Disponible en **www.hormigonyacero.com**
Hormigón y Acero 2023; 74(299-300):7-18
https://doi.org/10.33586/hya.2023.3115

The Origins and Some Highlights on the New Proposal for Eurocode 2

Los orígenes y algunos aspectos destacados en la nueva propuesta del Eurocódigo 2

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Recibido el 14 de noviembre de 2022; aceptado el 7 de febrero de 2023

ABSTRACT

This paper presents a summary of the Eurocode development procedures which began in the last two decades of the 20th century, with some emphasis in the Eurocode 2 on concrete structures. Besides, a general scope of the technical content of the new proposal for Eurocode 2 is commented and the main changes are highlighted.

KEYWORDS: Eurocodes, concrete structures, mandates, compressive concrete strength.

RESUMEN

Este artículo presenta un resumen de los procedimientos para la preparación de los Eurocódigos, trabajo que se inició en las últimas dos décadas del Siglo XX, con especial énfasis en el Eurocódigo 2 de estructuras de hormigón. Asimismo, se comenta el alcance de la nueva propuesta para el Eurocódigo 2, destacándose los cambios más relevantes.

PALABRAS CLAVE: Eurocódigos, estructuras de hormigón, mandatos, resistencia del hormigón a compresión.

1. INTRODUCTION

1.1. Origins and history

The Eurocodes have been developed to enable the design of structural construction works (building and civil engineering works) in order to comply with the Essential Requirement No.1 (mechanical resistance and stability) and partially Essential Requirements No.2 (safety in case of fire) and No.4 (safety in use), and to determine the performance of structural construction products.

In 1975, the Commission of the European Community decided to launch an action program in the field of construction, based on article 95 of the Treaty. The objective of the program was the elimination of the technical barriers to trade and the harmonization of construction-related technical specifications among the Member States. Within this programme, the Commission took the initiative to establish a set of harmonized technical rules for the structural design of construction works, which, in a first level, would serve as an alternative to the national regulations in the Member States and, finally, would replace them.

For fifteen years, the Commission, with the help of a Management Committee made up of representatives of the Member States, managed the development of the Eurocode Program and the publication of an experimental version of these European standards in the 1980s.

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How to cite this article: Arrieta, J.M., Rodríguez, J., & Ganz, H.R. (2023) The Origins and Some Highlights on the New Proposal for Eurocode 2, *Hormigón y Acero* 74(299-300):7-18, https://doi.org/10.33586/hya.2023.3115

In 1989, the Commission and the Member States decided to transfer to the European Committee for Standardization (CEN), the preparation and publication of the Eurocodes through a Mandate, by which in the future the Eurocodes would acquire the status of European standards (EN).

Originally, the Eurocodes were developed by CEN as 62 experimental European standards (ENV). Most of them were published between 1992 and 1998 but, due to the difficulties in harmonizing all aspects in the calculation methods, the ENV versions of the Eurocodes included "box values" for some parameters that allowed Member States to choose different values in their territories. The values that each Member State adopted were collected in the so-called "National Application Documents (NAD)", which allowed the application of the ENV Eurocodes in each Member State.

In 1998, CEN began the conversion of the ENV Eurocodes (experimental standards) to European Standards EN (first generation), in accordance with Mandate 265. In this conversion process, the national comments to experimental ENV standards, input and suggestions from users and editorial inconsistencies and, finally, the elimination or minimization of the "box values" were considered. In principle, the conversion was not intended to include significant alterations to the technical content, unless necessary for security reasons. The publication of the different parts of the EN Eurocodes, has taken place between 2002 and 2007.

The EN Eurocodes have been published by the National Standardization Bodies (NSB), which participate in the program developed by CEN (in the Spanish case, the Spanish Association for Standardization UNE), in their own language, and have been made up of the technical text of the Eurocode itself and a National Annex (NA). This National Annex contains the "Nationally Determined Parameters" (equivalent to the "box values" of the "National Application Documents"), the specific geographic and climatic data of the Member State and a reference to the national regulations dealing with the matter. The final pursued objective is the implementation and use of the EN Eurocodes in the Member States.

The technical aspects from the Eurocodes are both considered by the Technical Committees of CEN/TC250 and others responsible for Product Standards, for the purpose of achieving full compatibility between product specifications and EN Eurocodes.

Currently, within the Eurocodes programme, the following ten Eurocodes have been developed:

Eurocode 0	EN 1990: Basis of Structural Design [1]
Eurocode 1	EN 1991: Actions on structures [2]
Eurocode 2	EN 1992: Design of concrete structures [3]
Eurocode 3	EN 1993: Design of steel structures [4]
Eurocode 4	EN 1994: Design of composite steel and concrete structures [5]
Eurocode 5	EN 1995: Design of timber structures [6]
Eurocode 6	EN 1996: Design of masonry structures [7]
Eurocode 7	EN 1997: Geotechnical design [8]
Eurocode 8	EN 1998: Design of structures for earthquake resistance [9]
Eurocode 9	EN 1999: Design of aluminium structures [10]

Each Eurocode, except Eurocode 0 [1], is made up of a certain number of parts (58), which have been published as European Standards EN by June 2007. Most of these parts already existed as experimental standards (ENV).

1.2. Eurocode system: documents and committees

It has previously been indicated that CEN (European Committee for Standardization) is the body in charge of European standardization work. CEN is structured in several Technical Committees, with Committee CEN/TC250 "Structural Eurocodes" in charge of the development of all Eurocodes. This Committee, in turn, is made up of independent subcommittees for working on each specific Eurocode (for example, the CEN/TC250/SC2 Subcommittee "Design of Concrete Structures", is the one that deals with the Eurocode 2). Within these subcommittees, the work of drafting and reviewing the draft standards is developed by Working Groups made up of experts, who represent the different countries, and Project Teams made up of a set of experts contracted under the Mandate.

At the national level, the National Standardization Bodies participating in the program of Eurocodes are configured in a parallel and interrelated organization with CEN. In Spain, the UNE Committee mirroring CEN/TC250 is the Technical Committee for Standardization UNE/CTN 140 "Eurocódigos estructurales". The president and the secretary of this Committee attend the meetings of the Committee CEN/TC250 as national representatives.

