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BACK TO 4.0:

RETHINKING THE DIGITAL CONSTRUCTION INDUSTRY

A cura di

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"Hypothesis for an application of the Factor Method to reinforced concrete"

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Topic: Life Cycle Management

Abstract

The research is collocated in the general field of the studies on life cycle management for building components and especially on the durability of reinforced concrete. In particular, in reference to *Factor Method*, introduced in norm ISO 15686 for the ESL prediction, the objective of this study is to suggest a methodology aimed to the reduction of subjectivity in the determination of the multiplying factor for this specific component.

Factor Method currently represents the instrument that is probably used the most for the estimation of the life cycle of building components, also thanks to its adaptability and simplicity. Yet, the most frequent critics that are moved against this method are indeed tied – in addition to those against the criteria for RSL determination – to the excessive subjectivity for the appreciation of multiplying factors.

In view of mandatory and voluntary legislation of the last years (referring, for example to UNI-EN 206-1 and to UNI 11104 which derived from it, or to D.M. 14/01/2008 and to EC2:2005) which contributed to provide useful elements of comparative and absolute evaluation, but also on the spur of some suggestions that were formulated during recent years in the worldwide scientific scene, the research suggests – in the aim of evaluating service life for structures in reinforced concrete – in its first part the definition of a set of values of reference (among which the values to use for the specific case can be chosen) corresponding to the parameters that are considered to have influence on each multiplying factor. Then, in the second part, in order to simplify the assignment of the scores to the users, the conditions of unitary value for each parameter have been identified, considering the results of direct observations carried out on the field in the last decades. Eventually, starting from unitary values, a complete grid of values has been defined, containing the values to attribute to worsening and improving conditions.

The results obtained in the research can represent for designers a possibility of application of *Factor Method* without risks of oscillation between too distant and subjective values, due to the uncertainty in adopting more appropriate scores.

1. Introduction

The voluntary and mandatory legislation which developed on reinforced concrete in recent times, embodies undoubtedly a fundamental resource to attempt to make objective the application of *Factor Method* to those structural components. In fact, it has provided a number of useful references for the prediction of the service life of those components: for example, D.M. 14/01/2008 (so-called NTC '08) in the last paragraph of point 11.2.11, states: *in order to obtain the required performance in function of environmental conditions, and for the definition of their relative class, one can usefully refer to the indications in the Guidelines for structural concrete, written by the Central Service of the High Council of Public Works*, that is to say to UNI EN 206:2006 and UNI 11104:2004.

In this work a methodology for the evaluation of service life for elements in reinforced concrete is suggested, in the following procedural steps:

a. RSL identification;
b. individuation of the parameters with influence on service life;
c. identification of the condition to associate mid-normal value to;
d. individuation of improving and worsening conditions in comparison to mid-normal condition.

The practical applicability of the suggested methodology will be finally completed by the attribution of numerical values to each of the corrective sub-factors found, in an additional phase that is being carried out in reference both to the data in scientific literature, and to the experimental ones from the laboratory, and also to evaluations on the field.

2. Factor Method for estimating service life of reinforced concrete

Factor Method, as it is acknowledged, allows the evaluation of Service Life for a given component or system in given conditions, starting from a value of reference corrected through a series of factors related to the specific conditions of the case under exam. The formula that synthesizes the *Factor Method* is

$$\mathbf{ESLC = RSLC \times A \times B \times C \times D \times E \times F \times G}$$

The 7 factors are respectively related to: quality of component, design level, work execution level, indoor environment, outdoor environment, in-use condition, maintenance level. The main critics against *Factor Method* are linked to its high degree of subjectivity, as some studies (e.g., Cusmano G. et al. 2003) even issued that differences higher than 80% can show up in ELSC evaluation by varying RSLC by little numerical values (even less than 10%), using the same input values for the factors: hence, there is the need to define methodologies that can reduce, at least, the differences between the estimators in attributing the values to the corrective factors. Some propositions were focused on the articulation of sub-factors, that actually

implicit in every evaluation of this typology: the point is to make them evident, in order to make considerations easier on each specific case.
The research that was carried out focuses the attention on the evaluation of service life for reinforced concrete structural elements. The proposition aims to the constitution of a check-list, which aims to perimeter the variables to consider, and – in the final part of the work – to create a grid of values among which the designer only has to recognize the one that best adapts the general method to the specific case.

3. Considerations on RSL and individuation of sub-factors

3.1 Reference Service Life

It is evident that, even starting the examination of the corrective factors, it is necessary to understand which the most appropriate criteria for RSL determination.
A useful hint for reinforced concrete structures can be constituted by D.M. 14/01/2008, which provides an interesting contribute in the paragraph §2.4.1, defining "*Vita Nominale V_N*" as "*the number of years during which the structure, given its destination, has to be able to be used, provided that ordinary maintenance is executed on it. The* vita nominale *for different typologies of works is the one reported in Table 2.4.I and has to be detailed in the project documents*".

