

fib Model Code (2020)

**a sustainability-driven
performance-based approach
to design, execution and
life-cycle management
of concrete structures**

Dr. ir. A.J. Bigaj-van Vliet | TNO

Deputy owner fib C10.1 Model Code

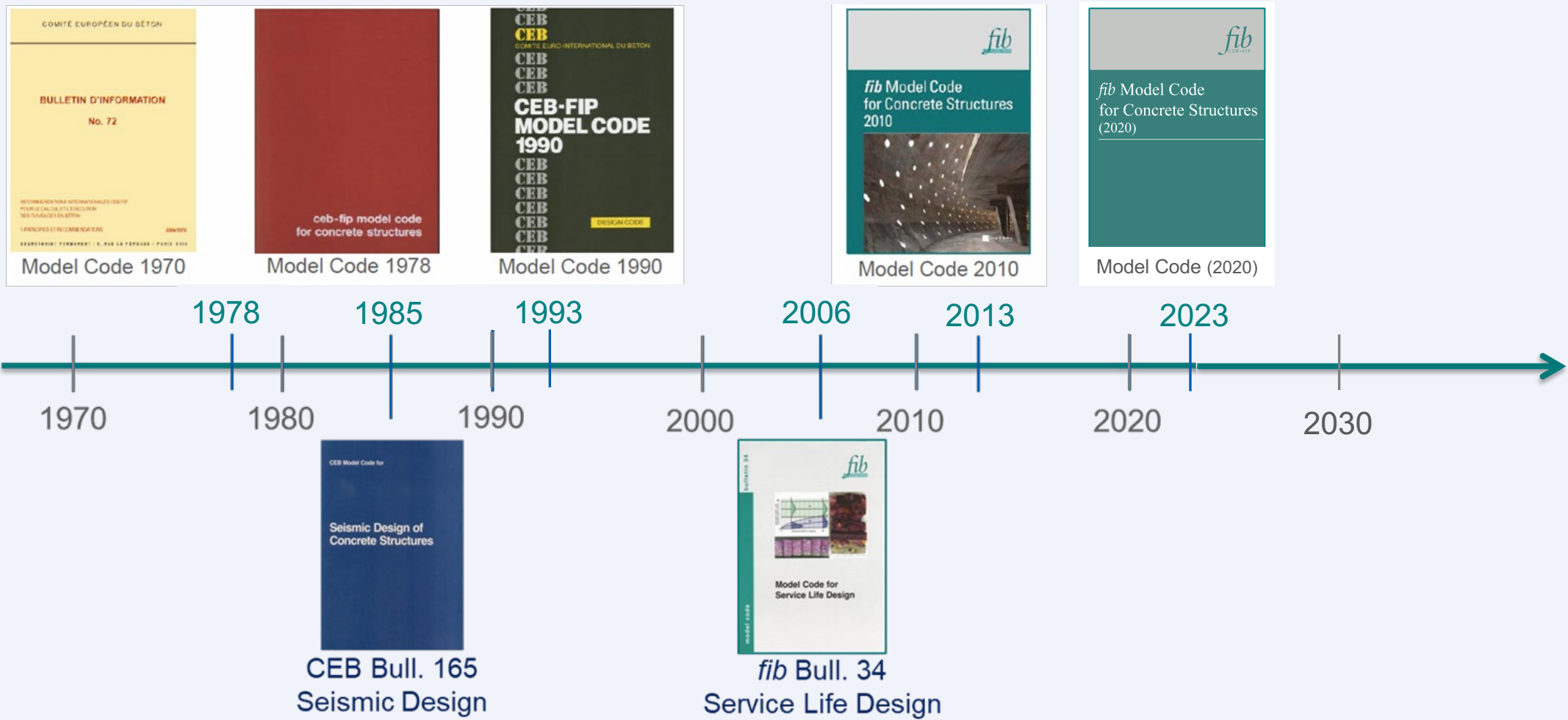


Contents

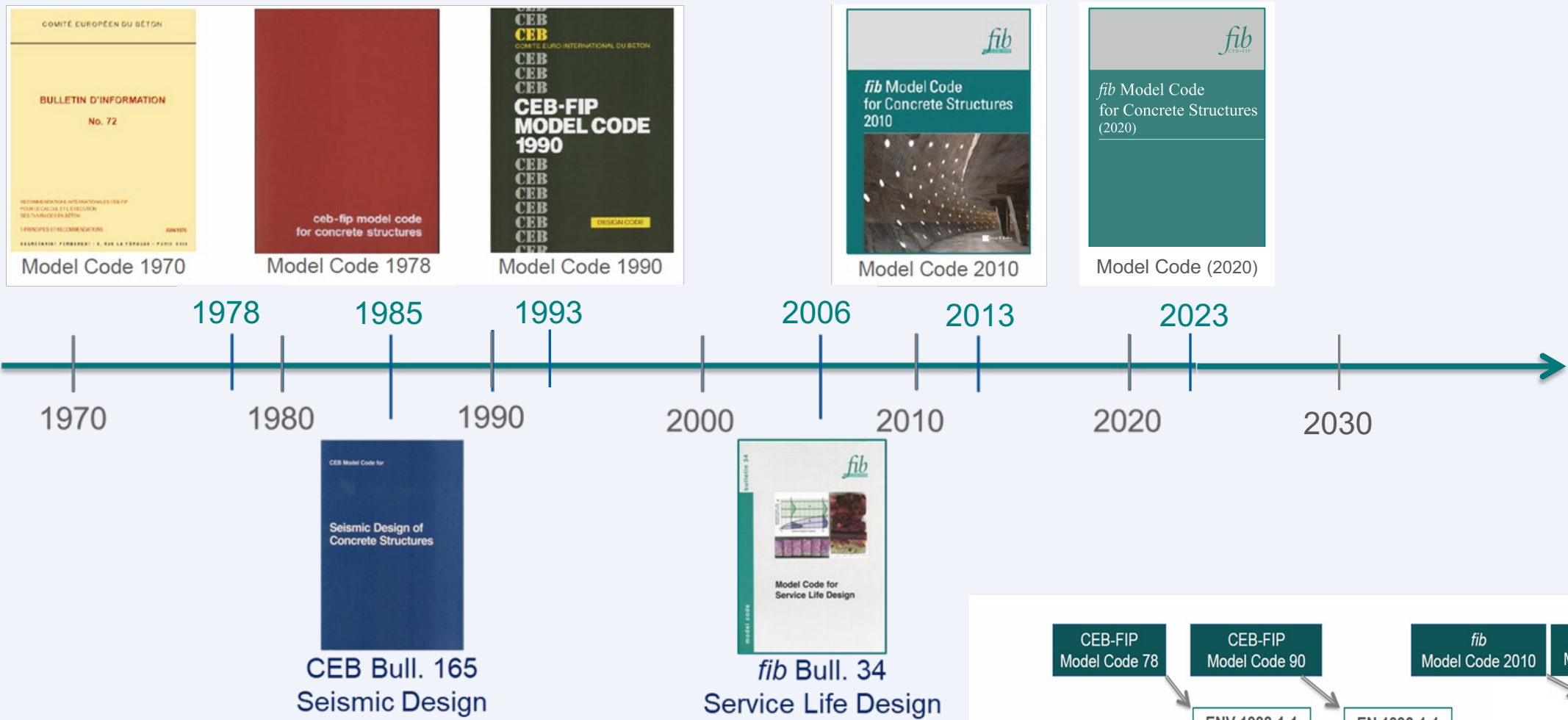
Evolution of *fib* Model Codes for structural concrete

