DURABILITY OF THE CONCRETE AND ITS DESIGN LIFE

Radu GAVRILESCU[1]

Rezumat. *Anul 2023 este cu totul deosebit sub aspectul revizuirii prevederilor naționale obligatorii privind proiectarea durabilității, producerea și punerea în operă a betonului uzual, monolit și prefabricat. Cu caracter obligatoriu, în 16 februarie a.c. au intrat în vigoare NE 012/2:2022 și SR EN 13670:2010 iar începând cu 19 aprilie a.c. NE 012/1:2022 împreună cu SR EN 206+A2:2021. În acest articol se prezintă pe scurt subiectul proiectării durabilității betonului cu referire directă la duratele de viață tehnic reglementate legal prin Eurocodul 0 și Codul CR 0/2012 și cu trimitere către specificitatea lucrărilor de artă din domeniul transporturilor feroviare și rutiere.*

Abstract. *The year 2023 is quite special in terms of the revision of the mandator national provisions regarding the durability design, production and execution of concrete works. Starting with February 16, NE 012/2:2022 and SR EN 13670:2010 entered into force and NE 012/1:2022 together with SR EN 206+A2:2021 also, on April 19. This article briefly presents the subject of concrete durability with direct reference to the design life legally regulated by Eurocode 0 and CR 0/2012 National Code, taken into consideration the specificity of works of art (eg. bridges) in the field of rail and road transport.*

Keywords: *concrete, durability, service life, performance approach*

1. Introduction

Concrete, correctly designed from a structural and durability point of view, by its physical-mechanical and chemical characteristics, by the low cost of the raw materials as well as by the favorable, specific way in which it responds to the environmental aggressions to which it is subjected during its working (service) life, represents the most effective technical-economic solution for many applications in the field of constructions.

2. History and transition

A series of books - e.g. [7, 8] - published shortly after the recent major earthquakes (1940, 1977) present a rather grim reality, namely that the designers and constructors of the old and heavily affected works were not concerned with ensuring durability, simply presence of concrete (of low strength class, most of the time) representing "a certification" that the structure will be resistant, stable and durable, for a long, unspecified time. The serious problems caused by major

[1]PhD, MSc, Eng HeidelbergCement Romania, E-mail: alternativa.beton@yahoo.com

earthquakes together with the identification of some natural degradations who shortly appear after the reception of some concrete structures imposed from a practical point of view - starting from the 70s - the design of the structures not only from the point of view of resistance and stability, but durability also. Strong degradations of concrete were noticed, especially on constructions located in the Black Sea influence area as well as on elements/structures in the road sector (e.g. bridges, rigid pavements, curbs, sewers etc.), these categories having as a common denominator environmental aggression from freeze-thaw on elements saturated (more or less) with salty water (exposure in XD, XS, XF2, XF4 classes).

In Romania, the design of concrete durability was done in accordance with the norms C140/1971-1979-1986, NE 012/1999, NE 012/1:2007 and currently it is done in accordance with SR EN 206+A2:2011 [2] and NE 012 /1:2022 [1]. Since the 2000s, the implementation of European standards paid attention to the durability of structural concrete which have led to special compositional measures (increasing compressive strength classes, reducing the A/C ratio etc.), to increases in the thickness of the covering layer for the steel reinforcements, to special measures for the curing and protection of the concrete, to the use of protective layers, etc. All this presupposes a high level of technical training of all personell involved, starting with designers.

The appearance on European and national levels of new models for assessing the durability of concrete, new test methods as well as (very important) Eurocode 0 [13] appearance led to the implementation of the notion of "*design life*"[1] in administration, design and execution of works, which represents a very important progress from many points of view, not only technical and economic. This new approach is in line with the evolution of society, with the emergence of constructions owners pragmatically oriented towards their exploitation (during its service/working life) with minimal maintenance and repair costs, based on a "*plan of business*" or of a "*judicious schedule of maintenance works*", as the case may be. In fact, by introducing the notion of "*design life*" there appears (right under our eyes) a very important transition in how the durability of a concrete construction is approached, depending of its type (e.g. usual building, bridge, monumental work, nuclear waste deposit etc.).

