

Cite this article

Chan TM and Mottram JT (2018)

Editorial.

Proceedings of the Institution of Civil Engineers – Structures and Buildings **171(11)**: 813–815,
<https://doi.org/10.1680/jstbu.2018.171.11.813>

Editorial

ICE Publishing: All rights reserved

Editorial

1 Tak-Ming Chan BEng, MSc, DIC, PhD, PCAPP, CEng, MIStructE, MASCE
Assistant Professor, Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hong Kong, China



2 James Toby Mottram BSc, PhD, DSc, CEng, FStructE, SFHEA
Professor, School of Engineering, University of Warwick, Coventry, UK

This Editorial is for the themed issue for *Structures and Buildings* on Structures and Buildings of Fibre Reinforced Polymer (FRP) Composites. FRP composites comprise of a polymer based resin matrix that is reinforced by fibres of, say, glass or carbon. This structural material has an overall property portfolio that makes them a popular choice for construction material in building and bridge structures. Their distinct advantages in structural engineering are for lightweight and low maintenance costs. One continuing research theme is for the use of FRPs to strengthen existing structures that are found to no longer be fit-for-purpose. A second developing research theme focuses on the use of FRP shape and systems in new-build projects. To provide practitioners with confidence to exploit this newer construction material in civil engineering works, robust research and development is on-going to enable the community to prepare design guidance that will be recognised in national and international design standards. In this themed issue we have a commentary and eight papers contributed by authors from seven countries.

The commentary by Mottram (2018) highlights current developments of design standards and design guidance in Europe and North America for the design of structures and buildings of FRP composites. Four papers report experimental studies for the characterisation of thin-walled FRP structural shapes for new-build made by the pultrusion manufacturing process. Two papers are for studies related to combining FRP with either stainless steel column tubes or concrete beams to achieve the most economical and efficient engineered solution. To complete the themed issue the penultimate paper reviews FRP strengthening methods for reinforced concrete structures in South Korea and the eighth paper reports on the delivery of a 40 m long FRP footbridge in Spain.

Presented in the paper by Nguyen *et al.* (2018) is a simple test method to determine the in-plane shear properties of pultruded materials, where the mat reinforcement is of randomly oriented continuous fibres. The straight-sided specimens have unidirectional fibre reinforcement oriented at 10° to the direction of tensile load. Tension generates a biaxial in-plane stress state that, by employing stress and strain transformations, it

enables the shear modulus to be determined. The study shows that it is easy to use this coupon test method and that it consistently measures the in-plane modulus in the range of 4.2 – 4.8 GPa.

Turvey and Szulik's (2018) paper experimentally investigate the uniaxial tensile failure of pultruded FRP single-bolt single-lap joints. The constant test variable is the lap width at four times the bolt diameter of 10 mm. In their investigation test variables are for five end distances and four test temperatures. Test results are used to compile graphs of ultimate stress and overall failure strain as functions of joint geometry and test temperature, from which corresponding characteristic mean strengths and strains are obtained. The evaluation then derives knockdown factors, which express the ultimate joint strength relative to the ultimate strength of the virgin pultruded FRP material, that may be used in the preliminary design process of single-bolt tension joints.

In the paper by Xie *et al.* (2018) an investigation is reported to determine the important geometric parameter of width-thickness ratio for the local buckling of pultruded FRP columns with square hollow sections (SHS). An experimental programme investigates changing the width-thickness ratio on failure modes and load-carrying capacities. Two SHS columns, having a width-thickness ratio of 10.7 or 15, reveal that local buckling occurs in the latter column only. From a theoretical analysis the authors formulate a closed form equation procedure for the critical width-thickness value at the boundaries between failure modes, considering boundary conditions along the SHS sides. It is shown that the test results from this study and previous ones are consistent with the developed theoretical estimations of the failure modes and strengths of pultruded SHS columns, considering the effects of both the flexural buckling non-dimensional slenderness and the width-thickness ratio.

In the fifth paper with pultruded FRP shapes, Vieira *et al.* (2018) present an extensive experimental and analytical study investigating the stability failures of I-sections subject to

flexure. To investigate flange local buckling (FLB) specimens had a range of flange slenderness ratios from 4 to 12, and for lateral torsional buckling (LTB) the specimens had a range of slendernesses from 24 to 52. Through a comparative study using closed-form equations and the finite-strip method (FSM) the authors find they all underestimated the critical FLB moment. Satisfactory accuracy when predicting critical FLB moments is demonstrated using FSM. The research shows that interaction between FLB and/or web local buckling and global LTB may lead to a reduction in critical FLB moment capacity. Such interaction tends to occur in shapes having lower flange slenderness ratios, as well as higher LTB slenderness ratios. On the other hand, the predictions for LTB strength are generally shown to be non-conservative when compared with test results. Such discrepancies tend to become more significant for flexure specimens having relatively high flange slenderness ratios and lower LTB slenderness ratios. Importantly, the authors find that this underestimation of critical LTB moment is because of interaction between local and global buckling deformation responses.

