Journal of Ferdowsi Civil Engineering, Vol.31, No.4, 2019.

Damage Detection of Plane Strain/Stress Problems using Modal Data

A. Motahari[1] J. Akbari[2]

1.Introduction

The researches in the field of structural health monitoring and damage detection could be categorized in analytical; numerical and experimental methods. In the analytical and numerical methods, mathematical modeling is created, and the damage such as the stiffness reduction is fabricated to clarify the strengths and weaknesses of the utilized algorithms. In these methods, there is no real damage, and the detection method is completely non-destructive. One of the most important challenges of health monitoring in practice is system excitation. In the experimental method, to excite a system appropriately, a small scale of a model is created for obtaining the output responses. In system identification and health monitoring in real conditions under static and dynamic loadings, the inputs and outputs are computed and processed through modern technologies. In the field tests, due to the structural complexities and considerable test costs, the output-only techniques are very popular and common.

In the numerical methods for assessing and identifying the damages, the mathematical modeling is created in the intact and damaged forms. Then, by extracting the modal data, the damage detection is carefully explored. From the vibration point of view, the natural frequencies, mode shapes, and modal damping of structures change when any crack or damage exists in the system. Using only natural frequencies for damage detection is straightforward, but applying the natural frequencies individually could not be an effective tool for this purpose, and frequency information can detect only the global damages. As well, the investigations indicate that applying only the mode shape information may not be an appropriate tool for identifying and finding the locations of the cracks or damages. Furthermore, In this research, natural frequencies and mode shapes, data are combined to assess and identify different damage scenarios.

In order to reduce computational costs, two distinct techniques are utilized here. Firstly, instead of using the genetic algorithm method, the particle swarm optimization (PSO) technique is applied. Therefore, this technique slightly reduced computational costs. Secondly, instead of using the fine meshes for calculating the modal parameters in the finite-element modeling; the coarse meshes are generated. The design variables in the optimization formulation and detection procedures are the element numbers and the ID of each element. Here for damage detection of the two-dimensional plane stress/strain type problems, the combination of the natural frequencies and mode shapes is considered as the objective function in the optimization procedure. For that reason, the finite-element based computer program is developed in the MATLAB environment for such calculations. The results illustrate that the non-gradient optimization techniques such as GA and PSO successfully detected the existence, location and the intensities of pre-defined damage scenarios.

2. Methodology & Results

In this research, damage is fabricated as a reduction of Young's modulus and therefore, stiffness reduction in finite-element model as Eq.(1). Here, Δa_e is the damage index between 0 to 1.0. As well, $(\mathbf{K_e})_\mathbf{u}, (\mathbf{K_e})_\mathbf{d}$ are the stiffness matrices of the intact and damaged elements respectively.

$$E_d = (1-\Delta a_e)\, E_u$$

$$\Delta\mathbf{K_e} = (\mathbf{K_e})_\mathbf{u} - (\mathbf{K_e})_\mathbf{d} \qquad (1)$$

$$(\mathbf{K_e})_\mathbf{d} = (1-\Delta a_e)(\mathbf{K_e})_\mathbf{u}$$

As seen in figure 1, for damage detection procedure, several scenarios are designed in the finite-element modeling. For this purpose, the two-dimensional plane stress type system is studied. By finite-element modeling of the studied system, the natural frequencies and mode shape are calculated. Then, using GA optimization toolbox in MATLAB, the objective function is written as Eq.(2) in the form of a combination of the natural frequencies and modes shape.

$$F(\alpha)=\left|\frac{\omega_j^d-\omega_j^u}{\omega_j^u}\right|+\sqrt{\frac{\sum_{i=1}^{ndf}(\varphi_{ij}^d-\varphi_{ij}^u)^2}{\sum_{i=1}^{ndf}(\varphi_{ij}^u)^2}} \qquad (2)$$

α=g(Number of Elements, Element Index)

Where, $\omega_j^u, \varphi_{ij}^u$ is the frequencies and mode shapes of the intact system, and $\omega_j^d, \varphi_{ij}^d$ are the modal parameters of the damaged structural model.

