JCSS

Joint Committee
on Structural Safety

Workshop on Assessment of Existing Structures

28th and 29th January 2021

Probabilistic Principles Applied in *fib* Model Code 2020

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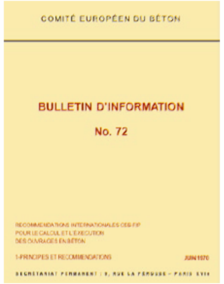
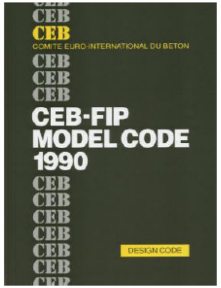
TNO

Evolution of *fib* Model Codes for structural concrete

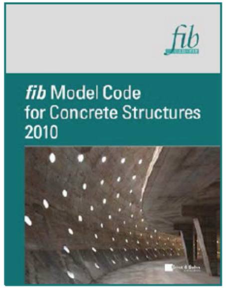


Model Code 1970

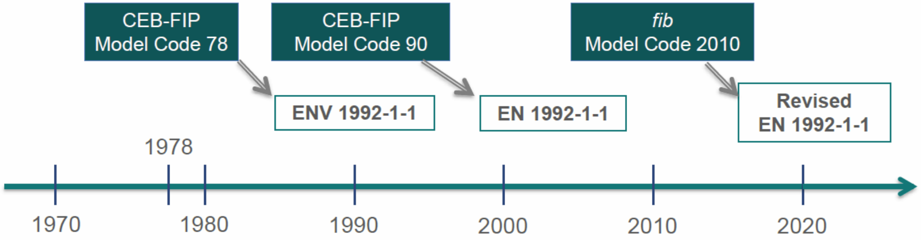
Model Code 1978



Model Code 1990

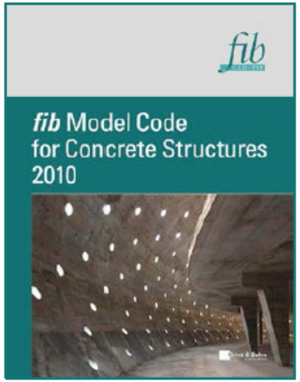


Model Code 2010



Aspiration and challenge *fib* Model Code 2020

- **Scope and basic principles:**
  - **dealing with new and existing concrete structures, and removing constraints for novel types of materials**
  - **reflecting the importance of sustainability and through-life management of structures**
  - **implementing fundamental principles and a safety philosophy based on reliability concepts**
  - **implementing consistent treatment of safety, serviceability, durability by performance-based approach**

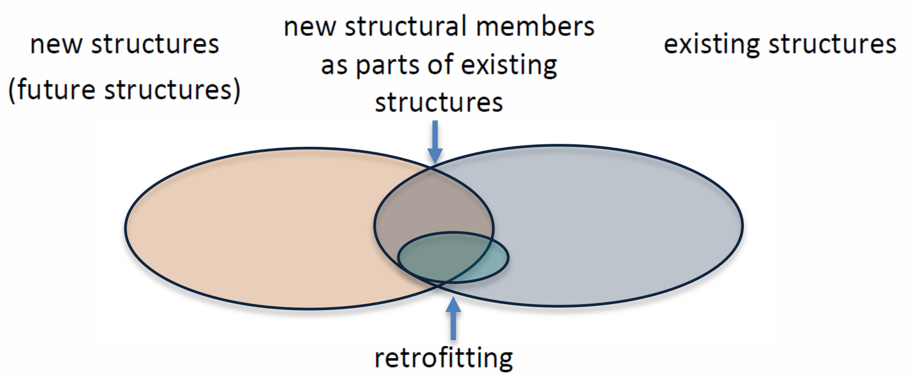


Model Code 2010

fib
Mode Code
2020

Aspiration and challenge *fib* Model Code 2020

- **Scope and basic principles**



New structures and existing structures are not always easy to distinguish (overlap region is very important for engineer's activity)

