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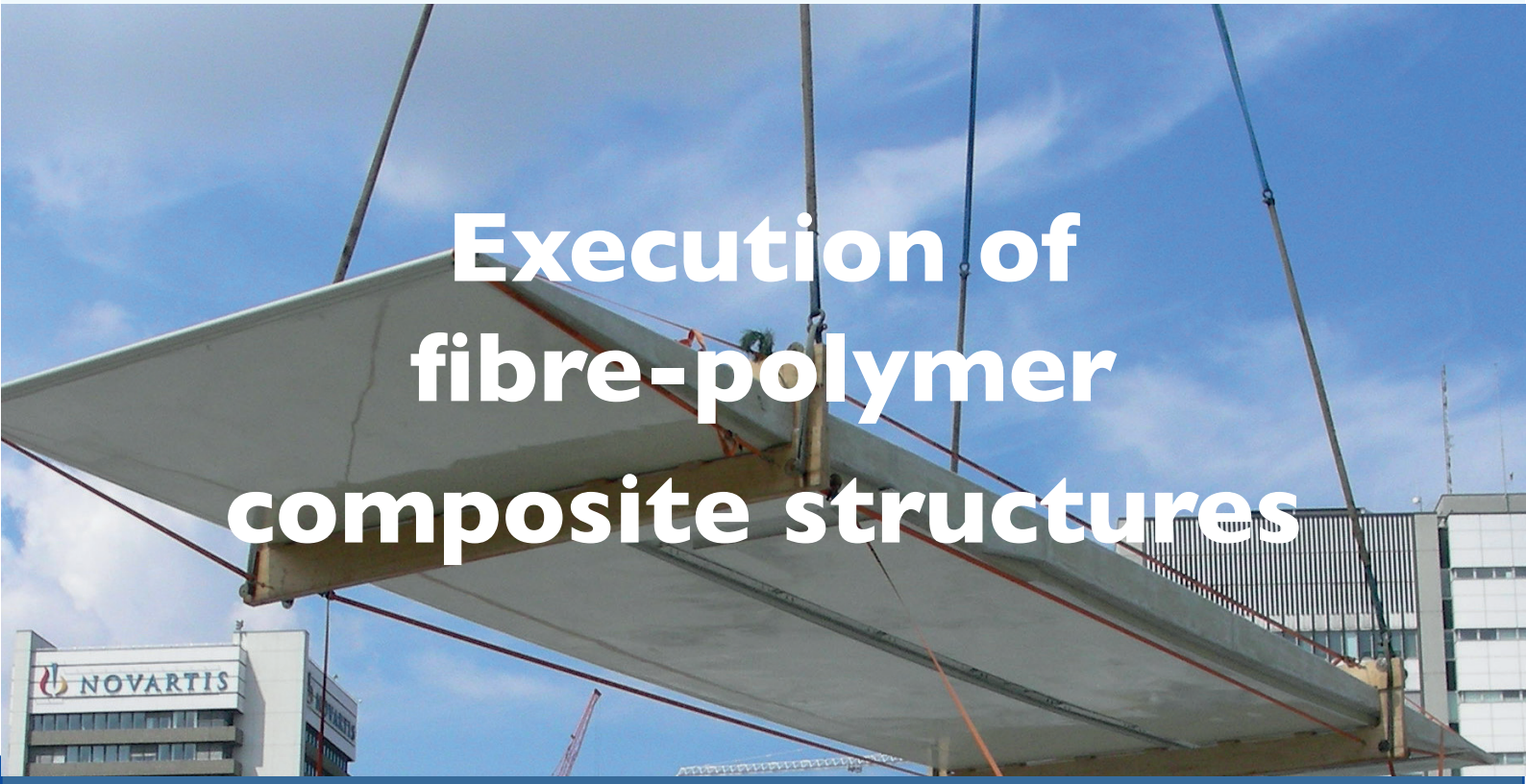

Execution of fibre-polymer composite structures

Excerpt from FprEN/TS 19101
"Prospect for new guidance in the design of FRP"