- Objective:** release model codes that can serve as the basis for future codes for concrete structures worldwide, reference for the research and development work, and a resource for professional education
- Innovative Integration:** go beyond conventional approaches by incorporating the latest advancements in concrete technology, reinforcing materials, and construction techniques
- Development approach:** respond to contemporary requirements and broad range of engineering needs
- Global Recognition:** acknowledge diverse engineering communities worldwide and cater to regional requirements while maintaining global applicability
- Joint Effort:** reflect collective efforts and expertise of more than 1'400 contributors from 67 countries

Evolution of *fib* Model Codes for structural concrete



Evolution of *fib* Model Codes for structural concrete



What has been achieved in *fib* Model Code (2010)

- A code, basically for new structures
- Improved **safety formats** for new structures
- **Design with due regard to service life of structures**
- Improved **constitutive relations** for conventional types of concrete, with due attention to durability aspects
- Wide scope of loading types (**static, fatigue, impact, explosion, seismic, fire, cryogenic**)
- **Steel fibres and non-metallic reinforcement** as new alternatives for reinforcing concrete structures
- **Introduction of sustainability**
- **Introduction of “conceptual design” to stimulate creativity**
- **Introduction of numerical analysis**
- **Introduction of maintenance strategies for through-life care**

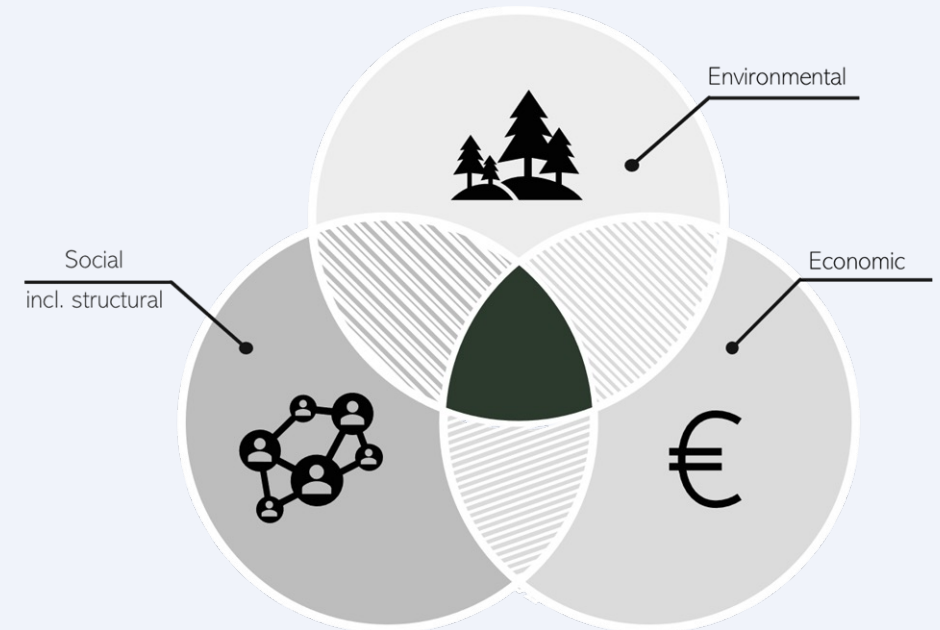
fib General Assembly voting on Model Code 2010, Lausanne, October 2011



Aspiration and challenge of *fib* Model Code (2020)

Sustainability framework in *fib* Model Code (2020)

- MC(2020) adopts a **sustainability-driven performance-based approach to design, execution and life-cycle management of concrete structures.**
- The sustainability-driven performance-based approach to design and assessment seeks to ensure that the **structure fulfills the performance requirements** it is expected to meet **throughout its full / extended service life cycle.**
- The essence of the concept of the performance-based approach is that the **requirements which have to be met should be defined, but not the manner in which this should be done**



- Sustainability is described by means of **3 interdependent pillars on which sustainable development depends:**