From *fib* Model Code 2010 to *fib* Model Code 2020

Consistent approach with differentiation to new and existing structures

- **substantial costs of interventions on existing structures in order to increase performance levels**

  adjusted target performance levels in assessment to be considered

- **remaining working life and reference period often smaller than design life of 50 years**

  adjusted reference period in assessment to be considered

- **testing, inspection and monitoring can be done in order to increase Knowledge Level**

  adjusted treatment of uncertainties to be considered

- **adequate structural models for existing (e.g. deteriorated) structures are needed**

  adjusted treatment of uncertainties to be considered

MAJOR CHANGES

From *fib* Model Code 2010 to *fib* Model Code 2020

Consistent approach with differentiation to new and existing structures

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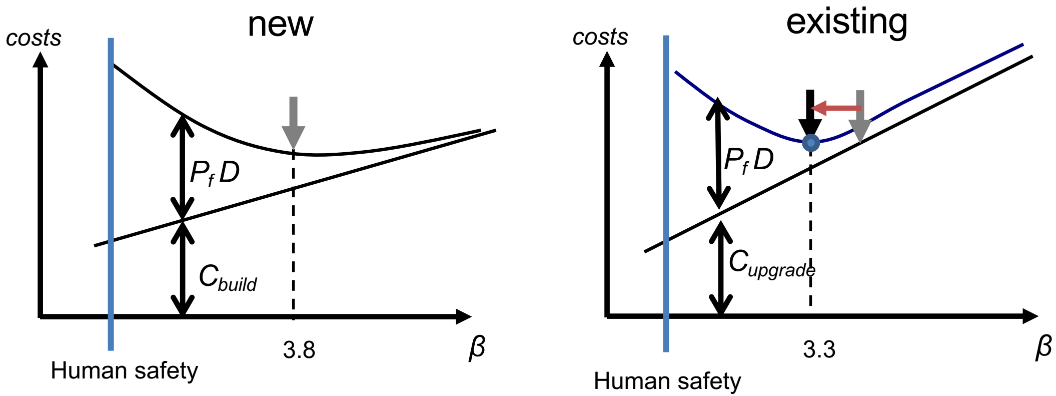
  → adjusted target performance levels in assessment to be considered



From *fib* Model Code 2010 to *fib* Model Code 2020

Model Code 2020 recommends principles of probabilistic structural limit state design with a possibility for differentiating the reliability level:

- β_{new} - level indicating desired reliability for design of new structures
- β_0 - level below which the existing structure is considered unreliable and should be upgraded
- β_{up} - level indicating an optimum upgrade strategy while upgrading of existing structures

Recommended target reliability levels for structural design (ULS)			
Annual target β-values for structures to be designed, based on economic optimisation			
Relative cost of safety measure	Consequence Class		
	CC1	CC2	CC3
Large (A)	3.1	3.3	3.7
Normal (B)	3.7	**4.2**	4.4
Small (C)	4.2	4.4	4.7
Informative target reliability indices β for structures to be designed, related to a 50-year reference period			
Relative cost of safety measure	CC1	CC2	CC3
Normal (B)	3.3	**3.8**	4.3
Recommended annual target reliability levels for assessment of existing structures (ULS)			
Relative cost of safety measure	CC1	CC2	CC3
Large (A)	3.1	3.3	3.7
Recommended target reliability levels for upgrade of existing structures (ULS)			
While slightly lower values can be normally justified for β_{up}-levels in comparison to design target levels, it is common and reasonable to require the compliance with the design levels when upgrading the structure.			

