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Model Code 2020: A fib Project for the advancement of structural concrete

Código Modelo 2020: Un proyecto fib para el avance del hormigón estructural

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ABSTRACT

Model Code is one of the most important documents produced by fib. Since its first edition in 1970, fib has published editions in 1978, 1990 and recently in 2010. All of these documents have influenced the production of National and Regional Codes. Model Codes 1978 and 1990 had a strong influence on current and previous versions of Eurocode 2. Model Code 2010 similarly guides the preparatory work of CEN for the new editions of Eurocodes. Model Codes are an important reference for researchers, designers and constructors. The new edition, to be published in 2020, intends to approach, at the same level, new and existing structures and present more general and rational models, removing any trace of previous empirical design rules. It will be an operational model code and will be oriented towards practical needs. This paper shows the content of the new Model Code 2020 and the ongoing work for its preparation.

Keywords: Model Code; Structural concrete; Structural design.

RESUMEN

El Código Modelo es uno de los documentos más importantes producidos por fib. Desde su primera edición en 1970, se han publicado ediciones en 1978, 1990 y, recientemente, en 2010. Todos estos documentos han influido en la producción de códigos nacionales y regionales. Los Códigos Modelo de 1978 y 1990 han tenido una gran influencia en las diferentes versiones del Eurocódigo 2. El Código Modelo de 2010 sirve de guía de manera similar al trabajo preparatorio de CEN para las nuevas ediciones de los Eurocódigos. Los Códigos Modelo siempre han sido una referencia importante para investigadores, diseñadores y constructores. La nueva edición del Código Modelo que se publicará en 2020 pretende abordar, al mismo nivel, las estructuras nuevas y existentes y presentar modelos más generales y más racionales, eliminando cualquier rastro de reglas de diseño empírico previas. Será un Código Modelo operativo y orientado a las necesidades prácticas. Este documento muestra el contenido del nuevo Modelo de Código 2020 y el trabajo en curso para su preparación.

Palabras clave: *Código Modelo; Hormigón estructural; Proyecto de estructuras.*

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1. MAIN IDEAS/GOALS OF THE NEW MC 2020

1.1. MC 2020 will be a single, merged structural code for new and existing structures

There were many different approaches for codes to be able to cover existing structures. A good summary of the evolutions of codes for existing structures was presented by Dr Steve Danton (1), at the first workshop to discuss the content of the new MC 2020 held in The Hague in June 2015.

The first approach/generation was to use the codes developed for new structures and apply them to existing structures. The result was not good because it failed to recognise the differences between design and assessment. Typically, the results obtained with this approach were conservative for assessment works, because it did not adequately take into account actual material properties, structural detailing and tolerances.

The second approach/generation was to write codes for existing structures. The result was also not good enough because there were cases of duplication of content, omission of content and it presented problems in the case of interventions (modification of existing structures).

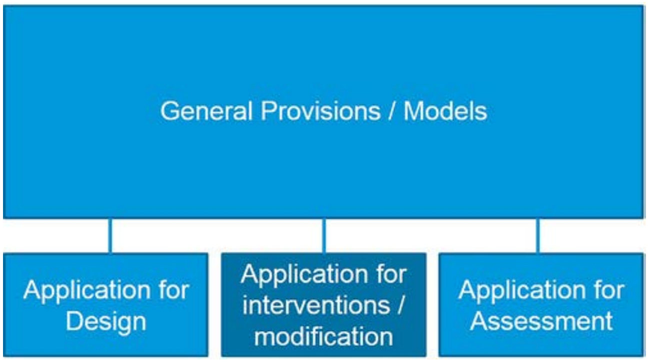


Figure 1. New generation of structural codes for new and existing structures. Figure presented by Dr. Steve Denton at the first workshop on Model Code 2020, held at The Hague on June 2015 (1).

The new approach, and what is often called the new generation of codes, is to develop a single, merged code structural code for both new and existing structures. And this is exactly what we decided to do for the new MC 2020.

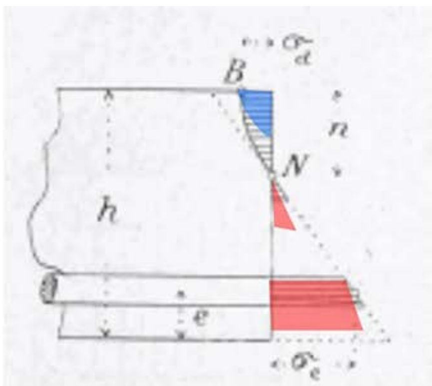
The principles for the development of a unified Model Code will be: General provisions / models common for design, assessment and interventions. Provisions / models have to be general to be applied for the different problems we have to solve. General provisions / models capable of taking into account actual material properties, structural detailing and tolerances that may be found on existing structures (Figure 1).

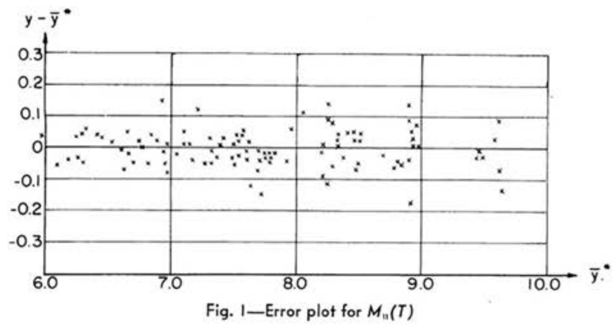
1.2. MC2020 has to present general and more rational models, removing any trace from previous empirical design rules

MC2010 was an important step forward in removing empirical design rules leaving space for general and rational models. This criterion has to be expanded in the new MC 2020.

Figure 2 shows the differences in using a general rational with an empirical rule for bending of a reinforced concrete section.

Ritter proposed in 1899 the model which is still used in fib, see Figure 3 taken from MC 2010. This general approach allows considering: axial force, different cross-section shapes, several reinforcement layers, prestressing, different concrete types, different types of loads (fire, seismic loads, etc.). In addition, the model can be easily adapted to a wide variety of cases (different types of concrete, non-metallic reinforcement, sections subjected to different types of deterioration, etc.). This model may be used to consider the different situ-





$$M_R = 0.431 \cdot b \cdot d^2 \cdot \rho^{0.75} \cdot f_y^{0.9} \cdot f_c^{0.1} \text{ (psi, in)}$$

Ritter, W., 1899, *Die Bauweise Hennebique*, Schweizerische Bauzeitung, Zurich

Courtesy of Aurelio Muttoni

Zsutty T.C., *Ultimate Strength Behaviour Study by* ***Regression Analysis of Beam Test Data***, ACI Structural Journal, May 1963