- **social pillar**
- **environmental pillar**
- **economic pillar**

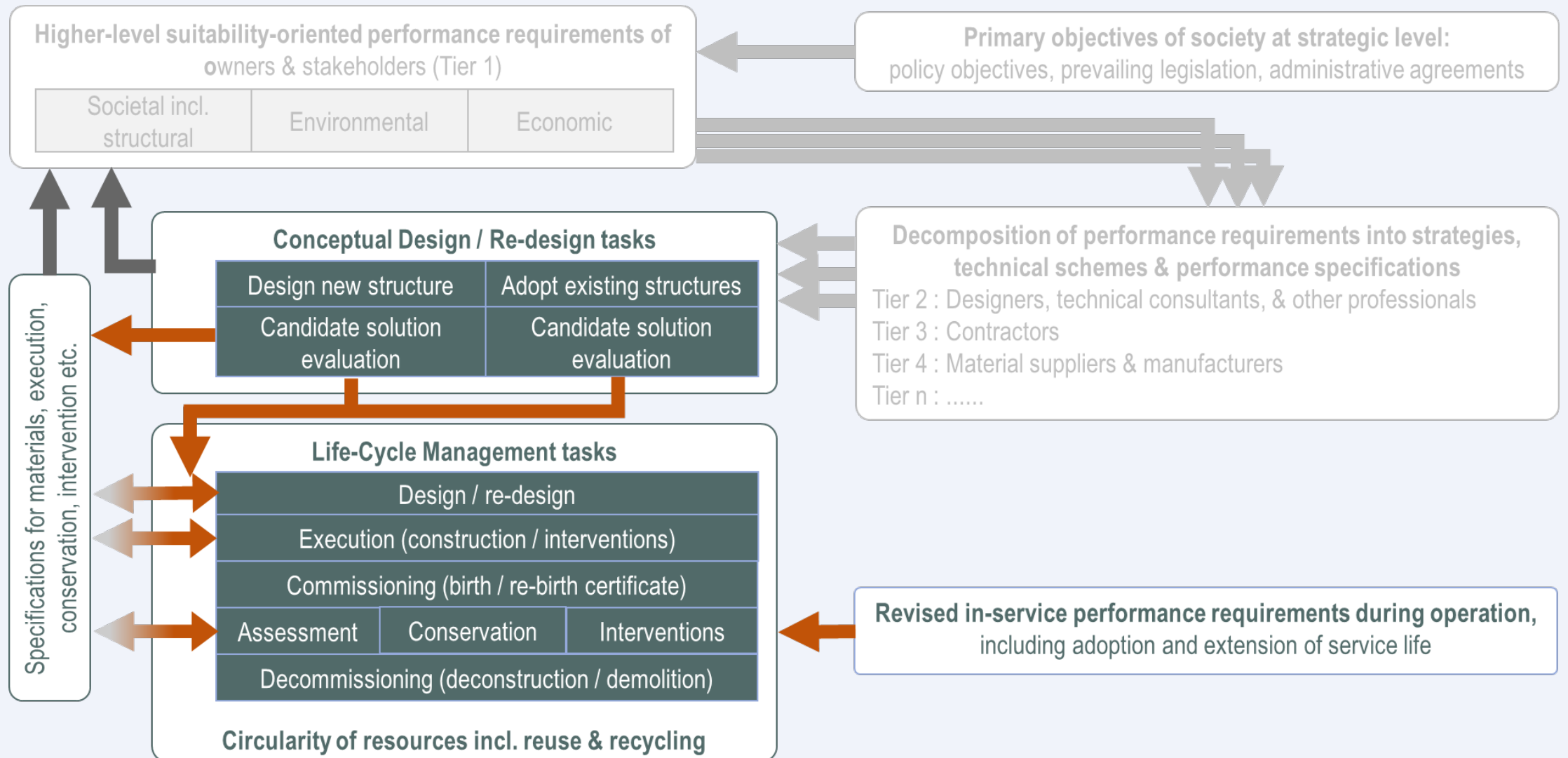
Performance-based approach supporting sustainability

Performance-based approach supporting sustainability

Performance-based approach supporting sustainability

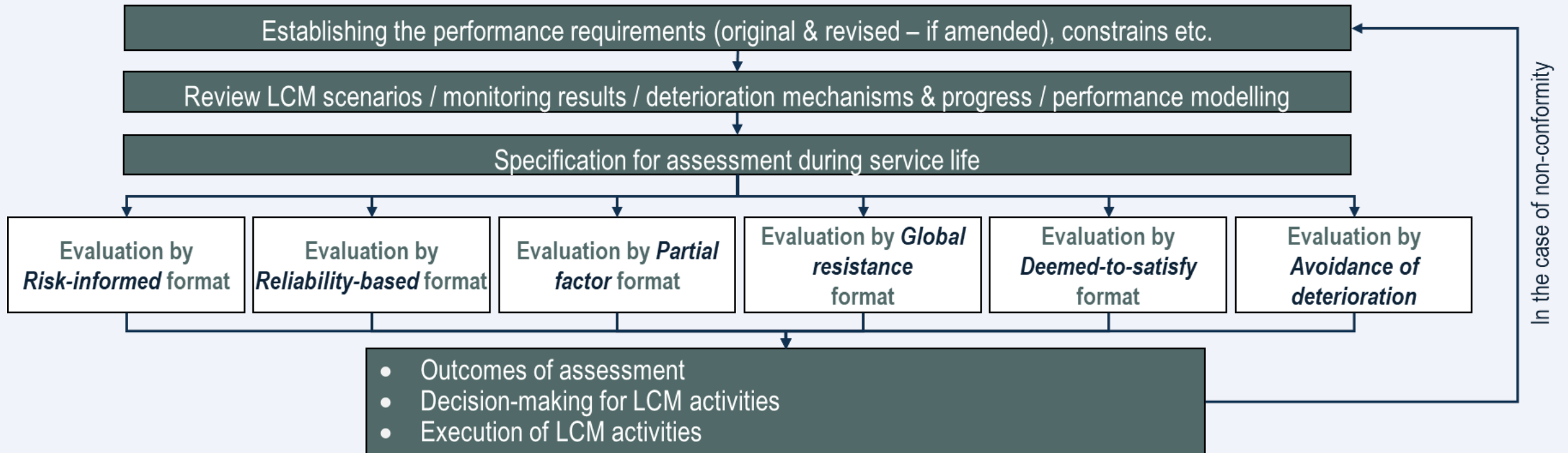
Performance-based approach supporting sustainability

