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Damage Detection in an Offshore Jacket Platform Using Genetic Algorithm Based Finite Element Model Updating with Noisy Modal Data

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Abstract

Offshore jacket platforms are one of the most motivating structures for damage detection due to their importance and productivity. In this study, the application of finite element model updating in damage detection of an offshore jacket platform is investigated. The objective function of this method is based on the measured and analytical modal data, including natural frequencies and mode shapes. However, the measured data is expected to be noisy. Also, to avoid obtaining false damage results, a penalty term is added to the objective function. To update the model, genetic algorithm is utilized as a robust global searching tool. Afterward, the efficiency of this method is evaluated on several damage cases in presence of 0, 1, 2 and 3 percent noise with measured modal data. The results show that this method can detect the damage of this kind of structure satisfactorily even if modal data is not precisely obtained.

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Keywords: damage detection; structural health monitoring; offshore jacket platform; model updating; genetic algorithm; damage penalization.

1. Introduction

Offshore jacket platforms are exposed to a couple of damage sources during their service life: first, environmental damage sources such as waves, winds, earthquakes, and also accidental damage sources including boat impacts and explosions. According to their high level of importance it will be so important not to let them shut down even for a short period of time. Therefore, there is a vital need to monitor their health and

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reliability. But, using visual inspections and other local tests on offshore jacket platforms are very costly due to their size and the placement of members under the water. Damage which poses structures to danger, usually affects the dynamic features of the system. Thus, several researches have been done in this field using measuring vibration responses of structures since 1970s (Doebling et al. 1998).

The researches lead to many ways to identify the damage location or damage intensity on the elements of the structure. One of the most successful methods is finite element model updating due to its applications on different civil infrastructures (Jafarkhani and Masri 2011). This method assumes the problem as an optimization problem which its aim is to correlate the measured modal properties extracted from sensors data with the outcomes of finite element model to minimize the error between them. Afterward, the damage will be detected by comparing the results between undamaged model and optimized model which is correlated with measured data from real structure. If there is some hesitation in harmony of undamaged model with the real undamaged structure the model should be updated using the sensors data obtained from undamaged structure.

Optimization methods used in model updating procedure are generally divided into two types: gradient-based methods and computational intelligence methods such as particle swarm optimization (PSO) and Genetic Algorithms (GA). These methods are based on laws in nature and biology which lead to coping with complexities and uncertainties in an appropriate way. For instance, the superiority of genetic algorithm based method is proved in comparison with gradient-based one in damage detection of a simple beam and portal frame (Gomes and Silva 2008). In this study, GA is used because of its ability to find global solution in the complicated search domain with different local minimum points without using some surplus constraints. Furthermore, this robust method uses multiple points to find the best solution rather than gradient-based methods. Several studies have been applied GA successfully in damage detection field, such as (Gomes and Silva 2008, Chou and Ghaboussi 2001, Park et al. 2006, Meruane and Heylen 2008, and Malekzehtab et al. 2011).

Another important issue in the case of offshore platforms is being in a noisy environment which makes it hard to get precise data from sensors. Although the technology of measuring instruments and sensors have been developed considerably during recent years, the effect of noise on measured data cannot be neglected as a result of inherently errors in measuring, gathering and processing procedures. So, for practical uses of current damage detection algorithms, it seems necessary to investigate their efficiency in presence of noise.

Therefore, the main purpose of this study is to evaluate the ability of the mentioned method for damage detection of an offshore platform on different damage cases when the used modal data is affected by different noise levels.