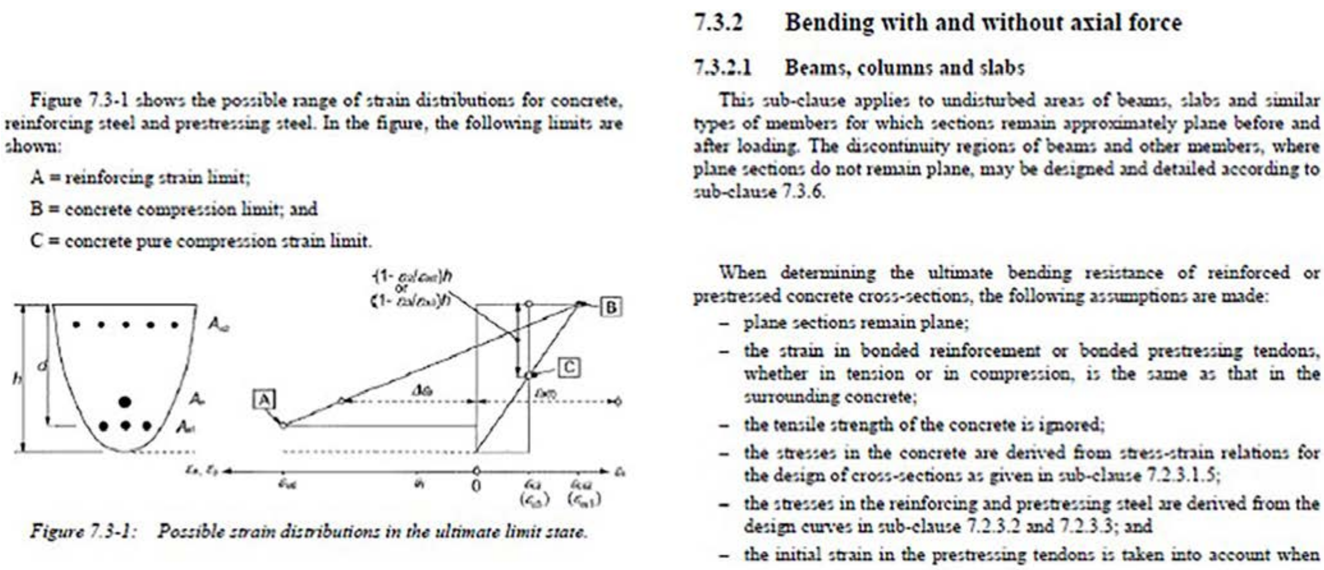
Figure 2. Mechanical models vs. empirical equations, the case of bending. Figure presented by Prof Aurelio Muttoni at the first workshop on Model Code 2020, held at The Hague on June 2015 (2).

ations we have in the design of new structures and in the assessment and interventions in existing structures.

In comparison, the empirical formula proposed by Zsutty in 1963 is only valid for the conditions for which was developed.

Figure 4 shows how the same fib model may be used for assessment of existing structures or for design of new structures or interventions.

The top part of Figure 4 shows different types of concretes that can be found in existing and in new structures, including new


7.3.2 Bending with and without axial force

7.3.2.1 Beams, columns and slabs

This sub-clause applies to undisturbed areas of beams, slabs and similar types of members for which sections remain approximately plane before and after loading. The discontinuity regions of beams and other members, where plane sections do not remain plane, may be designed and detailed according to sub-clause 7.3.6.

Figure 7.3-1 shows the possible range of strain distributions for concrete, reinforcing steel and prestressing steel. In the figure, the following limits are shown:

A = reinforcing strain limit;

B = concrete compression limit; and

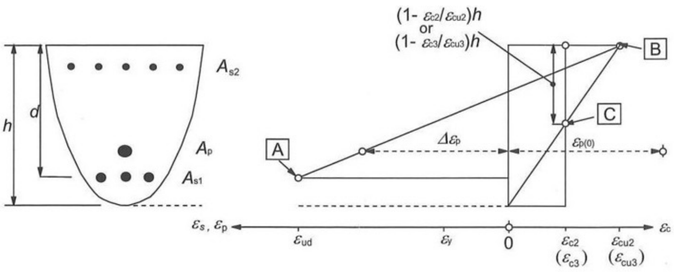
C = concrete pure compression strain limit.

Figure 7.3-1: Possible strain distributions in the ultimate limit state.

When determining the ultimate bending resistance of reinforced or prestressed concrete cross-sections, the following assumptions are made:

- plane sections remain plane;
- the strain in bonded reinforcement or bonded prestressing tendons, whether in tension or in compression, is the same as that in the surrounding concrete;
- the tensile strength of the concrete is ignored;
- the stresses in the concrete are derived from stress-strain relations for the design of cross-sections as given in sub-clause 7.2.3.1.5;
- the stresses in the reinforcing and prestressing steel are derived from the design curves in sub-clause 7.2.3.2 and 7.2.3.3; and
- the initial strain in the prestressing tendons is taken into account when

Figure 3. fib MC 2010 model for bending (3).



UNDAMAGED EXISTING CONCRETE						
fck	17	20	90	120	150	250
DESIGN CONCRETE						
fck	17	20	90	120	150	250
FIBRE REINFORCED CONCRETE (FRC)						
fck	17	20	90	120	150	250
UHPFRC						
fck	17	20	90	120	150	250

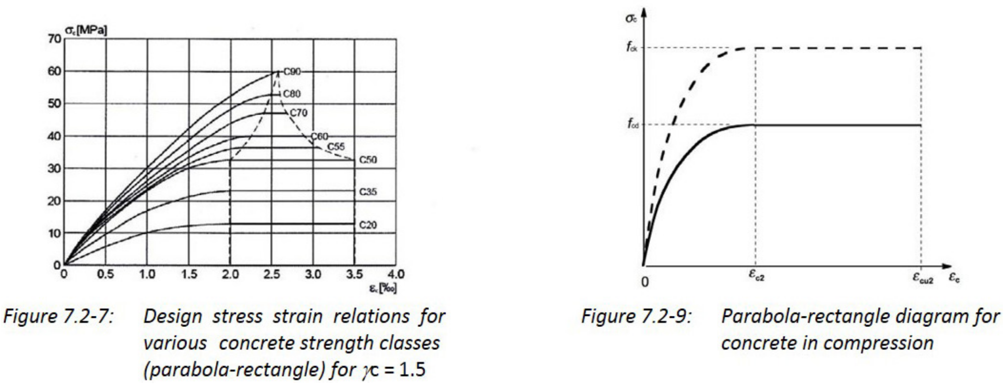


Figure 4. fib Model Code 2010 model for bending extended for assessment of existing structures or for design of new structures or interventions on existing structures. Constitutive equations for concretes with different compressive strengths.

types of concrete: FRC, UHPFRC, Green Concretes, Tailor-made concretes, etc. In order to use the model for all of the different concretes it is only necessary to have the correct constitutive equations for the different cases. The bottom part of the figure shows the constitutive equations currently available in MC 2010 for concretes with different compressive strengths.