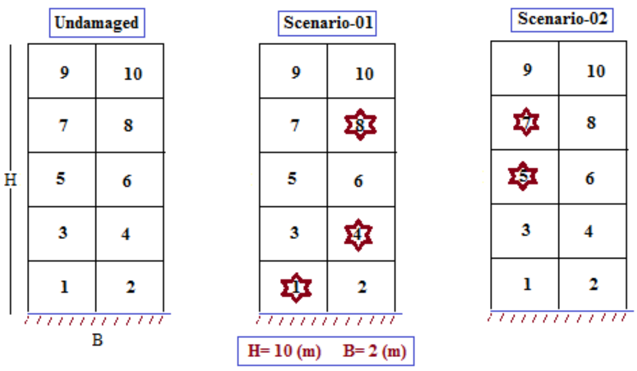

Fig. 1- the Schematic of intact and damaged structural models (2x10 m)

[1] Graduated from structural Engineering, Malayer University, Malayer, Iran,

[2] Corresponding Author: Assistant professor, Department of Civil Engineering, Malayer University, Malayer, Iran.
Email: akbari@malayeru.ac.ir

In figures 2, 3 the optimization results of the designed scenarios are presented. As seen from these figures, the GA successfully detected the damaged elements. The computational time in this case is about 48-hours for an ordinary computer system. However, the time of computation for PSO algorithm was about 20-hours for yhe same computer system.

3. Conclusion

The following conclusion could be drawn from the current research:

- The damage detection using the non-gradient based method is possible without involving in the complex mathematical formulation.
- The computational time extremely is increased when the fine mesh is used in finite-element modeling, and it is not cost- effective for real structures.
- By using a combination of natural frequencies and mode shape in the objective function, applying coarse mesh is a good alternative for reducing the computational.

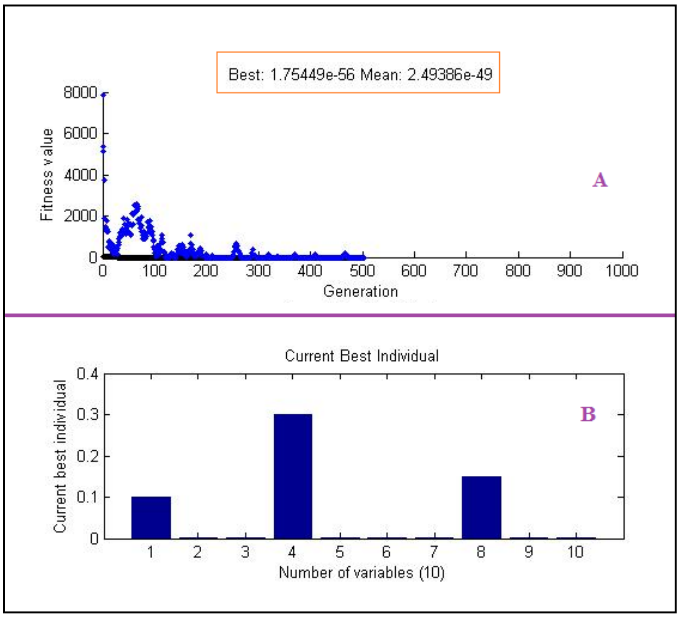

Fig. 2 the damage detection results for scenario no.1

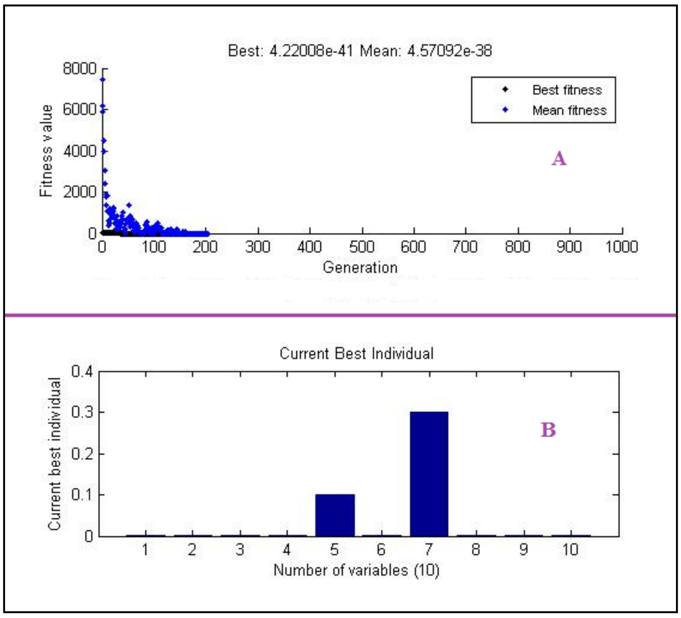

Fig.3 the damage detection results for scenario no.2