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Damage assessment in structures using combination of a modified Cornwell indicator and genetic algorithm

S. Tiachacht[a], A. Bouazzouni[a], S. Khatir[b], M. Abdel Wahab[c,d,e,*], A. Behtani[a], R. Capozucca[f]

[a] Laboratory of Mechanics, Structure and Energetics (LMSE), Mouloud Mammeri University of Tizi-Ouzou, B.P.N°17 RP, 15000, Algeria
[b] Department of Electrical Energy, Metals, Mechanical Constructions & Systems, Faculty of Engineering and Architecture, Ghent University, Ghent, Belgium
[c] Division of Computational Mechanics, Ton Duc Thang University, Ho Chi Minh City, Viet Nam
[d] Faculty of Civil Engineering, Ton Duc Thang University, Ho Chi Minh City, Viet Nam
[e] Soete Laboratory, Faculty of Engineering and Architecture, Ghent University, Technologiepark Zwijnaarde 903, B-9052 Zwijnaarde, Belgium
[f] Polytechnic University of Marche, Ancona, Italy

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ABSTRACT

This paper presents a new methodology for damage identification and quantification in two- and three-dimensional structures. The application of the proposed methodology is investigated numerically using Finite Element Method (FEM) and Matlab program. We propose a Modified Cornwell Indicator (MCI) that performs more efficient in damage detection than the standard Cornwell Indicator (CI). Furthermore, MCI is combined with Genetic Algorithm (GA) for further quantification of the detected damage. In GA, MCI, is used as an objective function to compare between measured and calculated indicators. The results of the analysis show that the proposed technique is accurate and efficient, when compared with other techniques in the literature, to estimate the severity of structural damage.

1. Introduction

A Nondestructive Damage Identification (NDI) and Structural Health Monitoring (SHM) become important tools for damage assessment of structures in recent years [1–5]. They form the basis of any decision to repair, rehabilitate, or replace a damaged structure. Shi et al. [6] developed an element wise damage sensitivity matrix based on Mean Square Error (MSE) changes in structure elements for quantifying the presence of damage. Yan et al. [7,8] published two papers based on MSE and generalized flexibility technique using mode shapes and natural frequencies. The proposed technique has shown good accuracy for locating and quantifying the presence of damage.

Optimization techniques have been recently used for SHM. Khatir et al. [9] used different optimization techniques coupled with reduced model based on Proper Orthogonal Decomposition (POD) and Radial Basis Function (RBF) for crack location using experimental data. Khatir et al. [10] presented new application in plates using using eXtended IsoGeometric Analysis (XIGA) and Particle Swarm Optimization (PSO) for crack identification with different scenarios. Zenzen et al [11] presented inverse problem technique based on frequency response (FR) and PSO for beam and truss structure. Khatir et al. [12] presented new application for crack identification in beams and 2D structures based on inverse problem using PSO. The proposed application was validated experimentally. The change in generalized flexibility matrix was presented by Li et al. [13] to detect the location and extent of structural damage. Villalba and Laier [14] used a self-adaptive multi-chromosome GA for damage assessment in structures. The results showed that the proposed approach could detect the damage with higher accuracy through different damage scenarios. An algorithm to solve the inverse problem of detecting inclusion interfaces in a piezoelectric structure was proposed by Nanthakumar et al. [15]. The material interfaces were implicitly represented by level sets which were identified by applying regularization using total variation penalty terms. Ghasemi et al. [16] presented a design methodology based on a combination of IsoGeometric Analysis (IGA), level set and point wise density mapping techniques for topology optimization of piezoelectric/flexoelectric materials. A computational design methodology for topology optimization of multi-material-based flexoelectric composites was presented in Ref. [17].

The inverse problem using several optimization techniques with different objective functions coupled with FEM for damage detection of single and multiple damages was presented in Refs. [18,19]. Many researchers used the measured natural frequencies for damage detection and localization based on loss of rigidity [19,20]. Pandey et al. [21]

* Corresponding author at: Division of Computational Mechanics, Ton Duc Thang University, Ho Chi Minh City, Viet Nam.
E-mail addresses: magd.abdelwahab@tdt.edu.vn, magd.abdelwahab@ugent.be (M. Abdel Wahab).

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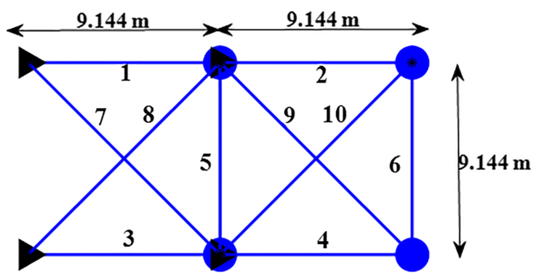

Fig. 1. A 10-bar planar truss.

Table 1
Material properties for the 10-bar planar truss.