UNE/CTN 140 Committee also has a series of Subcommittees that deal with the follow-up of a specific Eurocode (for example, UNE/CTN 140 subcommittee dealing with Eurocode 2 is the subcommittee UNE/CTN 140/SC2). Membership in any of these subcommittees is based only on the expertise. The chairs and secretaries of each of these subcommittees are members of the corresponding CEN subcommittees, whose meetings they attend as national representatives. As an example, at the spanish level, the Mirror Group UNE CTN140/SC2 met regularly during the last 10-12 years with about 30 members to follow up the progress in the preparation of the new version of Eurocode 2 and several experts participated in Project Teams and Working Groups of TC250/SC2.

The activities that take place within them, include tasks as varied as:

- Attendance at European meetings as a national representative and/or expert.
- Participation in European working groups focused on the analysis of some part of the Eurocodes, developing the drafts and generating proposals.
- Participation in national working groups focused on the analysis of some part of the Eurocodes, reviewing the drafts generated by the European Subcommittees and proposing alternatives and modifications to them.
- Holding conferences for the presentation and dissemination of the new regulations.
- Translation of the Eurocodes into the national language.
- Carrying out calibration studies to check the applicability of the standard, or to find out the differences between the new standards and the old ones.
- Preparation of manuals and guides that ease the application of Eurocodes by technicians, preparation of comput-

er developments, dissemination in technical schools, etc.
The final draft of a part of Eurocode is generated as follows:

- First, the National Standardization Bodies nominate the experts who are going to constitute the Working Groups and the responsible CEN Subcommittee selects the members of the Project Teams in charge of the conversion of a part of a Eurocode. In the composition of these groups, the expertise of members essentially prevails.
- These groups thus constituted, begin their conversion work of the European standard. Experts in working groups prepare technical input which is then considered and integrated by the Project Team into drafts of the revised standard. In addition, the CEN Subcommittee is informed about the development of the work, gives strategic guidance and takes decisions.
- In parallel the new documents are analysed and discussed in the National Subcommittees (Mirror Groups) to generate comments and proposals, that are sent and discussed in the European Subcommittees by the national representatives. The work is developed based on successive drafts, which are modified considering the comments and suggestions of the Member States, until an acceptable-to-all final draft is reached.
- Once the final draft of an EN Eurocode is available, it is sent by CEN for Enquiry to the National Subcommittees (NSBs) which have a period to review it and send comments. The European Subcommittee considers the national comments, modifies the document which is sent to CEN for the Formal Vote (FV). As the documents are drawn up in English, they must be translated into the two other official CEN languages (French and German) and formally verified by CEN before the Formal Vote takes place. If the document is approved in FV, it is sent to the NSBs before the Date of Availability (DAV) (4 months after FV). At this moment, the document can be translated into the national language and the National Annex can be elaborated by each country before the Date of Publication (DoP) (for 2nd generation Eurocodes set to October 2027). The National Annex will contain mainly the Nationally Determined Parameters (NDPs) and the Non-Contradictory Complementary Information (NCCI) for each country and allows to apply the Eurocode in the country. There is another important date, the Date of Withdrawal (DoW) , which stablishes when the old version must be withdrawn (6 months after DoP).

2.
MANDATE M515

2.1. Introduction

Commission Recommendation 2003/887/EC [11] encourages Member States to adopt the Eurocodes and to maintain the Eurocodes at the forefront of engineering knowledge and developments in structural design (research on new materials, products and construction methods). Recommendation indicates the need to assess the variations of the Nationally Determined Parameters (NDPs) between countries with the aim of further harmonization.

A sustained development of the Eurocodes programme is necessary to preserve the users' confidence:

- Encourage/accompany innovation (materials, products, construction techniques and design methods).
- Meet the new demands and needs of society.
- Harmonise national technical initiatives on new topics of interest for the construction sector.

They shall at least cover:

- Assessment, re-use and retrofitting of existing structures.
- Strengthening the requirements for robustness.
- Improving the practical use for day-to-day calculations.
- New Eurocode on structural glass.
- Fibre Reinforced Polymer (FRP) structures and tensile surface structures.
- Incorporation of ISO (International Organization for Standardization) Standards into the Eurocodes family, such as atmospheric icing of structures and actions from waves and currents on coastal structures.

2.2. Mandate content

Beyond the maintenance work considering the comments from the systematic review, the following tasks are established for Eurocode 2 [3]:

General

- Extension of existing rules for the assessment of existing structures and their strengthening.
- Extension of existing horizontal rules for robustness.

Further development

- Reduction of the number of Nationally Determined Parameters (NDPs).
- Improvement the “ease of use” of Eurocodes for practical users.
- Incorporation of recent results relevant to innovation and contribution of structural design to sustainability.
- Adoption, where relevant, of ISO standards to complement the Eurocodes.
- Developing auxiliary guidance documents.
- Providing a clear and complete list of background documents.
- Developing a technical report, analysing and providing guidance for potential amendments for Eurocodes regarding structural design addressing relevant impacts of future climate change (general and material specific).
- Assessing the link to harmonized Product Standards or other European standards.

2.3. The Mandate in Eurocode 2

Model Code 2010 [12] has been extensively used as a basis for this revision. A great work of updating knowledge has been done, including some specific research works and many calibrations of expressions against experimental data bases. In addition, a large set of background documents (near 1000 pages) has been generated.

The preference for formulations irrespective of the type of structural member and based on physical models more than on empirical ones, has been a general criterion all over the development of the documents. Physical models are easier to understand and facilitate the task of extrapolating the formulations to other conditions.

A refinement of many formulations has been done that may reduce the quantity of materials in the concrete design, and goes in favour of sustainability.

As in other Eurocodes, the numbering of the sections has changed from the actual version, as two new sections have appeared: 2. Normative references and 3. Terms, definitions and symbols. In general, the new number of a section can be obtained adding two to the old one.

An important number of design clauses of the Bridge Part have disappeared since new formulations are independent of the type of structure; some others were not specific for bridges and have been incorporated into the General Part; others have been transferred to Eurocode 1 [2] (actions during the construction) or Eurocode 3 [4] (cable stayed bridges, extradosed bridges). As the remaining content of Bridge Part is quite small, it has been decided to supress this part and incorporate its content into a normative annex (Annex K, Bridges).

Similarly, the contents of current Eurocode EN 1992-3 Containment Structures, has been integrated into informative annexes of the 2nd generation EN 1992-1-1: Verification of early age cracking into Annex D, and leak tightness into Annex H.

