Eric Moussiaux, Exel Composites Oyj
VP Techology

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I was included in the package when Exel Composites acquired Bekaert Composites in 2004

Core competens in composites in general, pultrusion in particular

Eric Moussiaux holds a Master of Science degree in Civil Engineering from the Free University of Brussels and a postgraduate Master of Science from Virginia Tech in composites and adhesives. He is currently vice president technology at Exel Composites, after previous positions in R&D, sales and marketing and business unit management in the field of pultrusion.
Eric Moussiaux is a long-term Board Member of the European Composites Industry Association EuCia, the European Pultrusion Technology Association EPTA and the Belgian technology federation Agoria Flanders. He is the liaison officer for EuCia in CEN TC250 WG4 writing the Eurocode for composites.
Privately Eric Moussiaux has a special interest in education, teaching his own course on 'Design of light weight composite structures' at the Free University of Brussels and having a seat in the Board of a group of 28 schools in the South-West region of Brussels.

EN TS 191010
The future Eurocode for composites

A fairytale story

Prof Eric Moussiaux

VP Technology Exel Composites

EuCIA Member of the Board

CEN TC250 WG4 Liaison officer for EuCIA

FIPIF Seminar, Pietarsaari, November 6, 2024

EPTA Conference Eiffel tower 1999

European organizations in pultrusion

EN standard on pultruded profiles
CEN TC 249 SC2 WG6

↑

Pultruders Workgroup

↑

GPRMC

↑

PROVIDE STANDARDS

Conferences
Tradeshows
Brochure
Internet site

↑

EPTA

↑

INCREASE AWARENESS

↑

LONG TERM GROWTH OF EUROPEAN PULTRUSION MARKET

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 13706-1

November 2002

ICS 83.120; 83.140.99

English version

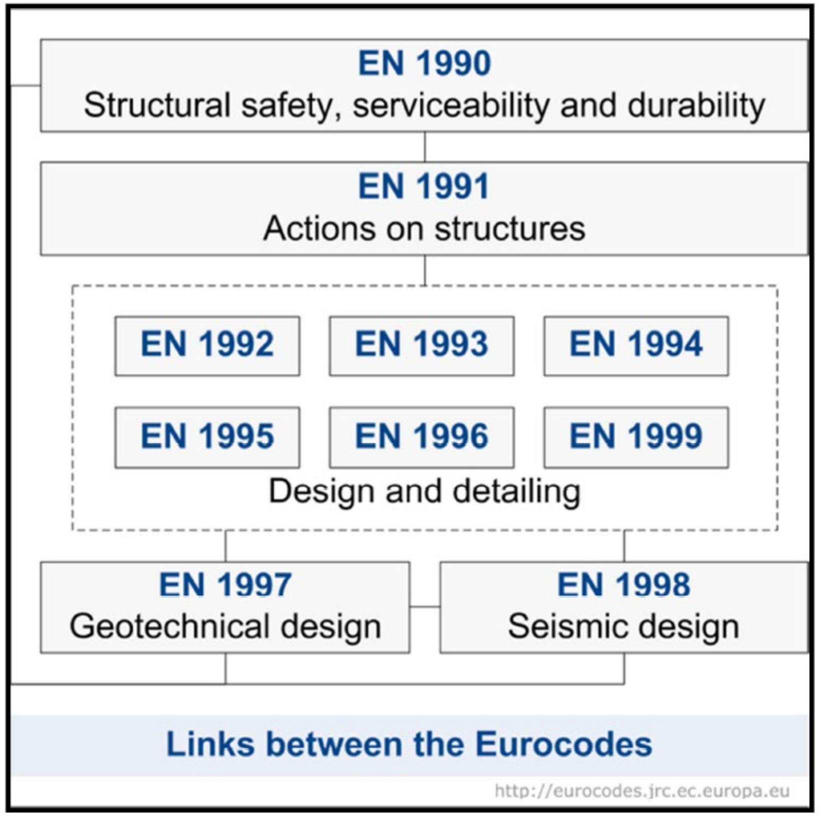
Reinforced plastics composites - Specifications for pultruded profiles - Part 1: Designation

