})^{-1} \tag{6}$$

$$\boldsymbol{Z}(\omega)=(\boldsymbol{K}+\mathrm{i}\omega\boldsymbol{C}-\omega^2\boldsymbol{M}) \tag{7}$$

where $\boldsymbol{H}(\omega)$ is standard FRF and $\boldsymbol{Z}(\omega)$ is inverse FRF. In the undamaged condition it can be written as

$$\boldsymbol{F}(\omega)_{n\times 1}=\boldsymbol{Z}(\omega)_{n\times n}\boldsymbol{X}(\omega)_{n\times 1} \tag{8}$$

But due to the damage interference, the Eq. (8) changes to the following form

$$\boldsymbol{F}(\omega)_{n\times 1}=\left[\boldsymbol{Z}(\omega)+\Delta\boldsymbol{Z}(\omega)\right]_{n\times n}\boldsymbol{X}(\omega)_{n\times 1} \tag{9}$$

where $\Delta\boldsymbol{Z}(\omega)$ represents the effect of damage on the inverse FRF.

Force damage vector can be defined by a slight manipulation of Eq. (9)

$$\boldsymbol{d}(\omega)=\boldsymbol{F}(\omega)-\boldsymbol{Z}(\omega)\boldsymbol{X}(\omega)=\Delta\boldsymbol{Z}\cdot\boldsymbol{X}(\omega) \tag{10}$$

Assuming that the inverse FRF has been measured at p discrete frequencies and the introduced defect has only affected one of the structural property matrices (either $\boldsymbol{M}$, $\boldsymbol{C}$ or $\boldsymbol{K}$), Eq. (10) can be rewritten as

$$\Delta\boldsymbol{Z}_{n\times n}\boldsymbol{X}_{n\times p}=\boldsymbol{D}_{n\times p} \tag{11}$$

where the frequency and space information of $\boldsymbol{X}(\omega)$ and $\boldsymbol{d}(\omega)$ were arranged as the rectangular matrices $\boldsymbol{X}$ and $\boldsymbol{D}$, respectively

$$\boldsymbol{X}_{n\times p}=\boldsymbol{X}\left(\omega_1\right)\ldots\boldsymbol{X}\left(\omega_p\right) \tag{12}$$

$$\boldsymbol{D}_{n\times p}=\boldsymbol{d}\left(\omega_1\right)\ldots\boldsymbol{d}\left(\omega_p\right) \tag{13}$$

2.2 Minimum rank perturbation theory

Eq. (11) can be solved by using the same approach as is used in the minimum rank perturbation theory (Kaoukand Zimmerman, 1994). In Zimmerman and Kaouk (1994), the symmetric minimum rank solution of Eq. (11) was derived and mathematical characteristics of the solution were investigated.

Minimum rank perturbation theory provides the unique minimum rank solution for Eq. (11) as

$$\Delta\boldsymbol{Z}=\boldsymbol{D}_{n\times n}(\boldsymbol{D}^{\mathrm{T}}_{p\times n}\boldsymbol{X}_{n\times p})^{-1}\boldsymbol{D}^{\mathrm{T}}_{p\times n} \tag{14}$$

This solution is motivated by the application of damage detection, where the perturbations could be assumed to be limited to a few isolated locations. The minimum rank stiffness matrix perturbation can be thought of as the stiffness matrix perturbation with the smallest number of nonzero values.

It should be decided by engineering judgment that perturbation to which property matrix (either $\boldsymbol{M}$, $\boldsymbol{C}$ or $\boldsymbol{K}$) has caused $\Delta\boldsymbol{Z}$. In this regard, practical experience with a comprehensive knowledge about the history of relevant structure (loadings, environmental conditions, any extreme events, age of the structure) may help. For example, if the damage has affected stiffness of the structure, then displacement should be measured by sensors, and $\Delta\boldsymbol{Z}$ would be equal to $\Delta\boldsymbol{K}$. This paper assumes that the referred perturbation is due to some stiffness reduction. All the required information such as the damage location and the extent of stiffness reduction are contained in the matrix $\Delta\boldsymbol{K}$.

2.3 Computational improvement

The key issue in the damage detection scheme is the ability to identify the matrix $\boldsymbol{D}$.