2. Definition of Damage Detection as an Optimization Problem

As mentioned before, model updating method converts damage detection problem to an optimization problem. Each optimization problem is defined by its feasible search area, constraints and cost function. Search area is a set of parameters that shows the condition of the elements of the structure. This kind of search domain originally has no constraints except the boundaries of the parameters. Cost function which indeed could be considered as the most important part, is a criterion to assess different solutions. Many researchers have worked on this field and introduced many criteria in Time-Domain, Frequency-Domain, Time-Frequency Domain and Modal-Domain for determining how far the solution is from the measured properties of the structure (Marwala 2010). In the case of Modal-Domain, natural frequencies and Modal-Assurance-Criterion (MAC) are common criteria where the latter depicts the correlation of mode shapes. Reference (Jafarkhani and Masri 2011) suggested using the combination of natural frequencies and mode shapes, as a consequence of the fact that the combination of these criteria is a better evaluating tool in this regard. Reference (Meruane and Heylen 2008) proposed to add a penalty term to the cost function which leads to the elimination of false damage from the solution. Therefore, due to the suggestions of (Jafarkhani and Masri 2011) and (Meruane and Heylen 2008), the cost function in Eq. 1 is applied in this effort.

$$Cost(Chr) = \sum_{i=1}^{n}\left[W_{f_i}\left|\frac{f_i^{(e)}-f_i^{(a)}}{f_i^{(e)}}\right|^2\right] + \sum_{i=1}^{n}\left[W_{\varphi_i}\left(1-\frac{\left|\varphi_i^{(e)^T}\varphi_i^{(a)}\right|^2}{\left(\varphi_i^{(e)^T}\varphi_i^{(e)}\right)\left(\varphi_i^{(a)^T}\varphi_i^{(a)}\right)}\right)\right] + \frac{\gamma}{k}\sum_{j=1}^{k}\beta_j \quad (1)$$

Where Chr is the set of input parameters to be identified, f_i represents the natural frequency, φ_i the normalized mode shape of the i^{th} mode, and W denotes the corresponding weight. Superscripts (e) and (a) stand for experimental and analytical results respectively. Moreover, n is the number of the modes which are taken into account With respect to the third term, β is the amount of damage of j^{th} element, k is the number of the elements of FE (Finite Element) model and γ is a weight factor which is used to guarantee the efficiency of the penalty term.

3. Optimization Algorithm

According to previous paragraphs, GA is used in this research as an optimization method. Genetic Algorithm (GA) is a global searching process based on the Darwin's principle of natural selection and evolution. A simple GA consists of three main operations: selection, genetic operations and replacement. Firstly, an initial population is created randomly; this population consists of a group of chromosomes. The term chromosome refers to a possible solution of the problem and is formed by a number of genes; each gene represents a variable in the problem which in our case shows health of an element of the structure. The fitness of each chromosome is evaluated based on the cost function. Then the initial population is passed through a selection process. This selection is based on the fitness of each individual. This means that chromosomes with a higher fitness have a higher probability to survive in the next generation. There are several selection processes such as roulette wheel and tournament (http://www.nd.com/products/genetic/selection.htm). In addition, elitism can be used to move the best solutions of current generation to the next generation directly. Then, crossover is applied to all chromosomes with a probability of Pc. In this procedure, the chromosomes are randomly paired as parents. As a result, new pairs of children are created. Next, mutation is applied to population with a probability of Pm. The simplest crossover is the single point crossover. The parents cross over genes at a randomly chosen point to form two children. Although these sorts of strategies work fine for binary coded chromosomes, in real coded algorithms there is a continuum of values, in which data points are merely interchanged. These approaches totally rely on mutation to introduce new genetic material (Meruane and Heylen 2008). So, blending methods such as arithmetic and BLX-α crossover could solve this problem. They combine values from the two parents into the new variable values in the children using different approaches like interpolation or extrapolation (F. Herrera et al. 1998). The mutation operation changes some of the genes in a chromosome with chosen random values from the solution domain. This operator avoids trapping the algorithm in local minima and loosing potentially useful information.

After the process of selection and genetic operations, old generation is replaced by new one. This process will be iterated to reach the stop conditions.

4. Definition of Damage

Damage could be presumed as a reduction of elasticity module of each element in the FE model because this reduction affects both bending and axial stiffness of elements which are important in this study (Marwala 2010).