Performance-based approach supporting sustainability



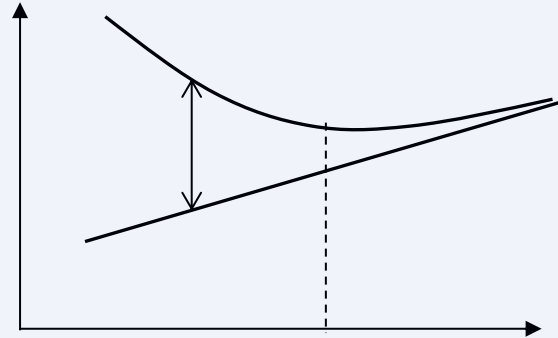
Principles of structural performance verification

- MC(2020) follows a consistent approach to design of new structures and assessment of existing structures with **safety philosophy based on risk and reliability concepts**



Principles of structural performance verification

existing



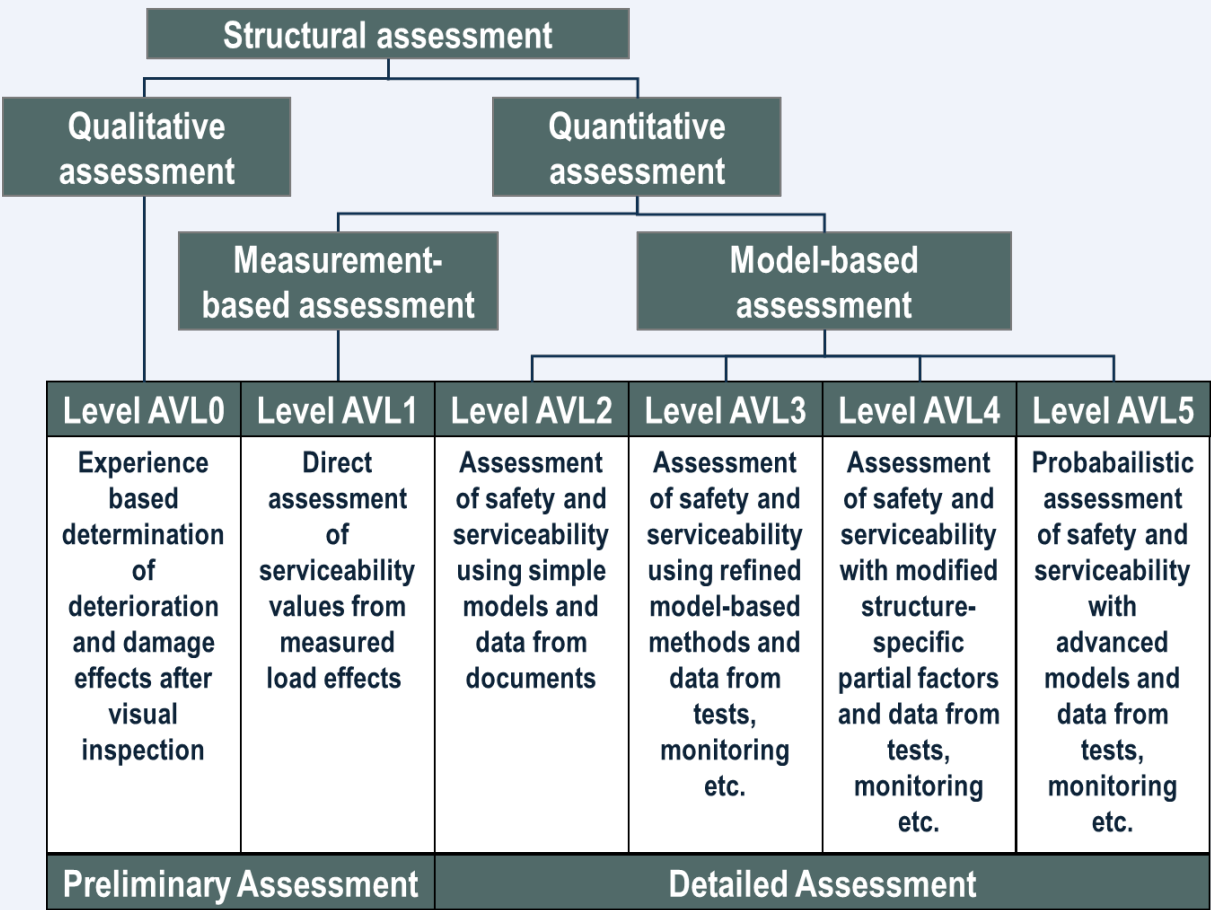
Levels-of-Approximation approach

Principles of structural assessment

MC2020 provisions for assessment cover :

- **Existing structures without deterioration**
Principally the same behavioural models apply as for new structures: if once the length and the properties are known the determination of the bearing capacity can be carried out, taking advantage of the LoA approach (?)
- **Existing structures with deterioration**
Principally the same basic behavioural models as for new structures only adjusted to include the effect of deterioration on the mechanism. The additional parameters are included.
- **Existing structures with non compliant detailing**
Principally the same basic behavioural models as for new structures with additional/different values of parameters to include effect of non compliant details.

The structural assessment process is commonly taken forward using an incremental approach



Structural assessment levels

Life-cycle perspective

Design and execution of preventative and remedial works

***fib* Model Code (2020) : ToC**

PART I : SCOPE AND TERMINOLOGY

- 1. Scope**
- 2. Terminology**

PART II : BASIC PRINCIPLES

- 3. Sustainability perspective**
- 4. Principles of performance-based approaches**
- 5. Life-cycle management**
- 6. Principles of quality and information management**
- 7. Principles of execution**
- 8. Principles of conservation**
- 9. Principles of circularity and dismantlement**
- 10. Implementation of quality and information management during LCM**

PART III : PRINCIPLES OF STRUCTURAL VERIFICATION

- 11. Structural performance evaluation framework**
- 12. Principles of structural design and assessment**