At the European level, the emergence of the notion of „*design life*” introduced by the Eurocode 0 [13] has accelerated the change in the field of concrete durability design. Until recently, this was done based on a traditional concept called "*deemed to satisfy*" whereby, based on specific 1970…1990 laboratory studies and (especially) on the basis of direct professional observations, the compositional parameters of the concrete were prescriptively established in correlation with the

[1] *in romanian language “durata de viață proiectată”*

level of aggressiveness of the surrounding environment. This approach has partially failed, providing ineffective, uneconomical and unsustainable concrete parameters, with serious degradations occurring after only a few decades, as I mentioned.

The evolution of testing methods (including the appearance of new accelerated ones), the mastery of new ways of interpreting the results and anticipating the evolution of the phenomena of transformation and degradation over time of concrete has led to a change in the design approach – gradually moving from a prescriptive to a performance-based one. In other words, in the last decades, performance rules (criteria) have been defined which, once met, ensure the achievement of a certain predetermined design life with a minimum of maintenance work. Analyzing the provisions of NE 012/1:2022 (especially Annex J) and NE 012/2:2022 through the lens of identifying some performance criteria, the user may be surprised by the abundance of their presence.

This is the "*new and modern approach*" to the way of design, construction and administration that will shape our professional life no matter in which field we operate - as an authority, designer, verifier, site engineer, execution technical responsible, manufacturer of building materials etc. Achieving the objectives of reducing the CO_2 footprint in the construction activity is subordinated to the fundamental objectives legally regulated through Eurocode 0 [13], CR 0/2012 [10] and others [9], [18], [20, 21].

3. Durability of the concrete and its design life

The durability of concrete is its intrinsec property to successfully resist to the climatic, chemical, abrasion or any other deterioration processes. A durable concrete is that which keeps its original shape, characteristics and functionality in the environmental conditions for which it was designed, for a certain (significant) period of time.

Starting from this definition - which correlates the design of the concrete composition with the environmental conditions in which it is to be exploited - we can always ask the justified questions "*how long is it possible for concrete of a certain composition to maintain its durability?*" or "*how can the durability of concrete be designed - at reasonable costs - for a predetermined period of time?*". Thus, the factor "time" appears as very important in the discussion of durability, in the technically regulated and precisely quantified form of "*design life*", which can enter as an important design parameter in the fatigue performance calculations for some bridge beams, e.g. Structures and structural components subjected to significant numbers of repeated load or deformation induced significant stress cycles shall be verified to endure the expected cyclic actions during the required design life.

The notion of durability of concrete is associated - in regulations and literature - with the agression of the surrounding environment, with the mandatory requirements regarding its composition (minimum compressive strength class, max. A/C ratio, etc.) as well as with its design life. A durable concrete is a concrete with a minimum porosity and absorbtion, this means a high compressive strength class with the lowest possible A/C ratio, an effective and sufficient treatment/protection after casting, a protective coating with specialized layers etc. Last but not least, the shape of the elements is very important to ensure durability, designers must always take into account the avoidance of water stagnation on the surface of the concrete, especially when is salty or chemical agressive. The real application – in design and practice - of the minimum necessary thickness of the covering layer is another mandatory condition in order to obtain a durable reinforced structural concrete exposed in XC, XS, XD.

A concrete, correctly proportioned compositionally for a certain surrounding environment, will remain durable for decades as long as that environment does not undergo major changes, in a negative sense. In other words, in the framework of durability design, an anticipation of the aggressiveness of the environment is necessary not only at the time of construction, but also over a long period of time, on the order of decades, while the structure remains in service.

The term "*design life*" can be found in recent European and national technical prescriptions under slightly different names and definitions, which should not, however, cause any confusion to users. According to SR EN 206+A2:2011 [2], the duration of use (*design life*) provided in the project represents "*the assumed period, in which a structure or one of its elements is intended (destined) to be used in accordance with the use was expected, under conditions of planned maintenance, without requiring major repairs*". This is a comprehensive definition.

The design life of a construction structure is of the order of decades, it starts after construction and during it a series of performance parameters in terms of durability must not exceed certain limits (or not reach certain limit states), predetermined by designer, under the conditions of current and inexpensive maintenance. These limits can and should be contained in performance criteria, in other words must be defined - for any structure - a series of limit states that once reached should lead ("*automatically*") to the administrative decision to carry out some works of maintenance or capital repair (as applicable).

