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An efficient finite element model for buckling analysis of grid stiffened laminated composite plates

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ABSTRACT

For the prediction of buckling response of grid stiffened composite panels having different stiffening arrangements, an efficient finite element modelling technique is presented. The laminated skin of the stiffened structure is modelled with a triangular degenerated curved shell element. An efficient curved beam element compatible with the shell element is developed for the modelling of stiffeners which may have different lamination schemes. The deformation of the degenerated beam element is completely defined in terms of the degrees of freedom of shell elements and it does not require any additional degrees of freedom. This modelling strategy has helped to reduce the number of unknowns significantly compared to the usual approac h where solid or shell elements are used for modelling stiffeners. As the usual formulation of degenerated beam elements overestimates their torsional rigidity, a torsion correction factor is introduced for different lamination schemes. Numerical examples are solved by the proposed finite element technique to assess its performance and it shows that the accuracy of the proposed model is quite satisfactory. A parametric study is presented to show the effects of skin thickness, stiffener breadth and stiffener depth on the buckling capacity of grid stiffened composite plates.

1. Introduction

Due to high specific strength and stiffness as well as flexibility in tailoring the structural performance, fibre reinforced polymer (FRP) laminated composites have been widely used in many weight sensitive structural applications such as aerospace structures, satellite launch vehicles, automotive structures and marine vehicles as well as modern bridge decks and buildings. On the other hand, a stiffened panel always performs better in resisting loads compared to an unstiffened panel of same weight. Thus a combination of lightweight composite materials and stiffened structural forms can efficiently enhance the load resisting capability that can be buckling strength of a structure. The structural behaviour of a stiffened composite panel is quite complex due to complex structural form and anisotropic material properties of the skin and stiffeners. These types of thin-walled structures are vulnerable to lose global and local stability under compression loadings. Consequently, the bucking analysis of these structures is a critical component for in-deep understanding of their buckling performances and also a prerequisite for a reliable bucking-resistant design of these panels.

There is vast literature on stiffened plates and shells specifically for these structures made of isotropic materials and simple stiffener orientations. The research carried out up to the middle of nineteen nineties was nicely reviewed by Sinha and Mukhopadhyay [1] who mostly covered research on isotropic stiffened panels. In 1998, Bedair [2] presented an extensive review on the methods for predicting global and local buckling responses of isotropic stiffened plates. Prusty [3] compiled the research on composite stiffened shells conducted up to the end of nineteen nineties. Dawe [4] elaborately summarised the work on the use of the finite strip approach for predicting buckling response of composite structures with unidirectional stiffeners in 2002. In order to avoid any repetition, only the recent investigations in this area are mentioned in the following two paragraphs.

Bisagni and Vescovini [5] presented two analytical solutions for local buckling of longitudinally stiffened composite panels where the skin was idealised as a thin plate and the stiffeners were modelled as torsion bars that provided torsional rigidity along unloaded edges to resist local buckling of the skin. Applying their model to calibrate buckling constraints, they [6] conducted the minimum weight design of longitudinally stiffened composite plates subjected to axial compression. Stamatelos et al. [7] proposed an analytical method to predict the local buckling load of plates with symmetrically exposed longitudinal stiffeners, while Sun and Harik

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[8] developed an analytical strip method for buckling analysis of composite plates with unidirectional stiffeners having anti-symmetrical exposure. A semi-analytical finite strip method was proposed by Mocker and Reimerdes [9], in which element stiffness matrices of each discretised strip of the whole structure were determined by closed-form solutions to the governing differential equations, for buckling analysis of stringer stiffened composite shells. Wang et al. [10] employed finite strip method to investigate the buckling load capacity of stringer stiffened composite panels with various number of T-shape stiffeners. Rikards et al. [11] developed a finite element model with six degrees of freedom at each node and applied to buckling analysis of an isotropic stiffened plate and a unstiffened composite cylindrical panel under axial compression. Guo et al. [12] proposed a layerwise finite element formulation to study the buckling responses of single rib stiffened composite plates according to different parameters such as plate aspect ratio and stiffener depth ratio. Chen and Soares [13] investigated the effects of plate thickness and stacking sequence on the post-buckling response of longitudinally stiffened composite panels, based on a non-linear finite element model using degenerated shell elements. Prusty [14] presented a finite element model for buckling analysis of laminated cylinder shell with a laminated central stringer and carried out a parametric study for shell thickness ratio, stiffener shape, number of layers and curvature ratio.