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0. Introduction

The aim of this document is to propose execution provisions for fibre-polymer composites structures. It was not possible to introduce this type of provisions in the final draft of the Technical Specification FprEN/TS 19101: 2021 [1], even if the authors had initially prepared a specific clause to them. Some provisions were already included in the JRC Scientific and Technical Report, which preceded FprEN/TS 19101: *Prospect for new guidance in the design of FRP* [2]. The formal reason is that the execution does not fall within the scope of CEN/TC 250. In special cases, CEN/TC 250 can propose to develop execution provisions if no other technical committee is available to undertake the work. The process can be started, as desirable, with inputs by the interested parties, including manufacturers. The members of the Working Group CEN/TC WG 4 are committed to promote this initiative as soon as possible. This document collects the execution rules not included in FprEN/TS 19101. They refer to production, installation and maintenance and address the type of fibre-polymer composite structures scoped by FprEN/TS 19101. The authors expect that the document can be used as a base for a CEN procedure dedicated to this topic, to be launched shortly.

1. General

1. In the absence of a European standard on the execution of composite structures, this document – addressed to designers, contactors and manufacturers – gives general provisions for the design, production, assembly, installation and maintenance of composite structures.
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.

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

2. Quality management

1. An appropriate project quality management plan shall be implemented to provide composite structures that correspond to the design requirements and assumptions.

NOTES:

1. *It is assumed that the project quality management plan is part of the project execution plan.*
2. *The term "quality", as used within the design (see Clause 3 below) and execution (see Clause 4 below) process of composite structures, comprises the use of adequate technical knowledge and its correct application to achieve the required resistance, stability, serviceability and durability of a structure.*
3. *The term "execution" covers the production of the members and joints of a composite structure, their assembly and installation.*

2. The following management measures should be taken into account in the implementation of the project quality management plan:
   - *organizational procedures in design, execution and maintenance.*
   - *controls at the stages of design, detailing, execution, as well as use and maintenance.*
3. The project quality management plan shall be implemented taking into account the requirements specified in EN ISO 9001.

3. Design quality

1. The design shall be checked to reduce the risk of human errors that might arise during the design process.
2. Self-checking shall be performed for each design.
3. Independent checking may be required for consequence classes CC2 and CC3 according to prEN 1990.
4. Design checking should include:
   - *actions, models for calculation of actions and design situations;*
   - *structural models, calculation of action effects and design verifications;*
   - *adequate knowledge of ground conditions and design parameters;*
   - *where appropriate, separate calculations as alternatives to reviewing the design calculations;*
   - *consistency of calculations, drawings, detailing, and execution specifications.*
5. Measures for design checking may concentrate on those parts of a structure where failure would have larger consequences with respect to resistance, stability, serviceability and durability.

4. Execution quality

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.
2. The quality assurance plan of the manufacturer shall describe, as a minimum, how the following aspects of the manufacturing process are monitored and controlled:
    - *constituent materials;*
    - *moulds;*
    - *composite manufacturing process parameters.*
3. The quality control plan of the manufacturer shall describe, as a minimum, how the following aspects of produced composite members and joints are controlled:
    - *weight;*
    - *geometrical dimensions and tolerances;*
    - *visual defects;*
    - *the material properties listed in Tables 5.1 to 5.3 used for the analysis and design of composite members and joints;*
    - *for sandwich panels, the adhesion between the face sheets and the core (e.g., by non-destructive techniques).*
4. The quality control plan of the manufacturer shall contain:
    - *a statement of the required characteristics and material properties of composite members and joints;*
    - *a test campaign describing the tests that shall be executed and the number of samples that should be prepared to check the compliance with the specified requirements.*
5. Acceptance levels for visual defects shall be defined on a project-by-project basis. Indicative acceptance levels for visual defects of composite members (pultruded or not) are given in EN 13706-2, Table A.
6. Geometrical tolerances shall be defined on a project-by-project basis. For composite profiles (pultruded or not), indicative values of geometrical tolerances are given in EN 13706-2, Table B.1.

4.2 Composite production quality assurance

4.2.1 General

1. Ambient temperature ranges shall be defined and the production area shall be well ventilated in order to remove dust, fume, chemicals, etc. that may affect the curing process and, consequently, the final material properties of composite members.

2. Humidity shall be controlled at places where chemical reactions occur. If humidity cannot be controlled, its effect shall be evaluated.