***fib* Model Code (2020) : ToC**

PART IV : ACTIONS ON STRUCTURES

13. Actions

PART V : INPUT DATA FOR MATERIALS

14. Concretes

15. Reinforcing steel

16. Prestressing steel & prestressing systems

17. Non-metallic reinforcement

18. Fibre reinforced concrete

19. Materials & systems for protection, repair and upgrading

PART VI : INPUT DATA FOR INTERFACES

14. Bond of embedded steel reinforcement : anchorages and laps

15. Bond of embedded non-metallic reinforcement

16. Bond of externally applied reinforcement

17. Concrete to concrete

18. Concrete to steel by mechanical interlock

19. Anchorages in concrete

***fib* Model Code (2020) : ToC**

PART VII - DESIGN AND ASSESSMENT PROCEDURES – MAIN TECH CONTENT

26. Conceptual design

27. Approach to design

28. Approach to assessment

29. Structural analysis

30. Evaluation of structural performance

- structural safety (ULS) for predominantly static loading
- structural safety (ULS) for non-static loading
- seismic design, assessment or retrofitting
- structural safety (ULS) for extreme thermal conditions
- serviceability (SLS) of RC and PC structures
- condition limit states (CLS) associated with durability
- structural safety, serviceability and condition limit states associated to durability for FRC structures
- structural safety, serviceability and condition limit states associated to durability for RC structures with externally applied reinforcement
- robustness
- evaluations assisted by non-linear finite element analyses
- verification of structural performance assisted by testing and monitoring
- evaluation of effectiveness of new structures, measures and intervention
- detailing
- evaluation of anchorages in concrete

26. Evaluation of other aspects of social performance

27. Evaluation of environmental quality

28. Evaluation of economic efficiency

29. Sustainable decision making

***fib* Model Code (2020) : ToC**

PART VIII : EXECUTION

- 31. Execution management**
- 32. Construction works**
- 33. Execution of interventions**

PART IX : CONSERVATION (LIFE-CYCLE MANAGEMENT)

- 38. Conservation**

PART X : CIRCULARITY - DISMANTLEMENT AND REUSE

- 39. Circularity and dismantlement**

***fib* MC (2020) Highlights : innovative materials**

fib MC (2020) highlights : innovative materials

Developing guidance documents for RAC

- scope definition and range of applicability
 - substitution
 - assessment of material properties
 - mechanical properties and properties related to durability
- design, assessment and execution guidance
 - assumptions used for design and in assessment incl. stochastic approach and determination of safety factors



14.18 Concretes with recycled concrete aggregates

14.18.1 Definitions

τ_{RC} is the substitution rate of recycled coarse concrete aggregates ($d > 4\text{mm}$) = quantity of recycled coarse aggregates/total quantity of coarse aggregates

τ_{TRA} is the total substitution rate of recycled aggregates = quantity of fine+coarse recycled aggregates/total quantity of aggregates

14.18.2 Principles

For reinforced concrete, when only recycled coarse aggregates are used, in order to facilitate recycling, when $\tau_{RC} \leq 0.25$ there is no change in the mechanical and structural properties. When $0.25 < \tau_{RC} \leq 1$ properties could be measured or relations given below could be used. When fine recycled aggregates are used the properties should be measured.

For prestressed concrete, when only recycled coarse aggregates are used and $0 < \tau_{RC} \leq 0.4$ properties could be measured or relations given below could be used. When fine recycled aggregates are used or $\tau_{RC} > 0.4$ the properties should be measured.

14.18.3 Physical properties

The density is expressed by the following relation:

$$\rho = 2'500 - 220 \tau_{TRA} \quad (14.18-1)$$

Unless more accurate information is available, the linear coefficient of thermal expansion may be taken equal to $10 \times 10^{-6} \text{ K}^{-1}$.

14.18.4 Mechanical properties

The relation between the mean value of the compressive strength and the characteristic strength is unchanged.

The variability of the tensile strength is unchanged.

$$E_{cm} = k_{RC} \cdot f_{cm}^{1/3} \text{ with } k_{RC} = k_A (1 - 0.25 \tau_{TRA}) \quad (14.18-2)$$

An application proposal may be found in the guidelines given in the French project RECYBETON^[14-101]. In the Spanish code a reduction of 5-15% of the density is suggested for "tau"TRA = 1.0.

No discernible effect of full RCA incorporation on the standard deviation is reported in Pacheco et al. 2019-1^[14-104].

According to Pacheco et al. 2019-2^[14-105] full RCA incorporations had no effect on the variability of the splitting tensile strength.

The equations and factors given are identical to those given in FprEN 1992-1-1:2023^[14-106].

Relations adapted from the project RECYBETON, papers from Tosić et al.^{[14-107], [14-108], [14-109]} and Silva et al.^[14-100].

fib MC (2020) highlights : innovative materials

Developing guidance documents for Fiber Reinforced Concrete

- classification
- assessment of properties of fibre reinforced concrete
 - taking advantage of information acquired by testing and monitoring
 - test methods for the determination of FR properties
 - durability of steel fibres in concrete
 - constitutive law incl. creep and shrinkage
- structural behavior
 - behavior in shear with/without additional fibre cement



18 Fibre reinforced concrete

18.1 Scope definition and range of applicability

Unlike rebars or welded mesh, fibres are generally designed to slip without failing in tension. Fibres are active as soon as micro-cracks are formed in the concrete. The main advantage of adding fibres to concrete or mortar is that they generate a post-cracking residual tensile strength in combination with a relatively large tensile strain. As such, the material fibre reinforced concrete (FRC) is characterised by substantial ductility and toughness with respect to plain concrete.

The properties of the composite depend on the characteristics of the constituent materials, as well as on their dosage. Other factors such as the geometry, the volume fraction and the mechanical properties of the fibres, the bond between fibre and concrete matrix, and the mechanical properties of the matrix, significantly affect the FRC properties.

Due to differences in casting and vibration procedures, FRC flowability and geometry of the moulds, anisotropic fibre distributions may occur, the effect of which should be taken into account since fibre orientation affects FRC mechanical properties after cracking.

The rules in this chapter are mainly based on experience with steel fibre reinforced concrete (SFRC). Proper precautions must be taken when using these rules for concrete reinforced with those non-steel fibres covered by this Model Code 2020.