For a railway bridge elevation, an example of an operational limit state (service) can be "*for a life of 100 years, the depth of carbonation in the areas of maximum stress, identified, exposed to precipitation in XC4, must remain lower than the thickness of the concrete covering layer of the reinforcements*". In other words, the passivation layer of the reinforcements must remain intact during the design life, its damage means the initiation of corrosion or sectional reduction, in the most vulnerable sections that are also exposed to precipitation („XC4"). In the case of road bridges, the presence of chlorides („XD") must be properly taken into account.

By the very definition of the notion of design life, it is shown that during it periodical inspections are carried out on the basis of which scheduled maintenance works can be decided and executed, as is normal. To ensure the design life, the level of technical supervision throughout the service life of the structure is very important. A technically appropriate and sufficiently detailed inspection, depending on the degree of importance of the structure, will give to the owner the possibility of applying some maintenance measures, including overschedule when his expectations in terms of durability are not met. The designer should identify the level of control conditions (inspection) applicable "CCL", as defined in the fib Model Code [23], as well as their periodicity.

"*Expiry of design life*" should not mean the accumulation of an unacceptable level of degradation that would require demolition of the structure. In my opinion, administratively and mandatory, when the design life is reached, a technical expertise should be made which should lead to decisions - either to more extensive maintenance work or to a capital repair work, based on which the service life of the structure can be significantly lengthened (as is otherwise expected from an engineering point of view).

In the example given previously - of service limit state regarding carbonation in XC4 - of course, the destruction of the passivation layer should lead to the urgent repassivation of the reinforcements as well as to a major repair of the structure (e.g. coatings), operatively decided, extensive and expensive but not prematurely (as it often happens...), but at the end of the service life, which for bridges is (minimum) 100 years according to Eurocode 0 and CR 0/2012 as mandatory documents.

In order to ensure the durability, respectively the mandatory design life, the role of the designer is particularly important as the parameters of the concrete (for example the minimum class of compressive strength), are sometimes established on the basis of the design of the durability and not from the structural calculations. The characterization of the environment with which the concrete will interact during its service/working life is done by means of the "X" exposure classes defined (including through suggestive examples) in the recent normative NE 012/1:2022 [1] which is constituted in the national application annex of SR EN 206+A2:2021 [2].

By classifying the concrete elements/structures in exposure classes "X" or, in most cases, in combinations of exposure classes, a series of design elements - particularly important - are obtained from NE 012/1:2022 [1] such as the minimum compressive strength class of the concrete, its maximum A/C ratio, the types of cement applicable and others that provide the premise of a life limited to (only) 50 years (see Appendix F). It is always necessary to complete the written parts of any project with a concrete cover thickness calculation, according to the new applicable regulations [10], [13 - 15], [24], which will provide thicknesses greater than those which we are used to - see [19] - especially for structural elements of bridges. A special situation from this perspective appear on prestressed concrete beams that are designed for a life of (minimum) 100 years, according to Eurocode 0 and CR 0/2012.

All these design elements significantly influence the durability of a structure, i.e. determine its service life. Durability design (which includes the calculation of concrete cover thicknesses) is a relatively simple operation and is advisable to precede structural design, given its particular impact. Failure to comply with the regulated requirements to ensure the design life brings with it the risk of more frequent than usual maintenance works, with higher cumulative costs, i.e. a certain technical-economic inefficiency.

4. Legal aspects regarding the determination of the design life

Concrete structures must be managed, designed, executed, maintained and monitored over time in such a way that they can satisfy - during the design life - the fundamental requirements contained in the Quality Law (Law 10/1995, last revision), [9]. Durability does not appear explicitly as a fundamental requirement in the mentioned legislation, but it can be clearly intuited that it represents the "*foundation*" of complying with the requirements of "*mechanical resistance*", "*stability*" and eventually "*safety in operation*", during the design life.

