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Experimental Investigation of Critical Buckle Load of Composite Specimens

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Abstract. Different carbon and glass fibre strips were subjected to the double clamp buckle beam test. Furthermore, thin-walled glass fibre box-beams were subjected to the three-point bending test. Results of experiments were compared to different numerical simulations using buckling analysis or static analysis considering large deformations.

Introduction

Fibre reinforced composite materials are being increasingly used in many structures and frequently replace traditional metals. Due to their high stiffness-to-weight and strength-to-weight ratios, they are applied to various structures in aerospace, automotive, and marine industry or in civil engineering. High strength and stiffness of composite materials in the fibre direction frequently result in thin-walled laminated applications of the material. Due to complex loading, a buckling failure can occur and should be analysed [1].

In this work, carbon and glass composite strips and glass composite thin-walled box-beams were subjected to the experimental analysis in order to partially verify the complex numerical model of an innovative composite bridge for pedestrians and cyclists [2] designed within the project TA02010501. Strips were subjected to the double clamp buckle beam test and box-beams were subjected to the three-point bending test. Critical buckle loads were investigated and compared to finite element method models [3].

Specimens

Carbon fibre (CF) strips were cut using a water jet cutter from plates consisted of 8 layers of high strength carbon fibres and epoxy resin. The cross-section of the CF specimens was 25 mm x 1.12 mm. Composite layups of the specimens were $[0_8]$, $[90_8]$, $[0/0/90/90]_S$, and $[+45/-45/+45/-45]_S$. A clamp length was set to 100 mm, 200 mm, and 300 mm.

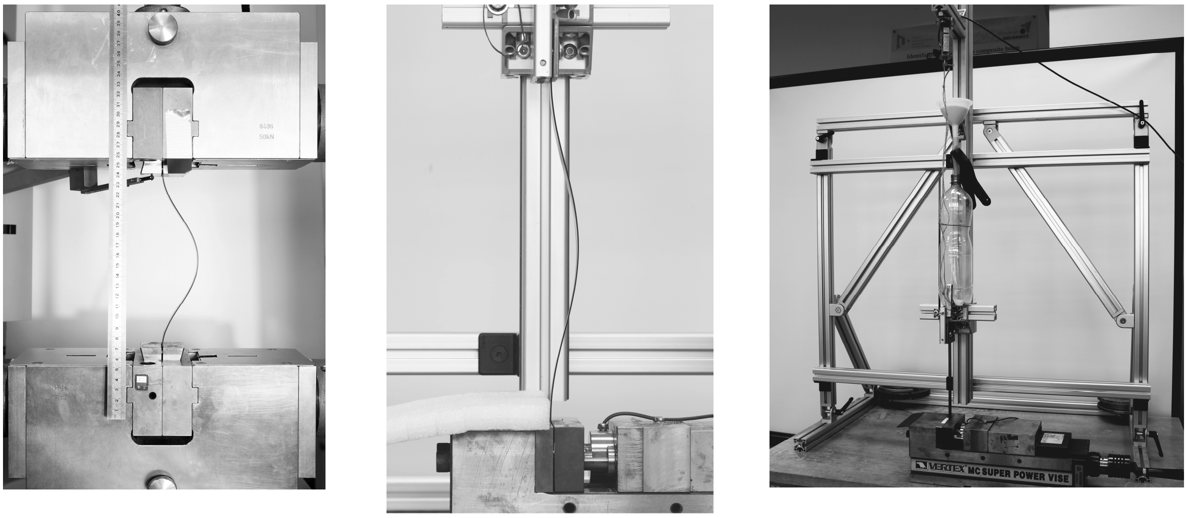
Glass fibre (GF) strips consisted of glass fibres or biaxial non-crimped fabric and polyester resin and were also cut using the water jet cutter. The cross-section of the GF strips was 20 mm x 3.0 mm. Composite layups of the strips were $[0_5]$ or $[0/90]_6$. A clamp length was set to 200 mm.

GF box-beams consisted of glass fibres, biaxial non-crimped fabric, or chopped strand mat (CSM) and polyester resin. Beams were manufactured using the pultrusion technique. The outer cross-section of the beams was 60 mm x 30 mm with a wall-thickness 2.5 mm. The length was 1200 mm. Composite layups of the beams were $[0_5]$, $[0/90]_6$, and $[CSM_2]$.

Double Clamp Buckle Beam Test with Composite Strips

First experiments were carried out using the testing machine Zwick/Roell Z050 (Fig. 1a) and were performed under displacement control. Forces were measured by a force sensor and displacements using an extensometer placed under the upper jaw. The experiments were terminated when noticeable decrease of stiffness occurred.