Property [unit]	Value
E, modulus of elasticity [N/m^2]	6.98×10^{10}
S, cross-sectional area of the members [m^2]	0.0025
Added mass [kg]	454
ρ, material density [kg/m^3]	2770
L, main bar's dimension [m]	9.144

presented a technique based on the change in the structure flexibility matrix. Hwang and Kim [22] presented a new indicator based on frequency response for damage identification in beam-like structures. The evaluation to use of Frequency Response Function (FRF) with the help of optimization technique was presented by Mohan [23]. Many researchers have proposed several applications in literature for detecting and location the presence of damage in various types of structures. The use of the changes in the mode shape and mode-shape-slope parameters was investigated by Yen [24]. Yen [25] proposed a numerical method for structural damage identification using modal residual force criteria and matrix disassembly technique. Wu et al. [26] used Neural Network (NN) in damage identification employing back-propagation algorithm in their neural network architecture with one and two layers to identify the presence of damage in a three-story frame. The inverse problem for damage identification using multi-objective PSO and GA has been evaluated by Perera et al. [27].

A review of damage detection and SHM of mechanical systems based on changes in the measured data of linear and non-linear vibrations was presented by Sinou [28]. Different detection techniques to diagnose damage detection in rotors with various modelling of the cracked elements was presented by Wauer [29]. A newly proposed approach for cracks detection in steel beams by sine-sweep vibration measurements was presented by Dougdag et al. [30]. Reduced model based on POD method was used for damage identification in beam-like structures coupled with optimization techniques to estimate the crack length and its position using boundary displacements as input to build data matrix. GA and PSO, were then applied to minimize the objective function expressed as the difference between the boundary displacements of the actual crack and those of the estimated ones [31,32].

Kaveh et al. [33] used Improved Charged System Search (CSS) for damage detection in truss structures using changes in natural frequencies and mode shapes. The CSS is a population based meta-heuristic algorithm proposed by Kaveh and Talatahari [34]. This algorithm is based on laws from electrostatics of physics and Newtonian mechanics. The proposed technique was used for damage detection and localization in different structures [35,36]. A mixed particle swarm-ray optimization together with harmony search (HRPSO) was applied to structural damage identification as presented in Ref. [37]. The application of recently developed optimization algorithms, so-called Colliding Bodies Optimization (CBO) and Enhanced Colliding Bodies Optimization (ECBO), in conjunction with structural modal information for damage detection of steel trusses were presented by Kaveh and Mahdavi [38]. Kaveh et al. [39] developed multi-agent meta-heuristic method, named Cyclical Parthenogenesis Algorithm (CPA), which was incorporated into a guided modal strain energy based structural damage detection technique. A structural damage identification approach was presented by Kaveh and Zolghadr [40] in order to localize and quantify multiple damage cases in different structures. The change of modal strain energy of a structural element due to damage was utilized to guide the structural identification process, which was formulated as an inverse optimization problem. The objective function of the optimization problem, which was defined using the generalized flexibility matrix (GFM) of the structure, was then optimized using the newly developed tug-of-war optimization (TWO) algorithm.

Maity and Saha [41] proposed neural network technique for detecting damage through response measurement of structures. The idea was applied to a simple cantilever beam, in which strains and displacements were measured for damage identification by a back-propagation neural network. Maity and Tripathy [42] used GA for damage identification based on changes in natural frequencies. The inverse problem was based on optimization terms and then utilized a solution procedure to assess the damage location. Sahoo and Maity [43] presented a hybrid neuro-genetic algorithm in order to optimize the design of neural network for different type of structures. Majumdar et al. [44] presented a method for damage identification from changes in natural frequencies using Ant Colony Optimization (ACO) algorithm. Liu and Chen [45] presented an inverse approach for identifying stiffness distribution on structures using structural dynamics response based on the frequency domain. Tripathy and Maity [46] proposed an approach based on neural network algorithm for damage identification. The natural frequencies and mode shapes were used as input parameters to the neural network optimization for damage detection and localization by Mehrjoo et al. [47].

In this paper, a robust and efficient method for damage identification is presented. First, a modified version of Cornwell Indicator (CI) is proposed, i.e. Modified Cornwell Indicator (MCI). It is shown that MCI provides more accurate damage detection and localization than CI. Then, the damage indicators are used as input in an objective function, to be minimized in order to quantify damage and predict its severity using GA.

2. Methodology

2.1. Cornwell indicator

There are several methods for damage localization in structures using modal data directly by considering the modal deformation energy before and after damage. Among these methods, Cornwell et al. [48] proposed a damage indicator based on the variation of strain energy.

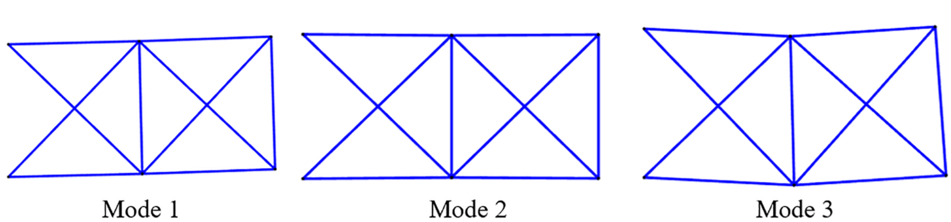

Fig. 2. The first three mode shapes of the 10-bar planar truss.