The components of this matrix are just associated with the measured degrees of freedom (DOFs). Therefore, the size of equation takes effect from measured DOFs (number of sensors). Note that vector $\boldsymbol{d}$, which appeared in Eq. (10), is a kind of residual force vector. Indeed, one interpretation of $\boldsymbol{d}$ is as a collection of externally applied loads acting on the undamaged structure to give a response similar to that of the damaged structure (Carrion *et al*., 2003). Matrix $\boldsymbol{D}$ in numerical examples without presence of noise is rank deficient, in other word; it has several singular values that are very close to zero. But, in practical examples, due to the presence of noise, matrix $\boldsymbol{D}$ is close to full rank. This fact causes Eq. (11) to be an ill-conditioned numerical problem. As mentioned above, the source of this numerical problem is mainly because of matrix $\boldsymbol{D}$, so the operations to improve the numerical condition concern matrix $\boldsymbol{D}$.

Subspace selection algorithm proposed by Zimmerman (2006) consists of determining a matrix $\boldsymbol{Q}$ such that Eq. (15) is numerically well-conditioned

$$\Delta \boldsymbol{ZXQ} = \boldsymbol{DQ} \tag{15}$$

Consider the singular value decomposition of $\boldsymbol{D}$ as

$$\boldsymbol{D} = \boldsymbol{USV}^{\mathrm{T}} \tag{16}$$

where $\boldsymbol{S}$ is the diagonal matrix of non-negative singular values in decreasing order, and $\boldsymbol{U}$ and $\boldsymbol{V}$ are the left and right singular vectors respectively. Here, we need a criterion for partitioning $\boldsymbol{S}$, $\boldsymbol{U}$ and $\boldsymbol{V}$ in the following order

$$\boldsymbol{D} = \boldsymbol{U}_1\boldsymbol{U}_2\begin{pmatrix} \Sigma & 0 \\ 0 & \varepsilon \end{pmatrix}\boldsymbol{V}_1\boldsymbol{V}_2^{\mathrm{T}} \tag{17}$$

where Σ is the matrix of top 'm' singular values (m is user defined).

With the selected m columns of $\boldsymbol{U}$, matrix $(\boldsymbol{U}_1)_{n\times m}$ can represent $\boldsymbol{DQ}$, the right hand side of Eq. (15), which will improve the computational efficiency by excluding damage vectors of smaller singular values.

$$\boldsymbol{D}_{n\times p}\boldsymbol{Q}_{p\times m} = (\boldsymbol{U}_1)_{n\times m} \tag{18}$$

Thus matrix $\boldsymbol{Q}$ can be computed by using pseudo-inverse of $\boldsymbol{D}$ as

$$\boldsymbol{Q} = \boldsymbol{D} + \boldsymbol{U}_1 \tag{19}$$

Then, with the substitution of $\boldsymbol{XQ}$ and $\boldsymbol{DQ}$ for $\boldsymbol{X}$ and $\boldsymbol{D}$ in Eq. (14), the minimum rank solution can be easily derived as

$$\Delta \boldsymbol{Z}_{n\times n} = \boldsymbol{D}_{n\times p}\boldsymbol{Q}_{p\times m}(\boldsymbol{Q}_{m\times p}^{\mathrm{T}}\boldsymbol{D}_{p\times n}^{\mathrm{T}}\boldsymbol{X}_{n\times p}\boldsymbol{Q}_{p\times m})^{-1}\boldsymbol{Q}_{m\times p}^{\mathrm{T}}\boldsymbol{D}_{p\times n}^{\mathrm{T}} \tag{20}$$

2.4 Element modal strain energy ratio

The element modal strain energy ratio (SER_{ij}), which is the jth modal strain energy in the ith element stiffness divided by the total strain energy in the jth mode, is defined as

$$\mathrm{SER}_{ij} = \frac{\phi_j^{\mathrm{T}} k_i \phi_j}{\phi_j^{\mathrm{T}} K \phi_j} = \frac{\phi_j^{\mathrm{T}} k_i \phi_j}{\omega_j^2} \tag{21}$$

where k_i is the ith element stiffness matrix, K is the system stiffness matrix, and ϕ_j is the jth mass normalized mode shape.

Each mode has its own contribution to the dynamic response of the structure. The effect of each mode on the dynamic response is related to the excitation frequency. When the excitation frequency is close to one of the system's natural frequencies, the dynamic response will usually reflect the shape of the nearby mode, but will not be identical to it because of the participations, though small, of all the other modes. Overall, dynamic response is the composition of all the structural modes.

In the damage detection procedure, it was observed that the damage location was usually assessed more accurately in the highly strained elements rather than the low strained elements. Therefore, the modal strain energy ratio for each individual element should be calculated before the damage detection. For inspecting each element, excitation frequency should be close to the mode, which has the highest modal strain energy for the specified element.