Then the experiments under load control were performed up to the failure. Specimens with critical buckle load higher than 70 N were tested using the testing machine. Specimens with critical buckle load lower than 70 N were tested in a special designed experimental device (Fig. 1b). The special device was constructed using aluminium ITEM profiles and a hydraulic power vice (Fig. 1c). It avoided the disadvantage of limited speed of the upper jaw of the testing machine after a collapse of a tested structure. The critical buckle load after the collapse was measured by the force sensor.



a) b) c)

Fig. 1. a) Testing in testing machine, b) testing in special experimental device, c) special device constructed from aluminium ITEM profiles and a hydraulic power vice.

Results of Double Clamp Buckle Beam Test

All experiments with CF and GF strips were compared to simulations with similar results. Examples of force-displacement diagrams in Fig. 2 and 3 illustrate results of CF strip tests with the $[90_8]$ composite layup and the 200 mm clamp length and results of GF strip tests with the $[0/90]_6$ composite layup with the 200 mm clamp length, respectively. Grey lines representing experiments indicate significant differences between specimens. Black lines representing numerical simulations using the buckling analysis and the static analysis considering large deformations (non-linear) [3] indicate very good agreement of both modelling approaches. It is obvious that the critical buckle loads investigated using simulations are lower than the loads from experiments. This denotes safe prediction of the numerical simulations.

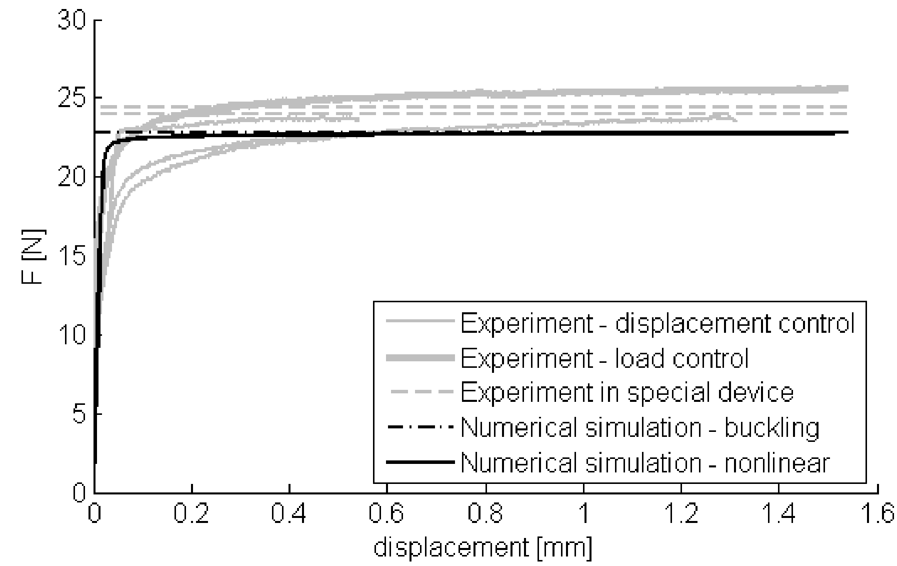


Fig. 2. Comparison of experiments and simulations in case of CF strips with $[90_8]$ composite layup and 200 mm clamp length.

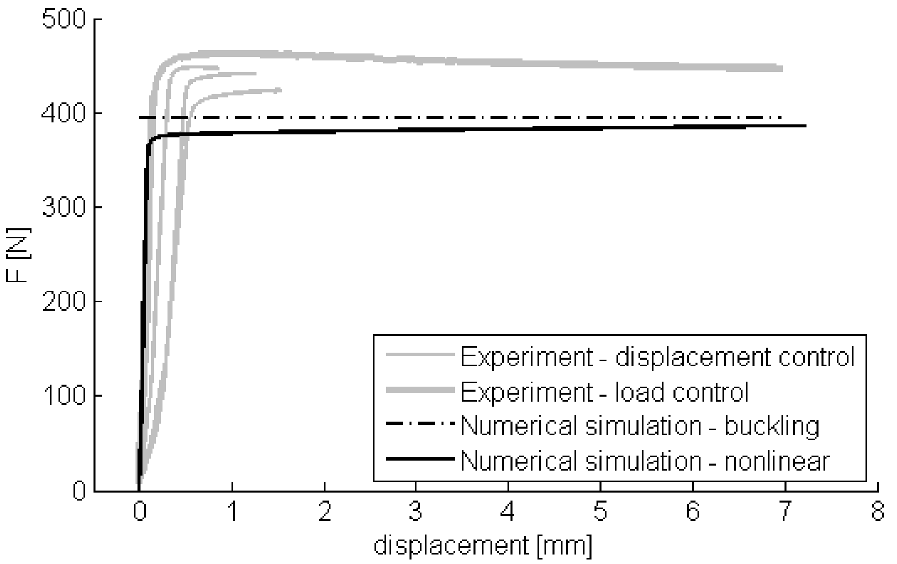


Fig. 3. Comparison of experiments and simulations in case of GF strips with $[0/90]_6$ composite layup and 200 mm clamp length.