The specific tasks performed in the revision of EC2 are the following:

General Part

- Reduction of the number of Nationally Determined Parameters [13], in particular those NPD that are not related to safety or geographic/climatic conditions of a country.
- Enhancement the ease of use [14] [15] by means of:
  - Improving the clarity.
  - Simplifying navigation routes through the Eurocodes.
  - Limiting, where possible, the inclusion of alternative application rules.
  - Avoiding or removing rules of little practical use in design:
    - "A code should be very easy to use for all common cases, but should also suitably address the remaining (less common) ones".
    - "An easy-to-use code should start with clear provisions for simple cases (sufficient and on the safe side, with clear limits for their applicability) and give the necessary rules for more general or less common cases in the following provisions.".
  - Allowing not only for an ease of use enhancement in case of simple cases, but also for:
    - Optimization of solutions (economic optimization, optimization of required dimensions, simplification of details, simplification of execution etc.).
    - Assessment of existing structures (Annex I) not complying with geometric or mechanical requirements given in sections 8 and 9 (see chapter 3 of this document).
    - Avoiding unnecessary strengthening (or minimizing it) in case of assessment of existing structures not complying with simple rules.
- Development of new technical contents on the following issues:
  - Performance based on durability design (section 6).
  - Design by non-linear FEM.
  - Consideration of size effect.
  - Early age thermo-mechanical design (Annex D).
  - Stainless Steel (additional clauses to EN 1992-1-1). [16]
  - Assessment of concrete structures (Annex I).
  - Strengthening with Fibre Reinforced Polymers (Annex J).
  - Steel Fibre Reinforced Concrete Structures (Annex L).
  - Recycled Aggregates Concrete Structures (Annex N).
  - Embedded FRP reinforcement (Annex R).

Fire Part

- Improving the ease-of-use within EN 1992-1-2 [17].
- Reduction of NDPs.
- Improvements and amendments of EN 1992-1-2 [17]:
  - Updating design rules.
  - New section for structural overall behaviour.
  - Improvement for braced/unbraced columns.
  - Ensuring consistency between tabulated data, simplified design, and advanced design provisions.
  - Thermal conductivity of concrete.
  - Spalling of concrete.
  - Robustness criteria.
  - Reducing the number of alternative methods.

3. MAIN CONTENTS OF THE NEW EUROCODE 2

The new FprEN 1992-1-1 [18] is organized into a main part which contains 15 sections (from Section 0 to Section 14) and 19 annexes (from Annex A to Annex R), covering the following content:

0. Introduction.
1. Scope.
2. Normative references.
3. Terms, definitions, and symbols.
4. Basis of design.
5. Materials.
6. Durability and cover.
7. Structural analysis.
8. Ultimate Limit States (ULS).
9. Serviceability Limit States (SLS).
10. Fatigue.
11. Detailing of reinforcement and post-tensioning tendons.
12. Detailing of members and particular rules.
13. Additional rules for precast concrete elements and structures.
14. Plain and lightly reinforced concrete structures.

Annex A (informative) Adjustment of partial factors for materials.
Annex B (normative) Time dependent behaviour of materials: Creep, shrinkage and elastic strain of concrete and relaxation of prestressing steel.
Annex C (normative) Requirements to materials.
Annex D (informative) Evaluation of early-age and long-term cracking due to restraint.

Annex E (normative) Additional rules for fatigue verification.
Annex F (informative) Non-linear analyses procedures.
Annex G (normative) Design of membrane, shell and slab elements.
Annex H (informative) Guidance on design of concrete structures for watertightness.
Annex I (informative) Assessment of Existing Structures.
Annex J (informative) Strengthening of Existing Concrete Structures with CFRP.
Annex K (normative) Bridges.
Annex L (informative) Steel Fibre Reinforced Concrete Structures.
Annex M (normative) Lightweight aggregate concrete structures.
Annex N (informative) Recycled aggregates concrete structure.
Annex O (informative) Simplified approaches for second order effects.
Annex P (informative) Alternative cover approach for durability.
Annex Q (normative) Stainless reinforcing steel.
Annex R (informative) Embedded FRP Reinforcement.
Annex S (informative) Minimum reinforcement for crack control and simplified crack control.
Bibliography.

The new FprEN 1992-1-2 on structural fire design [19] is organized in a main part which contains 10 sections (from Section 0 to Section 9) and 5 annexes (from Annex A to Annex E), covering the following content:

0. Introduction.
1. Scope.
2. Normative references.
3. Terms, definitions and symbols.
4. Basis of design.
5. Material properties.
6. Tabulated design data.
7. Simplified design methods.
8. Advanced design methods.
9. Detailing.
10. Rules for spalling.

Annex A (normative) Lightweight aggregate concrete structures.
Annex B (informative) Steel fibre reinforced concrete structures.
Annex C (informative) Recycled aggregate concrete structures.
Annex D (normative) Buckling of columns under fire conditions.
Annex E (informative) Load-bearing solid walls — complementary tables.
Bibliography.

4. IMPROVEMENT OF OLD CONTENT

An important effort has been made to update and improve the content of the previous version of the Eurocode 2, adapting it to the new knowledge, and some few examples are presented in this chapter.

4.1. Green concretes

Green concretes are produced replacing a portion or all the cement content by another binder, like fly ashes for example, to reduce the carbon footprint. Consequently, in order to benefit from the slower strength development of these concretes, 2nd generation EC2 permits to test the control specimens at a higher age. The new version of EC2 doesn't regulate these concretes, but leaves the door open to use them, as 5.1.3 (2) [18] allows ages tref higher than 28 days:

> (2) The value for t_{ref}
> (i) should be taken as 28 days in general; or
> (ii) may be taken between 28 and 91 days when specified for a project.