3 Numerical studies

In the present study, damage detection strategy is applied on two examples to illustrate the applicability of the proposed method for various types of structures. The first example is an idealized 3 degrees of freedom shear building system. In this example, a perturbation to stiffness property matrix is used to illustrate the numerical procedure of damage detection using FRF data. The second example, involves the identification and localization of some small damages which are artificially introduced to the two-dimensional model of an offshore jacket platform.

3.1 Idealized shear building system

This example consists of 3 degrees of freedom as shown in Fig. 1. Consider the undamaged model of the system to have the parameters

$$\begin{pmatrix} k_1 & k_2 & k_3 \end{pmatrix} = \begin{pmatrix} 10 & 10 & 10 \end{pmatrix} \tag{22}$$

$$\begin{pmatrix} m_1 & m_2 & m_3 \end{pmatrix} = \begin{pmatrix} 0.1 & 0.1 & 0.1 \end{pmatrix} \tag{23}$$

this has the undamaged mass and stiffness matrices

$$\boldsymbol{M}_u = \begin{pmatrix} 0.1 & 0 & 0 \\ 0 & 0.1 & 0 \\ 0 & 0 & 0.1 \end{pmatrix} \tag{24}$$

$$\boldsymbol{K}_u = \begin{pmatrix} 20 & -10 & 0 \\ -10 & 20 & -10 \\ 0 & -10 & 10 \end{pmatrix} \tag{25}$$

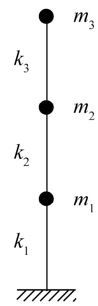


Fig. 1 Idealized shear building system

Natural frequencies of the undamaged structure were extracted as 0.71, 1.98 and 2.87 (Hz) for the first, second and third mode respectively. Modal strain energy ratio for the three members of the structure is shown in Table 1. It is anticipated from the modal strain energy that damage at member one could be better exhibited nearby frequency of mode one.

Table 1 Element modal strain energy ratio

members	mode 1	mode 2	mode 3
1	0.58	0.36	0.11
2	0.37	0.11	0.55
3	0.11	0.56	0.35

The study has now, considered a damage case in which parameter k_1, and decreases one unit.

$$\boldsymbol{K}_d = \begin{pmatrix} 19 & -10 & 0 \\ -10 & 20 & -10 \\ 0 & -10 & 10 \end{pmatrix} \tag{26}$$

where the subscripts $(\bullet)_u$ and $(\bullet)_d$ denote undamaged and damaged conditions, respectively. We want to detect damage by considering the frequency points of 0.7, 1.5 and 2.3 Hz. Assume that only the stiffness matrix is to be perturbed, thus displacement should be measured by sensors under the arbitrary excitation. In this way, $\boldsymbol{X}$ and $\boldsymbol{D}$ are computed by Eqs.(10), (12) and (13). As we had expected, the first frequency, which is near to the first mode, contains more valuable information about damage in member one.

$$\boldsymbol{F} = \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}, \quad \boldsymbol{X} = \begin{pmatrix} -3.77 & -0.100 & 0.079 \\ -6.437 & -0.101 & -0.015 \\ -7.857 & -0.013 & -0.078 \end{pmatrix}$$

$$\boldsymbol{D} = \begin{pmatrix} 3.77 & -0.10 & 0.079 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \tag{27}$$

Then the perturbation to stiffness property matrix from Eq. (20) yields.

$$\Delta\boldsymbol{Z} = \Delta\boldsymbol{K} = \begin{pmatrix} -1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \tag{28}$$

this is exactly anticipated perturbation to stiffness matrix

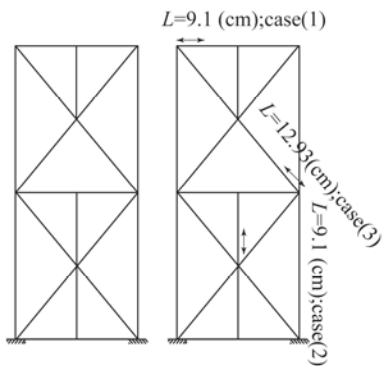
$$\boldsymbol{K}_u = \Delta\boldsymbol{K} = \boldsymbol{K}_d \tag{29}$$

3.2 Two-dimensional jacket platform

Two-dimensional jacket platform used in this example is shown in Fig. 2 (a). The structure consists of two stories and is fixed to the ground. The height of the two stories and the length of the beams are 18.3 meters. The material properties of the steel tabular members are: elastic modulus E=200 (GPa), Poisson's ratioν=0.3 and mass density ρ = 7800 (kg/m^3).

