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Buckling load prediction of laminated composite stiffened panels subjected to in-plane shear using artificial neural networks

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ABSTRACT

Stiffened panels are basic building blocks of weight sensitive structures. Design of laminated composite stiffened panels is more involved and requires the use of an optimization approach, which needs a computationally efficient analysis tool. This paper deals with the development of an analytical and computationally efficient analysis tool using artificial neural networks (ANN) for predicting the buckling load of laminated composite stiffened panels subjected to in-plane shear loading. The database for training and testing is prepared using finite element analysis. Studies are carried out by changing the panel orthotropy ratio, stiffener depth, pitch length (number of stiffeners). Using the database, key parameters are identified and a neural network is trained. The results shows that the trained neural network can predict the shear buckling load of laminated composite stiffened panels accurately and will be very useful in optimization applications where computational efficiency is paramount.

1. Introduction

Stiffened panels are widely used basic building blocks in weight sensitive structural systems such as box girder bridges, bridge decks, helidecks, aerospace structures, ship decks and super structure of offshore oil platforms where high stiffness/weight and strength/weight ratios are paramount. Being a thin walled structure the design of stiffened plates is governed both by stability and strength criteria. Stability of isotropic plates with and without stiffeners is reported by Timoshenko and Gere [1]. The accurate knowledge of critical buckling loads is essential for reliable and light weight structural design.

Composite materials are non homogeneous, anisotropic and difficult to characterise but offer several possibilities. Laminated composites earlier limited to aerospace industry are gradually being applied in structural applications. A concise state-of-the-art survey of fiber-reinforced polymer composites for construction application in civil engineering is presented in [2]. Laminated composites can be tailored as per the requirements but at the same time they introduce high degree of orthotropy, more number of design variables, which complicates the analysis and design.

The presence of in-plane loading may cause buckling of composite panels. The study related to the buckling of laminated composite panels has a relatively short history in comparison with isotropic, homogeneous plates. Researchers worked on the buckling of unstiffened composite panels subjected to different loadings [3–7]. Analytical and numerical methods are used to analyse and study the buckling behavior of laminated composite stiffened panels. Smeared stiffener solution is one of the analytical methods which is computationally efficient but involves error especially under in-plane shear and combined loading [8]. On the other hand, numerical methods like finite element method (FEM) are used as a competent tool for the analysis of these structures [9–11]. In addition to these, large number of references in the published literature deal with the buckling behavior of stiffened plates subjected to in-plane compressive loadings. The buckling phenomenon of laminated composite stiffened panels subjected to in-plane shear loading is destabilizing in nature. Loughlan [12] studied the buckling capacity of composite stiffened shear webs by considering stiffener size, pitch and the fiber orientation in the stiffeners as parameters. His studies reveal that for a given structural weight, shear buckling performance can be enhanced through favorable orientation of fibers in the stiffener. Mallela and Upadhyay [13] carried out linear buckling analysis of laminated composite blades stiffened panels and identified parameters influencing the buckling behavior. They developed a database in the form of design charts for different plate stiffener combinations. Hemendra and Upadhyay [14] carried out parametric studies for buckling of laminated composite blade-, angle-, T-, and hat stiffened panels subjected to in-plane shear. Their studies indicate that buckling behavior for different stiffeners is qualitatively same as that of the results presented in [13].

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Nomenclature

A_{11}, A_{12}, A_{22}	stiffness coefficients
$(A_{11}/A_{66})_p$	extensional stiffness to shear stiffness ratio of the plate
a	length of the panel
b	width of the panel
d	depth of the stiffener
C_T	torsional stiffness of a thin stiffener
D_{11}, D_{22}, D_{33}	stiffness coefficients
D_1	panel bending stiffness in the direction of stiffener
D_2	bending stiffness in the direction transverse to stiffener
D_3	torsional rigidity of stiffened panel
D_3'	torsional rigidity of the plate without stiffener
D_3''	torsional rigidity of stiffeners
D_1/D_2	orthotropy ratio of the stiffened panel
$(D_1/D_2)_p$	orthotropy ratio of the plate
$\sqrt{D_1D_2}/D_3$	shear buckling parameter
E_1, E_2	Young's modulus for composite material in fiber direction and transverse to fiber direction, respectively
EI	smeared bending stiffness for one period of the panel cross section
ET_k	longitudinal extensional stiffness of element k (plate or stiffener)
$(EA)_s/(EA)_p$	smeared extensional stiffness ratio of stiffener to that of the plate
G_{12}	shear modulus of composite material in coordinate system defined by fiber direction
N_x	applied longitudinal compression loading per unit width of the panel
N_{xy}	applied shear loading per unit width of the panel
$N_{xy,crit}$	value of shear load that causes buckling
P_1	stiffener spacing (pitch length) in transfer direction
t_p	thickness of the plate
t_s	thickness of the stiffener
Z_k	distance of the element centroidal axis from neutral axis
ρ	density
$\upsilon_{12}, \upsilon_{21}$	Poisson's ratio of composite material in coordinate system defined by fiber direction, respectively