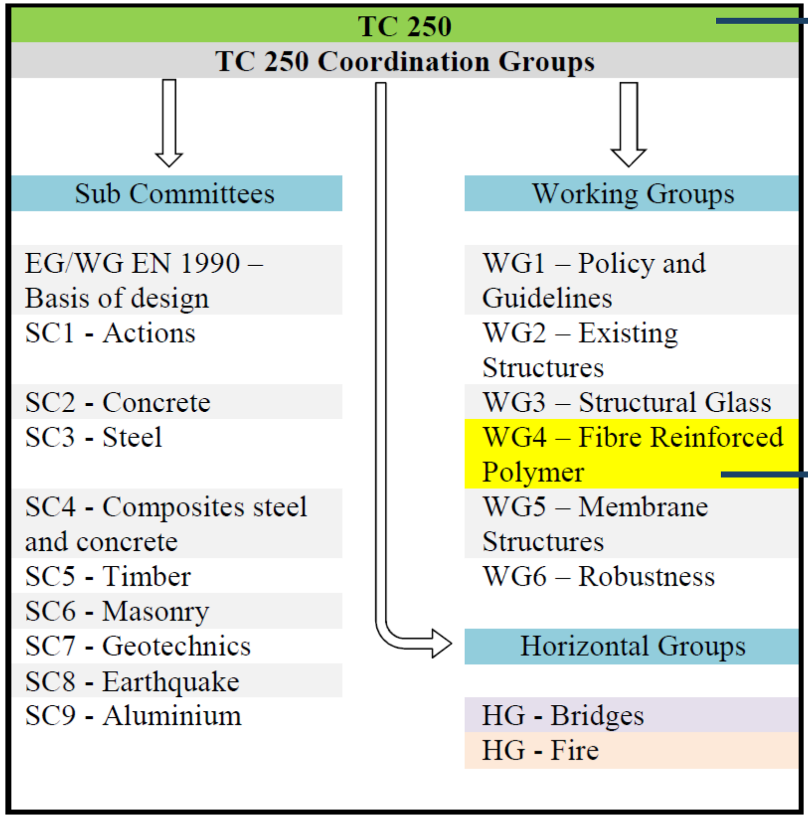
EuCIA
The European Voice of Composites

E23 / E17

What are these Eurocodes ?

- The Eurocodes are the standards to which all structures in Europe need to be designed (published 1990)
- Update of the Eurocodes started in 2010 and is approaching it's final stages (2024-2026)





Dr Steve Denton, Chairman

Prof Luigi Ascione, Chairman

Why would we need one for composites ?

prEN TS 19101 : Design of fibre-polymer composite structures

CEN/TC 250

Date: 2020 -10

prEN 19101: 2020

Secretariat:

Eurocodes Suite :

- EN 1990 Eurocode 0 : Basis of structural design
- EN 1991 Eurocode 1 : Actions on structures
- EN 1992 Eurocode 2 : Design of concrete structures
- EN 1993 Eurocode 3 : Design of steel structures
- EN 1994 Eurocode 4 : Design of composite steel and concrete structures
- EN 1995 Eurocode 5 : Design of timber structures
- EN 1996 Eurocode 6 : Design of masonry structures
- EN 1997 Eurocode 7 : Geotechnical design
- EN 1998 Eurocode 8 : Design of structures for earthquake resistance
- EN 1999 Eurocode 9 : Design of aluminium structures
- EN TS 19101 Eurocode xx : Design of fibre-polymer composite structures

Design of fibre-polymer composite structures

Bemessung und Konstruktion von Tragwerken aus Faserverbundwerkstoffen

Calcul des structures en matériaux composites

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A great job was done by Prof Ascione, project teams and TC 250 WG4 members

TC 250 WG4 Delft meeting October 10-11 2019
Clockwise starting at front : Liesbeth Tromp, Prof Joao Correia (project teams leader), Prof Luigi Ascione (Chairman),Prof Thomas Siwowsky, Prof Nuno Silvestre, Prof Eric Moussiaux, Prof Wouter De Corte, Prof Sena Cruz, Marta Gil Perez, Prof Jan Knippers, Lech Wlasak, Prof Jean François Caron, Carlo Paulotto, Prof Thomas Keller, Prof Marko Pavlovic