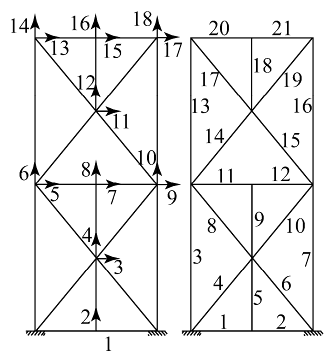
In this example, the damage is simulated by reducing the thickness of members. Four damage cases have been investigated. Locations of the damage cases are illustrated in Fig. 2 (b). Damage case number one involves upper-left beam of the second story with the length of 9.1 centimeter and the thickness reduction of 89.5%. Damage case number two engages upper zipper column of the first story with the length of 9.1 centimeter and the thickness reduction of 47.5%. Third case is at the bracing of second story with the length of 12.93 centimeter and the thickness reduction of 92%. The fourth damage case involves elements of both the first and third damage cases (multiple damages). In this example, 18 translational sensors have been used. Position and direction of them are illustrated in Fig. 3(a). Twenty one members are numbered in Fig. 3(b). We have avoided utilizing rotational DOFs because of considerable difficulty which is encountered when trying to measure or excite rotational DOFs. Due to this fact, mostly axial behavior of members of the platform is sensed and the damage is highlighted between DOFs which are axially related. Thus, axial modal strain energy is computed to find out which frequency is the most sensitive one for damage detection of any member. After solving the eigenvalue problem of this example, the natural frequencies and mode shapes of the jacket platform are shown in Fig. 4. Axial modal strain energy ratio for 21 members are computed and shown in Fig. 5. Summation of axial modal strain energy ratio for all the members in each mode is exhibited in Fig. 6. This figure indicates that at the higher modes, as opposed to lower modes, members are more flexural than axial. Therefore, the frequency domain of the first four modes is the most suitable frequency domain to detect damage by translational sensors which obtain only axial behavior of the members. In other words, this domain has the greatest potential to excite members axially as opposed to the other frequency domains.

This example uses 18 frequency points starting from 1.2 (Hz) and ending at 6.3 (Hz) with the step of 0.3 (Hz). Damage vectors $\boldsymbol{D}$ and stiffness matrix perturbations $\Delta\boldsymbol{K}$ due to damage case one, two and four are shown in Figs. 7, 8 and 9, respectively. Stiffness perturbation has localized damage by displaying greater values at corresponding DOFs as shown in Figs. 7(b), 8(b) and 9(b). Notably, matrix $\Delta\boldsymbol{K}$ has some negative values which could not be displayed easily on a three-dimensional plot. Thus, the authors made them positive artificially. As illustrated in Figs. 5(a) and 5(b), member number 20 (damage case one) is strongly excited at frequencies nearby the second mode (4.032Hz) and member 15 (damage case three) is excited at frequencies nearby the first mode (1.376Hz). Therefore, in Figs. 7(a), 8(a) and 9(a), frequencies of 1.5, 3.9, 5.7 and 6.3 (Hz), which are the closest frequencies to the first, second, third, and forth modes, are highlighted for easier tracing. As we had expected, these figures demonstrate that the second mode is the best frequency for indicating damage case one and in the same way, the third and the first modes are the best frequencies, respectively, for implying damage case two and three.



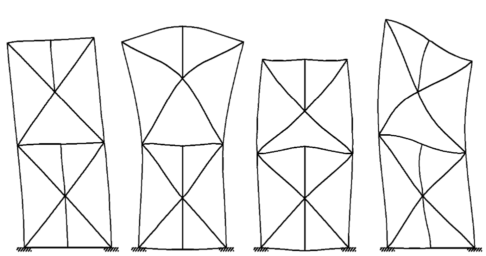
(a) The sketch of the structure; (b) The locations of damage cases

Fig. 2 The sketch of structure with damage cases



(a) Measured DOFs (sensors' placement); (b) Members' numbering

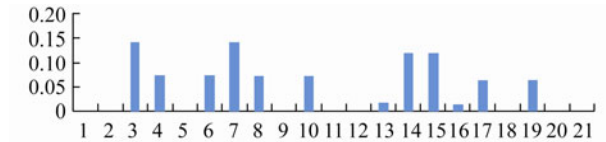
Fig. 3 Measured DOFs (sensors' placement) in addition to members' numbering