MC 2010 was drafted to take into account different types of actions, in addition to static actions, such as for example, seismic actions, fire and many others. This same philosophy was preserved in MC 2020, adopting models, like the one shown in Figure 4, where different types of actions can be represented only by considering the pertinent constitutive equations. Figure 5 shows the constitutive equations proposed by MC 2010 to represent the behavior of confined concrete for seismic actions, or concrete subjected to different temperatures, to consider the influence of fire.

The assessment of existing structure requires setting forth criteria to estimate representative characteristics of concrete. Thus, we must define the right experimental test campaign in order to obtain results that are actually representative of the structure.

Likewise, we also need more and better models, than the ones currently available in MC 2010, in order to represent the effect of different types of deteriorations in the bearing capacity of concrete.

In the case of reinforcing and prestressing steel it is possible setting forth constitutive equations that represent the situations found in the assessment, design and intervention of structure, both for static actions and other actions that may be found in the structures. In fact, MC 2010 has already established many of these equations, see Figures 6 and 7.

The same model can be used to represent non-metallic reinforcement, used lately in new structures and in retrofitting existing structures (Figure 8). For this type of material it will be necessary to revise the safety formats in order to define material safety factors that take into account the brittleness of these materials as well as other specific uncertainties.

The same fib model for normal stresses is capable of estimating the resistance of a reinforced section. In this case, it is necessary to elaborate a system to represent the tensional state in section under the loads, generally permanent loads, applied prior to the design forces. This can be materialized with a preliminary strain in all of the materials of the cross-section. Afterwards, taking into account the initial stress state, additional factored loads can be applied to the structure for a given combination.

Figure 9 shows a cross-section a) with dimensions of 0.30x0.50 and C25 concrete and 4 rebars with a diameter of 16 mm of B500B steel and a cover of 0.05 m. It also shows b) the section affected by a corrosion process of the reinforcing steel, showing how the concrete cover was lost as well as 80% of the original rebar area. Finally, it shows c) a section where the concrete cover was replaced and a steel plate with dimensions of 200x20 mm2 was added.

The original section had ULS strength of 142 kNm, as shown in Figure 10. The damaged section has ULS strength of 117 kNm, as shown in Figure 11. It is clear that the resisting capacity of the structure was reduced. Figure 12 shows the tensional state of the damaged section for permanent load forces. Finally, Figure 13 shows the ULS strength of the reinforced section, considering a preliminary deformation that corresponds to the permanent load forces on section b). The efficiency of the reinforcement can be strongly conditioned by the tensional state of the section prior the application of the reinforcement as well as its corresponding design loads.

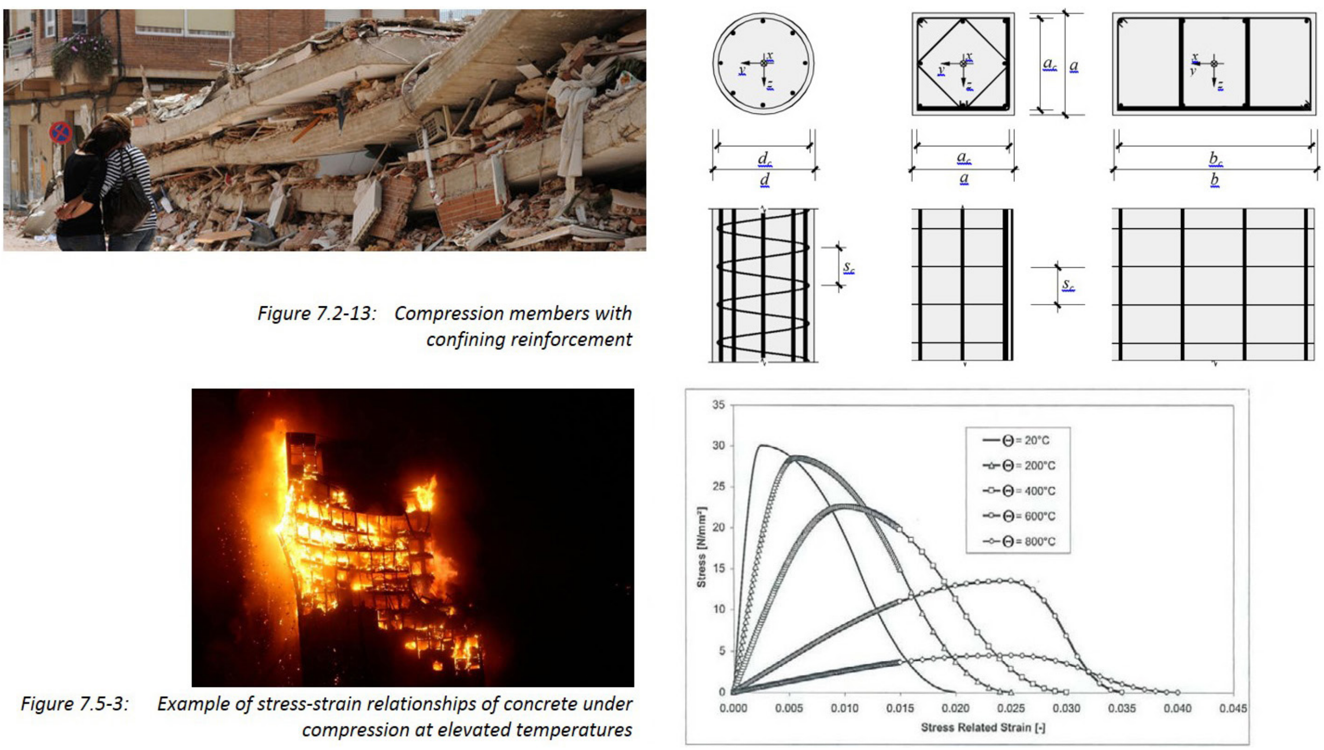
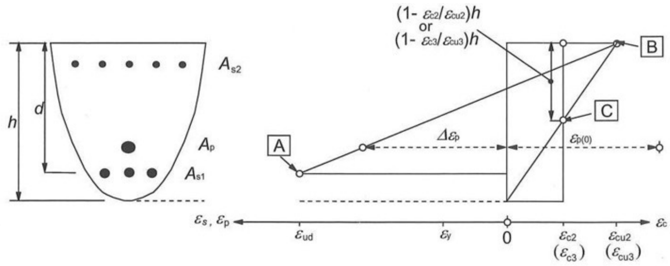


Figure 5. fib Model Code 2010 model for bending extended for the assessment of existing structures or for the design of new structures or interventions on existing structures. Constitutive equations for confined concrete and concrete subjected to different temperatures.