Damage types that may change the stiffness of structural members, which are detectable in this effort, include the loss of area due to corrosion or chemical degradation, material softening due to cyclic loading, loss of members and loosening the connections between elements. Besides, the undetectable damage may include cracks that remain closed during testing (raich and Liszkai 2007).

Introduced damage definition is presented in Eq. 2.

$$E_i^{(d)} = r_i \times E_i^{(u)} \tag{2}$$

Where r is the reduction factor and E is the Young modulus of elasticity of the i^{th} element. Also superscripts (d) and (u) demonstrate damaged and undamaged status, respectively. So, for explaining the condition of structure, reduction factors are used as genes on chromosomes.

5. Definition of Noise

To introduce noise into the measurements, normally distributed random noise was added to the simulated modal data with zero mean and a variance of 1.

6. Numerical Implementation

6.1. Description of the offshore platform model

The structure studied here is a two dimensional jacket-type offshore platform model which has been used in (Golafshani et al. 2010). The platform model is a steel frame with two legs braced with horizontal and diagonal members. The primary legs of the two first stories of the model have a two layer pipe whose interior has a diameter of 90cm with 2.54cm thickness. The exterior layer has the diameter of 98cm with 2.22cm thickness. The legs of the deck are the same as the exterior layer of the first and the second floor. All the horizontal braces have a diameter of 22.38cm (thickness 9.5mm). The first floor diagonal braces have a diameter 37.3cm (thickness 15.87mm). Also, the second floor diagonal braces have a diameter of 29.8cm (thickness 12.7mm). Moreover, the deck braces have a diameter of 44.7cm (thickness 19mm). The mass of the first floor, the second floor and deck are 430, 136 and 1133 tons respectively. The deck beams and leg supports presumed to behave rigidly and all other members assumed as an elastic beam-column. Young's modulus E is a constant equals to 200 GPa for all undamaged members. Other geometrical dimensions and elements' numbers are shown in Figure 1.

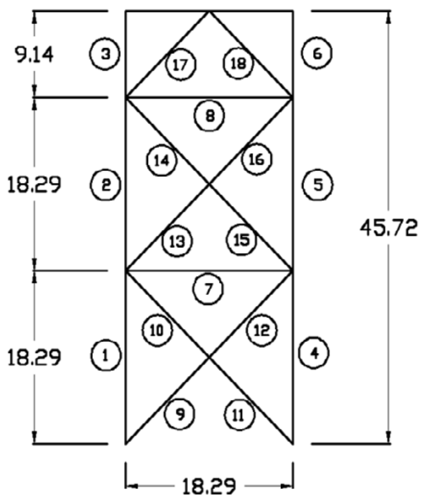

Figure 1. Geometry and element numbering of the investigated offshore jacket platform model.

6.2. Obtaining measured modal data and considering noise

In practice, several sensors should be placed on the elements of the structure to collect vibration data. Then, those signals will be processed to obtain different features, including modal properties of the structure to be used as key features in model updating. However, in this paper, measured modal properties are produced from outcome of modal analysis of a damaged finite element model through controlled damage scenarios instead of sensor data.

In addition, it is assumed that those sensors are located in every joint in horizontal direction. Moreover, as a consequence of noisy data, it is usually possible to get the modal properties of a few first modes of structure appropriately. Therefore, in this work, the five first natural frequencies and mode shapes are used.

Also, to simulate noisy data, the natural frequencies and mode shapes including noise are obtained from the natural frequencies and mode shapes without noise using Eq. 3 and Eq. 4 respectively similar to (Raich and Liszkai 2003).

$$f_p^{(n)} = f_p(1+\text{y}\times\text{randn}()) \quad (3)$$

$$\Phi_{p,q}^{(n)} = \Phi_{\text{p,q}}(1+\text{y}\times\text{randn}()) \quad (4)$$

Where f is p^{th} natural frequency and ϕ is the mode shape of p^{th} mode which is related to q^{th} degree of freedom of the structure. Also, superscript (n) stands for noisy parameters. Furthermore, y and randn() are noise level and normally distributed random noise function respectively.