The concern of all the factors involved in ensuring the durability of bridges must be all the greater as they must be ensured - according to Code CR-0/2012 [10], ISO/CD 16204 [11] and Eurocode 0 [13] - a life of (minimum) 100 years. Table 1 shows the design life categories for different concrete constructions types, provided by a series of mandatory and voluntary technical regulations, with the mention that there is a certain overlap of provisions to be discussed.

Table 1. Design life categories provided by various technical regulations

Design life category	*Applicable technical regulation*	*Indicative design life (years)*	*Examples*
1	*ISO 2394:1998*	*1…5*	*Temporary structures*
	Eurocod 0, SR EN 1990/NA:2006, NE 012/1:2022, CR 0/2012	*10*	*Temporary structures (structures or parts of structures that can be dismantled for reuse should not be considered temporary)*
2		*10 ... 25*	*Replaceable structural parts, e.g. gantry girders, bearings (*)*
3		*15 ... 30*	*Agricultural and similar buildings*
4	*ISO 2394:1998, Eurocod 0, NE 012/1:2022*	*50*	*Buildings and other common structures*
	SR EN 1990/NA:2006, CR 0/2012	*50 ... 100*	
5	*Eurocod 0*	*100*	*Monumental buildings, bridges and other civil engineering structures*
	ISO 2394:1998, SR EN 1990/NA:2006, CR 0/2012	*≥ 100*	

(*) – for this category ISO 2394:1998 provides for a life of 25 years

We can note the initiative of the national code CR 0/2012 and of the National Annex (SR EN 1990/NA:2006) for the application of Eurocode 0, to increase - compared to Eurocode 0 [13] - the design lifes in the case of categories 4 and 5, with the following effects:

a) In the case of common structures for construction ("*Buildings and other common structures*") falling into the service life category "4", we can design the durability of the concrete in accordance with the provisions of NE 012/1:2022 (Annex F) which provides us with all the necessary elements required (minimum compressive strength class, maximum $A/C_{efective}$ ratio, minimum cement dosage, applicable cement types, etc.) for a design life of 50 years. If it is desired to increase the design life over 50 years (according to CR 0/2012, for example) then it becomes logical to modify the parameters in order to increase the durability and/or to use additional means of protection to those regulated;

b) In the case of construction structures ("*Monumental buildings, bridges and other civil engineering structures*") falling into the "5" life category of (minimum) 100 years, the provisions of Annex F of NE 012/1:2022 [1] are (again) outdated. In NE 012/2:2022 [3] it is mentioned that when designing complex works, which have a long design life, the designers must provide (additionally) special and target oriented specifications for the execution of the respective works, indicating a level of demand higher[1] regarding the execution of the works. This mention - very important - paves the way for ensuring durability even for bridges that have (by definition) long service lifes, the requirement to ensure a life of 120 years for bridges being present in Romania;

c) By applying the regulations in force - presented in detail in [19] - it is possible to calculate the thickness of the concrete cover layers for service life categories "4" and "5", for conventional steps of 50 and 100 years and for elements/structures suitable for all exposure classes XC, XD, XS. The application of the calculation algorithm also provides the minimum compressive strength class of the concrete, so the durability design mode is regulated up to the life of 100 years, for these exposure classes. When exceeding the design life of 100 years, it becomes necessary, for the same compositional parameters of the concrete, to increase the thickness of the covering layer by comparison with the one related to the applicable life of 100 years, but not by much given the specificity of the carbonation speed of the concrete, which decreases drastically over time [5], [6]. Calculations should of course be made each time. My observation specifically refers to the fact that for a period of life of over 100 years, one leaves the field strictly regulated by technical point of view;

d) By applying SR EN 206+A2:2021 [2] and NE 012/1:2022 [1] (Annex F), concrete can be compositionally designed for a life of 50 years for exposure classes XF, XA and XM. When increasing the design life from 50 to 100 years (or 120 years) it is most likely necessary to take some additional safety measures, which may mean adjusting the limit values for concrete in the sense of increasing durability, increasing the requirement regarding curing and protection of the executed works, the use of additional (regulated) measures to reduce the internal and/or surface porosity of the exposed elements. In this context, it should be mentioned that there is a national regulation in force - CD 139:2002 [17] - which, even if not updated, helps the designer in making a favorable decision.