Our Technical Specification contains 12 Clauses and 5 Annexes …

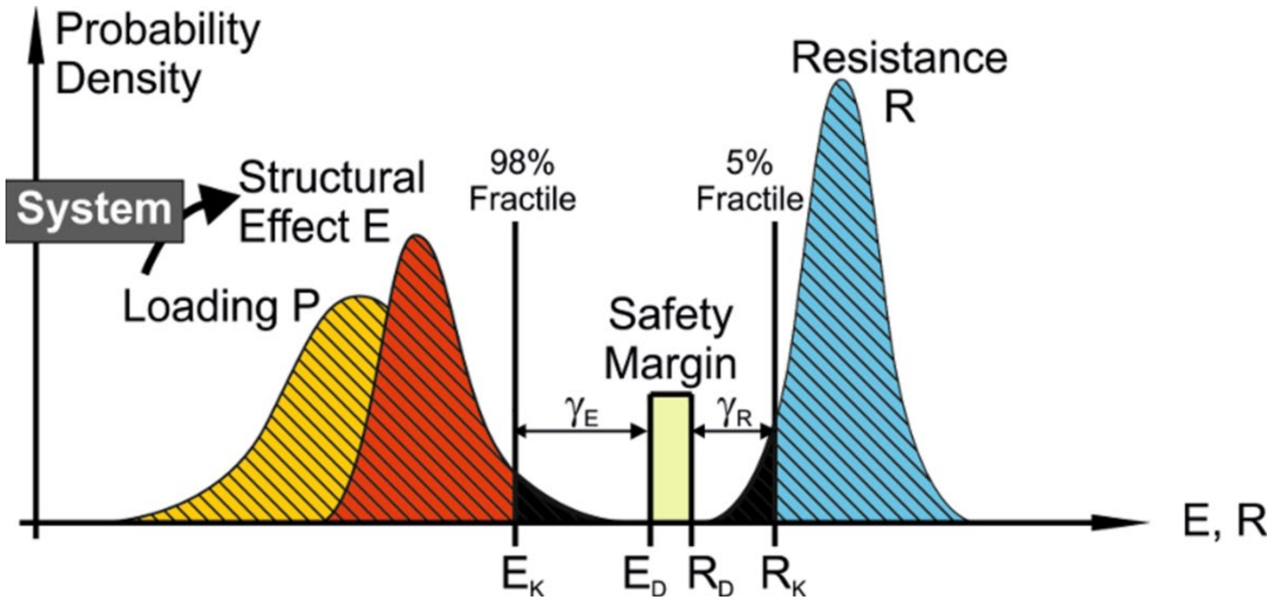
1	Scope
2	Normative references
3	Terms, definitions and symbols
4	Basis of design
5	Materials
6	Durability
7	Structural analysis
8	Ultimate limit states
9	Serviceability limit states
10	Fatigue
11	Detailing
12	Connections and joints

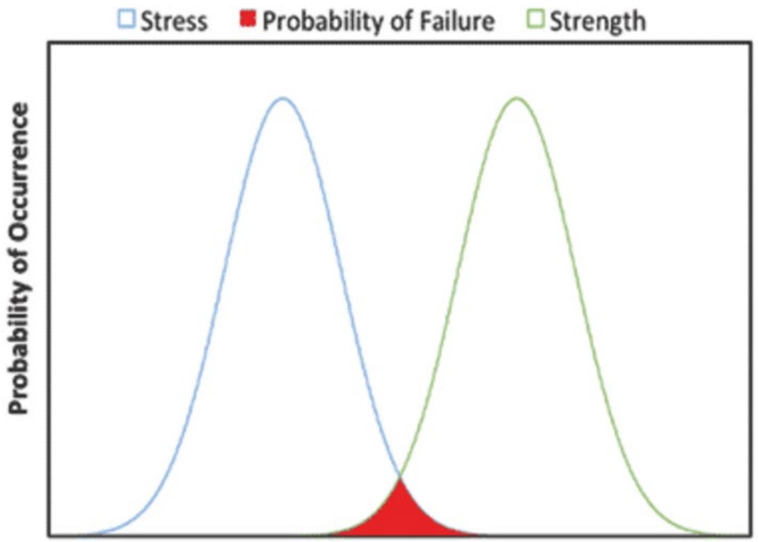
A	Creep coefficients
B	Indicative values of material properties for preliminary design
C	Buckling of orthotropic laminates and profiles
D	Structural fire design
E	Bridge details

… and applies to most composites processing methods and materials used.