	EXISTING REINFORCING STEEL	
fyd	200	600

	REINFORCING STEEL	
fyd	400	600

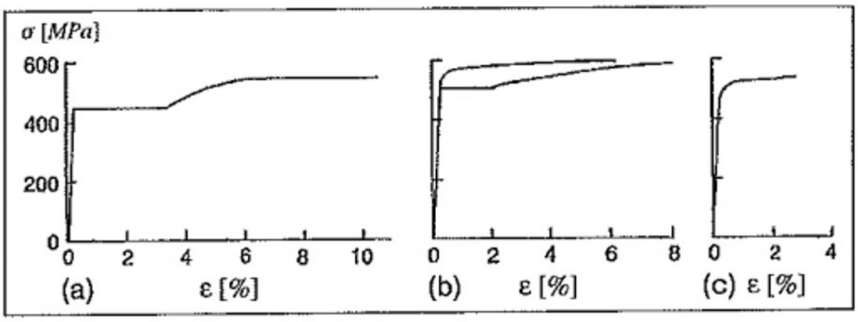
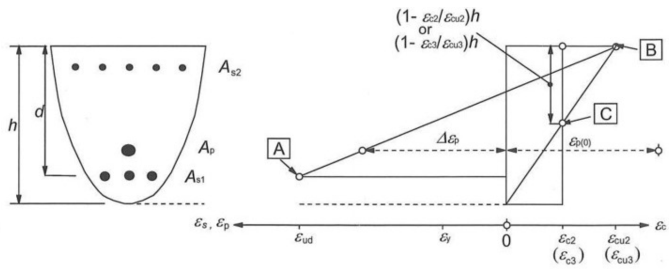


Figure 5.2-1: Stress-strain relationships of reinforcing steel: (a) hot-rolled bars; heat-treated bard; micro-alloyed bars, (b) low carbon, heat-treated bars (lower curve): cold-worked bars (upper curve); (c) cold-worked wires.

Figure 6. fib MC 2010 model for bending extended for assessment of existing structures or for design of new structures or interventions on existing structures. Constitutive equations for reinforcing steel.



	EXISTING PRESTRESSING STEEL		
fyp	1700	2000	2500

	PRESTRESSING STEEL		
fyp	1700	2000	2500

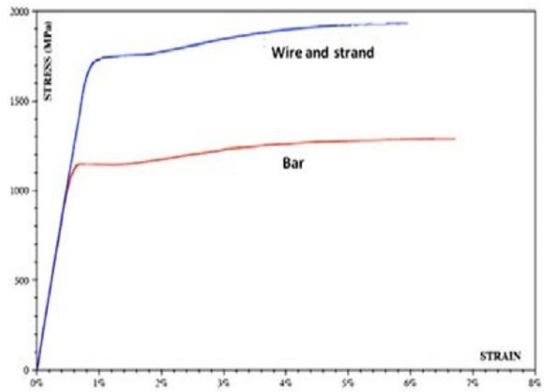
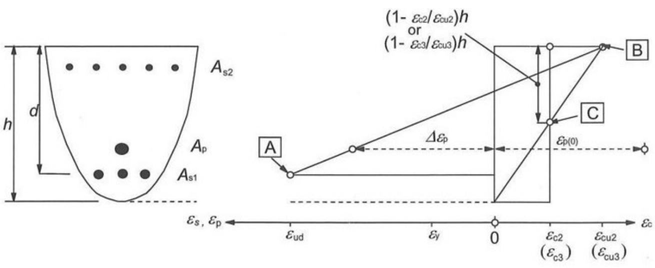


Figure 5.3-1: Typical stress-strain diagrams for prestressing steel

Figure 7. fib MC 2010 model for bending extended for assessment of existing structures or for design of new structures or interventions on existing structures. Constitutive equations for prestressing steel.



NON-METALLIC REINFORCEMENT / FRP

fck	1000	2500

	CFRP	GFRP	AFRP
Tensile strength f_f [MPa]	600-3000	400-1600	600-2500
Modulus of elasticity E_f [GPa]	80-500	30-60	30-125
Ultimate strain ε_{fu} [%]	0.5-1.8	1.2-3.7	1.8-4.0

Table 5.5-1: Tensile properties of FRP reinforcement

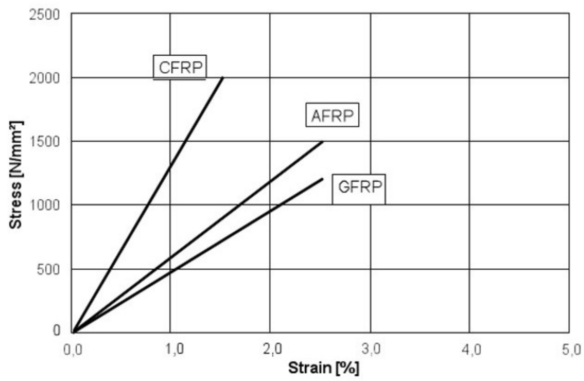
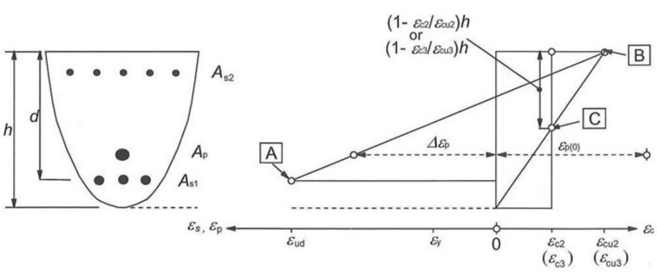


Figure 5.5-1: Stress-strain diagram of non-metallic reinforcement in the principal fibre direction



NON-METALLIC REINFORCEMENT / FRP

fck	1000	2500

Figure 8. fib MC 2010 model for bending extended for assessment of existing structures or for design of new structures or interventions on existing structures. Use of non-metallic reinforcement.