4.2. Unification of the design compressive strength of concrete

A new formulation of the design compressive strength of concrete f_{cd} has been defined in 5.1.6 (1) that unifies this strength among the different behaviours: bending, axial force, shear, punching…

> 5.1.6. Design assumptions
>
> (1) The value of the design compressive strength shall be taken as:
>
> $$f_{cd} = \eta_{cc}\, k_{tc} \frac{f_{ck}}{\gamma_c} \qquad (5.3)$$
>
> where
>
> η_{cc} is a factor to account for the difference between the undisturbed compressive strength of a cylinder and the effective compressive strength that can be developed in the structural member. It shall be taken as:
>
> $$\eta_{cc} = \left(\frac{f_{ck,ref}}{f_{ck}}\right)^{\frac{1}{3}} \leq 1{,}0 \qquad (5.4)$$
>
> k_{tc} is a factor considering the effect of high sustained loads and of time of loading on concrete compressive strength.
>
> NOTE The following values apply, unless a National Annex gives different values:
> — $f_{ck,ref}$ = 40 MPa;
> — k_{tc} = 1,00 for tref ≤ 28 days for concretes with classes CR and CN and t_{ref} ≤ 56 days for concretes with class CS where the design loading is not expected for at least 3 months after casting;
> — k_{tc} = 0,85 for other cases including when fck replaced by $f_{ck}(t)$ in accordance with 5.1.3 (4).

The parameters and effects, that are considered in the definition of the design value of the compressive strength of concrete f_{cd},, are the following:

a) Material, geometrical and model uncertainties, which are considered in the partial safety factor γ_c (see background document to Annex A [20]),
b) Difference between the strength of the control specimens $f_{c,cyl}$ and the actual in-situ concrete strength $f_{c,ais}$, due to different casting and curing conditions as well as the different behaviour of fresh concrete in control specimens and in the structure (bleeding and settlement). This effect is considered with coefficient $\eta_{is} = f_{c,ais} / f_{c,cyl}$ which is accounted for in γ_C similarly to EN 1992-1-1:2004 [15] and background document to Annex A [20]),
c) Sustained loading effect considered with coefficient ktc (see background document to subsection 5.1.6 [21]),

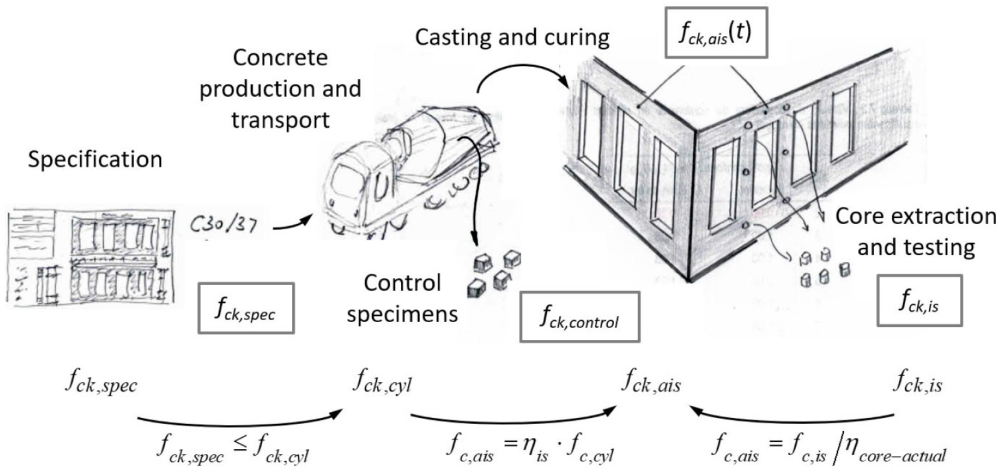

Figure 1. Representation of different compressive concrete strengths.

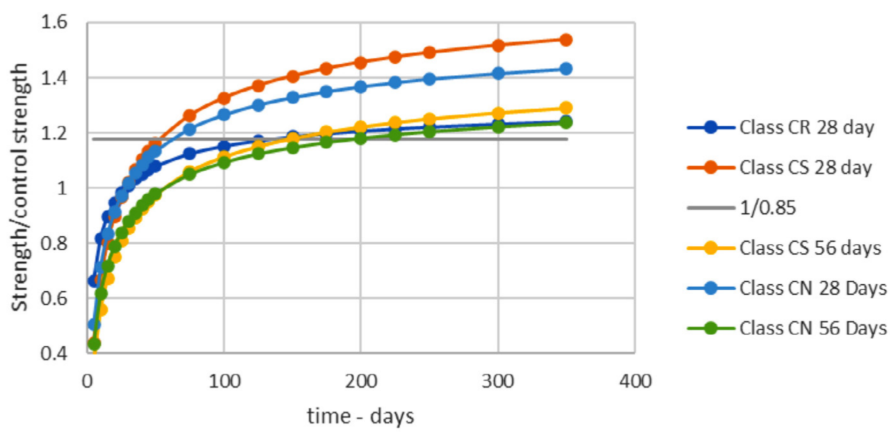

Figure 2. Comparison of strength gain for concretes of $f_{ck} \leq$ 35 MPa [21].

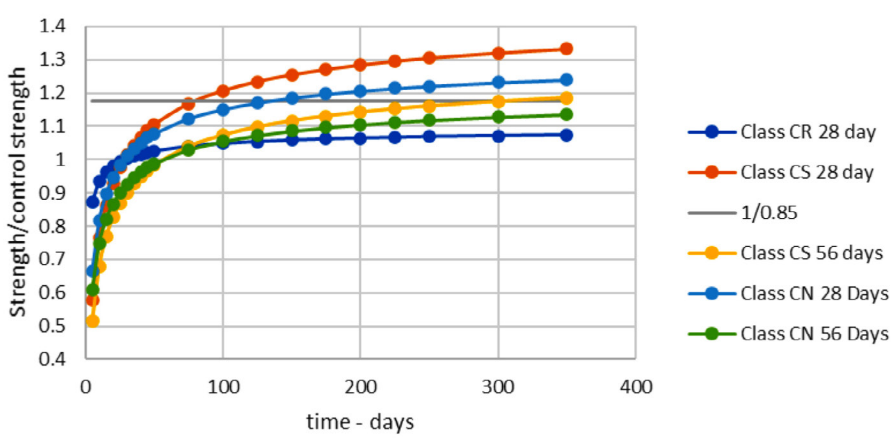

Figure 3. Comparison of strength gain for concretes of $f_{ck} \leq$ 35 MPa [21].

d) Influence of increased concrete brittleness of higher strength concretes and stress concentrations related to effects not considered in the analysis, which is taken into account with the strength reduction factor η_{cc}.

In the calculation of structural resistance, strain and stress states are typically simplified (assuming, for instance, that plane sections remain plane) and several local effects are neglected: the stress concentrations related to the interaction with the reinforcement and its restrained effects, the transversal tensile stresses originated by the local deviation of the stress field due to the presence of a reinforcement or due to the presence of voids under the reinforcement itself resulting from bleeding and settlement of fresh concrete, simplifications of the stress state considered in the analysis, etc.