- EN TS 19101 is applicable to
  - Buildings, bridges and other civil engineering structures
  - Permanent and temporary structures
  - All-composite and hybrid-composite structures
  - Pultruded profile beam and column structures, 3D molded structures (eg infusion), sandwich panels
  - Bolted and bonded joints
  - Glass, carbon, basalt and aramid fibres
  - Thermoset resins and adhesives
  - Polymeric foam, balsa wood cores
- EN TS 19101 is not applicable to :
  - Cable stayed structures
  - Internal (rebars) and external concrete reinforcements
  - Honeycomb cores
  - Thermoplastic resins
  - Natural fibres

Probabilistic design is the basic of structural design in the Eurocodes





$$E_d \leq R_d$$

$$R_d = \frac{1}{\gamma_{Rd} \cdot \gamma_m} R\left\{\eta_{c,i} \cdot X_{k,i} ; a_d\right\}$$

where E_d and R_d are the design values, in the considered direction, of the generic action and corresponding capacity (in terms of resistance or deformation) respectively, within a generic limit state.

EN TS 19101 provides values for material partial factors, conversion factors, ….

A.3 Pultruded composite profiles

(1) Table A.1 gives values for the creep coefficient, $\phi(t)$, for different elastic moduli of pultruded composite profiles, which are valid for linear viscoelasticity and the environmental conditions indicated in the table.

$$X_m(t) = \frac{X_m(0)}{1+\phi(t)}$$

Table A.1 — Values for the creep coefficient, $\phi(t)$, for different elastic moduli of pultruded composite profiles (glass, carbon or basalt reinforcement; fibre volume fraction of at least 35%; temperature up to 25 °C; relative humidity up to 65%)

Property	Period of time (years)										
	1	**5**	**10**	**15**	**20**	**25**	**30**	**40**	**50**	**75**	**100**
E_x^{full}	0,25	0,38	0,46	0,51	0,55	0,58	0,61	0,66	0,70	0,78	0,84
G_{xy}^{full}	0,57	0,98	1,23	1,40	1,54	1,66	1,76	1,94	2,09	2,39	2,62
$E_{x,t}$	0,20	0,22	0,24	0,24	0,25	0,25	0,25	0,26	0,26	0,27	0,28
$E_{x,c}$	0,20	0,23	0,27	0,30	0,32	0,34	0,36	0,38	0,41	0,45	0,48

… duly motivated in a commentary document containing 396 individual background reports in ca 1000 pages.

Page 1 of 965

COMMENTARY TO

FprCEN/TS 19101: 2021

"Design of fibre-polymer composite structures"

BACKGROUND DOCUMENTS IN SUPPORT TO THE IMPLEMENTATION, HARMONIZATION AND FURTHER DEVELOPMENT OF THE EUROCODES

J. R. Correia | T. Keller | J. Knippers | J. T. Mottram | C. Paulotto | J. Sena-Cruz | L. Ascione

31 MARCH 2022

REPORT NUMBER	BR_10.1_PAR_1
CLAUSE / ANNEX	10. FATIGUE
SUB-CLAUSE	10.1 General
PARAGRAPH	(1)
AUTHOR(S)	Thomas Keller
REVIEWER(S)	Lee Canning, Wendel Sebastian
DATE	30 April 2021

CONTENT

(1) The structural design should ensure that stress concentrations are avoided or minimized by appropriate detailing of geometrical changes in sections or changes in materials.

NOTE 1: Since fatigue failure, in most cases, occurs in such singular areas where a stress-based verification is difficult (e.g. in a web-flange junction), the fatigue verification, including testing, can be performed at the structural member or joint level (e.g. for a bridge deck or a deck-to-girder joint), based on the action effects, i.e. internal forces and/or moments.

NOTE 2: Testing at the member and joint level also takes into account geometrical and material imperfections and size effects.

Appropriate detailing

Background

Eurocomp [1], citations:
4.13.2, P(5): The designer shall ensure by appropriate detailing that, wherever possible, the theoretical point of failure of FRP (composite) components subject to fatigue loading would occur away from joints, connections, changes of section and areas of stress concentration.
4.13.3 (4): When designing for fatigue, the designer should pay particular attention to areas where stress concentrations are likely to be present. These may occur at connections, re-entrant corners and points of acute change of direction. The resulting stresses may be far greater than those present in the adjacent plane section and thus significantly reduce the member's resistance to fatigue.

References

[1] CLARKE, John L. (ed.). *Structural design of polymer composites: EUROCOMP Design code and handbook*. London: E & FN Spon, 1996. ISBN 0 419 19450 9

Testing at structural member level

Background

See BR_10.3_PAR_1.