The noise levels which are decided to add to modal data are 1, 2 and 3 percents. Because, usually the noise on extracted features, such as natural frequencies and mode shapes, are less than the noise on raw data from sensors as a result of applying different signal processing approaches.

6.3. Damage cases

To show the robustness of this damage detection method, several damage cases are studied as presented in Table 1. Unmentioned elements are supposed to be undamaged with reduction factor equal to 1.

Table 1. Damage cases

Case number	Damaged element(s)	Reduction factor(s)
1	18	0.6
2	1	0.7
3	13	0.4
4	7	0.7
5	9, 18	0.7, 0.4 respectively
6	9, 13, 17	0.7, 0.6, 0.5

6.4. Model updating procedure

The method which is decided to update the model to correlate with measured data, which different noise level is added on, is genetic algorithm. Figure 2 depicts diverse steps of this method. Considering the fact that the computational cost of GA is considerably more than other conventional methods, the model updating procedure is programmed in C++ language due to its high performance and flexibility. Also, OpenSees (http://opensees.berkeley.edu) is used as a powerful and swift tool to analyze the finite element model which is built based on each chromosome for calculating its modal properties. Afterward this modal information is used for calculating the cost of each chromosome.

Although different choices are available for genetic operators, there are some considerations to achieve good result, such as encoding type, population size, probabilities of cross over and mutation, elitism and type of crossover. For instance, in the case of encoding type, the real coded GA is selected because it is more applicable in problems with large domain, including damage detection problems (F. Herrera et al. 1998). The other settings of GA are: population size 80, crossover probability 0.85, mutation probability 0.06, and the number of generations 60. But in most of the studied cases this method reaches answer in the earlier generations.