Because of these effects, the resistance of a member in compression is not directly proportional to the concrete compressive strength measured in control specimens and this is considered by the coefficient η_{cc}. This coefficient has been calibrated with the resistance of column elements measured in laboratory tests.

As a summary (Figure 1), the compressive strength $f_{c,cyl}$ is obtained from control specimens (or $f_{c,is}$ from drilled core tests), it is converted into undisturbed compressive strength of cylinder (without reinforcement, and with a size effect not taken into account) by the coefficient η_{is}, which is included in γ_C, and then it is converted into effective compressive strength in structural member (with reinforcement) considering brittleness effect by the coefficient η_{cc} (possible splitting). The mentioned size effect on the undisturbed compressive strength of unreinforced cylinders is not taken into account because it is supposed that the minimum reinforcement stated in the Eurocode reduces significantly this effect.

With the introduction of the coefficient η_{cc} considering brittleness effect directly in Formula (5.3) [18] for calculating f_{cd}, the design procedure is simplified since:

- All strength reduction factors ν in section 8 (ULS) [18] are simplified becoming constant values not dependent on f_{ck} anymore.
- The stress distributions in the compression zones (stress block and parabola-rectangle) can be simplified with a constant value of the strain limits, independent of the concrete classes (ε_{c2}=0.002 and ε_{cu}=0.035).
- The constant values for the strains related to the parabola-rectangle distribution even enhance the accuracy of the results.

The factor k_{tc} considers the effect of high sustained loads and the effect of loading time on concrete compressive strength [21]. The effective strength of concrete is reduced under high sustained load, but this may be compensated by the continued increase in concrete strength beyond the normal 28 days, when strength is typically specified. The Code considers a 0.85 reduction in strength under sustained loads as a conservative value, once the nature of testing used to calibrate the codes is considered. When loading is some time after the time of concrete testing, t_{ref}, the reduction in strength, due to high sustained loading, may be offset by continued hydration of the concrete. On this basis, to justify k_{tc} =1.0, at the time of loading the relative increase in strength after t_{ref} ($f_{ck,t,load}$ /$f_{ck,t,ref}$) should be at least 1/0.85 = 1.18 in order to compensate the effect of sustained loads. Thus, the general expression of the coefficient is: $k_{tc} = 0{,}85(f_{ck,t,load}/f_{ck,t,ref}) \leq 1{,}0$.

where:

$f_{ck,t,load}$: concrete compressive strength at the time of loading.

$f_{ck,t,load}$: concrete compressive strength at the time of concrete testing, usually 28 days.

On this basis, the coefficient ktc has been calibrated for different cement types and concrete strengths [21], resulting in the values included in the note. In this note, Classes CS, CN and CR stand for slow, normal and rapid strength development of concrete, respectively (Figure 2 and Figure 3)

4.3. *Partial factors for materials*

Great improvements have been done in the treatment of partial factor for materials:

1) Now, the hypothesis that underlies the values included in Table 1 are clearly given. As it is indicated in the note of this table, these coefficients correspond to Tolerance Class 1 and Execution Class 2 in EN 13670 "Execution of concrete structures" [22].

In Annex A, the statistical data (coefficient of variation and bias factor) of the main variables (concrete and steel strength, dominant geometric values, model uncertainty, etc.) that support these coefficients can be found, see Table 2.

2) In Annex A [18], there is a procedure [A.3(3)] to obtain the partial factors of materials for different values of statistical data of material strength, dominant geometrical value or model uncertainty. This is very important, because if the actual value of this statistical data is known, the partial factors can be modified by NSBs and the design can be adjusted to a particular case. In the following lines, as an example, the procedure to obtain the adjusted partial factor for the compressive strength of concrete γ_C is developed. The compressive capacity Rc of an area of concrete depends on several variables:

$$R_c = f_{c,cyl}\,\eta_{is}\,A_c\,\theta_c \qquad [1]$$

where:

$f_{c,cyl}$ is the compressive strength of the control specimen

η_{is} is the coefficient to obtain the in situ compressive strength of concrete

A_c is the area of concrete

θ_c is the model uncertainty

Design situations — Limit states	γ_S for reinforcing and prestressing steel	γ_C and γ_{CE} for concrete	γ_V for shear and punching resistance without shear reinforcement
Persistent and transient design situation	1,15	1,50[a]	1,40
Fatigue design situation	1,15	1,50	1,40
Accidental design situation	1,00	1,15	1,15
Serviceability limit state	1,00	1,00	—

NOTE The partial factors for materials correspond to geometrical deviations of Tolerance Class 1 and Execution Class 2 in EN 13670.

[a] The value for γ_{CE} applies when the indicative value for the elastic modulus according 5.1.4(2) is used. A value γ_{CE} = 1,3 applies when the elastic modulus is determined according to 5.1.4(1).

Table 1. Partial factors for materials (*)

(*) This table corresponds to Table 4.3 in [18].

	Coefficient of variation	Bias factor[a]
Partial factor for reinforcement γ_S		
Yield strength f_y	$V_{fy} = 0{,}045$	$f_{ym}/f_{yk} = \exp(1{,}645 V_{fy})$
Effective depth d	$V_d = 0{,}050$[b]	$\mu_d = 0{,}95$[b]
Model uncertainty	$V_{\theta s} = 0{,}045$[c]	$\mu_{\theta s} = 1{,}09$[c]
Coefficient of variation and bias factor of resistance for reinforcement	$V_{RS} = 0{,}081$[i]	$\mu_{RS} = 1{,}115$[i]
Partial factor for concrete γ_C		
Compressive strength f_c (control specimen)	$V_{fc} = 0{,}100$	$f_{cm}/f_{ck} = \exp(1{,}645 V_{fc})$[d]
Insitu factor $\eta_{is} = f_{c,ais}/f_c$ [e]	$V_{\eta is} = 0{,}120$	$\mu_{\eta is} = 0{,}95$
Concrete area A_c	$V_{Ac} = 0{,}040$	$\mu_{Ac} = 1{,}00$
Model uncertainty	$V_{\theta c} = 0{,}070$[f]	$\mu_{\theta c} = 1{,}02$[f]
Coefficient of variation and bias factor of resistance for concrete	$V_{RC} = 0{,}176$[i]	$\mu_{RC} = 1{,}142$[i]
Partial factor for shear and punching γ_V (see 8.2.1, 8.2.2, 8.4, I.8.3.1, I.8.5)		
Compressive strength f_c (control specimen)	$V_{fc} = 0{,}100$	$f_{cm}/f_{ck} = \exp(1{,}645 V_{fc})$[d]
Insitu factor $\eta_{is} = f_{c,ais}/f_c$ [e]	$V_{\eta is} = 0{,}120$	$\mu_{\eta is} = 0{,}95$
Effective depth d	$V_d = 0{,}050$[b]	$\mu_d = 0{,}95$[b]
Model uncertainty	$V_{\theta v} = 0{,}107$[g]	$\mu_{\theta v} = 1{,}10$[g]
Residual uncertainties	$V_{res,v} = 0{,}046$[h]	–
Coefficient of variation and bias factor of resistance for shear and punching (members without shear reinforcement)	$V_{RV} = 0{,}137$[i]	$\mu_{RV} = 1{,}085$[i]