Fibre reinforced concrete (FRC) is a composite material characterised by a cement matrix and discrete fibres (discontinuous). Fibres can be made of steel, polymers, carbon, glass or natural materials.

Fibre materials with a Young's modulus that is significantly affected by ageing and/or thermo-hygrometrical phenomena in the range of environmental conditions in service are not covered by this Model Code since the cement composites made exclusively with such fibres should not be recommended for structural use.

Mixtures with fibres of different types and/or dimensions can also be used (called hybrid fibre reinforced concrete).

Structural design of FRC elements is based on the post-cracking residual strength provided by fibre reinforcement. Other cases, such as early age crack-control or spalling resistance in case of fire, are considered non-structural use of FRC.

For structural use, a minimum mechanical performance of FRC must be guaranteed.

Fibres can be used to improve the behaviour at SLS since they can reduce crack width, thereby improving durability.

Fibres can be used to improve the behaviour at ULS where they can partially or, if certain conditions are fulfilled, totally substitute conventional reinforcement.

The mechanical properties of a cementitious matrix are modified when fibres are added. However, elastic properties and compressive strength are not significantly affected by fibres, unless a high percentage of fibres is used. Design values for compression are described in 18.6.1.

Depending on their composition, FRC can show hardening or softening behaviour under uniaxial tension (Figure 18.1-1).

In the case of softening behaviour (a) the deformations localise in one crack. In the case of hardening behaviour (b) multiple cracking occurs before reaching the peak value.

The relation between strain softening and strain hardening behaviour is shown in Figure 18.1-1. A FRC with softening behaviour in tension can develop hardening behaviour in bending. A FRC with softening behaviour in bending can exhibit a monotonically increasing load in the structure (Figure 18.1-2).

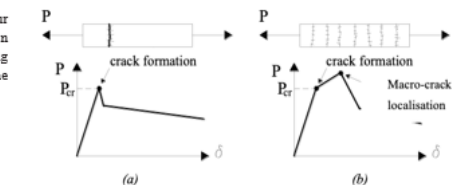


Figure 18.1-1: Softening (a) and hardening (b) behaviour in axial tension

fib MC (2020) highlights : innovative materials

17 Non-metallic reinforcement

17.1 Scope definition and range of applicability

Fibres occupy the largest volume fraction (40–70%) and have an elastic modulus much higher than that of the matrix. As such, fibres are the principal stress-bearing constituent, while the resin transfers stresses among fibres and protects them.

In general, FRPs are characterised by high axial strength, high ratio of axial to transverse strength, limited ultimate strain, low weight, excellent chemical resistance and non-susceptibility to a wide range of aggressive media, electromagnetic neutrality, excellent fatigue characteristics (depending on fibre type), and limited ratio of long term to short term static strength for some fibre types.

Several types of fibres are used for FRP reinforcement, the most popular are: glass (GFRP), carbon (CFRP), aramid (AFRP), basalt (BFRP) and rarer as polyphenylene bezobisoxazole (PBO). Typical matrix materials are vinyl ester and epoxy, amongst other polymer matrices. Thermosetting matrices are often used, although FRP products based on thermoplastic matrices also exist. For rebar applications special attention is given to the surface treatment (Section 17.4.3) to achieve proper bond with the concrete.

For further information see *fib* Bulletin 40^[17-1].

For further information see *fib* Bulletin 90^[17-2]. Externally applied reinforcement techniques are listed in figure 17.1-1.



Figure 17.1-1: Externally applied reinforcement

The methods of testing and certification of conformity are as defined in standards and recommendations at the national or international level. For the latter reference can be made to ISO 10406^{[17-3],[17-4]}, that covers in Part 1 methods of testing for FRP bars and grids and in Part 2 methods of testing for FRP sheets. At the European level, FRP performance characteristics and conformity can be declared via ETA

Non-metallic reinforcing elements consist of a large number of continuous, directionalised, organic or inorganic fibres, typically embedded in a polymeric matrix. Both the terms “non-metallic reinforcement” and “FRP (fibre reinforced polymer) reinforcement” are used for this reinforcement type.

The properties of FRP reinforcement basically depend on fibre and resin type and properties, constituent volume fractions, production parameters, shape (including bent FRP) and surface texture.

For rebar applications, amongst other, glass fibres (electrical/chemical resistant type) are used. For prestressing and externally applied reinforcement, carbon fibres are predominantly used.

For new structures pre-cured bars, tendons, grids or technical textiles are used to reinforce and prestress concrete elements.