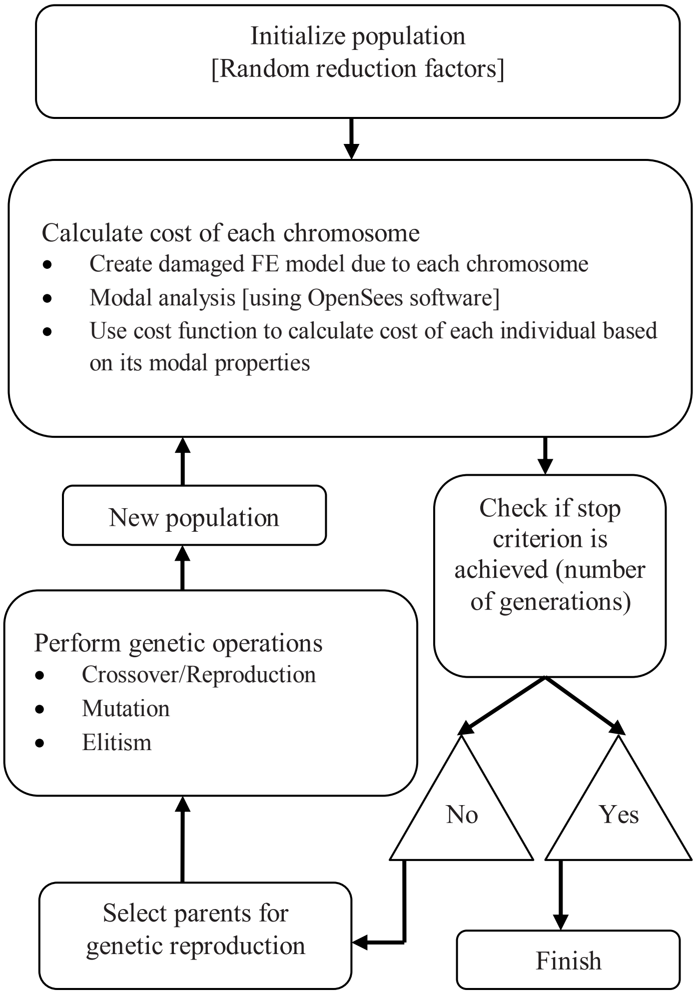

Figure 2. Flowchart of model updating procedure using GA

6.5. Choosing weights for cost function terms

In the case of weight factors for cost function, the first two factors (W_f and $W\varphi$) are assumed to be equal to one for having the same priority in optimization procedure. As regards the third term, the role of this term is eliminating the false damage from the damage set afterward the first two terms have converged to a stable value. So, to achieve this goal γ should set the order of third term to the numerical order of two first terms after their convergence. If this item is justified inaccurately it might affect the search procedure and leads to invalid results. Therefore, γ is set to 0.001 in this regard.

6.6. Results and Discussions

The best correlated instance after model updating procedure for each damage case is illustrated in Figure 3 to Figure 8. The results of single element damaged scenarios are presented in Figure 3 to Figure 6 whereas the result of two multi damaged element scenarios are depicted in Figure 7 and Figure 8. Each figure shows the reduction factor of the Young modulus of all elements in 4 states. The First bar represents the results of model updating procedure when no noise is added on modal data. Additionally, the second, third and forth bars indicate the results of model updating procedure where simulated measured modal data is polluted with 1, 2 and 3 percent noise respectively.

According to the "Without Noise" state, it is clear that this method is a robust method in localizing and quantifying the damage through the structure. Because it can detect all damage almost without any false damage among all damage cases in Figures 3 to Figures 8. Besides, these results verify the efficiency of used penalty term to avoid false damage in final results. Another important feature which can be obtained is the fact that using 5 first modal data are enough for identifying damage in this case.

As regards noisy states, the pattern of damage is detected in an appropriate way in every noise levels. But, when the noise volume is increasing, the errors will be growing accordingly. However, these errors rarely exceed more than 20 percent. Consequently, the results are acceptable and can be a good representative of the condition of structure even if used modal data is not precisely measured.

Another important note is the more discrepancies of elements 7 and 8 in comparison with other elements in higher noise levels in different damage cases. The reason is the placement of those members.

These elements are horizontal beams between two legs of the platform which participate less in modal behaviour of the whole structure in comparison with other members especially when just horizontal sensors are available. So, the noise effects might dominate their portion in modal data. Therefore, the results for them are more likely to be inaccurate.