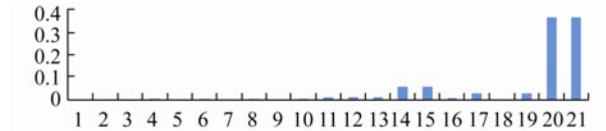
(a) (b) (c) (d)

. (a) 1st mode (1.376Hz); (b) 2nd mode (4.032Hz); (c) 3rd mode (5.664Hz); (d) 4th mode (6.419Hz)

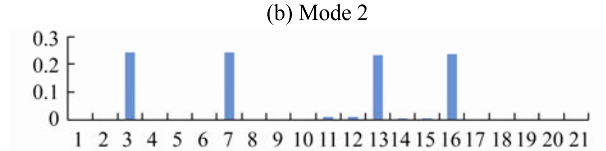
Fig. 4 Shapes of first modes



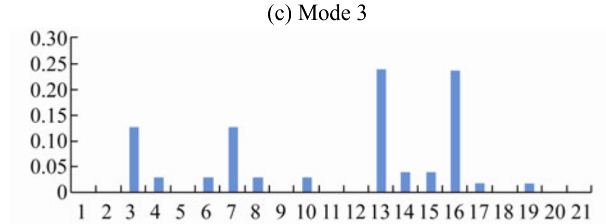
(a) Mode 1



(b) Mode 2



(c) Mode 3



(d) Mode 4

Fig. 5 Element modal strain energy ratio for 4 modes

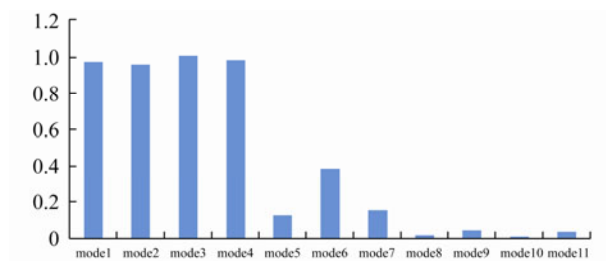
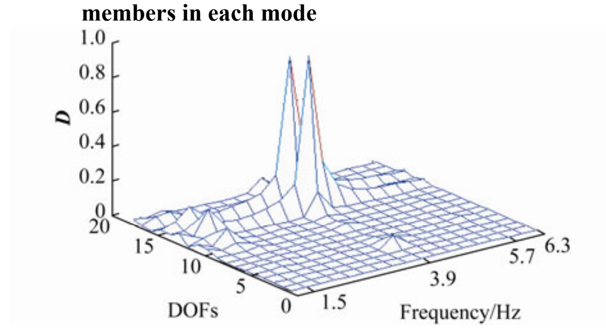
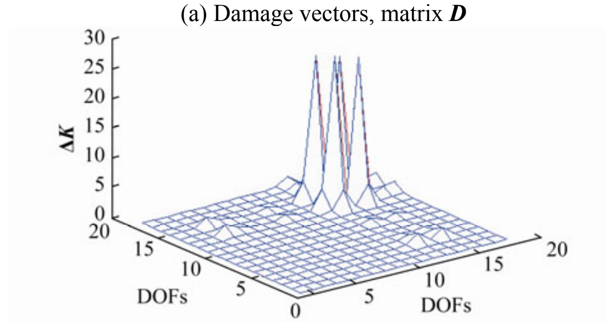


Fig. 6 Summation of axial modal strain energy for all members in each mode

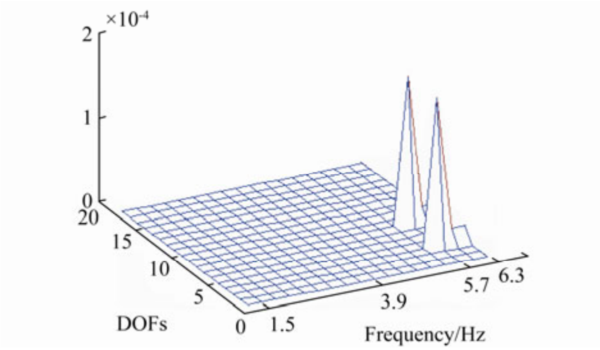


(a) Damage vectors, matrix $\boldsymbol{D}$

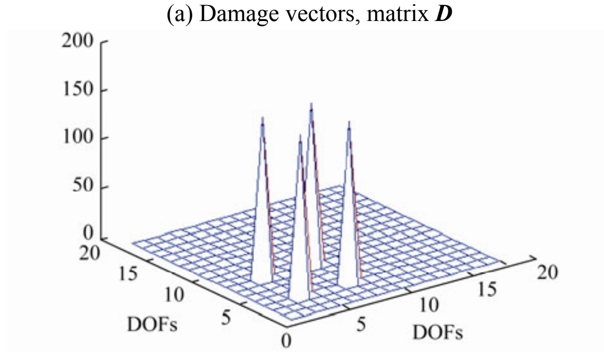


(b) Stiffness perturbation, matrix $\boldsymbol{\Delta K}$

Fig. 7 Damage case one.