5. Limitations of current technical regulations on establishing a design life

In order to correctly establish the design life of a structure and take the necessary measures (in administration, design, execution and operation), it is necessary to consult - first of all - Eurocodes 0 [13] and 2 (both for buildings [14] and for

---

[1] *by comparison with the provisions of NE 012/2:2022*

bridges [15]), taken over with a mandatory character from 2005 [18] in the national system of technical regulation.

Eurocode 0 is limited to present categories of lifes up to the maximum value of (fixed) 100 years, in the last category („*monumental buildings, bridges and other structures of engineering works*”). Through its national application annex (SR EN 1990/NA:2006) and the CR 0/2012 Code, the design lifes for categories 4 and 5 have been increased in accordance with those previously presented (Table 1). Obviously, for design lifes greater than 100 years, more restrictive measures should be adopted at all stages of construction, but for the administrator and designer an exact time limitation is still necessary.

Eurocode 2 for buildings considers (#2.1.2.) the design of works within the RC2 reliability class, to which the verification levels DSL2 and IL2 (ordinary constructions) correspond, an aspect also mentioned in NE 012/2:2022, (#12.2.3.), regarding the execution of the works.

According to SR EN 206+A2:2021 (#5.3.2.2), the provisions in force at the place of use of the concrete must include requirements corresponding to a design life provided in the project of at least 50 years, under the maintenance conditions foreseen in the project. The same standard indicates in Annex F recommended limit values for the composition and properties of concrete based on the assumption of a design life of at least 50 years. NE 012/1:2022 (which is constituted in its national application annex) restricts through Annex F the value of the design life to (fixed) 50 years, it being understood by this that compliance with the limit values indicated will lead, in compliance with the requirements imposed on durability design, concrete preparation and maintenance of the element/structure, upon reaching the respective design life. Therefore, we witness the limitation of the life to 50 years by NE 012/1:2022, this having to be completed with specific provisions for "*monumental buildings, bridges and other civil engineering structures*".

We can design the durability of concrete in exposure classes XC, XD, XS up to a design life of 100 years using Eurocode 2 and its national annexes, for buildings and bridges, but no more. Over a 50-year design life, concrete durability design in exposure classes XF, XA and (possibly) XM should be considered by the designer in additions (so necessary, obviously) to NE 012/1:2022 ones, respectively for each individual project.

SR EN 13670:2010 does not make explicit and concrete references to design life, having a general approach to the field of execution of concrete works. NE 012/2:2022, which is the national application document of SR EN 13670:2010, refers (#1.2.) to the execution of concrete, reinforced concrete and pre-stressed concrete construction works made with concrete produced in accordance with the provisions of NE 012 /1:2022 (#9.1.1.1.), so the limitation regarding the design life of (fixed) 50 years is also transmitted to the execution of the works, according to this regulation. NE 012/2:2022 (at #12.2.3.) also shows that the provisions of Eurocode 2 (SR EN 1992-1-1) only consider the design and execution of works included in the reliability class RC2, to which the levels of check levels DSL2 and IL2. The verifications (quality control) provided for in NE 012/1:2022 (#12.2.3.2.d) are those that correspond to the IL2 verification level. For the design, execution and verification of the works included in the reliability class RC3 (to which the verification levels DSL3 and IL3 correspond), special provisions are necessary for which the designers are responsible, by drawing up special and target oriented specifications for the respective works, having a level of high demand.

6. Conclusions

The appearance in 2023 of the revisions of the national annexes (normatives) NE 012/1,2 regarding the design of durability, preparation and execution of plain, reinforced and prestressed concrete works opens the way to a new approach to the field, a modern, performance approach based on compliance of explicit rules (criteria). Following the need to comply with some administrative requirements, the user of the new NE 012/1:2022 and NE 012/2:2022 must also use the corresponding European standards SR EN 206+A2:2021, respectively SR EN 13670:2010 in the current activity.

As shown, the mandatory nationally applicable technical documents NE 012/1:2022 and NE 012/2:2022 regulate - through the provisions contained - all the steps necessary to achieve the objective of a design life limited to 50 years.