From *fib* Model Code 2010 to *fib* Model Code 2020

Consistent approach with differentiation to new and existing structures

- **substantial costs of interventions on existing structures in order to increase performance levels**

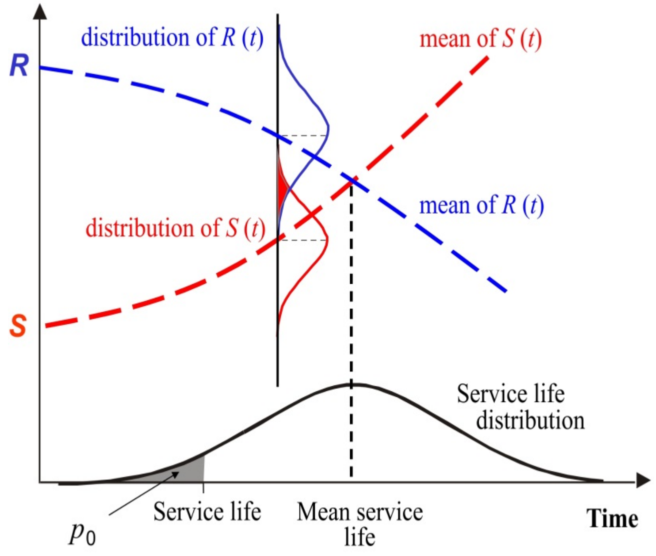
  → **adjusted target performance levels in assessment to be considered**

How to deal with deterioration?

From *fib* Model Code 2010 to *fib* Model Code 2020

Improved approach to assessment of 'actual' capacity

- Performance-based design
  - Ability of a structure to fulfil the performance requirements for the designed service life at required probability level
- Limit state concepts
  - Transition between the desired state and the adverse state
- Incorporation of deterioration effects reducing structural resistance R(t)
- Increase in load effect S(t) with time
- Recognition of resistance effects not accounted for in design (e.g. compressive membrane action)



Decrease in structural resistance R(t) with time & increase in the load effect S(t) with time

Benefit of unaccounted behaviours upon structural resistance and on actual service life

From *fib* Model Code 2010 to *fib* Model Code 2020

Consistent approach to non-deteriorating and deteriorating existing structures

- **Model Code 2020 recommends the performance-based assessment of the remaining service life:**
  - **ultimate limit state or serviceability limit state verification (e.g. in case damage is already existing) using annual target reliability values, corresponding to the target reliability levels. Such verifications take basis in a coupled modelling of the initiation time and propagation time and in the present condition of the structure should take into account:**
    - **the uncertainties typically considered in structural reliability calculations for ULS/SLS (as done for non-degrading structures);**
    - **the uncertainties in relation to the initiation phase modelling;**
    - **the uncertainties in relation to the propagation phase modelling;**
    - **the uncertainties associated with monitoring, inspections and the interpretation of such data, if applied.**

uncertainties can be reduced by updating on the basis of measurements and inspections

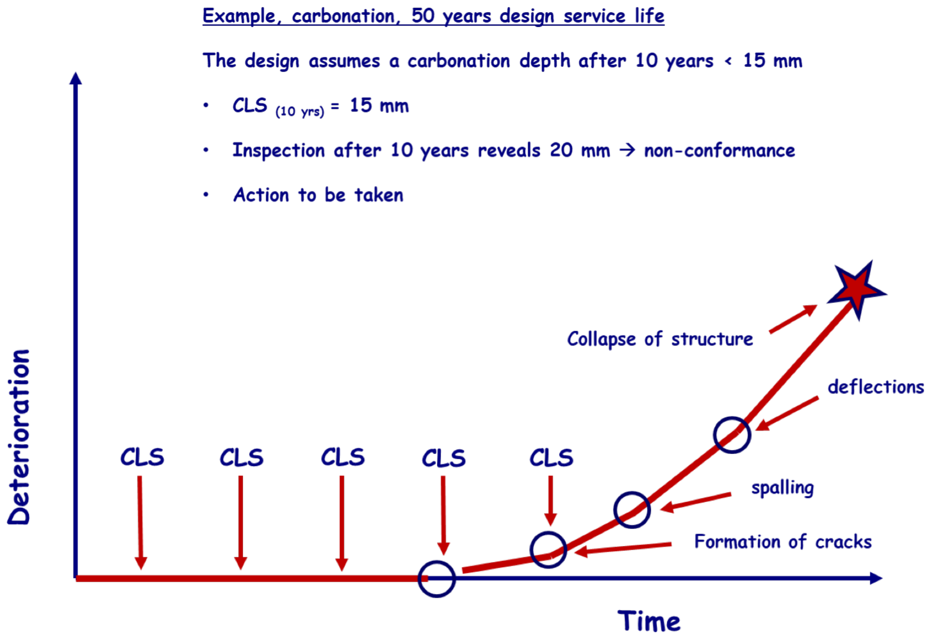
  - **condition limit states verification (e.g. corrosion initiation phase not yet reached). In the case of performance-based assessment of existing structures with respect to durability on the basis of full-probabilistic methods, the same target reliability level for condition limit state associate to durability can be applied as for new structures, unless ULS and/ or SLS verifications or the application of risk-based methods justify a different β level.**

