FRPs in Structural Engineering – Rise to Prominence and Design Guidelines

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Dynamic Performance of

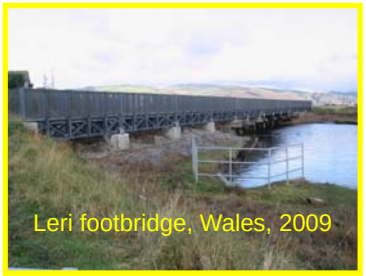
Fibre-Reinforced Polymer Structures

EPSRC Project Workshop

Warwick University

22 June 2018

FRP Structures having dynamic designs



Leri footbridge, Wales, 2009

Church in L'Aquila, Italy, 2010

Foryd Harbour Bridge, Rhyl, Wales, 2013

Startlink house, England, 2012

Status on Design Guidance – North America

ASCE Manual No. 63 - 1984

Pultruded standard shapes:

Richard Chalmers – 2000 - promoted

Bruce Ellingwood - 2003 – structural reliability tools

ASCE/PIC of ACMA pre-standard project – ***Load and Resistance Factor Design (LRFD) of Pultruded Fiber-Reinforced Polymer (FRP) Structures*** - 2006-2010

Now with Fiber Composites and Polymers Standards Committee (ASCE) – from 2011 to date (36 ballots)

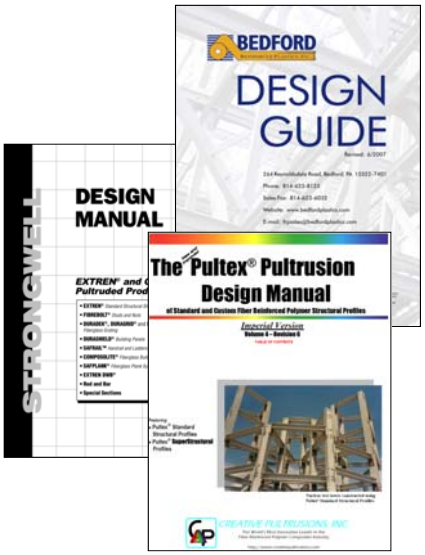
Code of Standard Practice for Fabrication and Installation of Pultruded FRP Structures ACMA - 2012

J. T. Mottram, Fibre reinforced polymer structures: Design guidance or guidance for designers, Proc. 8th Inter. Conf. on Advanced Composites in Construction (ACIC 2017), Sept 2017.

Status on Design Guidance – North America

LRFD standard:

- Supported by pultruder's guidance
- Standard is a legal document if referenced by statute in the local building code
- Easier to market pultruded structures
- Competes better with conventional structural materials
- **No clauses for dynamics design, except for seismic**



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Dynamics – North America

AASHTO. *Guide Specifications for Design of FRP Pedestrian Bridges*. American Association of State Highway and Transportation Officials, 2008.

3.2 Vibration

Fundamental frequency (in vertical direction) without live load shall be > 5 Hz to avoid any issues associated with 1st and 2nd harmonics. Fundamental frequency (in horizontal direction) without live load shall be > 3 Hz to avoid any issues due to side to side motion involving 1st and 2nd harmonics. These two fundamental frequencies shall be different to avoid potential adverse effects associated with combined effect.

Recommends the use of damping ratio between 2% and 5% when connections are bolted.

Audubon Canyon Ranch, Marshall, CA, USA (ET Techtonics)

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Status on Design Guidance – Europe

EUROCOMP – ***Structural Design of Polymer Composites*** - *Design Code and Handbook* - 1996 - 4 composite processing methods

Guide for the Design and Construction of Structures made of FRP Pultruded Elements, Advisory Committee on Technical Recommendations for Construction, National Research of Italy – 2007 – pultruded shapes

BÜV-Empfehlung - *Tragende Kunststoffbauteile im Bauwesen [TKB] – Entwurf, Bemessung und Konstruktion* - In German – 2014 - pultruded shapes and recognised

No clauses for dynamics design

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Status on Design Guidance – Europe

Stage 1 (of 3) to an FRP Structural Eurocode:

Ascione, L., Caron, J-F., Godonou, P., van IJselmuijden, K., Knippers, J., Mottram, T., Oppe, M., Gantriis Sorensen, M., Taby J. and Tromp, L., ***Prospect for New Guidance in the Design of FRP***, JRC Science and Policy Report, Policy Framework Existing Regulations and Standards, Prospect for CEN Guidance, European Commission, Joint Research Centre Institute for the Protection and Security of the Citizen, JRC99714, EUR 27666 EN, European Union, Luxembourg.- 2016 & 2017

http://eurocodes.jrc.ec.europa.eu/showpublication.php?id=539# (12 June 2017)

WG4 of CEN/TC 250 into Stage 2 (2018-2020)

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'Eurocode' clauses - Today

7.3 VIBRATION AND COMFORT

(1) Specific reference to the applicable conversion factors provided in Section 2.3.6 should be made. (2.3.6 - *Table 2.4*)

7.3.1 VIBRATION

(1) Resonance should be taken into account in the design of FRP structures. The vibration behaviour should be verified in both the loaded and unloaded situation.

(2) The natural frequency and the vibration behaviour should be determined in situations with and without aging effects.

