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Performance guidelines for design of concrete structures using fibre-reinforced polymer (FRP) materials

Lignes directrices de performance pour la conception des structures en béton utilisant des polymères renforcés de fibres (PRF)

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 71, *Concrete, reinforced concrete and pre-stressed concrete*, Subcommittee SC 6, *Non-traditional reinforcing materials for concrete structures*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

This second edition cancels and replaces the first edition (ISO 14484:2013), which has been technically revised. The main changes compared to the previous edition are as follows:

— the scope of the document now extends from concrete structures with the sole use of FRP materials to those with the combined use of FRP materials and steel reinforcement;

— the compressive strength of FRP materials is now allowed to be accounted for in design; and

— the creep-rupture and fatigue limit states of FRP materials have been specified.

Introduction

Continuous fibre-reinforced polymer (FRP) materials are widely applied to concrete structures. FRP materials have many advantages, such as a high strength/weight ratio and immunity to corrosion. FRP materials are available in a variety of geometries, including rod, grid, plate, sheet, strand, etc.

This document describes the general performance requirements for concrete structures with the use of FRP materials. This document is an umbrella document with general provisions and guidelines and lists the regional consensus guidelines/standards that are deemed to satisfy this document. Regional guidelines/standards are generally more prescriptive in nature and vary somewhat from region to region.

This document is intended to provide wide latitude in terms of general requirements for performance verification and assessment of concrete structures with the use of FRP materials. It is meant to be used in conjunction with sound engineering judgment.

Performance guidelines for design of concrete structures using fibre-reinforced polymer (FRP) materials

1 Scope

This document provides general principles for the verification and assessment of the performance of concrete structures with the applications of different fibre-reinforced polymer (FRP) systems varying from internal FRP reinforcements/tendons, external FRP tendons, externally bonded FRP sheets/plates, to near-surface mounted FRP reinforcement. It can be used for the international harmonization of the design of un-reinforced, conventionally reinforced, and pre-stressed concrete structures with the use of the above-mentioned FRP systems.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 2394, *General principles on reliability for structures*

ISO 10406-1, *Fibre-reinforced polymer (FRP) reinforcement of concrete — Test methods — Part 1: FRP bars and grids*

ISO 10406-2, *Fibre-reinforced polymer (FRP) reinforcement of concrete — Test methods — Part 2: FRP sheets*

ISO 19338, *Performance and assessment requirements for design standards on structural concrete*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 19338, ISO 10406-1, ISO 10406-2, and ISO 2394 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
bonding
attachment between fibre-reinforced polymer and substrates

3.2
concrete substrate
concrete or any cementitious material used to repair or replace the original concrete

Note 1 to entry: The substrate can consist entirely of original concrete, entirely of repair materials, or of a combination of original concrete and repair materials.

3.3
debonding
separation at the interface between the substrate and the near-surface mounted or externally bonded fibre-reinforced polymer materials

3.4
fibre-reinforced polymer material
FRP material
assembly of dissimilar materials with a polymeric matrix and continuous fibre reinforcement of aramid, carbon, glass, etc.

3.5
near-surface mounted fibre-reinforced polymer reinforcement
near-surface mounted FRP reinforcement
fibre-reinforced polymer bar or strip which is bonded inside a groove near the surface of a structural component

3.6
fibre-reinforced polymer plate
FRP plate
single or multiple layers of fabric or mat reinforcement bound together in a resin matrix, precured prior to application

3.7
fibre-reinforced polymer sheet
FRP sheet
dry, flexible component which consists of continuous fibres aligned in one or more directions and held together in-plane to create a ply of finite width and length, and is used in wet lay-up systems

4 Design basics

4.1 General

Concrete structures with FRP materials include concrete structures with the sole use of FRP materials and those with the combined use of FRP materials and steel reinforcement.

Design of concrete structures with FRP materials should consider safety, serviceability, and restorability during service life. Where applicable, limit states caused by fire, seismic actions, or other extreme loading or actions (e.g. impact and fatigue) should also be appropriately considered, according to the intended applications of FRP materials (i.e. as the strengthening layer or the internal reinforcement). In addition to the above, costs should also be taken into consideration.

Suitable analysis should be performed to verify that the performance requirements for concrete structures with FRP materials in terms of limit states such as serviceability limit states (SLS) and ultimate limit states (ULS) in accordance with ISO 2394 are satisfied.