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A textbook will help engineers and designers applying TS 19101 with worked examples on structural elements …

No.	TITLE	AUTHOR(S)	REVIEWER(S)
1	*ULS verifications of a balanced symmetrical laminate subjected to in-plane and out-plane loading*	José Sena-Cruz	João Ramoa Correia, Luigi Ascione
2	*ULS verifications of a balanced symmetrical laminate subjected to in-plane and out-plane loading (preliminary design)*	Wouter De Corte	João Ramoa Correia, Luigi Ascione
3	*ULS verifications of a simply supported FRP profile with double symmetric cross-section subjected to axial compression*	Mário Sá and João Ramoa Correia	Luigi Ascione and José Gonilha
4	*ULS and SLS verifications of a simply supported FRP profile with double symmetric cross-section subjected to a uniformly distributed transverse load*	Mário Sá and João Ramoa Correia	Luigi Ascione and José Gonilha
5	*USL verifications of a uniformly loaded, simply supported sandwich beam (verifications with respect to the face sheets, core, web, interface, local and global buckling*	Wendel Sebastian and Andre Pitt	Thomas Keller, Marko Pavlovic
6	*ULS and SLS verifications of a simply supported sandwich panel subjected to a uniformly distributed transverse load*	Mário Garrido and João Ramoa Correia	Thomas Keller, Marko Pavlovic
7	*ULS and SLS verifications of a simply supported web-core sandwich panel subjected to a uniformly distributed transverse load*	João Ramoa Correia and Mário Garrido	Thomas Keller, Marko Pavlovic
8	*ULS verification of double-lap adhesive joint with pultruded adherends (stress-based approach)*	M. Pavlovic and A. Christoforidou	Thomas Keller, Luigi Ascione
9	*ULS verification of an adhesive double-lap joint with pultruded adherends (fracture-mechanics approach)*	M. Pavlovic and A. Christoforidou	Thomas Keller, Luigi Ascione
10	*Design of the loading device configuration to perform fatigue testing on composite bridge deck specimens*	Wendel Sebastian	Thomas Keller, Marko Pavlovic

… and full structures or parts thereof.

No.	TITLE	AUTHOR(S)	REVIEWER(S)
1	*Ultimate Limit State (ULS) verifications for bolted connections of pultruded profiles of a truss bridge with a span length of 13.50 m*	Matthias Oppe Reza Haghani Dogaheh	Toby Mottram Jan Knippers
2	*ULS verifications of a GFRP footbridge*	Jean-François Caron, Emilie Lepretre, Samuel Durand	Carlo Paulotto, Wendel Sebastian
3	*Design of a vacuum infused composite web-core sandwich traffic deck.*	Liesbeth Tromp, Fibercore	Thomas Keller, Wendel Sebastian
4	*ULS verification of an adhesive joint at a truss node, between pultruded chord and brace member (stress-based approach)*	Teodor Gheorghe, Angeliki Christoforidou;, Marko Pavlovic	Thomas Keller Luigi Ascione

EXAMPLE NO. B4	
TITLE	ULS verification of an adhesive joint at a truss node, between pultruded chord and brace member (stress-based approach)
AUTHOR(S)	Teodor Gheorghe; Angeliki Christoforidou; Marko Pavlovic
REVIEWER(S)	Thomas Keller, Luigi Ascione
DATE	September 2020 (version v1.0)
TS DRAFT NO.	Second draft, 25/09/2020
UNITS	Length / Force / Stress: [mm] / [N] / [MPa]

1. Data of the problem

In this example, Ultimate Limit States (ULS) verifications are performed for a symmetrical truss joint with pultruded profiles. The analysis of the adhesive joint is done by finite element analysis (FEA). The geometry of interest is the connection between the chord and brace member, and presents the following characteristics (see Figure 1):

- Cross-section dimensions brace member (SHS 100x8):

Length L (x_u) × width b (y_u) × thickness t (z_u) = 100 × 100 × 8 [mm];

- Cross-section dimensions chord member (U 240x72x10):

Height H (x_m) × width b (y_m) × thickness t (z_m) = 240 × 72 × 10 [mm];

- Dimensions adhesive:

Length L (x_a) × width b (y_a) × thickness t (z_a) = 240 × 100 × 2 [mm];

- Adhesive: SikaDur 330 two-component epoxy adhesive;
- Manufacturing process for truss members: pultrusion;
- Manufacturer of truss members: Fiberline;
- Laminates: E-glass fibers and isophthalic polyester resin; 2 combi-mats (CSM + 0/90 woven) on each side and main roving layer in the middle; architecture of the laminate is shown below.