Zhou *et al.* (2018) present a numerical investigation and propose a strength equation for web crippling of cold-formed stainless steel tubes strengthened with bonded and bolt-anchored plates of carbon FRP. The presence of the bolt-anchoring had already been proven to delay or totally prevent FRP de-bonding failure, and to significantly improve web-crippling response. Numerical results from non-linear finite-element simulations are verified by experimental test results. An extensive parametric study is carried out with different web slendernesses, bearing-plate lengths and FRP thicknesses to investigate the increased resistance of strengthened tubes to failure by web crippling. Two load conditions of end two-flange loading and interior two-flange loading are studied. Test and numerical results are compared with US and European web-crippling design rules for unreinforced stainless-steel tubes. A comparison is reported for test results against a proposed web-crippling design equation in the literature. The evaluation leads the authors to propose their own unified web-crippling equation for bolt-anchored FRP strengthened of stainless steel tubes subjected to either of the two loading conditions.

The development of a fatigue model for reinforced concrete (RC) beams, which are externally bonded with FRP is the subject of the paper by Meneghetti *et al.* (2018). FRP strengthening reduces the stress levels in steel rebars and, for stresses up to 80% of steel yield strength, fatigue failure is normally marked by a gradual deterioration of the reinforcement, which leads to a stress transfer to the FRP, until failure. Higher steel stresses are associated with FRP debonding, while stresses below the fatigue limit never lead to fatigue failure. Based on this knowledge, the authors use the maximum likelihood estimation method to establish stress-cycle curves and confidence intervals.

To modify their model they use experimental data (with fatigue runouts) extracted from the literature. The proposed fatigue model is shown to reliably predict the slope of the fatigue curve for FRP-strengthened RC beams taking into account the large scatter in fatigue test results from different sources.

Kim *et al.* (2018) review paper introduces that many buildings and civil infrastructure projects in South Korea are now close to 40 years old, and much of the RC used in the construction has deteriorated. To extend their service life, an attractive renovation method for structural retrofitting and rehabilitation is to use FRPs, owing to their high strength, durability, constructability and light weight. This paper discusses current FRP strengthening methods and design recommendations for RC bridges and buildings. It provides a summary of FRP strengthening methods, such as bonded FRP sheets, near-surface-mounted reinforcement, externally prestressed FRP strips and tendons.

An application paper by Primi *et al.* (2018) describes the design, manufacture, installation and load testing of a 40 m long urban footbridge over the River Manzanares in Madrid, Spain. The main structure of the footbridge consists of an FRP girder manufactured using the resin-infusion composite process. Potential problems that can arise in the manufacture of such large structural elements are highlighted with the strategies adopted to cope with them explained. The 40 m girder was transported to the site where, after lifting, it was connected using steel fixtures to reinforced concrete abutments. To demonstrate compliance with local load test requirements, results from static and dynamic testing are presented.

We hope you gain knowledge and understanding from your research from the commentary and one or more of the eight papers in this themed issue and will add to our congratulations to the authors for their achievements.

REFERENCES

- Kim SW, Choi WC and Yun HD (2018) Strengthening methods for reinforced concrete infrastructure using FRP composites in Korea. *Proceedings of the Institution of Civil Engineers – Structures and Buildings* **171(11)**: 898–907, <https://doi.org/10.1680/jstbu.17.00057>.
- Meneghetti LC, Garcez MR, Teixeira RM and da Silva Filho LCP (2018) Stress-cycle curves for concrete beams with fibre-reinforced polymer using runout data. *Proceedings of the Institution of Civil Engineers – Structures and Buildings* **171(11)**: 886–897, <https://doi.org/10.1680/jstbu.16.00231>.
- Nguyen TT, Chan TM and Mottram JT (2018) Reliable in-plane shear modulus for pultruded-fibre-reinforced polymer sections. *Proceedings of the Institution of Civil Engineers – Structures and Buildings* **171(11)**: 818–829, <https://doi.org/10.1680/jstbu.16.00194>.
- Primi S, Paulotto C, Llago Acero R and Calvo Herrera I (2018) Delivery of a 40 m long fibre-reinforced polymer composite footbridge in Madrid, Spain. *Proceedings of the Institution of Civil Engineers – Structures and Buildings* **171(11)**: 867–885, <https://doi.org/10.1680/jstbu.16.00233>.

-
- Turvey GJ and Szulik M (2018) Thermo-mechanically loaded glass-fibre-reinforced polymer single-bolt single-lap joints. *Proceedings of the Institution of Civil Engineers – Structures and Buildings* **171(11)**: 830–841, <https://doi.org/10.1680/jstbu.16.00211>.
- Vieira JD, Liu T and Harries KA (2018) Flexural stability of pultruded glass fibre-reinforced polymer I-sections. *Proceedings of the Institution of Civil Engineers – Structures and Buildings* **171(11)**: 855–866, <https://doi.org/10.1680/jstbu.16.00238>.

- Xie L, Bai Y, Qi Y, Caprani C and Wang H (2018) Effect of width–thickness ratio on capacity of pultruded square hollow polymer columns. *Proceedings of the Institution of Civil Engineers – Structures and Buildings* **171(11)**: 842–854, <https://doi.org/10.1680/jstbu.16.00227>.
- Zhou F, Lou C and Ling Y (2018) Web crippling of stainless-steel tubes with bolt-anchored carbon-fibre-reinforced polymer. *Proceedings of the Institution of Civil Engineers – Structures and Buildings* **171(11)**: 998–904, <https://doi.org/10.1680/jstbu.16.00223>.