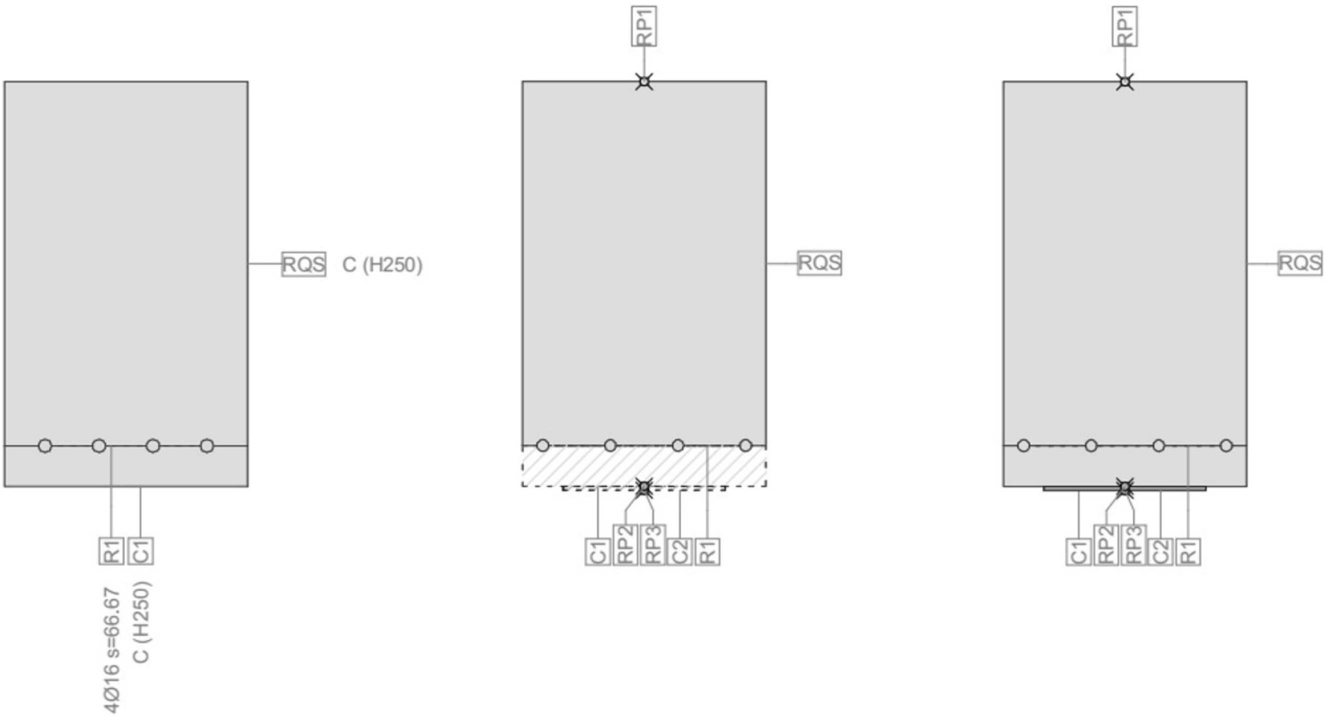
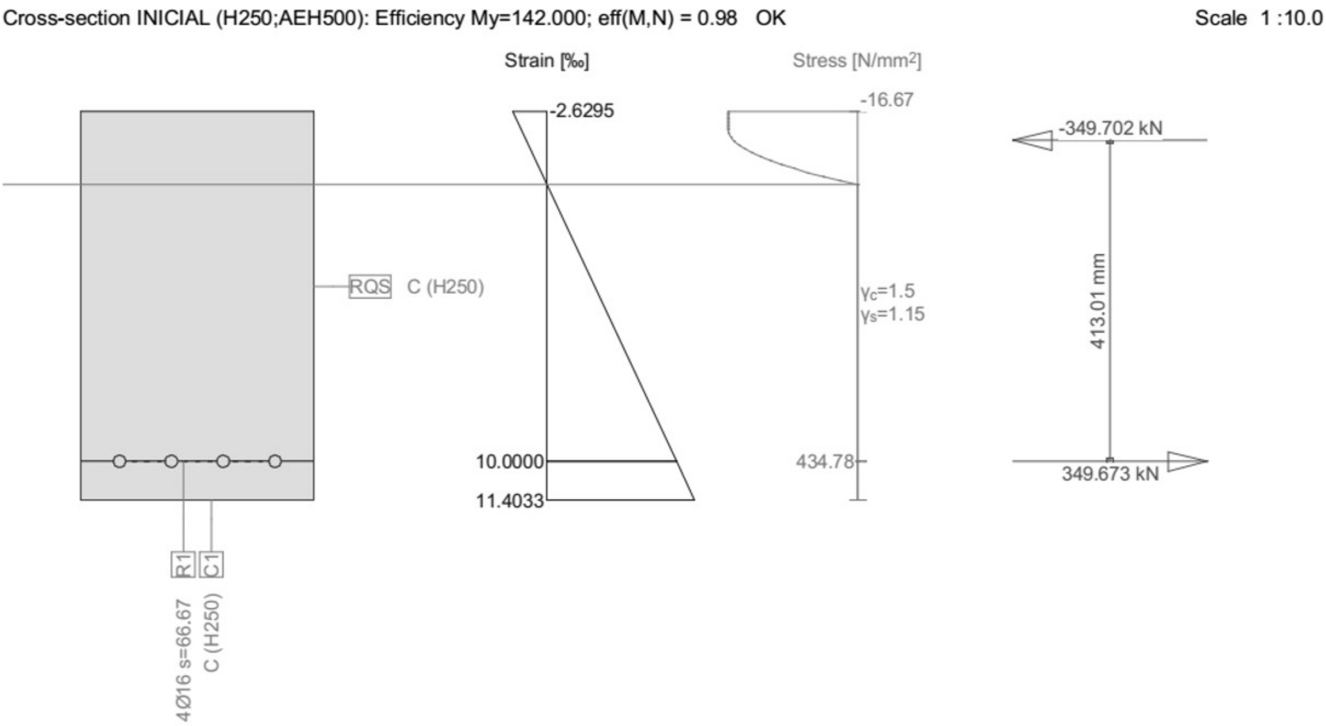


Figure 9. a) Original cross-section design b) Deteriorated cross-section, for a reinforcing steel corrosion process. C) Reinforced cross-section, where the part of the missing cover was replaced and a steel plate was added to the bottom face.