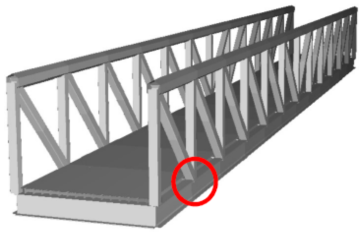

Figure 1 – Truss girder

The example is focused on the joint at the bottom chord of the truss structure shown in Figure 1. The chosen joint, shown in Figure 2 is close to the support, having the largest axial force in the diagonal. The joint configuration between two C-profiles, forming the bottom chord, and the brace diagonal, made of a square hollow section and placed at a 45° angle, is shown in Figure 2.

Real infused footbridge worked example

EXAMPLE B2	
TITLE	ULS verifications of a glass fibre-polymer composite footbridge
AUTHOR(S)	Emilie Leprêtre, Samuel Durand, Kévin Brunellière, Jean-François Caron, Philippe Jandin, Anthony Pruvost
REVIEWER(S)	Carlo Paulotto, Sebastian Wendel
DATE	31 May 2023
TS VERSION	CEN/TS 19101: 2022
UNITS	Length / Force / Stress / Mass: [mm] / [N] / [MPa] / [ton]

1. Data of the problem

In this example, Ultimate Limit State (ULS) verifications are performed for a pedestrian glass fibre-polymer composite bridge of one span (isostatic span) which presents the following characteristics:

- Total length $L = 21\ 000$ [mm];
- Width $B = 2400$ [mm];
- Fibre reinforcement: E-glass fibres;
- Matrix: polyester resin;
- Manufacturing process: vacuum infusion.

The bridge is a sandwich structure. The cross-section of the bridge is given in Figure 1. Four parts can be identified:

- Top and bottom skins (in blue colour);
- External webs (in green colour);
- Flange (in red colour);
- Internal webs (in grey colour).

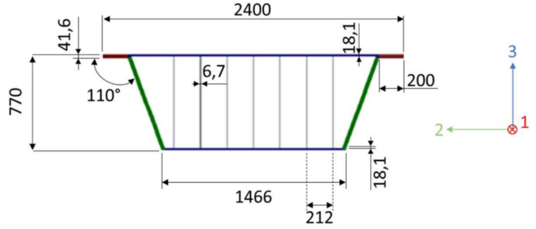

Figure 1 – Cross-section of the footbridge [mm]

The top and bottom skins are structurally most effective (i.e. fibres are concentrated in these skins). For an effective transfer of the shear forces, the fibre-polymer composite webs are connected to the top and the bottom skins. A foam core material is present between each web but it is supposed to be non-structural (only acts as a placeholder during construction).

Each bridge part (namely each skin, flange and web) consists of a combination of a number of UD plies in different directions. The combination and the total thickness of each part are summarized in Table 1.

Figure 1. Pedestrian FRP Bridge, Saint-André de Cubzac, France, ©Photo P. Charbonneau

6. Conclusions

Table 8 summarizes the ULS safety verifications performed for the different bridge parts analysed. It can be concluded that the different constitutive parts of the bridge fulfil the ULS safety verifications when subjected to the load combinations specified in section 2.

Table 8 – Summary of the verifications performed

ULS_2	Type of verification	E_d/R_d	Check
Face sheet	Tensile failure	0,5	✓
	Crushing	0,3	✓
	Local buckling	0,2	✓
Internal web	Shear failure	0,1	✓
	Local buckling due to shear	0,5	✓
	Bending failure	0,4	✓
	Local buckling due to in-plane bending	0,9	✓
	Crushing due to transverse compression	~0	✓
	Buckling due to transverse compression	0,2	✓
External web	Shear failure	0,1	✓
	Local buckling due to shear	~0	✓
	Bending failure	0,6	✓
	Local buckling due to in-plane bending	~0	✓
	Crushing due to transverse compression	~0	✓
	Buckling due to transverse compression	~0	✓
Global stability	Buckling	-	✓

Unfortunately TC 250 eliminated our elaborate execution and quality assurance clauses …

13 Production, installation and maintenance

13.1 General

(1) In the absence of an European standard on the execution of composite structures, this clause – addressed to designers, contractors and manufacturers – gives general provisions for the design, production, assembly, installation and maintenance of composite structures.

NOTE: It is assumed that the project is delivered according to a design-build system led by the contractor.

(2) The design, production, assembly, installation and maintenance procedures of composite structures shall be described in the project execution plan.

