Multi-Pultrusion Fibre Composite Truss Systems for Deployable Shelters

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Abstract

Deployable shelters of various forms have been utilized since ancient civilization. The need for these systems has not diminished over time and development continues for military forces, civilian humanitarian aid, and natural disaster scenarios. Recent developments have focused mainly on tent-type structures, air-beam technology and steel frames supporting soft fabric; yet none of these have fully satisfied the deployability requirements. The Military Modular Shelter System (M^2S^2) initiative is a research project with the University of Southern Queensland that aims to develop a fibre composite re-deployable arched shelter system with rigid PVC or fabric cladding. The main frames are formed from modular fibre composite truss panels that are connected and stressed into position by prestressing cables. Flexibility in defining the geometry of frames constructed by using this system is achieved by changing the number of panels per frame and the packer sizes between panels.

The current study is the first to investigate a suitable truss system for the M^2S^2 concept. Accordingly, it was necessary to validate the M^2S^2 concept by searching the literature for previously developed deployable shelter concepts and locate the currently used fibre composite truss systems. Then try to establish a suitable truss system that fulfils the deployability needs with sound structural performance.

An innovative all-composite truss concept, named Multi-Pultrusion Truss-System (MPTS), was developed as a result of this study. It overcame the classical difficulty of joining composite members by loading each component of the truss in its strength direction. In addition, the system had inherent redundancy that provided alternate load paths after reaching ultimate capacity. The basic idea of this system was to have chord and vertical members formed from a few pultrusions of the same size. The traditional usage of gussets was eliminated by using laminates for the bracing system which directly connected between the pultrusions. This system allowed direct

transfer of the bracing forces to the connected members (pultrusions). This layout led to reducing the concentration of stresses in the adhesive layers (due to its continuous nature), while providing symmetric joints with two double-lap joints. All these factors contributed to having failure away from the joint area. The confinement of the bracing system, due to its finite dimensions, was one of the characteristics of this construction technology.

Two MPTS alternatives were developed, tested and investigated. The first alternative used a Discrete-Diagonal (DD) bracing system made of sandwich diagonal. Two panels DI-MPTS panels were tested using this configuration, one with the diagonals under tension and the other with the diagonals under compression.

The second alternative used a Diaphragm (DI) bracing system. Three different DI-MPTS panels were investigated. The first panel had an empty diaphragm (no core); the second panel had a partially-filled sandwich diaphragm while the third panel had a completely-filled sandwich diaphragm.

To achieve understanding of the basic behaviour of each of these panels, finite element (FE) analyses were conducted at micro level. The different components of the panel were included in each model, with idealisations to achieve an efficient analysis process. The FE analysis results were used to investigate the distribution of forces in each of the panel components.

Due to the associated costs of micro-model analyses, macro-analysis models are important tools for engineers interested in modelling this system, conduct pre-micro-analysis parametric studies and in modelling the overall frame structure. This study ended with presenting simplified analysis procedures for the different panel types.

The work conducted in this study has revealed that this new fibre composite truss system suits the characteristics of fibre composites and accordingly provides an efficient solution for general truss applications. It combines simplicity, easiness of manufacturing, high-load carrying capacity and structural redundancy. In addition, its behaviour and failure modes can be accurately predicted by using the currently available finite element software packages.

Certification of Dissertation

I certify that the ideas, experimental work, results, analysis and conclusions reported in this dissertation are entirely my own effort, except where otherwise acknowledged. I also certify that the work is original and has not been previously submitted for any other award, except where otherwise acknowledged.

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Signature of Candidate Date

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Signature of Supervisor/s Date

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Putting my name, solely, as the author of this thesis is not quite fair. I was one of a team and, without the contribution of each member, this work would not be in this form. Many people in the Centre of Excellence in Engineered Fibre Composites (CEEFC) and the Faculty of Engineering and Surveying (FOES) made a direct and indirect contribution in helping me to complete my research work successfully. I sincerely appreciate the efforts of my supervisors - Prof. Gerard Van Erp, who introduced me to the world of composite materials in civil engineering, Assoc. Prof. Thiru Aravinthan for help in testing procedures and prestressing technologies, and Dr. Tim Heldt for starting the research work in this project. It would have been difficult to finish this thesis without their continual patience, advice, support and understanding.

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Associated Publications

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Omar, T., Heldt, T., Key, P. W., and Van Erp, G. (2005). "Development of modular deployable composite shelters." *Australian Structural Engineering Conference - ASEC2005*, Newcastle City Hall, Newcastle, NSW, Australia.

Omar, T., Van Erp, G., Aravinthan, T., and Key, P. W. (2007). "Innovative all-composite multi-pultrusion truss system for stressed-arch deployable shelters." *Sixth Alexandria International Conference on Structural & Geotechnical Engineering (AICSCE 6)*, Alexandria, Egypt.

Omar, T., Heldt, T., Key, P. W., and Van Erp, G. (2006). "M^2S^2 Modular deployable composite shelters - concept and loading criteria." *Australian Journal of Structural Engineering*, 6(3), 217-226.

Omar, T., Van Erp, G., Aravinthan, T., and Key, P. W. (2007). "M^2S^2 modular deployable shelter system - concept and analysis technique." *Structural Engineering & Construction Conference (ISEC-4)*, Melbourne, Australia.

Omar, T., Van Erp, G., and Key, P. W. (2007). "Modular deployable composite shelters - truss system." *Proceedings of ACIC 07, Advanced Composites in Construction*, University of Bath, Bath, UK.

Omar, T., Van Erp, G., and Key, P. W. (2006). "Stressed-arch modular deployable composite shelters, concept and development." *Third International Conference on FRP Composites in Civil Engineering (CICE 2006)*, Miami, Florida, USA.

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