Innovative Multi-level Methodology Incorporating the Techniques of Finite Element Modelling and Multimodal Optimization for Concept Design of Advanced Grid Stiffened Composite Panels against Buckling

Liang Huang

B.Eng., M.Eng., Ph.D.

Thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

The University of Adelaide

Faculty of Engineering, Computer and Mathematical Sciences

School of Civil, Environmental and Mining Engineering

To my beloved parents

Tie-Jun Huang & Xiao-Lan Yuan

Preface

Since the Second World War fiber reinforced polymer (FRP) composites have become more attractive as a structural material in a variety of engineering practices, such as infrastructure construction, automobile industry and aerospace engineering, due to high specific strength and stiffness as well as flexibility in tailoring the structural performance. 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.

Stiffened composite panels are subjected to any combination of in-plane, out-of-plane and shear load conditions during service life. These types of thin-walled structures are vulnerable to lose global and local stability under compression loadings. Consequently, buckling-resistant design is one of the most critical issues of stiffened composite panels applied in real practices. Moreover, the buckling optimization design of composite panels is usually a typical multimodal optimization problem, in which there exist multiple global optimal solutions with identical or closely comparable optima of structural performance.

Recently, with the development of manufacturing techniques, advanced grid stiffened (AGS) composite panels have increasingly emerged and gained more attention as these grid-stiffening configurations help to enhance the structural efficiency in a more effective way in complex loading conditions compared with conventional unidirectionally-stiffened composite panels. These grid-stiffening configurations provide more available options to select outstanding concept designs of AGS composite panels against buckling for the final appropriate design development at the final construction stage.

In this PhD thesis, a novel multi-level optimization methodology for concept design of advanced grid stiffened composite panels against buckling has been developed. Furthermore, an efficient finite element (FE) modelling component for buckling analysis and a robust particle swarm optimization (PSO) algorithms for multimodal optimization have been presented, in order to further consolidate the performance of the proposed methodology.

The thesis is divided into six chapters, which are briefly described below:

In Chapter 1, a general background along with the objective and originality of the present research is presented.

An efficient FE modelling technique is presented in Chapter 2, for the prediction of buckling response of grid stiffened composite panels having different stiffening arrangements. 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 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.

Chapter 3 aims to extend conventional unimodal optimization to challenging multimodal optimization of composite structures, by means of newly emerged multimodal PSO using niching techniques. It has shown that the ring topology based PSO without any niching parameter is more robust and efficient for multimodal optimization of composite structures, compared with the species-based PSO (SPSO) and the fitness Euclidean-distance ratio based PSO (FER-PSO).

In Chapter 4, a random reflection boundary is proposed to replace the conventional fixed absorption boundary for the range-exceeding particles, in order to eliminate/reduce the significance and sensitivity of an empirical parameter of particles' maximum velocity in PSO. Based on the results obtained from the experimentation on the abovementioned test functions, empirical guidelines for appropriately using the half-range/full-range random reflection boundary are further proposed.

Chapter 5 presents an efficient methodology to conduct concept design of AGS composite panels, based on a multi-level approach where an inner 3-stage optimization process is nested within an outer 3-step optimization process. The proposed methodology is applied to a design optimization problem of an AGS composite plate against its buckling resistance, by incorporating a ring topology based multimodal PSO algorithm with an improved FE buckling analysis model.

Finally, the conclusions of the present research are summarized in Chapter 6. The limitations and the future development directions of the present study are also described in this chapter.

Statement of Originality

I, ***Liang Huang***, hereby declare that this work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution in my name and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

I give consent to this copy of my thesis when deposited in the University Library, being made available for loan and photocopying, subject to the provisions of the Copyright Act 1968.

The author acknowledges that copyright of published works contained within this thesis resides with the copyright holder(s) of those works.

I also give permission for the digital version of my thesis being made available on the web, via the University's digital research repository, the Library catalogue, the Australian Digital Thesis Program (ADTP) and also through web search engines, unless permission has been granted by the University to restrict access for a period of time.

Signed: ……………………………………………Date: …………………..

Acknowledgments

I would like to express my sincerest gratitude to my beloved parents, Tie-Jun Huang and Xiao-LanYuan, who have been trying their best to support my life and dreams all the time without any requirement of return. My father was diagnosed with nose cancer of late stage at the sixth month of my candidature, thus I had to interrupt the research and took care of my aged parents in China as their only child. Without getting the sufficient recovery of body and mind from this sudden misfortune, my parents pushed me to return Australia and hoped me to complete my second PhD degree as well as possible. Therefore, to revere and reciprocate my parents' goodness, unselfishness, integrity and perseverance has driven me to keep moving on for the finial submission of thesis.

I am highly grateful to my principle supervisor Associate Professor Abdul Hamid Sheikh as well as the co-supervisors Professor Michael Griffith and Dr. (Alex) Ching-Tai Ng. Without Professor Michael Griffith and Associate Professor Abdul Hamid Sheikh, I would not take this project and could not submit this thesis as soon as possible (This project is finished within two years and a half). The critical and constructive comments from Dr. (Alex) Ching-Tai Ng contribute to the quality refinement of this thesis.

It has been my good fortune to hold the Adelaide Scholarship International (ASI) providing tuition fees and annual living allowances. In the meanwhile, I have done my best to take the responsibility for the scholarship.

I am also highly indebted to those nice people who have generously helped me in various aspects during the time of my study in Adelaide. Especially, I deeply and sincerely appreciate Professor Richard Russell, Ms. Patricia Anderson and Ms. Xiaochun Liu, who offered me so firm trust and support that I could have broken through the most difficult period of my research career so far.

Finally but the most importantly, I would like to appreciate two precious experiences of research at the University of Adelaide as an invited visiting academic and an international PhD candidate, respectively. Just these two research experiences have made it clear that dignity, independence, freedom, belief, justice, dreams, happiness, health, success, contribution, reputation, wealth, status, power, and so on are no more than the by-products of achievement of inner peace and enlightenment in my whole life.

Table of Contents

List of Tables

List of Figures