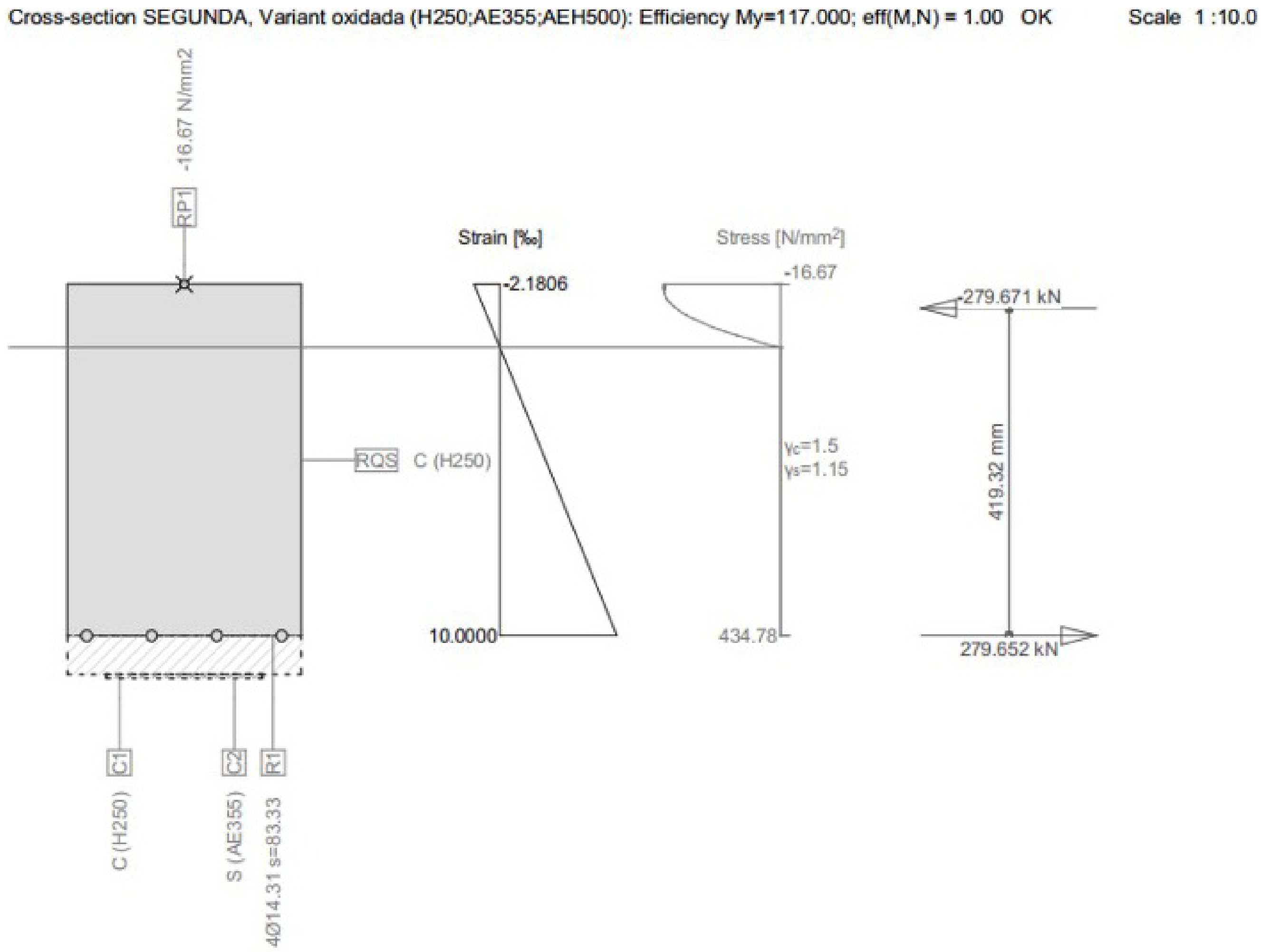


Action forces / Efficiency: eff(M,N) = 0.98 OK

No.	AP	P	Bending and axial force N [kN]	M_y [kNm]	M_z [kNm]	eff(M,N) [-]	Shear forces and torsion V_y [kN]	V_z [kN]	T [kNm]	eff(V,T) [-]	Complete CS eff(M,N,V,T) [-]
1	AP4		0	142.000	-	0.98					

- : Calculation with uniaxial bending (neutral axis is horizontal)!!

Figure 10. ULS strength of the original design of the cross-section.



Action forces / Efficiency: eff(M,N) = 1.00 OK

No.	AP	P	Bending and axial force N [kN]	M_y [kNm]	M_z [kNm]	eff(M,N) [-]	Shear forces and torsion V_y [kN]	V_z [kN]	T [kNm]	eff(V,T) [-]	Complete CS eff(M,N,V,T) [-]
1	AP4		0	117.000	-	1.00					

- : Calculation with uniaxial bending (neutral axis is horizontal)!!

Figure 11. ULS strength of the cross-section after it was damaged by corrosion.

The fib model for normal stresses is capable of taking into account all of the different situations that occur in a section for the design of a new structure, for the assessment of an existing structure and for the evaluation of the bearing strength of possible interventions.

Nevertheless, it will be necessary in the new MC 2020 to adequately describe the process to take into account the tensional state of the section before considering the designed reinforcement.

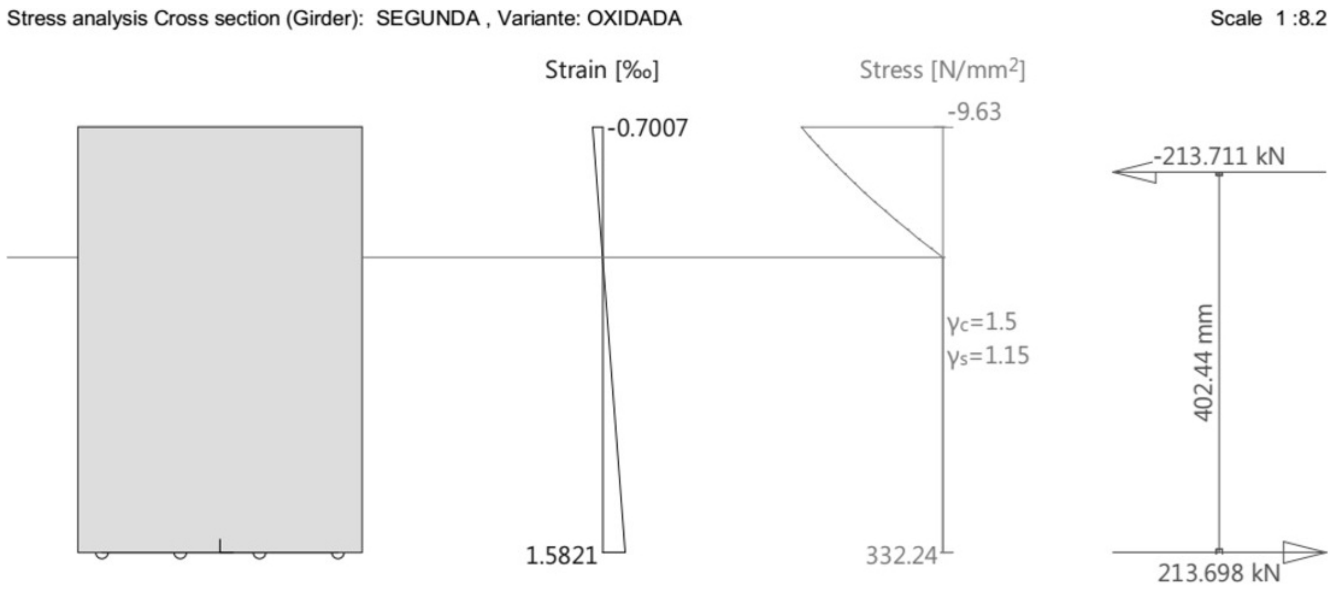
It will also be necessary to clarify how to deal with the ULS safety of the loads on the structure, generally, permanent loads, before the application of the reinforcement. For new structures, load factors are applied at once because, in this case, the initial deformations are not taken into account. For reinforcements and retrofitting of existing structures, we first take into account the tensional state under the loads that act prior the execution of the reinforcement, possibly with characteristics values and, afterwards, at the ULS, these loads will be considered with their corresponding safety factor, which was not considered at the initial state.

The analysis proposed in this paper corresponds to normal stress models. It is still necessary to carry out a detailed work to adapt the available models for other forces such as shear, punching shear and torsion, in order for these models to consider all of the situations described above.

1.3. Model Code 2020 will be an operational model code and oriented towards practical needs

The evolution of codes has grown in content and pages see Figure 14. In addition, modern codes generate the false impression that all problems in structural engineering are solved, when it is manifestly evident that each time that we face a structural engineering problem we show how little we really know and how much we need to research, see Figure 15. Research is an ever-increasing field in structural concrete but it is often not focused on practical problems.