Subscripts

k	type of the element (plate or stiffener)
p	plate
s	stiffener

Numerical analysis is competent from analysis point of view but it is not computationally efficient from design point of view. In the design of laminated composite structures, due to involvement of large number of variables, use of an optimization tool becomes necessary. Venkataraman [15] reported that performing design optimization of laminated composites using FEM based analysis is often too expensive to be practical as stiffened panel design often involves remeshing and reanalysis for acceptable accuracy. Stroud and Agranoff [16] studied the minimum mass design of composite panels and concluded that composite shear panels offer substantial mass savings over metal panels. Stroud and Anderson [17] developed PASCO and Williams et al. [18] developed a buckling and strength constraint program VICONOPT which is based on feasible direction algorithm which is mathematical programming method. Gradient information is required in mathematical programming based optimization which is difficult to evaluate especially when the variables are high and discrete. During optimization, the analysis has to be repeated a number of times. As reported earlier [8] the smeared stiffener solution is to be used only with caution. Also, there is no closed form solution to calculate the buckling load of laminated composite stiffened panels subjected to in-plane shear loading. These factors demand a computational efficient analysis approach which can be directly used in the optimum routines. For these situations the biologically motivated Artificial Neural Network (ANN) can be effectively used as an efficient tool to solve a wide variety of engineering problems. There are sufficient evidences in literature where ANN is successfully used in structural engineering [19–22]. Few researchers have used ANN for predictions in composites [23–28]. Zhang and Friedrich [29] presented a review on considerations involving the various applications of ANN in the field of polymeric composite property prediction and design. They also reported that the applications of ANNs to polymeric composites are still in their basic stages. El Kadi [30] in a review paper addressed the application of ANN to the mechanical properties of fiber-reinforced polymeric composites. In addition to this, researchers have found this computing technique (ANNs) to be very useful in structural engineering such as approximate analysis, preliminary design and optimization.

The majority of the research concentrates on the buckling response of unstiffened and stiffened panels subjected to in-plane compressive loadings. Some contributions in the form of design charts and guidelines have been developed for unstiffened panels subjected to in-plane compression and shear loadings, but the buckling response of laminated composite stiffened panels subjected to in-plane shear loading received less attention. In addition to this, due to the inexistence of analytical function to evaluate buckling load of laminated composite stiffened panels, a simplified computationally efficient model/analysis tool in the form of ANN is vital.

This paper attempts to fill the gap in the literature on optimization of simply supported laminated composite blade stiffened panels subjected to in-plane shear loading with the development of a computationally efficient analysis procedure using ANN for predicting the buckling load. The artificial neural network is trained by using numerical data generated by Mallela and Upadhyay [13]. Adequacy of the ANN model for the prediction and generalization capabilities is checked by using testing data as well as new data.

2. Finite element analysis

The finite element analysis (FEA) is used to generate the structural responses for the training and testing data of the neural network.

2.1. FE modeling

Eigen-buckling analysis is performed for the laminated composite blade-stiffened panels by using the finite element package ANSYS 7.1. Modeling laminated stiffened panels needs care in defining the properties of the plate and stiffener, number of layers, symmetric or unsymmetric, thickness and fiber orientations of each layer. Out of the several elements available in the ANSYS library [31] for modeling laminates, Shell91, having six degrees of freedom at each node which is designed to model thin plates and shell structures, is taken for the analysis. Equivalent joint load corresponding to given uniformly distributed shear load is applied on all boundary nodes of the panel. The buckling factor obtained from the analysis is multiplied by the intensity of loading to get the buckling load.