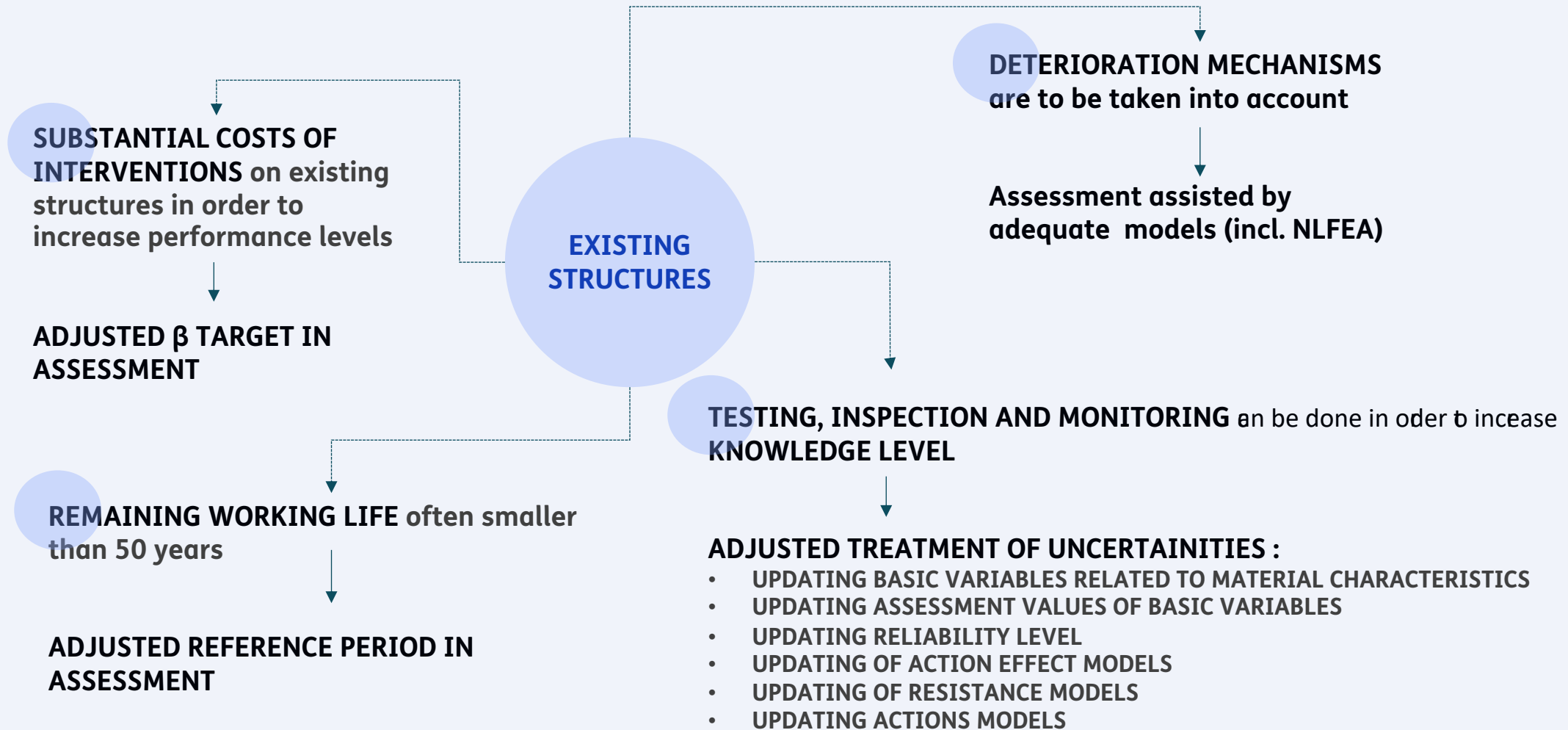
To retrofit and strengthen existing structures, FRP elements—prestressed or non-prestressed—are used as externally applied reinforcement (EAR). Mainstream EAR techniques are surface bonded reinforcement, often referred to as externally bonded reinforcement (EBR) and near-surface mounted (NSM) bars. The FRP may be in the form of:

- pre-cured strips or laminates for surface bonding
- sheets or fabrics applied by wet lay-up or pre-impregnated (prepreg) surface bonding
- pre-cured bars, small strips or profiles for NSM
- pre-cured tendons or strips for external post-tensioning
- grids, fabrics or technical textiles for TRM

17.2 Provisions for quality control

Non-metallic reinforcement must comply with national or international product standards that specify their geometrical, mechanical and technological properties, such as the international product standards ISO 10406^{[17-3],[17-4]}.

***fib* MC (2020) highlights : Structural assessment**



***fib* MC (2020) highlights : use of information in assessment**

Use of structure-specific information in verification of performance during the assessment of existing structures implemented in fib Model Code

TESTING of materials	TESTING of elements & systems	INSPECTION & MONITORING
<ul style="list-style-type: none">- updating the basic variables related to material characteristics in the assessment model(s)- updating the material behaviour model for the assessment on the resistance side, taking into account the intrinsic variability of material properties and the material behaviour model uncertainties- updating the assessment values of basic variables related to material characteristics in the assessment model, which is the basis for updating of the partial safety factor γ_M for the basic variables related to material characteristics, used in the limit state verifications at the semi-probabilistic level	<ul style="list-style-type: none">- assessing directly the compliance with reliability requirements with regard to the limit state under consideration by proofload testing- assessing directly the compliance with performance requirements under service load and/or structural identification based on diagnostic testing- updating the action effect model for the assessment	

Concluding comments & future outlook

Aspiration : *fib* Model Code for Concrete Structures which is better suited to future demands and the circumstances encountered in the years ahead

fib MC (2020) impact:

- assisting the creation of **sustainable concrete structures (new / adapted / upgraded etc)**
- **including improved technical guidance and providing better tools and techniques for :**
 - **design / execution/ life cycle management** of new concrete structures
 - **assessment / adaptation / alteration** of existing concrete structures incl. structures after interventions
- **educating** the engineering community to master the processes and procedures involved in **performance-based approaches**, in which the standards / specifications will have to play a necessary supporting role