The new MC 2020 must be an example of trend change. How to solve this enormous challenge?

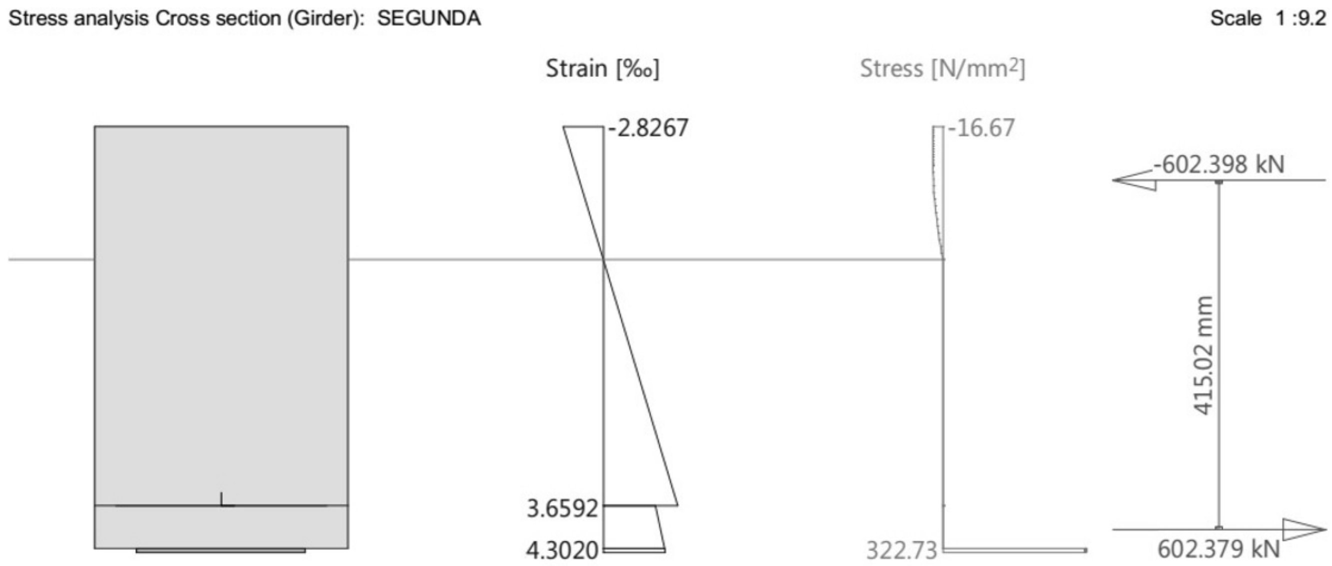


Action forces / Loading history - calculation with loading steps, (in-)active parts,

No.	AP	P	Bending and axial force N [kN]	Bending and axial force M_y [kNm]	Bending and axial force M_z [kNm]	Shear forces and torsion V_y [kN]	Shear forces and torsion V_z [kN]	Shear forces and torsion T [kNm]	Remarks -
1									Set inactiv
2	AP4		0	86.000	0				

1 : Set inactiv: C2,C1

Figure 12. Tensional state of the cross-section subjected to the bending moment that corresponds to the permanent load.



Action forces / Loading history - calculation with loading steps, (in-)active parts,

No.	AP	P	Bending and axial force N [kN]	Bending and axial force M_y [kNm]	Bending and axial force M_z [kNm]	Shear forces and torsion V_y [kN]	Shear forces and torsion V_z [kN]	Shear forces and torsion T [kNm]	Remarks -
1									Set inactiv
2	AP4		0	86.000	-				
3									Set activ
4	AP4		0	164.000	-				

Figure 13. ULS strength of the reinforced section, considering the tensional state of the cross-section for permanent loads, prior the reinforcement installation.

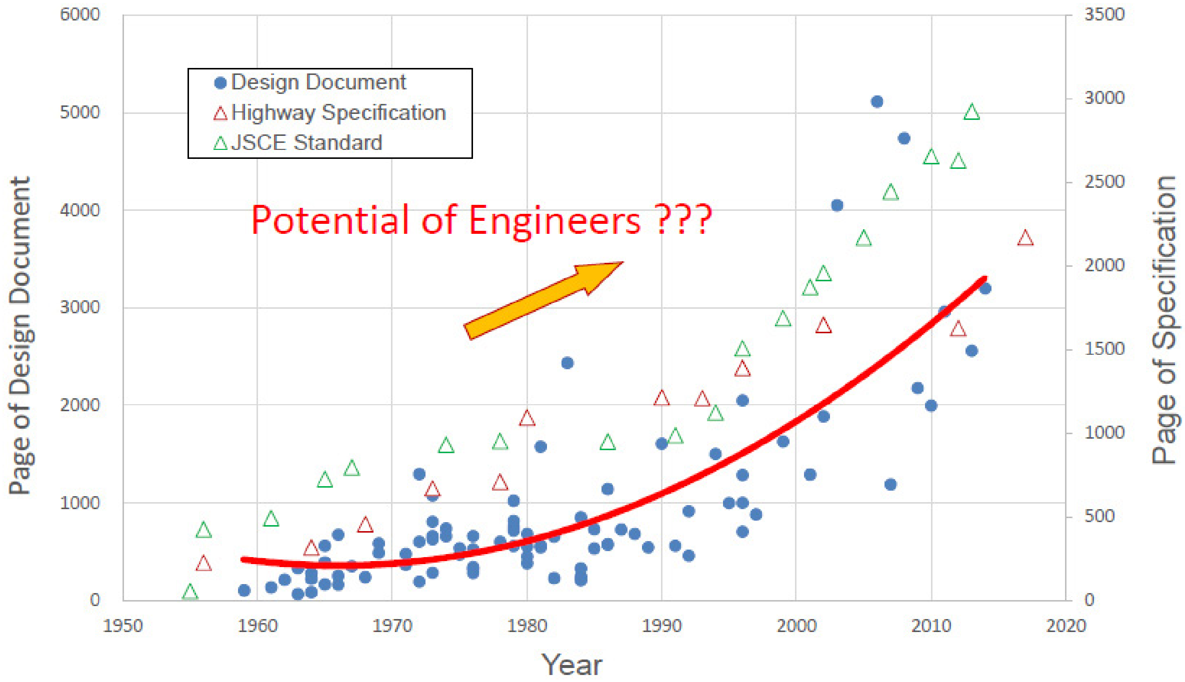


Figure 14. Evolution of the number of pages of Design Documents, Highways Specifications and JSCE Standars over time. Courtesy of Dr Akio Kasuga (5).