[a] The values in this column refer to ratio between mean value and values used in the design formulae (characteristic or nominal).
[b] These values are valid for $d = 200$ mm. For other effective depths: $V_d = 0{,}05(200/d)^{2/3}$ and $\mu_d = 1 - 0{,}05(200/d)^{2/3}$.
[c] The partial factor γ_S is calibrated for the case of pure bending according to 5.2.4 and 8.1.
[d] This formula replaces relationship given in Table 5.1 for the purpose of Annex A.
[e] Insitu factor η_{is} accounts for the difference between the actual insitu concrete strength in the structure $f_{c,ais}$ and the strength of the control specimen f_c. For strength $f_{c,is}$ assessed on extracted 2:1 cores according to EN 13791, see (7).
[f] The partial factor γ_C is calibrated for the case of axial compression according to 5.1.6 and 8.1.
[g] The partial factor γ_V is calibrated for the case of punching according to 8.4 and applies also for the case of shear without shear reinforcement according to 8.2.2 (similar statistical values).
[h] The residual uncertainties refer to aggregate size, reinforcement area and spacing and column size.
[i] Based on the statistical values above and calculated using Formulae (A.2) to (A.7).

Table 2. Statistical data assumed for the calculation of partial factors (*)
(*) This table corresponds to Table A3 in [18].

Design situations/Limit states	**Sensitivity factors for resistance α_R**	**target value for the 50-year reliability index β_{tgt}**
Persistent or transient design situation	0,8	3,8
Fatigue design situation	0,8	3,8
Accidental design situation	0,8	2,0
NOTE 1 These values refer to CC2. For others Consequence Classes, refer to EN 1990.		

Table 3. Sensitivity factors for resistance α_R and target values for the 50-year reliability index β_{tgt} (*)
(*) This Table corresponds to Table A4 in [18].

If the coefficients of variation and bias of the variables described in Table 2 are known, the values of these coefficients for the compressive strength Rc may be calculated using equations (2) (3) and (4) from [18]:

$$V_{Rc} = \sqrt{V_{fc,cyl}^2 + V_{\eta is}^2 + V_{Ac}^2 + V_{\theta c}^2} \quad [2]$$

$$\mu_{Rc} = \mu_{fc,cyl}\ \mu_{\eta is}\ \mu_{Ac}\ \mu_{\theta c} \quad [3]$$

$$\text{where} \quad \mu_{fc,cyl} = \frac{f_{cm}}{f_{ck}} = e^{1{,}645 V_{fc}} \quad [4]$$

Finally, the adjusted partial factor for the compressive strength of concrete γ_C may be calculated applying equation (5) from [18] as:

$$\gamma_C = \frac{e^{\alpha_R \beta_{tgt} V_{Rc}}}{\mu_{Rc}} \quad [5]$$

where:

α_R is the sensitivity factor for resistance according to Table 3 ($\alpha_R = 0{,}8$)

β_{tgt} is the target value for the 50-year reliability index according to Table 3 (for persistent design situation $\beta_{tgt} = 3{,}8$)

Condition for adjusted material factors	persistent and transient design situations			accidental design situations		
	γ_S	γ_C	γ_V	γ_S	γ_C	γ_V
a) if the execution ensures that geometrical deviations of Tolerance Class 2 according to EN 13670 are fulfilled	1,08	1,48	1,33	0,97	1,15	1,11
	in case also at least one of the conditions d), e), f) or h) is fulfilled, the partial factors may be calculated according to (3) with the statistical values given in (4) and in (7) for d) or in (8) for e); with the updated values of the resistance model for (f) and with the values given in Table A.4 for h)					
b) if the calculation of design resistance is based on the value of the dominant geometrical data measured in the finished structure and the CoV of the measurement is not larger than the values given in (5)	1,04	1,48	1,29	0,95	1,15	1,08
	in case also at least one of the conditions d), e), f) or h) is fulfilled, the partial factors may be calculated according to (3) with the statistical values given in (5) and in (7) for d) or in (8) for e); with the updated values of the resistance model for (f) and with the values given in Table A.4 for h)					
c) if the calculation of design resistance is based on the design value of the effective depth according to (6)	1,03	1,50	1,29	0,94	1,15	1,07
	in case also at least one of the conditions d), e), f) or h) is fulfilled, the partial factors may be calculated according to (3) with the statistical values given in (6) and in (7) for d) or in (8) for e); with the updated values of the resistance model for (f) and with the values given in Table A.4 for h)					
d) if the insitu concrete strength in the finished structure is assessed according to EN 13791:2019, Clause 8	γ_C and γ_V according to (7)					
e) if the yield strength of the reinforcement is assessed from tests on samples taken from the existing structure	γ_S according to (8)					
f) if the verification of the structure or of the member is conducted according to more refined methods ensuring reduced uncertainties of the resistance model.	γ_S and γ_C according to (3) where the statistical values describing the model uncertainties in Table A.3 are replaced by the actual ones					
g) if the verification of the structure or of the member is conducted using non-linear analysis and the model uncertainty is considered separately according to F.4(1).	1,20	1,46	1,31[a]	1,09	1,16	1,16[a]
h) if the target value for the reliability index β_{tgt} given in Table A.4 is modified in accordance with the relevant authority	γ_S and γ_C according to (3) with the statistical values in Table A.5					

[a] These values apply for failures modes similar to punching and shear failures in members without shear reinforcement.