(3) When determining the necessary level of experience of the personnel, for all activities, the complexity and consequence class of the structure shall be taken into account according to prEN 1990.

…

13.4 Execution quality

13.4.1 Composite production quality

(1) For composite members and joints used in a structure, the manufacturer shall carry out, under a system of Production Quality Management (PQM), a factory production control, based on a quality assurance plan and a quality control plan and should follow the AVCP-system (Assessment of Verification of Consistency of Product) or a comparable approach.

…

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… WG4 will investigate our options with EuCIA.

- Designing with the Eurocodes
  - EN Eurocodes & related standards
    - Execution standards
    - Product standards
    - Test standards
    - ISO standards
  - Eurocodes Software
  - Structures designed to EN Eurocodes

Execution Standards

Within the Construction domain, CEN is developing European Standards which cover a wide range of products, materials and structures. For the complete design and construction of buildings and other civil engineering works, the EN Eurocodes are intended to be used in combination with Execution Standards that cover, for example, concrete, steel and aluminium structures, special geotechnical works as well as laboratory and field testing of soil.

Execution Standards related to EN Eurocodes

ENV 13670	Execution of concrete structures
EN 1090	Execution of steel structures – Technical requirements
EN 1536	Execution of special geotechnical work – Bored piles
EN 1537	Execution of special geotechnical work – Ground anchors
EN 14199	Execution of special geotechnical work – Micro piles
EN 12063	Execution of special geotechnical work – Sheet-pile walls
EN 12699	Execution of special geotechnical work – Displacement piles
EN 1011	Recommendations for arc welding of steels
EN 12732	Gas supply systems – Welding steel pipe work – functional requirements
EN 25817	Arc-welded joints in steel: Guidance on quality levels for imperfections
EN 30042	Arc-welded joints in aluminium and its weldable alloys – Guidance on quality levels for imperfections

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Next steps on our Eurocode for composites

- …
- CEN TC 250 approved FprCEN/TS 19101 on July 21st 2022 → now CEN/TS 19101
  - 23 countries (National Standard Bodies) voted positively, 0 countries voted negatively, 9 countries abstained
- CEN TS 19101 Design of Fibre-Polymer Composites structures was published in October 2022
  - CEN/TS 19101 is now for sale in several countries like all other EN standards
  - Several countries are upgrading the CEN TS to a National Standard
  - The trial phase of the CEN/TS 19101 takes two to three years
- Final approval : After the period for trial use and commenting, CEN/TC250 will decide to convert the CEN Technical Specifications into Eurocode Parts.
  - That process will be initiated at the next TC250 Plenary session in Delft on November 28 & 29 (2024)
- On March 27th 2023, after a unanimously positive vote, CEN TC 250 gave the green light to develop the 'Execution code for composite structures'
  - Work has started under leadership of Prof Thomas Keller (University of Lausanne)
  - Aimed finishing date: May 2026
- Publication of background report and worked examples now expected first quarter 2025