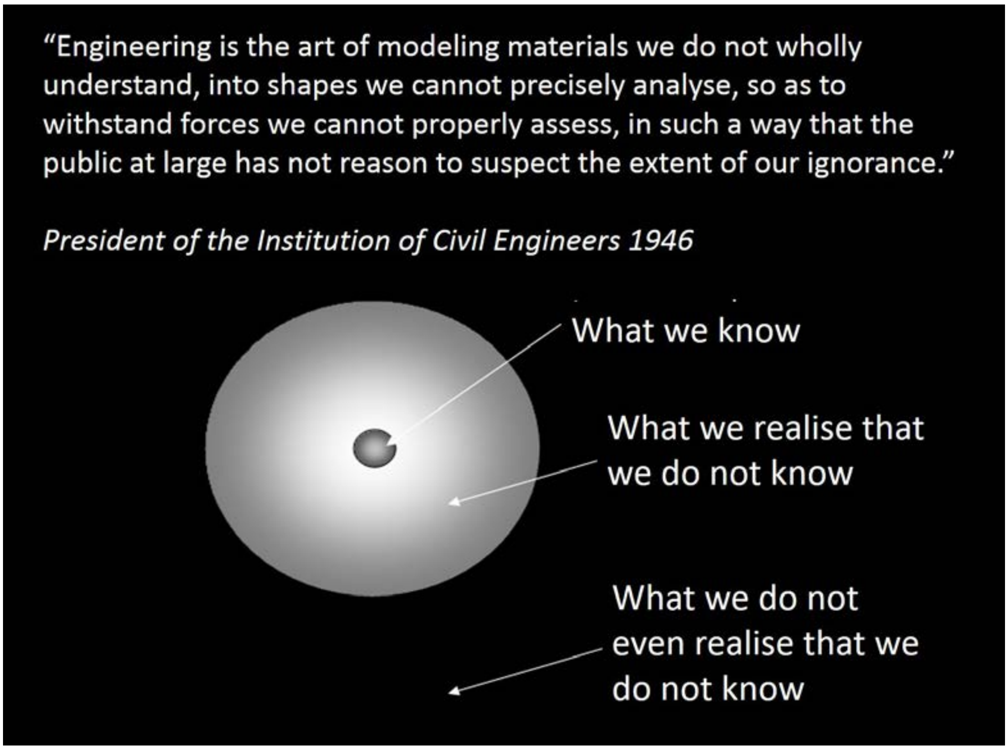


Figure 15. Words of the president of the Institution of Civil Engineers in England in 1949.

Traditionally, MC's have been drafted using the right part for principles and application rules and the left part for comments. The rules must be clear, general and coherent with the content in other parts of the document. The comments should be very specific and above all, referenced to other documents that support the proposed rules and even that show more specific application aspects of these rules. It has always been desired for the models and rules in Model Codes to be explained in background documents. The current goal is to publish the background documents in the bulletings, as in the recent Bulletin 80 (4) on safety formats for existing structures, or in the Structural Concrete Journal of the fib. All effort on this matter will save explanations in the code text and it will help for a better comprehension of the considered principles and rules.

The new MC 2020 has the ambition to have indications on what is currently unknown and therefore is susceptible to be studied. It is possible that this document can also help to coordinate research efforts towards necessary subjects.

MC 2010 introduced the concept of different approximation levels. This a very intelligent way to use complex models with different approximation levels to allow the use of the same conceptual base and, depending on the required precision level, the use of simplifications in determined initial design levels or the total capacity of the models when the problem requires it, see Figure 16.

1.4. Model Code 2020 will recognize the needs of engineering communities around the world. MC 2020 has to be a real International Code

From an open perspective there is no justification that structural engineering can be so different from some countries to others. Although, it is acceptable to think that there may be different environmental, or action or specific constraints in each region.

In reality there are very different problems to solve, very different traditions to solve them and very distinct social and economic conditions to approach them.

The fib the International Federation for Structural Concrete has set forth the need to collect information on this diversity and gather information on the needs of different regions. Therefore, it has programmed workshops in different continents that present the evolution of MC 2020 at the same time that local experts in different areas present their respective points of view and specific needs (Figure 17). This labor results in a more international character of the new MC 2020.

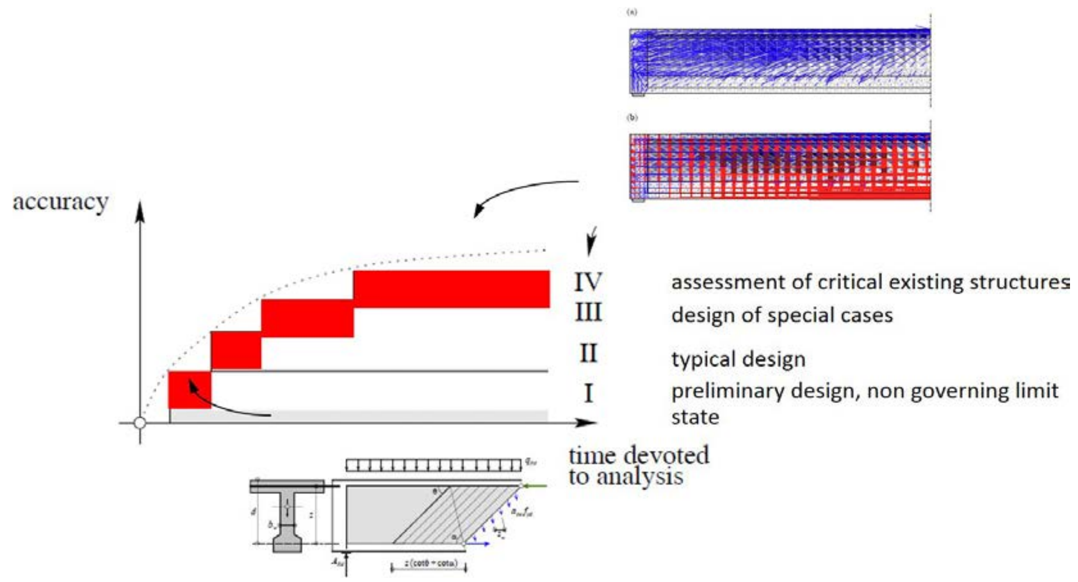


Figure 16. Different levels of Aproximations. Figure presented by Prof Aurelio Muttoni at the first workshop on Model Code 2020, held at The Hague on June 2015 (2).

Figure 17. fib Model Code 2020 Workshops in different continents.

2. FINAL CONSIDERATIONS

The new version of MC 2020 has a solid starting point, MC 2010. It is a thorough document that shows many of the ideas that are needed in the new version and only require more or less development.

There has been a great discussion on what was needed for the future. The established criteria promise a MC 2020 that without a doubt will become a major reference in the future of structural engineer, just as it has happened with the previous versions. A MC for new and existing structures that aims for a single and consistent approach of problems. A MC that proposes, depending on the available knowledge, general and physical models that can be used indistinctly for new and existing structures. A MC that is practice-oriented. Finally, an international MC that represents the aspirations of fib that really is an international association formed by 45 countries from all of the continents.

It must a document that shows a new trend in the preparation of codes that has gradually become overwhelming.

The new MC must, in addition, serve to identify different fields where current knowledge is insufficient in order to, as much as possible, lead research in the direction where it is most needed.

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