	Typologies of works	**"Vita Nominale" VN** (in years)
1	Temporary works – Provisional works - Structures during construction	≤ 10
2	Ordinary works, bridges, infrastructure works and sized dams contained or of normal importance	≥ 50
3	Great works, bridges, infrastructure works and large dams or of strategic importance	≥ 100

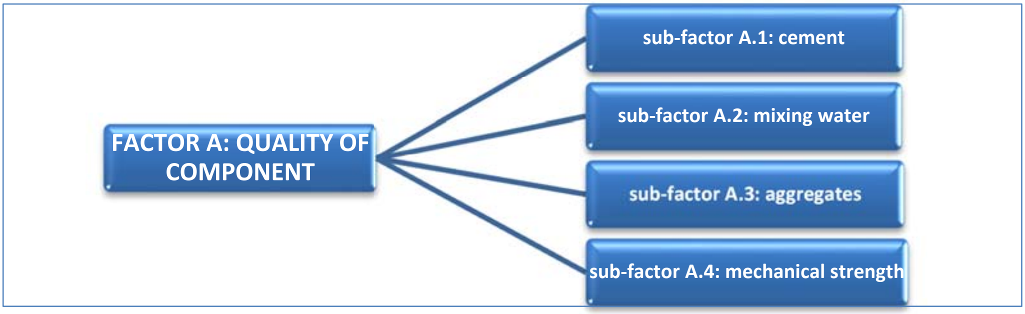
Fig.1 - Table 2.4.I NTC2008 – "Vita Nominale" for different typologies of works

Also in view of studies carried out since the '80s inside RILEM in the international scene, and in CTE and in some universities in the national scene, (e.g. Siviero E. et al., 1995) it seems opportune to consider that an ordinary reinforced concrete work, with characteristics epitomized by unitary values as explained in the following, has a value of V_N of 50 years.

3.2. Sub-factors and reference conditions

Considering the above, and making use of the help from scientific literature and from mandatory and voluntary legislation, the parameters that characterize the performance degree for each factor and influence service life will be individuated, and the possible conditions for each parameter, too.
Factor A: quality of component.
In order to find the mid-normal characteristics to which the unitary value is to be attributed, it has to be pointed out that the characteristics of the component depends on the characteristics of the elements that constitute the product (cement, water,

aggregate) and from the characteristics that concrete has in the fresh state and in the hardened state. Then, the sub-factors that can be considered are the characteristics of the components (cement, water and aggregate) and the characteristics of the concrete (fresh state and hardened state), as shown in the table reported below.



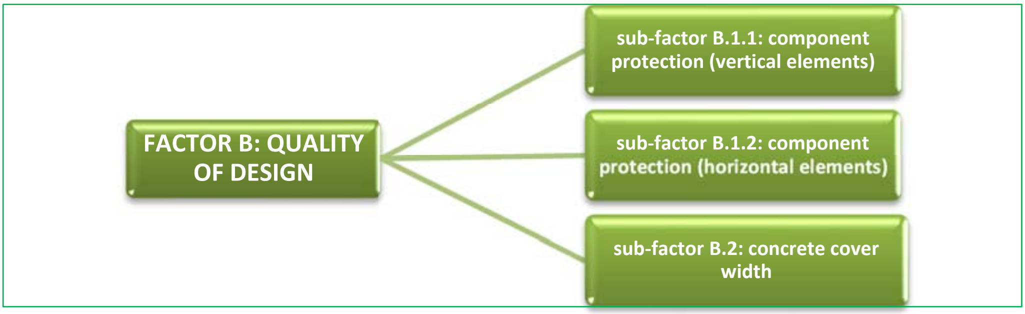
<u>A.1 Cement:</u> the European norm recognizes 150 types of cement, but the main typologies that are produced in Italy are only 5: Portland, Portland blend, Blast furnace, Portland pozzolan, mixed. Considering the intrinsic characteristics of the material and its current employment in the territory, the reference condition for the unitary value of the sub-factor is to be attributed to Portland blend cement.
<u>A.2 Mixing water:</u> it can be affirmed that the percentage of sulphate and chloride in the mixture water mustn't be higher than 0,5-1%, as they cause a reduction of the mechanical resistance; the same effect can be caused by the presence of humus substances in suspension, if more than 2g/l (UNI 1108:2003). The reference condition for the unitary value is then represented by the interval of values indicated above.
<u>A.3 Aggregates:</u> the presence of chlorides can contribute to the corrosion of iron bars, so it has to be lower than 0,05%, while the content of sulphate has to be lower than 0,2%, as it is responsible for the formation of secondary ettringite, with an increase of volume and consequential cracking (UNI 12620:2008). The limit values reported above represent then the limit reference condition for the unitary value.

Among the characteristics of the concrete in the fresh state and in the hardened state – homogeneity, workability and consistence for the former, and mechanical resistance and deformability for the latter – the ones that will be taken into consideration are the workability for the fresh state and the mechanical resistance for the hardened state.
The characteristics that can be referred to workability – fluidity and plasticity – mostly depend on the W/C ratio that, if opportunely defined, can avoid phenomenon such as the segregation of the coarse aggregate and the low fluidity. It seems difficult to characterize workability with a numerical parameter, but it is possible to define the W/C ratio in function of the class of exposition, as it will be explained below, and refer indirectly to the characteristic of workability.

