Abstract

This thesis focuses on developing a novel damage identification method for different civil structures utilizing metaheuristic algorithms with multi-stage strategies using sparse modal data collected from limited sensors. Structural damage identification (SDI) is formulated as an inverse optimization problem where damage severity in each element of the structure is considered as an optimization variable. A weighted linear combination of the natural frequencies and modes shapes of the structure is used to construct the objective function. The formulated objective function is minimized by the multi-stage strategy employing a metaheuristic algorithm. In the present work, two new multi-stage strategies are developed, and these strategies with different metaheuristic algorithms are applied for the SDI of different types of structures.

At first, a self-controlled multi-stage optimization method for damage identification of truss structures utilizing standard particle swarm optimization (PSO) algorithm is proposed. The objective function is minimized by a self-controlled multi-stage (SCMS) strategy to identify and quantify the damage extent of the structural members. In the first stage, the standard PSO is utilized to get an initial solution to the structural damage identification problem. Subsequently, the algorithm identifies the most damage-prone elements of the structure using an adaptable threshold value of damage severity. These identified elements are included in the search space of the standard PSO at the follow-up stages. Thus, the algorithm reduces the dimension of the search space and subsequently increases the accuracy of the damage prediction with a considerable reduction in the computational cost. The efficiency of the proposed method is investigated and compared with available results through three numerical examples considering both with and without noise. The obtained results demonstrate that the present method can accurately estimate the location and severity of multi-damage cases in structural systems with less computational cost.

Next, a multi-stage optimization technique is proposed for damage detection of the thin plate-like structures using sparse modal data collected from the limited sensors. The response of the thin plate structures is obtained from a finite element (FE) model, which is developed with constant strain triangle elements. The second-order approximation of the Neumann series expansion-based model reduction is applied to numerically simulate the state of sparse sensors. The objective function is minimized by the proposed multi-stage (MS) strategy employing a hybrid metaheuristic algorithm based on the particle swarm optimization and gravitational search algorithm (PSOGSA). The algorithm identifies the healthy elements in each stage and eliminates them from the search space of the next stage. Thus, the search space dimension of the optimization problem reduces in each stage, and actual damaged elements are identified effectively. The efficiency of the proposed method is demonstrated through two numerical examples with different damage scenarios. It is observed that the proposed PSOGSA with the developed novel MS strategy can identify the damage in the thin plate structures with sparse modal data more accurately and cost-efficiently than the other well-established algorithms.

Finally, an efficient multi-stage optimization-based damage identification method is proposed for the truss and frame structures equipped with a limited number of sensors. In this approach, FE model is developed to simulate the response of the actual structure. The limited sensor condition for this FE model is achieved by the modal reduction method. A comparison study among the three well-established modal reduction methods has been performed, and the iterated improved reduction system (IIRS) approach has been selected for the present study. This objective function is minimized by the improved teaching learning-based optimization - particle swarm optimization (ITLBO-PSO) utilizing both SCMS strategy and MS strategies. The SCMS and MS strategies automatically reduce the search dimension of the optimization problem in each stage, and their results are compared. Four examples with different damage scenarios from the relevant literature are considered in the present study to demonstrate the efficacy of the proposed method. The results for both with noise and without noise are compared with nine other well-established algorithms. The results show that the proposed ITLBO-PSO with SCMS strategy identifies damages with adequate precision and outperforms the other algorithms with SCMS strategy and ITLBO-PSO with MS strategy regarding the accuracy and computational cost.

The main contribution of this thesis includes the development of two novel multi-stage strategies and an extensive comparative study of these proposed strategies for SDI utilizing metaheuristic optimization methods. In addition, an efficient novel hybrid metaheuristic algorithm (ITLBO-PSO) is proposed for structural damage identification with incomplete modal data employing the SCMS strategy.

Keywords:
Structural health monitoring, Damage identification, Inverse problem, Vibration response, Metaheuristics, PSO, Hybrid PSO-GSA, Hybrid ITLBO-PSO.