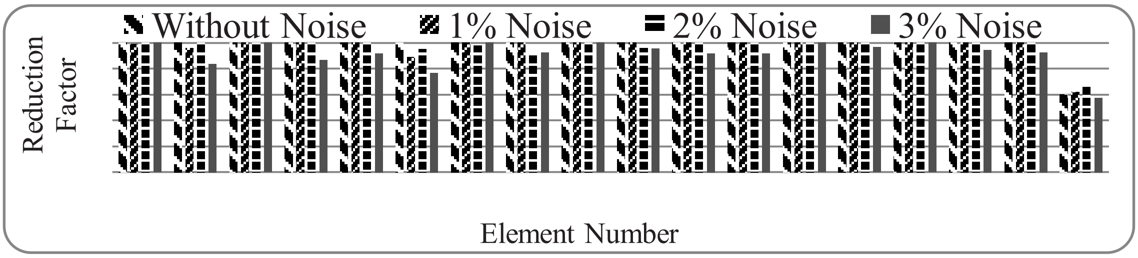

Figure 3. Result of damage case 1

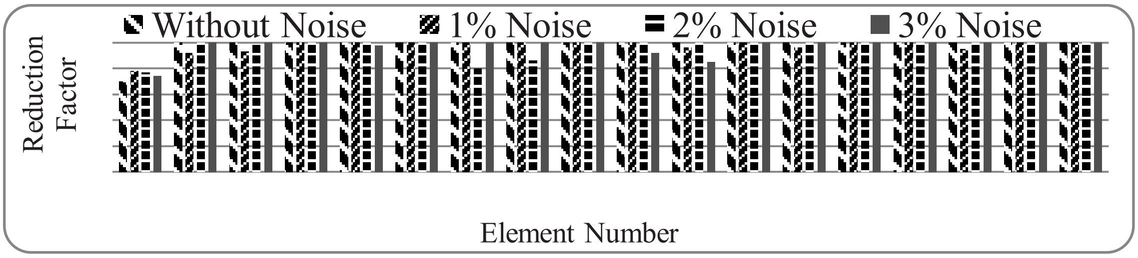

Figure 4. Result of damage case 2

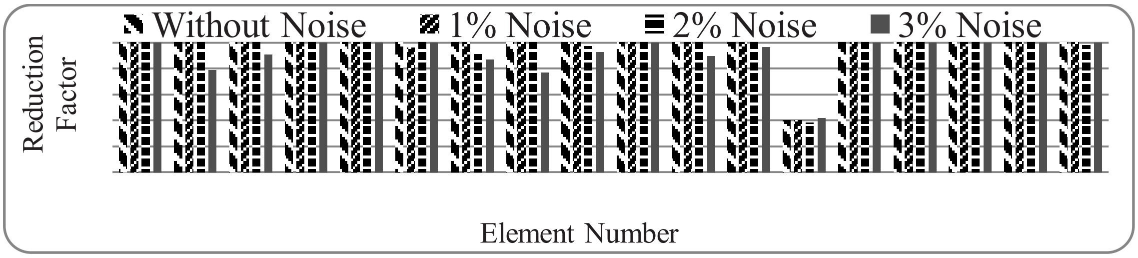

Figure 5. Result of damage case 3

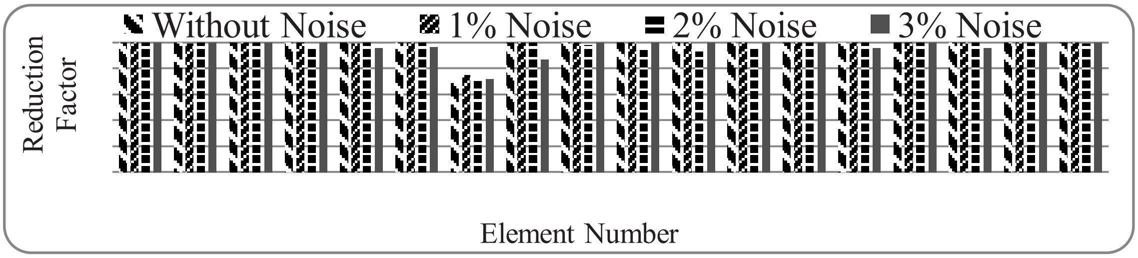

Figure 6. Result of damage case 4

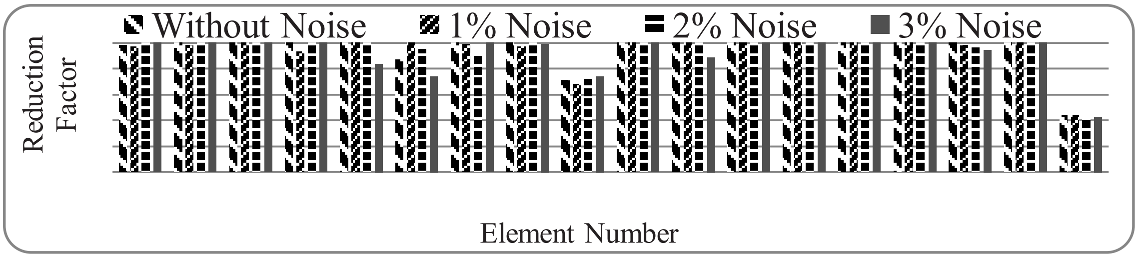

Figure 7. Result of damage case 5

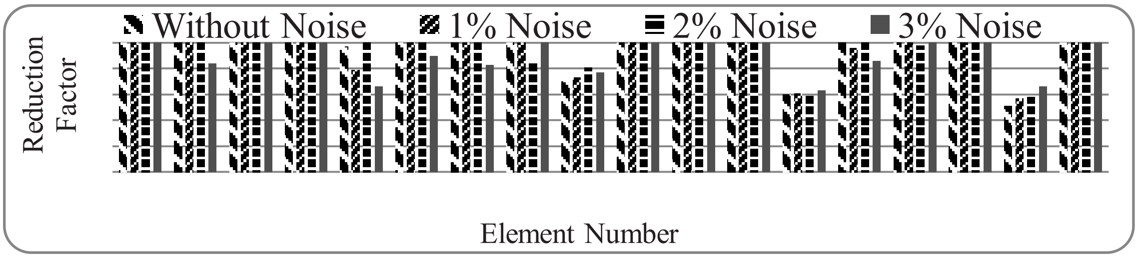

Figure 8. Result of damage case 6

7. Conclusion

This effort introduced a procedure to evaluate damage extent and location in an offshore jacket platform. The genetic algorithm with real coded representation is used as an optimization tool to match noisy natural frequencies and mode shapes of damaged structure with those obtained from updated finite element model, since almost no simplification is taken into account for dynamic behaviour of the system contrary to conventional methods. Also a penalty term is used in cost function to avoid false damage in the results. Furthermore, a technique is suggested to estimate the weight factor of this penalty term to work as required. This methodology was tested on single and multi damaged element scenarios considering several noise levels on measured modal data. The results show that, although the accuracy of achieved results will diminish by higher noise levels, it remains in the acceptable range, and also, show the damage pattern satisfactorily. However, it should be noticed that the damage intensity of members, which are not participated well in modal data, generally are more likely to be inaccurate.

References

Chou JH and Ghaboussi J 2001. Genetic algorithm in structural damage detection, Computers & Structures, vol. 79, pp 1335–1353.

Doebling SW, Farrar CR and Prime MB 1998. A summary review of vibration-based damage identification methods, The Shock and Vibration Digest, vol. 30, pp 91–105.