From *fib* Model Code 2010 to *fib* Model Code 2020

Durability considerations in through-life management of structures

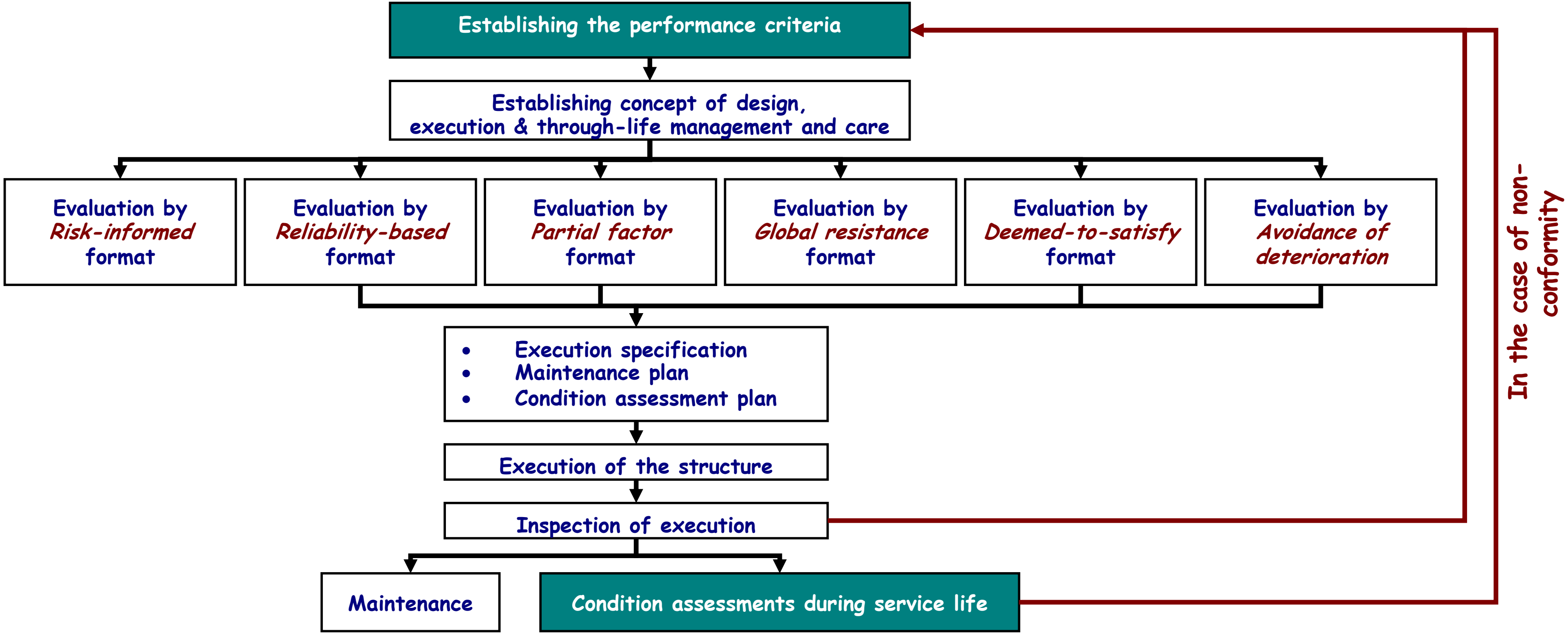
- **Condition Limit States (CLS) to be considered in a Condition Assessment Plan & Maintenance Plan**
- **Condition/damage limitation to be considered in reparability concepts**
- **Condition Limit States (CLS) criteria to be optimized considering economic consequences of damage**