4.2 Design methodology

A design methodology for concrete structures with FRP materials should be based on quantitative performance evaluation at the limit states. A rational method should be adopted for analysing each limit state.

Design of concrete structures with FRP materials should consider the linear elastic material properties of FRP and the properties of bond, if available, between the FRP and concrete, based on quantitative performance evaluation at the ultimate limit states.

5 Properties of materials

5.1 Properties of concrete and steel

Properties of concrete and steel should be determined in accordance with those specified for general structural concrete in ISO 19338.

In the case of upgrading existing concrete structures with FRP materials, the strengths of concrete and steel should be determined with consideration of the in situ conditions, such as measured material and geometric properties of the existing concrete structures, instead of their material strength values used in the original design.

5.2 Properties of FRP materials

5.2.1 General

The FRP materials used for concrete structures should be those whose quality and performance characteristics have been confirmed to be compatible with environmental conditions under which the structure will be exposed.

The characteristics of FRP materials should be defined in general conformance with reliability-based design requirements.

The elastic moduli of FRP materials deviate significantly from that of steel reinforcement depending on the types of fibre used, such as carbon, aramid, glass or basalt, and the fibre volumetric ratio.

The compressive strength of FRP materials should be generally ignored in design unless specified otherwise.

If necessary, the temperature-sensitive characteristics of FRP materials should be appropriately considered in design, with attention to its possible strength and stiffness loss at elevated temperatures.

An environmental reduction factor should be introduced to account for the environmental effect on the strength of FRP materials during the expected service life of the structure.

FRP materials shall be designed against creep-rupture under sustained loads unless otherwise noted.

FRP materials shall be designed against fatigue under cyclic loading unless otherwise noted.

5.2.2 FRP bars, grids, and plates

Properties of FRP bars, grids, and plates should be determined in accordance with ISO 10406-1.

5.2.3 FRP sheets

Properties of FRP sheets should be determined in accordance with ISO 10406-2.

5.2.4 Other FRP systems

Properties of other types of FRP systems should be determined based on appropriate test methods, with consideration to their intended applications.

5.3 Resins

Mechanical and physical properties of resins (matrix for fibres and bonding adhesives) should be determined in accordance with appropriate standards, such as corresponding ISO technical standards.

6 Structural analysis

Structural analysis of concrete structures with FRP materials should consist of the determination of structural response for the examination of limit states such as ultimate limit states and serviceability limit states. In general, structural analysis methodologies specified in ISO 19338 for structural concrete with traditional reinforcing materials may be applied for concrete structures with FRP materials.

Structural analysis of concrete structures with FRP materials should take into account the linear elastic material properties of FRP and the possible debonding failure between the FRP and concrete, which limit development of ductility in the structure. In general, moment redistribution away from sections with FRP materials should not be considered unless otherwise specified.

7 Serviceability limit states

7.1 General

Serviceability limit states should be verified to ensure the intended performance of concrete structures with FRP materials under service conditions during their design life.

7.2 Calculation of stress and strain

Unless otherwise specified, linear analysis should be used in the computation of stresses and strains in FRP in member sections under service.

In the case of upgrading existing concrete structures using FRP materials, the initial stresses in the member sections due to the permanent loads existing before FRP upgrading should be appropriately considered for analysis.

7.3 Cracking

7.3.1 Allowable crack width

The allowable crack width should be determined based on the intended purpose of the structure, environmental conditions, member conditions, etc.

When determining the allowable crack width, the non-corrosive property of FRP can be taken into account.

7.3.2 Tension and flexural cracks

The calculated crack width should be limited as appropriate through detailing the size, spacing and location of FRP reinforcement appropriately.

Conventional formulae may be used to calculate the tension and flexural crack width, provided that they are modified to take into account the stiffness of the FRP and the bond characteristics between the FRP and concrete.

It may not be necessary to consider the limit for tension and flexural crack width from the viewpoint of durability for those concrete structures in which FRP is used as the only reinforcing material.

In the case of FRP-upgraded concrete structures, crack widths should be checked to ensure that the internal steel reinforcement is protected against corrosion at service conditions. The upgrading effects of FRP materials should be taken into account in the calculation.

7.3.3 Shear and torsion cracks

Where necessary, shear and torsion crack widths should be checked with appropriate methods.

7.4 Deflections

Displacements and deformations exhibited in concrete structures with FRP materials should meet the requirements of current design code for structural concrete with the use of traditional reinforcing materials.