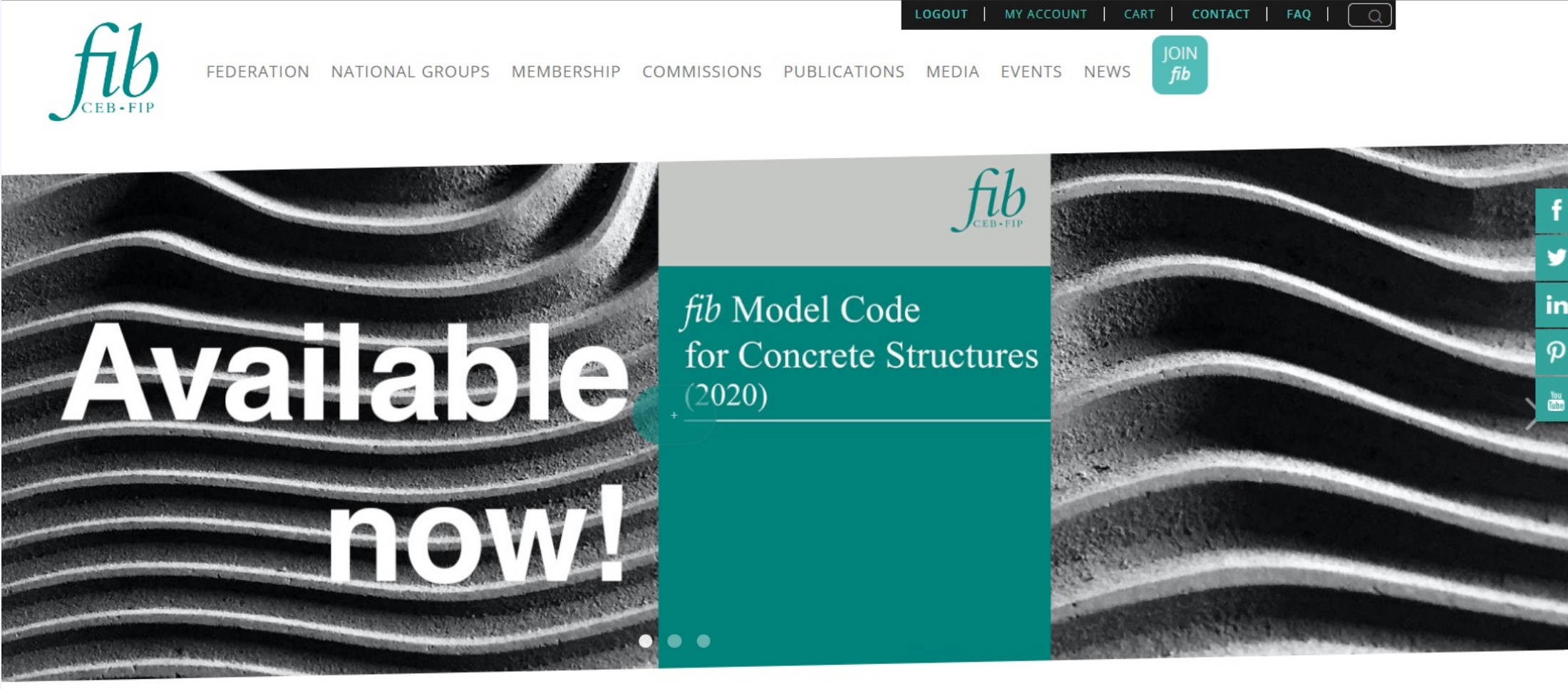
Concluding comments & future outlook

Aspiration : *fib* Model Code for Concrete Structures which is better suited to future demands and the circumstances encountered in the years ahead

***fib* MC future research needs (with potential trigger effect within the JCSS) :**

- **safety philosophy reflecting sustainability objectives (TG.SAG.2)**
- **uncertainty treatment in sustainability-oriented multicriteria decision making (TG.SAG.2)**
- **design optimization incl. e.g. calibration of simplified approaches,..., risk-based design approaches (COM2, COM3)**
- **operational methods for design by testing with innovative materials (TG.SAG.2 incl. COM2, COM3, COM4)**
- **operational methods for design with reclaimed elements (TG.SAG.2 incl. COM2, COM3, COM4)**
- **assessment methods for existing structures - ULS verification under degradation (TG.3.1)**
- **operational methods for assessment of existing structures by proof loading (TG3.2 & IABMAS)**
- **operational methods for SHM and data-informed diagnostics of existing structures (TG3.3)**
- **assessment of existing structures based on past performance of structural element(s) and/or system(s)**
- **uncertainty treatment in modeling of structural performance and durability by data-driven approaches / AI**
- **verification framework for resilience (of concrete structures)**

References



<https://www.fib-international.org/publications/model-codes/model-code-2020.html>

References



fib Model Code 2020 | ENABLING
ADVANCEMENTS FOR NEW AND EXISTING...



fib Model Code 2020 | PERFORMANCE-
BASED APPROACH : WORKING ON THE...



fib Model Code 2020 | SUSTAINABILITY
PERSPECTIVE: CONTRIBUTION OF...



fib Model Code 2020 | VALIDATION OF THE
HARMONIZED PARTIAL FACTOR METHOD...



fib Model Code 2020 | MODELLING
CONCRETE PROPERTIES: NEW...



fib Model Code 2020 | APPROACH TO
ASSESSMENT OF EXISTING STRUCTURES



fib Model Code 2020 | ASSESSMENT OF
EXISTING STRUCTURES : SOLUTIONS AND...



fib Model Code 2020 | DEVELOPMENTS IN
SHEAR & PUNCHING IN MC2020



fib Model Code 2020 | VERIFICATION OF
DURABILITY OF NEW AND EXISTING...



fib Model Code 2020 | MONITORING & DATA
INFORMED APPROACHES FOR THE...



fib Model Code 2020 | CONSERVATION AND
INTERVENTION IN MC2020

<https://www.youtube.com/@fib-international>

References



Table of Contents

- ☐ **Free Access**
Outlook upon fib Model Code for Concrete Structures (2020)
- ☐ Evolution of fib model codes: Mastering challenges and encountering new ones
- ☐ fib Model Code 2020: Enabling advances for new and existing concrete structures
- ☐ **Open Access**
Sustainability perspective in fib MC2020: Contribution of concrete structures to sustainability
- ☐ Performance-based approach in model code 2020: Working on future-oriented standardization
- ☐ Validation of the harmonized partial factor method for design and assessment of concrete structures as proposed for fib model code 2020
- ☐ Verification of durability of new and existing structures through the design, construction and operational phases
- ☐ Approach to assessment of existing structures in the fib Model Code 2020
- ☐ Modeling concrete properties: New approaches in MC2020
- ☐ **Open Access**
The basis for ductility evaluation in SFRC structures in MC2020: An investigation on slabs and shallow beams
- ☐ Assessment of existing structures in fib modelcode 2020: Solutions and examples
- ☐ **Open Access**
Monitoring and data-informed approaches for the assessment of existing structures
- ☐ **Open Access**
A new fib Model Code proposal for a beam-end type bond test
- ☐ Conservation and intervention in MC2020

[https://onlinelibrary.wiley.com/doi/toc/10.1002/\(ISSN\)1751-7648.Model-Code-2020](https://onlinelibrary.wiley.com/doi/toc/10.1002/(ISSN)1751-7648.Model-Code-2020)

Thank you for your attention