MC2020 includes information on corrosion rate and modelling of corrosion damge, but the possible structural consequences depend on which rebars are affected and the role of these rebars.



From *fib* Model Code 2010 to *fib* Model Code 2020

Testing, inspection and monitoring in order to increase Knowledge Level



From *fib* Model Code 2010 to *fib* Model Code 2020

Consistent approach with differentiation to new and existing structures

- **testing, inspection and monitoring can be done in order to increase Knowledge Level**

  → **adjusted treatment of uncertainties to be considered**

- **Model Code 2020 recommends verification assisted by testing, inspection and monitoring with due consideration of :**
  - Value of information
  - Extent of surveys, testing and monitoring activities
  - Tools and techniques for surveys and monitoring
  - General flow of condition survey process
  - Data evaluation and statistical analysis of the results
  - Updating of performance prediction
    - Consideration of information from (e.g. condition) survey in quantifying governing uncertainties
    - Consideration of past performance as evidence of suitability for future performance
    - <u>Consideration of proof loading of structures as means of conformity evaluation</u>

From *fib* Model Code 2010 to *fib* Model Code 2020

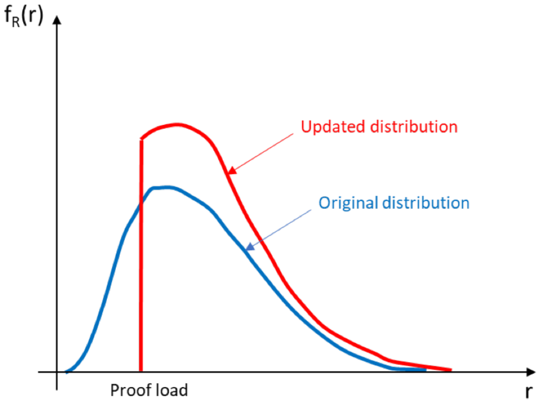
Consistent approach with differentiation to new and existing structures

- **Verification by proof loading**
  - Basic principles
  - Conversion of target limit state to proof load
  - Effect of spatial variability
  - Loading procedure
  - Stop-criteria
  - Acceptance criteria

From *fib* Model Code 2010 to *fib* Model Code 2020

Verification by proof loading to be included in MC2020

- performed to check the ability of the structure to carry a specified variable load (e.g. design loads given in the codes)
- use of results of proof load tests in reliability-based approach to safety assessment:
  - updating of uncertainty on the resistance of the structure based on attained proof load level
  - updating of failure probability



$$P(F|I) = \frac{P(F \cap I)}{P(I)}$$

structural failure

survival of proof load test

Ongoing work:

- definition of <u>target proof load</u> level depending on residual service life, current and future deterioration, etc.
- implementation of proof loading in semi-probabilistic safety assessment as a function of <u>attained proof load level</u>