Three-point Bending Test with Box-beams

These experiments were carried out in the testing machine Zwick/Roell Z050 with installed table designed for bending tests with long specimens. The distance between supports was 1000 mm and displacement controlled loading was applied in the middle of the beam (Fig. 4). The extensometer, placed under the upper jaw, was used for the measurement of displacements.

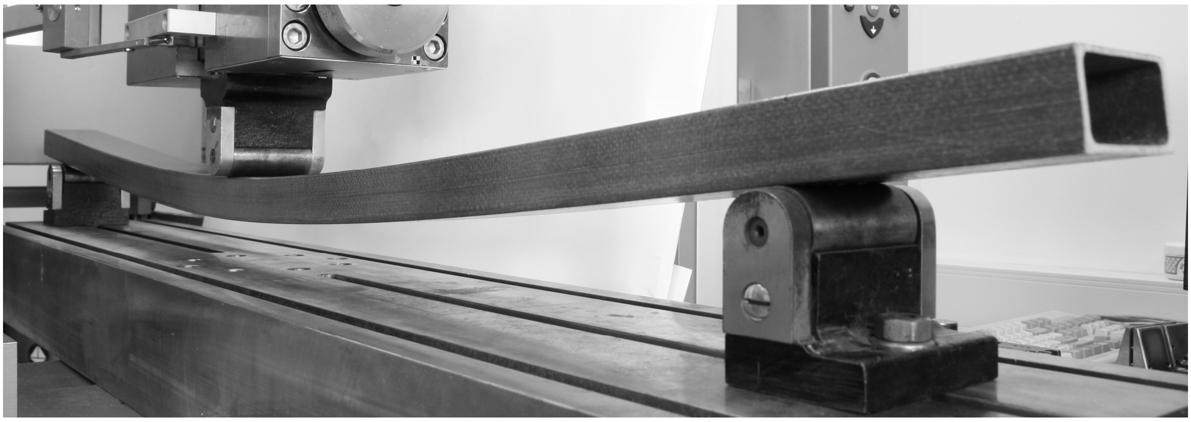


Fig. 4. Three-point bending test.

Results of Three-point Bending Test

As in case of the double clamp buckle beam test, numerical simulations using the buckling analysis and the static analysis considering large deformations (non-linear) were performed. A local buckling was observed on the box-beams with the [CSM_2] composite layup. Corresponding buckled areas are marked with arrows in Fig. 5 and 6 illustrating the experiment and the non-linear numerical simulation, respectively. Flexural stiffness and critical buckle loads are compared in Fig. 7. Average critical buckle load investigated from the experiments was 2394 N (grey arrow), from the numerical simulation using the buckling analysis 1879 N (dot-and-dash line), and from the non-linear numerical simulation 1788 N (black arrow). Both numerical simulations indicate very good agreement. The loads from simulations were lower than the loads from experiments. The non-linear numerical model becomes stiffer for forces higher than approximately 2000 N because no progressive failure was simulated.

At beams with the [0_5] and [$0/90$]$_6$ composite layups, no buckling failure was observed. A failure occurred due to crossing of material strength.

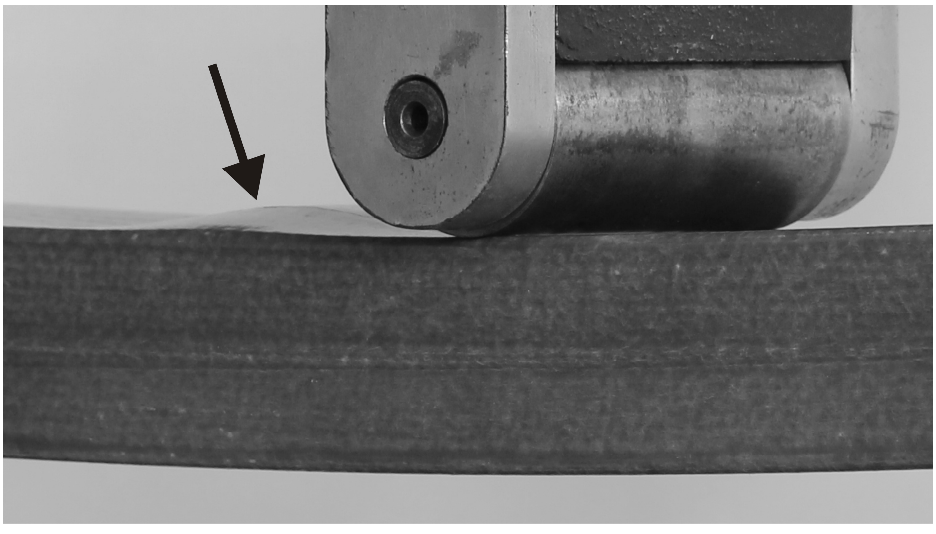


Fig. 5. Detail of local buckling of box-beam with [CSM_2] composite layup.