F Herrera, M Lozano, and JL Verdegay 1998, Tackling real-coded genetic algorithms: operators and tools for behavioural analysis, Artificial Intelligence Review, vol. 12, pp 265–319.

Golafshani AA, Ebrahimian H and Bagheri Baygi V 2010. A technical framework for probabilistic assessment of existing offshore platforms in Persian gulf under extreme environmental (wave) loading, 5th National Congress on Civil Engineering, Iran.

Gomes HM and Silva NRS 2008. Some comparisons for damage detection on structures using genetic algorithms and modal sensitivity method, Applied Mathematical Modeling, vol. 32, p 22.

Jafarkhani R and Masri SF 2011. Finite element model updating using evolutionary strategy for damage detection, Computer-Aided Civil and Infrastructure Engineering, vol. 26, pp 207–224.

Meruane V and Heylen W 2008. Damage detection by a real-parameter hybrid genetic algorithm, European Workshop on Structural Health Monitoring, Poland.

Malekzehtab H., Golafhani, A. A. and Mohajeri, S., 2011. Application of Genetic Algorithm Based Finite Element Model Updating in Damage Detection of Offshore Jacket Platforms, Second International Conference on Recent Trends in Transportation, Environmental and Civil Engineering, Bangalore, India.

Marwala, T., 2010, Finite-element-model updating using computational intelligence, Springer.

Park JH, Lee JM, Kim JT and Ryu YS 2006. Genetic Algorithm-based damage detection method using natural frequency and modal strain energy, Symposium on Optimization of Structural and Mechanical Systems, China.

Raich AM and Liszkai TR 2007. Improving the performance of structural damage detection methods using advanced genetic algorithm, Journal of structural Engineering, vol. 133, pp 449 – 461.

Raich AM, and Liszkai TR 2003. Benefits of an Implicit Redundant Genetic Algorithm Method for Structural Damage Detection in Noisy Environments, Proceedings of the 2003 international conference on Genetic and evolutionary computation

http://www.nd.com/products/genetic/selection.htm

http://opensees.berkeley.edu