From *fib* Model Code 2010 to *fib* Model Code 2020

Consistent approach with differentiation to new and existing structures

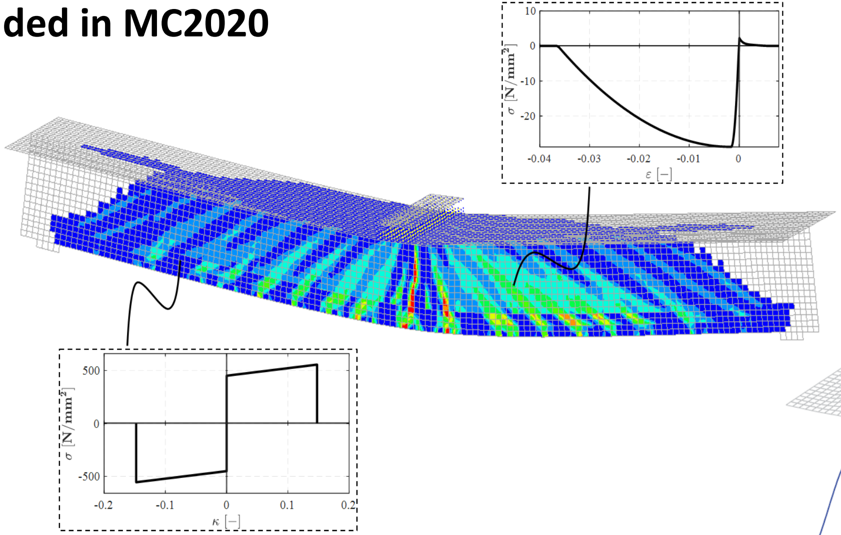
- **adequate structural models for existing (e.g. deteriorated) structures are needed**

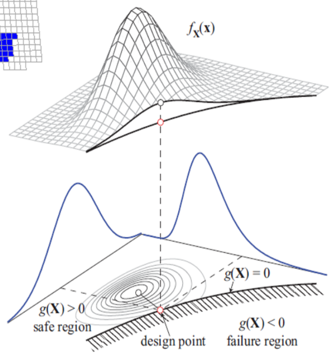
  → **adjusted treatment of uncertainties to be considered**

- **Model Code 2020 recommends verification assisted by NLFEA analysis with due consideration of the need of performing NLFEA** :
  - areas of NLFEA for concrete structures are those where <u>simplified analytical models fail to accurately predict structural resistances</u>, e.g. where non-linear behaviour related to material properties and/or geometry significantly affects structural reliability or where load effects are difficult to assess due to interaction of structural members or dynamic nature of the phenomenon

From *fib* Model Code 2010 to *fib* Model Code 2020

Verification assisted by NLFEA to be included in MC2020





Major challenges :

- Adequacy of estimating the resistance with NLFEA calculations
- Formulating safety formats for compliance check
  - Modelling uncertainties to be used in NLFEA based reliability analyses
  - Treatment of multiple failure modes
- Extending scope of application: static and non-static (seismic, dynamic) conditions, analysis of damaged structures, accounting for progressive deterioration processes

From *fib* Model Code 2010 to *fib* Model Code 2020

Verification assisted by NLFEA to be included in MC2020

Safety formats for estimating the resistance with NLFEA.	
I: Partial Factors Method	$R_{\mathrm{d}} = \dfrac{R_{\mathrm{NLFEA}}(x_{\mathrm{d,NLFEA}})}{\gamma_{\mathrm{Rd}}}$
II: Global Factor Method	$R_{\mathrm{d}} = \dfrac{R_{\mathrm{NLFEA,m}}}{\gamma_{\mathrm{R}}\gamma_{\mathrm{Rd}}}$
III: Sampling-based Method	$P(\theta R_{\mathrm{NLFEA}}(\boldsymbol{x}) \leq R_{\mathrm{d}}) = \Phi(-\alpha_{\mathrm{R}}\beta)$

The modelling uncertainty, which represents the accuracy of the selected solution strategy in predicting the capacity, should be properly accounted for before conclusions are drawn based on the analysis results

* for I & II, the partial factor for modelling uncertainty (γ_{Rd}) should be appropriately assessed or updated.

From *fib* Model Code 2010 to *fib* Model Code 2020

The provisional future programme for work of *fib* TG10.1 and delivery of *fib* MC2020

- **2021: A first draft version of *fib* MC2020 available to TG10.1 for initial review and improvement**
- **2022: A first harmonised version of *fib* MC2020 available as a *fib* Bulletin for Public Review**
- **2023: Final draft of fib MC2020 presented for voting upon by the *fib* General Assembly**

WORK IN PROGRESS

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