Structural Damage Identification Using MOPSO and MOEA/D Multi-Objective Evolutionary Optimization Algorithms

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1- Introduction

Structures are subject to different types of damage during their operation due to confrontation with a variety of destructive phenomena. Many currently operative structures such as dams, tunnels, hospitals, schools and public places that have been built a few decades ago, are facing the risk of destruction. In the case of failure of such structures, above the drastic losses are imposed to the infrastructures and large scale assets of the country, and irreparable human tragedies will be inevitable. Accordingly, early or at least on time detection of damage, analysis of the damaged structures and monitoring of their health is a critical concern for retrofitting, rehabilitation and useful lifetime increase of the structures.

Early reports on applications of optimization algorithms in the field of damage detection are based on single-objective optimization methods. On the other hand, many optimization problems in engineering field are too complex to be solved by traditional gradient based methods. Consequently, in recent years, several evolutionary optimization algorithms have been introduced as powerful and efficient tools to solve complex engineering optimization problems which are not easy to solve by traditional optimization methods. Therefore, in the current study, Multi-Objective Particle Swarm Optimization (MOPSO) and Multi-Objective Evolutionary Algorithm Based on Decomposition (MOEA/D) have been used for simultaneous optimization of the objective functions.

This paper investigates the ability of multi-objective optimization methods for structural damage identification in a simply supported beam and two fixed end moment beams. Finally, multi-objective evolutionary algorithms were applied to explore the best answer for structural damage identification, among all points of the optimal Pareto.
front curve by computation of discrepancy function. For final verification of the proposed method, the results of our numerical modeling procedure are compared with those reported by other researchers.

2- Objective Functions and Optimization Algorithms

The main objective of this research study is to investigate the capability of multi-objective optimization methods for diagnosis and assessment of damage in structures. "Damage Diagnosis" signifies the geometric position identification of the damage and "Damage Assessment" corresponds to evaluation of the severity of the damage in the structure. Hereupon, it has been tried first to diagnose the damage on the basis of numerical modeling of the structure, i.e., vibrational modal analysis, in both intact and damaged states using a finite element method.

$$F_1 = 1 - \prod_{i=1}^{NM} MACSTIF_i \quad (1)$$

$$[K] = \sum_{i=1}^{NM} \frac{\omega_i^2}{M_i}.[M].\{\Phi_i\}.\{\Phi_i\}^T.[M] \quad (2)$$

$$F_2 = 1 - \prod_{i=1}^{NM} MACPHI_i \quad (3)$$

$$MAC = \frac{|\{x\}^T\{y\}|^2}{(\{x\}^T\{x\})(\{y\}^T\{y\})} \quad (4)$$

Subsequently, the multi-objective particle swarm optimization method and multi-objective evolutionary algorithm based on decomposition method are employed to find the feasible answer on the optimal Pareto front curve. The objective functions used include modal assurance criterion of mode stiffness (MACSTIF) and modal assurance criterion of mode shapes (MACPHI).

The first objective function (MACSTIF) is sensitive to the intensity of damage and it has been defined using properties of structural stiffness. Modal stiffness of the structure indicate a pattern of structural stiffness in each vibration mode. The second objective function (MACPHI) is sensitive to the location of damage and it has been defined using properties of mode shapes. Mode shapes of the structure indicate a pattern of structural deformation in each vibration mode.

3- Structural Damage Identification

For the final verification of the proposed method, the results of our numerical modeling were compared with those of other researchers. It was demonstrated that the proposed method is an effective and appropriate structural modal analysis based technique for localization and estimation of the severity of damage.

4- Conclusions

Based on the optimal pare to front curves with the MOPSO and MOEA/D evolutionary algorithms and their numerical results of structural damage identification for two fixed end moment beams and

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comparison with experimental results through Hu et al., the following conclusions are drawn:

1. Structural damage identification in this research is based on two approaches: a) detection of the damage geometry position; and b) investigation of the intensity of damage. Identifying the location of damage and assessing the severity of it in each element requires two powerful objective function to be resolved. Hence, using multi-objective optimization is considered.
2. The natural frequency variation of the structure has a significant effect on the response of the modal assurance criterion based on the mode stiffness. Since natural frequency variations in the form of modal square summation are affected in this objective function, the first objective function is sensitive to the intensity of damage in the structure.
3. The location of the damage in the structure is very effective in the values of the mode shape vectors. In other words, the modal assurance criterion based on mode shape is sensitive to the location of damage. Therefore, the second objective function is an appropriate function for determining the geometric position of damage in the structure.
4. The CPU time for running the multi-objective particle swarm optimization algorithm is about 50 seconds for plotting the optimal Pareto front curve for each iteration, while for multi-objective evolutionary algorithm based on decomposition, plotting an optimal Pareto front curve for each iteration takes about 40 seconds. Therefore, the multi - objective evolutionary optimization algorithms used in this study have an appropriate convergence rate. Moreover, it is observed that a multi-objective evolutionary algorithm based on decomposition has better performance in terms of speed and accuracy than the multi-objective particle swarm algorithm.

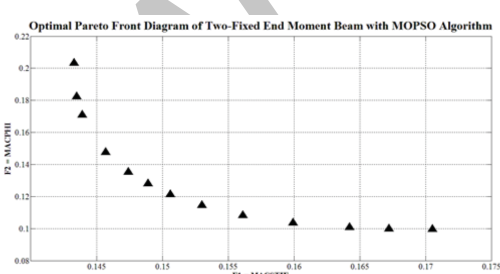

Fig. 1. Optimal Pareto Front Curve with MOPSO

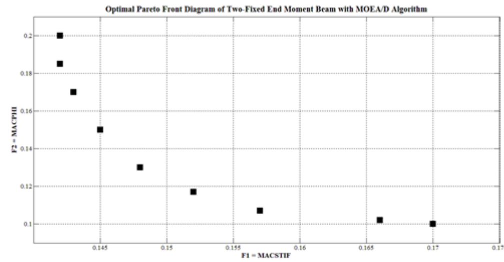

Fig. 2. Optimal Pareto Front Curve with MOEA/D

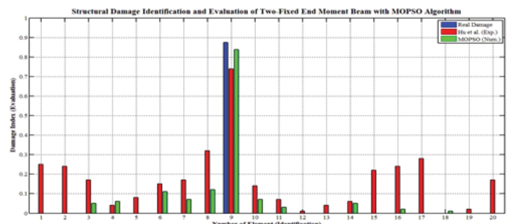

Fig. 3. Comparison MOPSO and Hu. et al

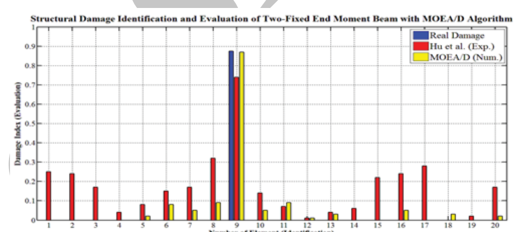

Fig. 4. Comparison MOEA/D and Hu. et al

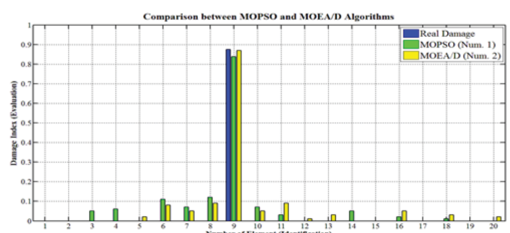

Fig. 5. Comparison MOPSO and MOEA/D