4.2.2 Constituent materials

1. Constituent materials shall be stored according to the suppliers' indications.
2. Constituent materials shall be processed in accordance with the suppliers' technical specifications and shall not be used beyond the expiry date.
3. Foam cores shall be stored long enough to allow the enclosed gases to diffuse out.

   NOTE: *In sandwich panels, delamination between face sheets and core can occur if the gases remain in the core.*

4. When taking materials out of storage, they shall reach the same temperature as in the production facility while remaining inside their sealed storage bag or container in order to prevent the condensation of air moisture on the materials.
5. Resins with two or more components shall be mixed according to the supplier's instructions.
6. The viscosity of the resin system and its gel time shall be measured for all processes where the flow properties of the resin system are important.
7. Changing accelerators or other additives in a matrix that control the speed of the cure is only permitted if it can be shown that the change does not adversely affect the mechanical properties of the new composite material (with respect to the measured mechanical properties of the previous composite material).

4.2.3 Moulds

1. Moulds should match all tolerances required by the design of the composite members.

   NOTE: Moulds or part of moulds include laying tables, mandrels and vacuum bags.

2. Sharp corners and discontinuities at joining points should be avoided.
3. Possible deformations of the moulds should be considered in their design. The moulds shall be able to withstand all the stress and strain states induced by the manufacturing process.
4. If moulds are heated, a controlled distribution of temperature shall be ensured.
5. If vacuum is applied inside the moulds, it shall be ensured that no major leaks exist so that the vacuum can be maintained at the level prescribed by the quality assurance plan of the manufacturer.
6. The vacuum shall be measured far away from the points where the vacuum is applied.
7. Large moulds may require more than one measurement point of the relevant processing parameters.

8. When demoulding composite members, large stresses and strains may be induced, especially if parts of the surfaces of composite members that are in contact with the mould remain adhered to it during the curing phase. These effects should be avoided or at least carefully controlled.

4.2.4 Manufacturing process parameters

1. During the production of composite members, the following parameters shall be controlled, as a minimum:
    - *temperature and pressure;*
    - *number, weight, position, and orientation of rovings and/or tows;*
    - *number, weight, architecture, position and orientation of fabrics and/or mats;*
    - *position of fabric splices and their overlap lengths;*
    - *fibre tension (filament winding);*
    - *quantity of resin injected (resin infusion processes);*
    - *flow patterns (resin infusion processes).*

4.3 Assembly and installation quality

4.3.1 General

1. The contractor should have a management system that assures adequate levels of skill and experience and qualifications for the execution of the works.
2. Inspection during the execution of the works shall be undertaken to check their compliance with the design drawings and with the execution procedures included in the project execution plan in order to reduce human errors.
3. Self-inspection should be carried out for all works.
4. Independent checking may be required for consequence classes CC2 and CC3 according to prEN 1990.
5. Inspections should ensure that:
    - *the project execution plan is available during assembly and installation;*
    - *the assembly and installation are performed according to the project execution plan;*
    - *the personnel have the skills and training required for the work;*
    - *inspection is properly documented;*
    - *materials and construction products are used as specified.*
6. Measures for inspection should concentrate on those parts of a structure where failure would have larger consequences with respect to resistance, stability, serviceability and durability.

4.3.2 Handling and storage

1. Composite members shall be lifted at the points and following the procedures specified in the project execution plan.
2. Damage (e.g. scraping, wear, and tear) to composite members shall be prevented during their transport and handling (e.g. by using protective pads).
3. Composite members shall be stored in accordance with the manufacturer's recommendations.

4.3.3 Bolted connections

1. Hole positions, diameters, and tolerances shall be specified in the project execution plan.

NOTE: *Indicative values for the tolerances of the positions and diameters of the holes are given in Table 1.*

Table 1 — Tolerances for bolted connections

Aspect	Tolerance
Hole positions	+/- 1,0 mm
Nominal bolt hole diameters up to 12,7 mm	+/- 0,4 mm
Nominal bolt hole diameters from 12,7 mm to 25,4 mm	+/- 0,8 mm
Nominal bolt hole diameters greater than 25,4 mm	+/- 1,0 mm
Slotted bolt holes	+/- 1,0 mm

2. Washer sizes shall be specified in the project execution plan (see 12.2.1(8) and (13)).
3. The tightening torque shall be specified in the project execution plan (see 12.2.1(14)).