Some researchers used commercially available finite element packages to conduct buckling analysis and optimisation of stiffened composite panels. Herencia et al. [15] performed buckling analysis using quadrilateral shell elements having 4 nodes and used an optimisation aid of MSC/NASTRAN for optimum design of longitudinally stiffened composite plate with T-shaped laminated stiffener subjected to buckling loads. A longitudinally stiffened composite panel was modelled by Lanzi and Giavotto [16] using 10120 4-node shell elements (S4R) of ABAQUS to optimise the structure under buckling loads. Mallela and Upadhyay [17] conducted a parametric study for in-plane shear buckling for uni-directionally stiffened composite plates based on 450 finite element models developed in ANSYS using 8-noded quadrilateral shell elements. Jain and Upadhyay [18] extended their work for in-plane shear buckling of angle-stiffened, T-stiffened and hat-stiffened composite plates to enrich the database for sensitivity of different parameters of shear-loaded stringer stiffened composite plates.

All these studies mentioned above have considered simple stiffener orientations and did not address the problem of advanced grid stiffened (AGS) panels with ortho-grid, x-grid, bi-grid or iso-grid stiffenening arrangements, as shown in Figs. 1 and 2. One of the earlier works on buckling of grid stiffened composite cylindrical panels was due to Reddy et al. [19] who idealised the stiffened panel as an equivalent bare shell panel by smearing the stiffeners within the shell skin. They [19] used Donnell shell theory to model the structure and proposed an analytical solution based on Galerkin

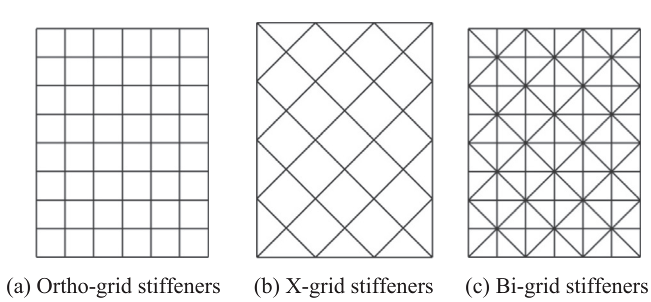

Fig. 1. Ortho-grid, x-grid and bi-grid stiffened panels.

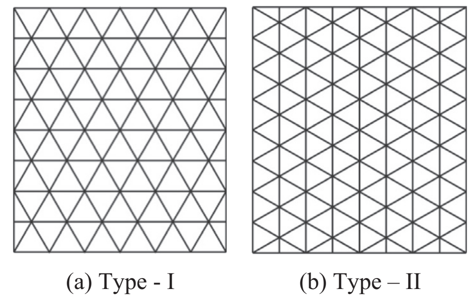

Fig. 2. Iso-grid stiffened panels.

approach of the shell problem. The transverse shear deformation of stiffeners was included whereas the torsion of these ribs was ignored. A similar modelling approach was proposed by Chen and Tsai [20] where the torsion of stiffeners was incorporated in their model. Kidane et al. [21] also proposed an analytical solution based on smeared model to calculate the equivalent stiffness parameters of iso-grid stiffened composite cylinders where the stiffeners were assumed to bear uniform axial loading only to predict the global buckling load. Using this model [21], Wodesenbet et al. [22] conducted a parametric study and Rao and Lakshmi [23] optimised the buckling load capacity for iso-grid stiffened composite cylindrical shells. Zhang et al. [24] developed a stiffened plate element model for buckling analysis of ortho-grid and iso-grid stiffened composite panels, without considering the rotational compatibility of stiffeners and skin along their interface. Based on the smearing theory and the minimum potential energy principle, Shi et al. [25] presented an equivalent stiffness model for grid stiffened conical composite shells considering a non-uniform grid distribution.

It shows that a limited number of investigations have been conducted on AGS composite panels and all these studies are based a simplified idealisation of the structural system. Moreover, an analytical solution is used in most of the cases which is attractive in terms of computational involvement but it lacks in terms of generality because an analytical model can only be applicable to simple structural geometry, loading and boundary conditions. These limitations may be overcome by using a reliable commercially available finite element code but the computational involvement will be reasonably high if the skin and stiffeners are modelled with shell elements. This modelling strategy is applicable for blade stiffened panels only where stiffeners are made with thin laminates with their layers stacked perpendicular to the skin surface. If the stiffeners are thick and their layers are stacked parallel to the skin surface, the modelling should be done with 3D solid elements where the computational involvement will be extremely high. Thus these modelling strategies are not suitable in a situation where a repetitive analysis of the structure is required. This type of scenario is quite common in a problem of optimum design of a structure which is a part of this ongoing research.

Therefore there is genuine need for a computationally efficient as well as reliable modelling technique that can be used for buckling analysis of different grid stiffened composite panels accommodating different stiffener configurations, as well as buckling modes under arbitrary loadings and boundary conditions. In the present study an efficient finite element modelling technique having sufficient generality is proposed for the buckling analysis of grid stiffened composite panels having different grid configurations. The detail of the finite element formulation is presented in the following Section 2. The laminated plate skin is modelled with a shear deformable triangular curved shell element having 6 nodes where each node contains 5 degrees of freedom. An efficient curved beam element compatible with the shell element is developed for the