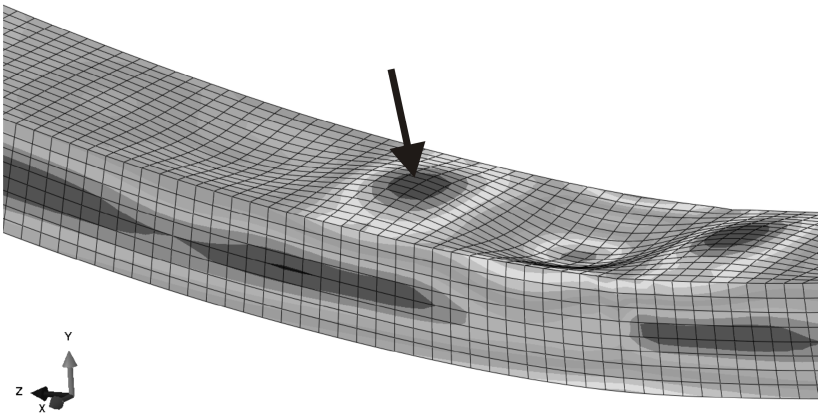


Fig. 6. Numerical simulation of local buckling of box-beam with [CSM_2] composite layup.

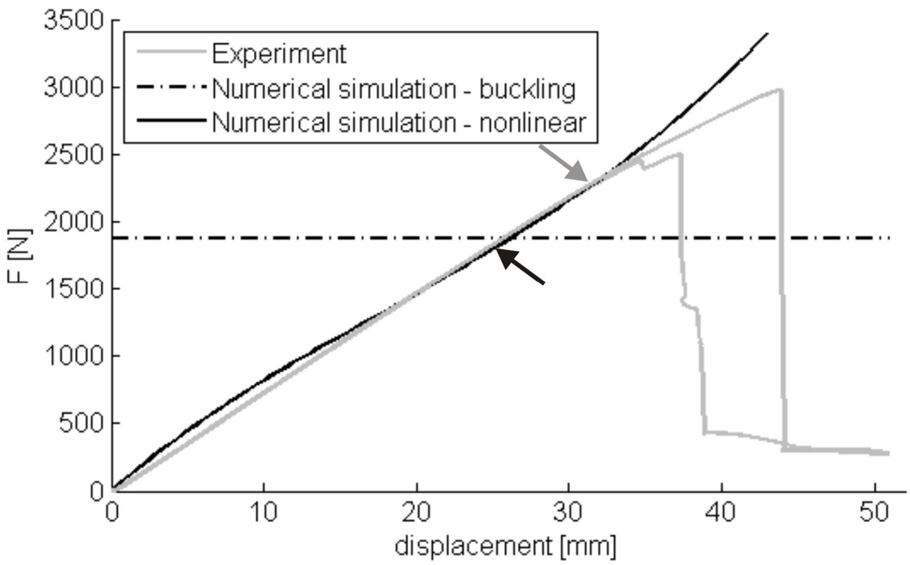


Fig. 7. Comparison of flexural stiffness of box-beam obtained from experiments and simulations.

Conclusion

Performed double clamp buckle beam tests with different carbon and glass fibre specimens and three-point bending tests with the glass fibre box-beam showed significant differences between buckling behaviour of corresponding specimens. The buckling numerical analysis and the static numerical analysis considering large deformations predicted in all cases lower critical buckle load than in case of the experiments. Both numerical analyses were in very good agreement. The ability of the analyses of safe prediction of the buckling behaviour was proved.

Acknowledgements

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References

[1] M.A. Komur, F. Sen, A. Ataş, N. Arslan, Buckling analysis of laminated composite plate with an elliptical/circular cutout using FEM, Advances in Engineering Software 41 (2010) 161-164.

[2] R. Kottner, T. Kroupa, V. Laš, Design of composite footbridge, in: Proceedings of Mechanika kompozitních materiálů a konstrukcí 2014, University of West Bohemia, Pilsen, 2014, pp. 69-70.

[3] Theory manual for Abaqus 6.12, Dassault Systèmes 2012.