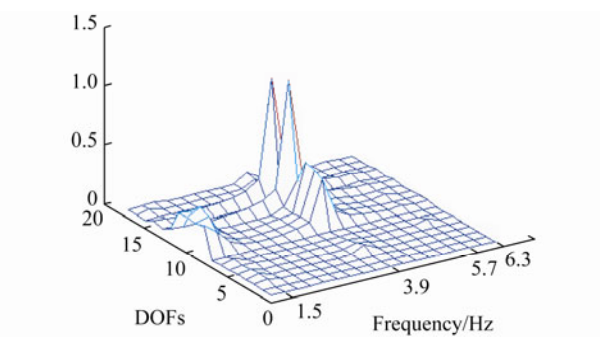


(a) Damage vectors, matrix ***D***

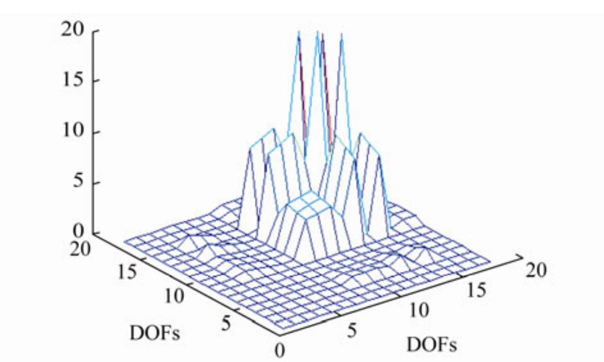


(b) Stiffness perturbation, matrix ***ΔK***

Fig. 8 Damage case two



(a) Damage vectors, matrix ***D***



(b) Stiffness perturbation, matrix ***ΔK***

Fig. 9 Damage case four

Golafshani *et al*. (2010) has investigated the same structure and found the fact that sometimes in the case of multiple damages, one defect dominates and the effect of the other diminishes. This fact relates to energy level of damaged member.

4 Selection of frequency points

Before the damage detection procedure, modal analysis should be performed. Eigen values and eigenvectors are extracted using undamaged model. After that, modal strain energy ratio for all members should be computed. Now two questions arise here. The first is how to specify a suitable frequency domain for damage detection purpose. The second is how to select p discrete frequency points that were used in Eqs. (12) and (13). For the first question, as the preceding example, the 'regions' around the modes with higher axial strain energy are suitable. But, those regions of the FRF which show low coherence due to either noise or nonlinearities, must be eliminated (Zimmerman *et al*., 2005).

As far as the second question, Zimmerman *et al*. (1995) investigated the effect of selecting a subset of measured frequency points by five different subset selection techniques. These selecting techniques could be characterized as (1) evenly spaced throughout the frequency range, (2) clustered about the resonances, (3) clustered about the anti-resonances, (4) placed away from the resonances and anti-resonances, and (5) placed at points of maximum percentage difference between the healthy and damaged FRF. It was observed in this study that the selection technique (1) performed the best, and provided nearly the same assessment of damage as when the full FRF data set was used.

5 Conclusions

This paper investigated damage detection of offshore jacket platforms utilizing a method, which applies FRF data set. The method aims to arrive at stiffness matrix perturbation due to damage occurrence. The proposed method was carried out on a simple idealized 3-DOF shear building system and a two-dimensional jacket platform.

This paper also introduced a methodology for selecting frequency points in an efficient manner such that it was clear before analysis which frequency will probably detect possible damage in each member. This methodology includes performing modal analysis before damage detection and obtaining the modal strain energy of members. Frequency domain of each mode detects those members of higher strain energy. Thus, frequency domain of each mode was determined to be suitable. Translational DOFs only measured the axial modal strain energy. Summation of axial modal energy decreases as the mode number increases. Therefore, frequency domain of lower modes is usually more helpful than those of the higher modes. Notably, regarding the issue of multiple damages, the results will be more precise if the frequency points are selected wisely. Overall, the proposed methodology opens up the possibility of greater damage detection efficiency.

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