When designing works that have a design life of more than 50 years, falling into reliability class RC3 - works that include third-party checks for design (DSL3) and execution of works (IL3) - designers should provide (in additional) special and durability target oriented specifications for the execution of the respective works. This implies a great professional responsibility as well as the need for a unitary approach (at the national level) of how to respond to this challenge, i.e. a technical regulation of the subject.

Finally, I point out that HG 2139/2004 provides "*normal operating periods*" from a financial point of view and not from a technical point of view. Between the "*normal operating period*" of a reinforced concrete bridge (32...48 years, according to # 1.3.17.2. of the catalog on the classification and normal operating periods of fixed assets from HG 2139/2004) and the „*design life*” of (minimum)

100 years (according to Eurocode 0, CR 0/2012 etc.) is a big and strongly relevant difference.

R E F E R E N C E S

[1] - NE 012/1:2022 - Regulations for concrete production and execution of concrete, reinforced concrete and prestressed concrete works - Part 1: Concrete production;

[2] – SR EN 206+A2:2021 - Concrete. Specification, performance, production and conformity;

[3] - NE 012/2:2022 - Regulations for the production and execution of concrete, reinforced concrete and prestressed concrete works. Part 2: Execution of concrete works;

[4] – SR EN 13670:2010 - Execution of concrete structures;

[5] – Dan Paul Georgescu, Adelina Carmen Apostu – Practical guide for evaluating the strength and durability of concrete in accordance with the new national and international regulations (2 volumes);

[6] - Dan Paul Georgescu - Concrete durability design guide in accordance with the national application annex of SR EN 206. Durability classes, Tipografia Everest 2001, Bucharest;

[7] - Achim Theodor – 1941. The causes of the collapse of the Carlton flatblock;

[8] - Bălan Ștefan, Cristescu Valeriu and Cornea Ion – 1982. The Romanian earthquake of March 4, 1977;

[9] - Law no. 10 of January 18, 1995 regarding quality in construction with subsequent additions;

[10] – Design code. Basics of construction design - Indicative CR 0 – 2012

[11] – ISO/CD 16204 – Durability – Service life of concrete structures, 2011;

[12] – ISO 2394:1998 – General principles on reliability for structures;

[13] – SR EN 1990:2004 – Eurocode 0 - Basics of structural design, with amendment and national annex;

[14] – SR EN 1992-1-1 – Eurocode 2: Design of concrete structures. Part 1-1: General rules and rules for buildings, with amendment, errata and national annex;

[15] – SR EN 1992-2 – Eurocode 2: Design of concrete structures. Part 2: Concrete bridges – design and constructive provisions, with amendment, era and national annex;

[16] - C170-2007 – Regulations regarding the anti-corrosion protection of reinforced concrete and prestressed concrete elements located in aggressive atmospheric environments;

[17] – CD 139:2002 – Normative for the anti-corrosion protection of the concrete elements of the bridge superstructure exposed to climatic factors, noxes and the action of chemical fondants used in winter.

[18] - Order of the Ministry of Transport, Construction and Tourism no. 620 of April 29, 2005 regarding the implementation and use of Eurocodes for construction, published in the Official Monitor number 399 of May 11, 2005;

[19] - Radu Gavrilescu - Concrete durability design. Establishing the thickness of the concrete cover layer of the reinforcements of monolithic and prefabricated elements (including calculation examples), in the Roads and Bridges Magazine ("Drumuri.Poduri") - Year XXVIII, No. 284, 285, 286, 287, 290, 291, 292;

[20] - Order of the Minister of Regional Development and Tourism no. 1530 of 23.08.2012 published in the Official Monitor, Part I no. 647 and 647bis of September 11, 2012. Regulation CR 0 / 2012 was supplemented by Order 2411 of August 1, 2013 published in the Official Monitor, Part I, no. 555bis of September 2, 2013;

[21] - Regulation (EU) no. 305/2011 of the European Parliament and of the Council of March 9, 2011 establishing harmonized conditions for the sale of construction products and repealing Council Directive 89/106/EEC;

[22] - Government Decision no. 2139/2004 for the approval of the Catalog regarding the classification and normal operating periods of fixed assets;

[23] - fib (International Federation for Structural Concrete) - MODEL Code 2010 – First complete draft, March 2010, based on the 1996 edition;

[24] – SR EN 13369:2018 - Common rules for precast concrete products.