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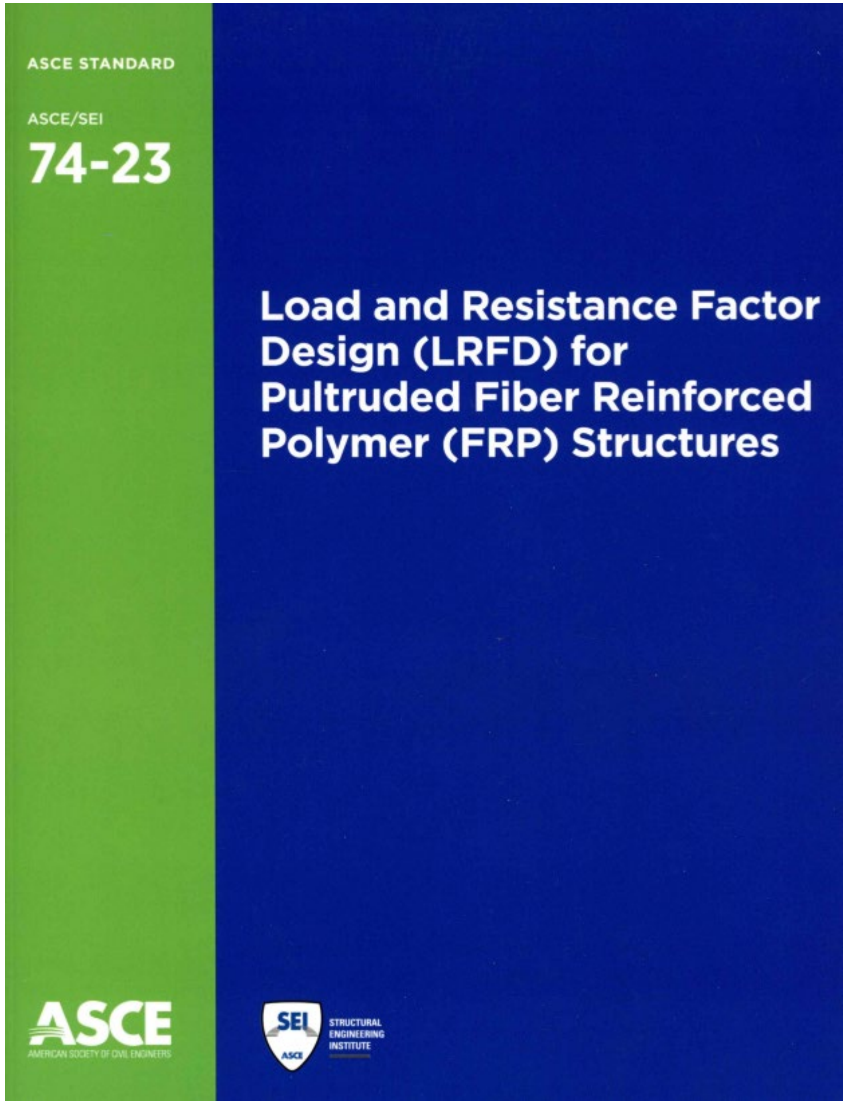
The American Society of Civil Engineers approved the LRFD Manual on May 18th 2023



Conclusion : our Eurocode has great value for the whole composites industry

TECHNICAL SPECIFICATION
SPÉCIFICATION TECHNIQUE
TECHNISCHE SPEZIFIKATION

CEN/TS 19101

October 2022

ICS 91.010.30

English Version

Design of fibre-polymer composite structures

Calcul des structures en matériaux composites

Bemessung von Tragwerken aus Faserverbund-Kunststoffen

This Technical Specification (CEN/TS) was approved by CEN on 22 August 2022 for provisional application.

The period of validity of this CEN/TS is limited initially to three years. After two years the members of CEN will be requested to submit their comments, particularly on the question whether the CEN/TS can be converted into a European Standard.

CEN members are required to announce the existence of this CEN/TS in the same way as for an EN and to make the CEN/TS available promptly at national level in an appropriate form. It is permissible to keep conflicting national standards in force (in parallel to the CEN/TS) until the final decision about the possible conversion of the CEN/TS into an EN is reached.

CEN members are the national standards bodies of Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Türkiye and United Kingdom.

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

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- It provides clear and reliable design methods for the engineer to safely design a composites structure, be it a pultruded beam and column, a large infused 3D or another sandwich structure
- Above all, it solidly confirms fibre-polymer composites as a credible structural material.

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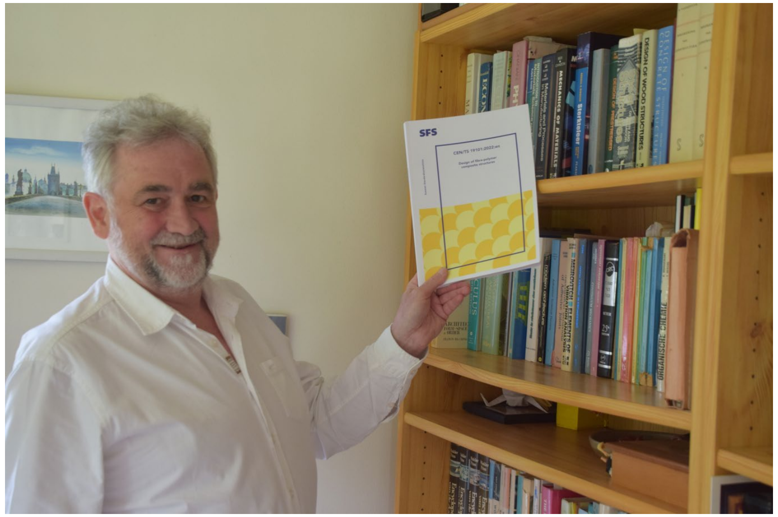
THANK YOU



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FOR
FORWARD
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