4.3.4 Adhesive connections

1. The overlap lengths and the thicknesses of the adhesive layers shall be specified in the project execution plan.
2. The alignments and tolerances of the adherends shall be specified in the project execution plan.
3. Adhesive connections shall be executed in environmental conditions that are consistent with the application instructions provided by the adhesive supplier.
4. The surface of the adherends should be prepared according to the instructions provided by the adhesive supplier, which shall be included in the project execution plan.
5. The preparation of the surfaces of the adherends shall be exactly the same as for the specimens that were tested to qualify the corresponding adhesive connection.

4.3.5 Installation

1. If accidental loads and/or restraints are introduced into the structure before or during its installation, their effects should be assessed.
2. After the assembly and installation of a structure composed of more than one composite member, it shall be verified that the geometrical tolerances are met.

5 Maintenance

5.1 General

1. Composite structures should be delivered together with a maintenance plan to ensure that they retain their performance within the specified tolerances throughout their design service life.
2. An appropriate maintenance plan should contain, as a minimum:
    - *as-built drawings of the structure and specifications of the used materials;*
    - *points of the structure to be inspected;*
    - *inspection procedures;*
    - *acceptance criteria;*
    - *inspection intervals;*
    - *regular maintenance procedures;*
    - *restrictions for maintenance operations (e.g. indicating cases where cleaning with high pressure is not allowed);*
    - *instructions to repair components;*
    - *instructions to replace components.*
3. To evaluate the performance of composite structures over their design service life, it is recommended to execute a time-zero assessment of their behaviour immediately after installation.

NOTE: *Depending on the consequence class of the composite structure, time-zero assessment can involve load tests.*

5.2 Inspections

1. Three types of inspections should be defined in the maintenance plan: general, principal and special inspections.
2. The frequency of each type of inspection should be defined in the maintenance plan based on the type of composite structure and its consequence class.
3. A general inspection should aim at providing information on the physical conditions of all the visible parts of a structure.

NOTE: *A general inspection comprises a visual inspection of all parts of a structure that can be inspected without the need for special access equipment.*

4. A principal inspection should aim at providing information on the physical conditions of all inspectable parts of a structure.

NOTES:
1. *A principal inspection is more comprehensive and provides more detailed information than a general inspection.*
2. *A principal inspection comprises a close examination, within touching distance, of all inspectable parts of a structure. Testing is not required for a principal inspection.*

3. A special inspection should aim at providing detailed information on a particular part, area or defect that is causing concern, or to inspect aspects that are beyond the requirements of general or principal inspections.

4. Through a visual inspection within touching distance the following defects, amongst others, can be identified:

- *discolorations, crazing, tears, blistering;*
- *permanent deformations;*
- *visible damage caused by vandalism or accidental actions;*
- *untightness of connections;*
- *cracking, delamination, damage to adhesive layers.*

5. Visual inspections can be supported by non-destructive techniques, including the following:

- *(coin) tapping;*
- *acoustic measurements;*
- *infrared thermography;*
- *laser shearography;*
- *ultrasonic measurements;*
- *strain measurements.*

NOTE: *Strain measurements can be made by embedded optical fibre sensors for structural health monitoring.*

5.3 Repairs

1. A repair procedure shall be given for each component.

2. A repair procedure shall restore the same level of safety and serviceability as provided by the original structure.

3. Practical repair methods include:

- *creation of a bypass through the application of components (bonded or mechanically connected plates);*
- *laminating with composite materials;*
- *applying a resin layer (in case of superficial damage);*
- *replacing the damaged component.*

4. Suitable conditions (including environmental conditions) for repair works shall be guaranteed and maintained during the repair operations, irrespective of whether the repair is carried out on site or elsewhere. If suitable conditions cannot be guaranteed and maintained on site, the part should be moved to a more suitable site.

5. For the design and execution of the repair, the remaining design service life of the structure should be taken into account.
6. Any repair operation should be provided with appropriate inspection instructions.

5. References

[1] FprEN/TS 19101, Design of Fibre-polymer composite structures, November 2021

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[6] BD 90/05, Design of FRP bridges and highway structures, 2005

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