7.3.2 COMFORT

(1) EN 1990, Annex A and the national annex apply with respect to the comfort criteria for pedestrians.

(2) Comfort should be determined in situations with and without aging effects.

(3) When determining the response, a material damping value of 0.5% and an average value of 1.0% can be assumed as a realistic conservative lower limit for calculations involving monolithic and sandwich structures. Higher damping values may be used if these have been substantiated by representative experimental data.

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Status on Design Guidance – Europe

BS EN 13706:2002. *Reinforced Plastic Composites - Specification for Pultruded Profiles*, British Standards Institution, London, UK, 2002.

CUR Commission C124, *Recommendation 96 Fibre-Reinforced Polymers in Civil Load Bearing Structures*, CUR Gouda, The Netherlands, 2003.

No clauses for dynamics design

Dover sea wall footbridge, Dover, England (Pipex px)

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Status on Design Guidance – Europe

Design of FRP Bridges and Highway Structures, Design Manual for Roads and Bridges. Vol. 1 Highway Structures: Approval Procedures and General Design, Section 3 General Design, Part 17, Design Manual for Roads and Bridges, **BD 90/05**. The Highways Agency, (2005).

Vibration

4.9 The lightweight nature of FRP may result in a “lively” bridge. Excessive vibrations may cause user discomfort and affect the bond in joints and between surfacing and FRP. Dynamic analysis shall be carried out to determine the natural frequencies of the structure to indicate the susceptibility of the bridge to traffic induced vibrations. Experience with conventional bridges suggests that if the fundamental natural frequency is above 5 Hz, then dynamic effects are not significant.

4.10 Vibrations due to wind shall be considered in accordance with BD 49 (DMRB 1.3.3).

4.11 For footbridges and the structural components of bridges whose prime function is to carry pedestrian loading, the requirements of BD 37 (DMRB 1.3.14), Appendix B shall be applied.

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Preparing Standards – Why Long Time?

My reasons are:

- rudimentary statistical data and rudimentary technical know-how; relatively short construction history
- continual development of new structural shapes and systems
- drafters working on design rules are not full-time – *are enthusiastic volunteers*
- drafters need time to evaluate and analysis data/information, and to formulate rules that can be quantified and verified
- the biggest unknown is to have data/information for the state of FRP structures and FRP components at the end of their design working lives
- gaps in knowledge linked to: structural engineering of connections and joints; strengths and stiffnesses of sandwich panels; dynamic behaviour
- 'engineering judgment' remains paramount - it takes years to assimilate knowledge and understanding, and to apply these appropriately with confidence and rigor

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Preparing Standards – Why Long Time?

Weaknesses with published research relevant to informing the preparation of design rules are:

- no clear definition of the domain of applicability of the work
- no critical review of previous research relevant to that domain
- test results that omit crucial data on properties of specimens
- test specimens with materials having strengths different to typical design strength
- theory that fails to allow for imperfections that can occur in practice

Weaknesses because of little historical precedence:

No official national or international design standard on which one can build valuable information and for template for the specification of targeted and beneficial Research and Development

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Preparing Standards – Why Long Time?

Catch 22 : "*to be able to write a codified standard (say for a Eurocode) the FRP R&D community needs (matured) practice to learn lessons from, and to have practice at this level we need the standard to overcome cost and an inherent reluctance to choose FRP as the structural material*"

Preparing Standards – Going Forward

Publish online R&D reports that are detailed/complete not to have weaknesses

Use ASCE LRFD pre-standard and WG4 JRC Science and Policy Report as templates for research with added value for code writing

Expect a step change in practice when we have the ASCE LRFD standard in 2020

We need e.g., Guidance for Designers - Composites UK Construction Sector Group – ***FRP Bridges – Guidance for Designers***, CIRIA, Sept. 2018

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Preparing Standards – Gaps in Knowledge

We need:

- mechanical properties of FRP materials and sandwich constructions that are appropriate and with statistical relevance – are there the coupon test standards to do this?
- test results for the strengths/stiffnesses of connections and joints having mechanical fasteners, adhesive bonding or a hybrid combination (details to correspond to what is designed and executed)
- to understand how to account for long-term durability effects; it is likely that for many years the best we can do is to have non-calibrated factors
- for SLS, design rules information/data for the dynamic performance of FRP structures – *exactly what this EPSRC project is doing*
- develop know-how for having other material components working structurally with FRP shapes or systems

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Concluding Remarks

It will be 20 years from conception to we have a recognised design standard for FRP structures, published by 2020

ASCE LRFD standard is limited to FRPs of standard pultruded shapes

Take a minimum of another 10 years to have an FRP Eurocode, one reason being that it scopes a number of composite material processing methods – Stage 2 is for a CEN Technical Specifications, by 2020

We need reliable and relevant statistical data and/or technical information to inform the reliable formulation of specific design rules – *this project's data is helping*

A standard will provide the community with a template for executing targeted and beneficial R&D to inform further code development or refinement

In the meantime we must use state-of-the-art publications having **Guidance for Designers**, such as *FRP bridges – Guidance for Designers* that the community in the UK has written and published by CIRIA in Sept. 2018 (*will be free*)

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