Table 4. Values of adjusted material factors - General (*)

(*) This Table corresponds to Table A1 in [[18].

In Table 4, adjusted material factors are defined for different conditions related to:

a) Geometrical deviations belong to Tolerance Class 2 instead of Class 1 [22].
b) The value of dominant geometrical data has been measured in the finished structure and the covariance (CoV) of the measurement is not larger than the values given in A.3(5) [18].
c) Calculation of design resistance is based on the design value of the effective depth according to A.3(6) [18].
d) In-situ concrete strength in the finished structure has been assessed on core tests according to EN 13791:2019, Clause 8 [23].
e) The yield strength of the reinforcement has been assessed from tests on samples taken from the existing structure.
f) Verification of the structure or member is conducted according to more refined methods ensuring reduced uncertainties of the resistance model.
g) Verification of the structure or member is conducted using non-linear analysis and the model uncertainty is considered separately according to F.4(1) [18].
h) Target value for the reliability index β_{tgt} given in Table 3 has been modified in accordance with the relevant authority.

3) There is a special partial factor γ_V for the shear and punching resistance without shear reinforcement, that replaces γ_C in all formulae for calculating the shear and punching resistance in members without shear reinforcement. This change has been explicitly introduced to take into account the fact that for shear, the model uncertainties become dominant, whereas the influence of the variability of the compressive concrete strength is reduced by the fact that the compressive concrete strength f_{ck} appears with an exponent of 1/3 in the design formulae. In this way a better and more transparent fitting of the formulation with the data bases of tests is achieved, increasing the sustainability.

4) It is possible to reduce γ_V and γ_S by using design values for the effective depth: for thin members, geometrical uncertainties govern the calibration of γ_V and γ_S, whereas for deep members, the effect of geometrical uncertainties become almost negligible. For this reason, it is more rational to adopt reduced values of γ_V and γ_S by using design values for the effective depth. This possibility is defined in 4.3.3(2) [18]:

> (2) Lower values of partial factor γ_S and γ_V for the verification of the ULS in case of persistent, transient and accidental design situations may be used according to A.3(1) if a design value of the effective depth dd is considered.

whereas the design value of the effective depth is given in Annex A (A.3(6)) [18]:

> (6) The statistical data of the effective depth in Table A.2 may be replaced by V_d = 0,00 and μ_d = 1,00 if the calculation of the design resistance is based on the design value of the effective depth d_d:
> d_d = dnom – Δd (A.4)
> where
> Δd is the deviation value of the effective depth:
> Δd = 15 mm for reinforcing and post-tensioning steel,
> Δd = 5 mm for pre-tensioning steel.
>
> NOTE: The design value of the effective depth d_d can be used unless a National Annex gives limitations.

and the reduced partial factors γ_S =1,03 and γ_V =1,29 (Figure 4) can be used.

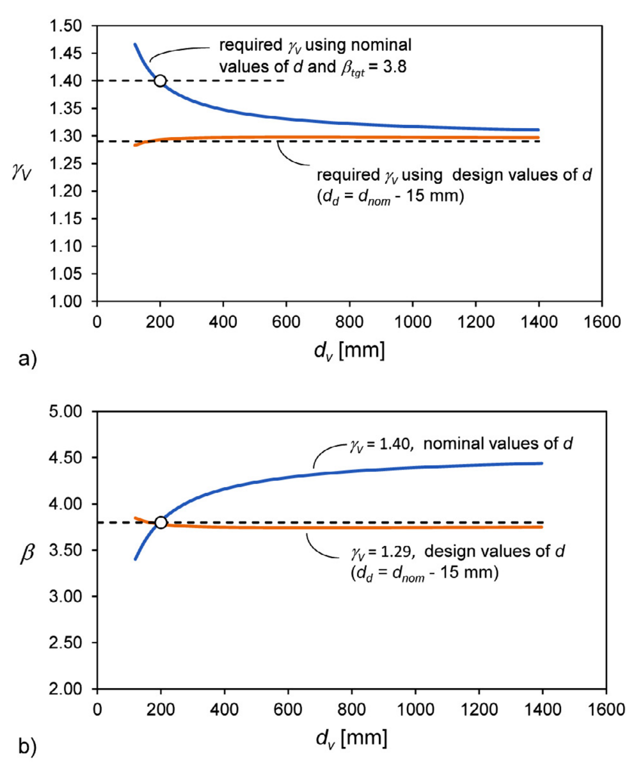

Figure 4. (a) Required partial safety factors γ_V to obtain β_{tgt} = 3,8 (b) Obtained reliability indexes with the assumed partial safety factors γ_V [20].

4.4. Other changes

- Section 4. Basis of design
  - Improved presentation (imposed deformations, partial safety factors in tables…)
  - References to other Eurocodes and, in particular to EN 1990 [1], suppressing contents that are not specific to Eurocode 2 [3].
  - Definition of partial factors for geometrical deviations of Tolerance Class 1 and Execution Class 2 in EN 13670 [22].
  - Specific partial factor for shear γ_V.
  - Design value of the effective d_d depth that allows to use lower values of partial factors for steel γ_S and concrete γ_V (see 4.3.4), see also text in 4.3 above.
- Section 5. Materials
  - Green concrete has finally been permitted. Green concrete uses fewer resources during production, substituting a portion of cement with more eco-friendly materials (fly ashes, for example) (see 4.1).
  - Cube specimen strength has been supressed in the definition of concrete classes for design purposes.
  - Unification of the concrete compressive strength among the different behaviours of concrete (bending, shear, punching…) through the factor η_{cc} (see 4.2).
  - Extending the range of material strength classes: for concrete up to f_{ck} = 100 MPa, for reinforcing steel up to f_{yk} = 700 MPa, and for prestressing steel strand up to f_{pk} = 2060 MPa.
- Section 6. Durability and cover [24]
  - New performance-based approach with Exposure Resistance Classes ERCs, that will be defined in the new version of EN 206 Concrete [25], is considered in Section 6 of the new Eurocode 2.
  - Exposure resistance classes ERC are used to classify concrete with respect to resistance against corrosion induced by several attacks (carbonation (class XRC), chlorides (class XRDS XRSD) and freeze/thaw (XRF)).
  - Exposure classes (EC) related to environmental conditions currently given in EN 206 are now defined in this section.
  - For each EC and design service life (50 or 100 years) a combination of ERC and minimum concrete cover may be chosen.
  - Compliance with a particular ERC may be confirmed either following some prescriptive rules for mix composition for conventional/well-known concrete mixes, or by doing some short-term performance tests (carbonation, chloride attack, etc.), for new or also for conventional concrete compositions.
- Section 7. Structural analysis
  - A new analytical method for explicit verification of rotation capacity is given.
  - Consideration of the effects of prestress in analysis and design (as action effects or as resistance) has been clarified.
- Section 8. Ultimate Limit States (ULS) [26] [27] [28]
  - Several formulations for shear without reinforcement in linear members have been developed, and finally