The adopted analytical model for calculating displacements and deformations should be able to reasonably predict the actual behaviour of the structure. If necessary, due consideration should be given to cracking and the bonding between the FRP and concrete.

8 Ultimate limit states

8.1 General

Ultimate limit states should be verified to ensure the intended performance of concrete structures with FRP materials under ultimate conditions during their design life.

8.2 Axial and flexural capacity

8.2.1 Axial strength and deformation capacity

FRP materials arranged in the direction of compressive forces generally should not be considered for strength computations unless specified otherwise.

In cases where lateral FRP confinement is available, the axial strength and deformation capacity of structural members should be determined through appropriate modelling of the lateral pressure provided by FRP.

8.2.2 Flexural strength and deformation capacity

The flexural strength and deformation capacity of structural members with FRP materials should be determined using appropriate methods, giving consideration to the failure mechanisms corresponding to concrete crushing and to rupture of the FRP at the ultimate state. In cases of FRP sheets/plates and NSM FRP reinforcements, the possible debonding of FRP from concrete substrates should also be taken into account.

Analysis of the flexural strength of concrete members with FRP materials should account for:

a) nonlinear stress-strain behaviour of concrete;

b) stress-strain relationship of the steel reinforcement;

c) linear stress-strain relationship and rupture of the FRP; and

d) strain compatibility.

8.3 Shear capacity

8.3.1 Shear strength

The shear strength of structural members with the use of FRP materials should be determined considering the contributions of FRP, concrete, and steel transverse reinforcing bars when available. The contribution of the FRP should be determined using appropriate methods, giving consideration to the linear material property and rupture of FRP materials. In cases of FRP sheets, plates, or NSM FRP reinforcements, the possible debonding of FRP from concrete substrates should also be taken into account.

8.3.2 Punching shear strength

When the loaded area is positioned far from free edges or openings, and the eccentricity of the load is small, the design punching shear capacity should be determined considering the contributions of the FRP, concrete, and steel transverse reinforcing bars when available. The contribution of the FRP should be determined using appropriate methods, giving consideration to the linear material property and rupture of FRP materials. In cases of FRP sheets, plates, or NSM FRP reinforcements, the possible debonding of FRP from concrete substrates should also be taken into account.

8.3.3 Torsion

The torsion capacity of structural members should be calculated using appropriate methods to account for the contributions of the FRP, concrete, and steel reinforcing bars when available.

8.4 Creep-rupture and fatigue

The stress levels in the FRP materials under sustained, cyclic and fatigue loading conditions should be limited to avoid creep-rupture and fatigue failure.

9 General structural details

9.1 FRP reinforcements/tendons

9.1.1 Bent configurations

When FRP reinforcements/tendons are arranged in a curve, the radius of the curve should be large enough to allow the FRP reinforcements/tendons to be bent within their elastic limits. The strength of the bent portion should be determined in accordance with ISO 10406-1. The stresses induced by the curvature in the FRP should be taken into account in the design.

9.1.2 Anchorages

The ends of FRP reinforcements should be sufficiently embedded in the concrete. The anchoring should be achieved either by the bonding force between the FRP and concrete or by mechanical anchoring including FRP hooks.

9.1.3 Splices

The FRP reinforcements should be sufficiently spliced by the bonding force between the FRP and concrete or by mechanical splicing.

9.2 Externally bonded FRP sheets/plates

9.2.1 Anchorage of FRP sheets/plates

The end anchorage of FRP sheets/plates should be verified by confirming that the bonded length between the FRP sheets/plates and the concrete substrate is sufficient. Mechanical anchorage accomplished with any system should be verified by confirming that it has sufficient strength to develop the anticipated stress in the FRP and to prevent anchorage failure.

9.2.2 Splice of FRP sheets/plates

The overlap splice sections of FRP sheets/plates should be verified by assuring that the overlap length is enough to secure the required overlap splice strength. The necessary overlap splice length should be determined through tests in accordance with ISO 10406-2.

NOTE ISO 10406-2 does not include a test standard for the overlap splice strength of FRP plates at the moment. The test standard for the overlap splice strength of FRP sheets is consulted to evaluate the overlap splice strength of FRP plates.

9.2.3 FRP sheets at rounded corners

In the case of FRP jacketing or wrapping, the corners of the members should be well-rounded, with a sufficient radius of curvature to avoid brittle breakage of the FRP sheets due to stress concentrations at the corners.

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