the formulation based on the Critical Shear Crack Theory (CSCT) as in Model Code, was adopted. The decision was to use CSCT also for punching for members without shear reinforcement and to continue use of variable inclination struts / compression field for members with shear reinforcement.
  - Provisions for the consideration of transverse bending on the in-plane shear strength have been added.
  - Provisions for strut-and-tie models have been amended mainly for verification of struts and nodes.
- Section 9. Serviceability Limit States (SLS) [29]
  - For the cracking control many improvements have been implemented and the result has been a refined formulation, very well fitted to the data base of tests, but somewhat more complex.
  - Simplified methods have been moved to an informative annex.
  - For the deflection control, simplified and refined methods based on zeta procedure (see equation 9.28 of 9.3.4 (3) in FprEN 1992-1-1: 2022 [18]), have been implemented.
- Section 11. Detailing of reinforcement and post-tensioning tendons [30]
  - The section has been significantly updated, simplified and reorganized.
  - The model from fib Bulletin 72 has been adopted for anchorage length of straight bars but updated and calibrated against recently amended test data base. The provisions now consider size effect and the non-linear effect of reinforcement stress on the anchorage length. Bond strength has not been explicitly defined because the great number of factors that influence its value and by the fact that it varies along the bar.
  - Robustness conditions have been included to define the force in the anchorages and the staggering conditions of laps.
  - New methods for anchoring and lapping have been added: U-bar loops, headed bars, post-installed bars.

5. NEW TOPICS

Following the Mandate, new topics have been developed and included in the new version of Eurocode 2 and in this chapter some of them are summarized.

- Stainless steel reinforcement
  Alterations for design with stainless steel compared to carbon reinforcing steel have been summarised in normative Annex Q. Nevertheless, for the ease of use, it is permitted to use the same formulations as for carbon steel unless considered significant and relevant. For example, for the stress-strain law, instead of using the Romberg-Osgood Law, a bilinear law has been adopted combined with a reduced value of the elasticity modulus (180 GPa).
- Assessment of existing structures (deteriorated) [31]
  Annex I [18], which is informative, contains additional rules for materials and systems not covered in the main part and additional rules for assessing existing structures where detailing does not comply with the provisions of the main part. Additional rules for the anchorage of plain bars are also included. Some considerations about the deterioration of existing structures are given, but only in a general way. Annex A [18] provides information for modifying materials´ partial factors, to consider the information obtained in the tests made on the existing structures.
- Strengthening of Existing Concrete Structures with FRP [32]
  Annex J [18] contains rules for strengthening existing structures with Carbon Fibre Reinforced Polymer (CFRP). The reinforcement can be externally bonded to the surface (EBR) or near surface mounted in the concrete (NSM). The reinforcement material can be either in the form of prefabricated strips (EBR or NSM), prefabricated bars (NSM) or in-situ lay-up sheets (EBR). Specific rules for materials, durability, and limit states have been developed and, in particular, those related to bond and anchorage of systems and detailing of CFRP.
- Embedded FRP Reinforcement [33]
  In the informative Annex R [18], supplementary information can be found for new structures reinforced with non-prestressed glass and carbon fibre-reinforced bars or meshes subjected to predominantly static loads. It does not apply to lightweight aggregate concrete and to recycled aggregate concrete.
- Steel Fibre Reinforced Concrete Structures (SFRC) [34] [35]
  Annex L [18] provides supplementary rules for structures constituted by steel fibre-reinforced concrete with or without reinforcing steel, pre-tensioning or post-tensioning tendons. In section L.5 the way to characterize this material by the residual tensile strengths and the stress-strain relationship in both tension and compression is described. Formulations for bending, shear, punching, torsion and cracking have been adapted to SFRC and detailing rules for members have been developed.

6. MAIN TOPICS IN FIRE PART [36]

Some relevant changes have also been introduced in FprEN1992-1-2 [19] regarding the previous version, dealing with:

- Material properties such as thermal conductivity of concrete, mechanical properties of high strength concrete and steel reinforcement.
- Simplified design methods: tabulated data for buckling of columns, tabulated data for walls, analytical determination of temperature profiles (simplified method) .
  - Rules for concrete spalling.
  - Extending the scope to lightweight aggregate concrete structures, steel fibre reinforced concrete structures and recycled aggregate concrete structures.
- In addition, the structure of the fire part has been harmonised across all Eurocodes´ material.

7. CONCLUSIONS

The first generation of Eurocode 2, consisting of four documents, was published as EN standard by the middle of the first decade of the present century, but works started much earlier in the 1980s.

Since then, a lot of research on concrete structures has been developed, and knowledge has significantly improved, so an updated version of Eurocode 2 was required. On the other hand, the application field has been enlarged and new topics and materials, not included in the first EN versions, have emerged.

This paper summarizes the generation of the first Eurocodes, addressing the organization, the documents and their contents, and how progress has been made with the preparation of the second generation of the Eurocode 2, which will be approved and published as EN new standards within 2023. The scope has been extended, the ease-of-use has been improved and the number of documents has been reduced, simplifying the structure of the code and including sustainability issues.

Main content of new Eurocode 2 is related in a general way in this paper and some issues have been presented in more detail, such as green concretes, unification of the design compressive strength of concrete and reliability of material strength, including existing structures. New topics, as stainless steel reinforcement, assessment of existing structures (deteriorated and non-deteriorated), steel fibre reinforced concrete or fibre reinforced polymer have been covered.

References to other published papers are also included in this paper, describing in detail some of the most relevant technical changes and improvements in the new Eurocode.

Acknowledgements

The authors want to acknowledge the contribution of Antonio Madrid Ramos to section 1 of this paper.

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