<u>A.4 Mechanical resistance:</u> in this case the reference is once again to the D.M. 14/01/2008, which defines 16 classes of resistance, from a minimum value of C8/10

to a maximum value of C90/105. The reference condition can be identified with C28/30.

Factor B: design level.
This factor is constituted by the level of definition and attention in the design of the concrete. The categories of sub-factors that can be analyzed are those reported in the table below.

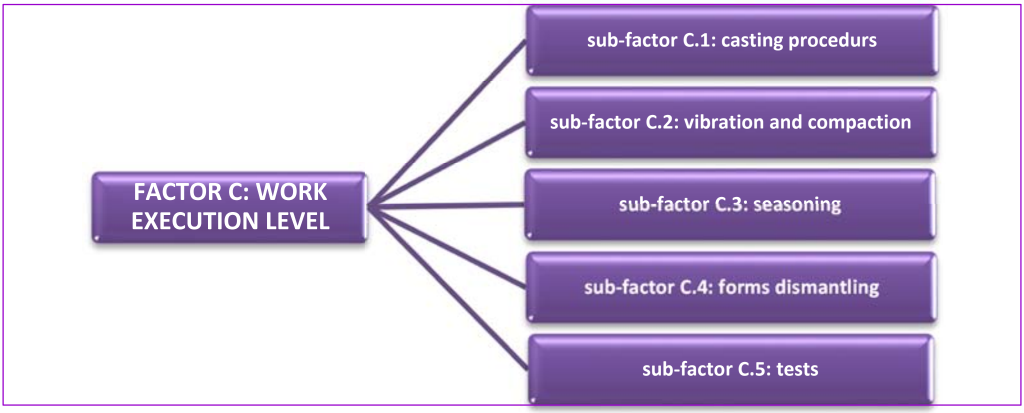


<u>*B.1 Component protection:*</u> the level of definition of the architectonical project allows to individuate the degree of protection from the external agents of the structural elements. The degree of protection is represented by the thermal insulation and the waterproofing; then, the reference conditions can be defined on the basis of the protection degree. For vertical structures, the mid-normal condition is the absence of thermal insulation and the presence of waterproofing of the cement plaster. For horizontal structures, the mid-normal condition is represented by the only presence of waterproofing.
<u>*B.2 Concrete cover width:*</u> On this matter, NTC'08 states: *in the aim of the protection of iron bars from corrosion, the layer of concrete cover (*"copriferro"*) has to be sized in function of the degree of aggression of the environment, also taking into account the tolerances of setting of the iron bars"*. In accordance with the European norm, it is possible to use the norm UNI EN 1992-1-1 for a correct sizing of the concrete cover; the procedure individuates – also in function of the structural class and of the class of environmental exposition – a value of the 'nominal' concrete cover c_{nom}. This condition represents the reference condition for the attribution of the unitary value.

Another parameter of certain interest could be the mix design, though it represents a complex process, determined by multiple variables. In this phase it is probably best to delay its evaluation, considering its close relation with other parameters of reference and the necessity of a specific in-depth analysis.

Factor C: work execution level.
This includes all the aspects linked to the quality of manpower, to the climatic conditions during setup and to what involves the construction site. The main legislative reference for the individuation of the execution level is constituted by the

Guidelines of the High Council of Public Works "*Guidelines for the setup of structural concrete and for the evaluation of the mechanical characteristics of the hardened concrete through non-destructive tests*". In particular, the aspects to analyze can be divided into the following sub-factors:



C.1 Casting procedures: the main requirements involve the homogeneous filling of the formworks, avoiding the segregation of the mixture. The main legislative prescriptions, relatively to the operational phase, provide indications on the free drop height of fresh concrete, on the width of the horizontal layers of concrete, on the opportunity to employ specific typologies of pipes and avoid construction joints. The fulfillment of 3 prescriptions out of these 4 constitutes the reference condition with unitary value.
C.2 Vibration and compaction: the Guidelines quoted above indicate specifically the procedures to follow for the execution of these 2 operations. The fulfillment of prescriptions is the reference condition, with unitary value.
C.3 Seasoning: also in this case, the Guidelines provide indications on the parameters to check; in particular, the following have to be kept under control: insulation and waterproofing of the formworks, temperature of the concrete, pouring protection and evaporation. Again, the fulfillment of 3 prescriptions out of these 4 constitutes the reference condition for the unitary value.
C.4 Forms dismantling: the procedures for a correct dismantling are regulated by a number of procedural indications, individuated by the Guidelines. The fulfillment of the prescriptions represents the reference condition for the unitary value.
C.5 Tests: the testing procedures involve the execution phase with tests of A-Type or B-Type, carried out in conformity with NTC08 and UNI-EN 206-1, and the phase that succeeds the implementation with probing carried out in accordance to UNI EN 12504 and UNI EN 12390 codes. The execution of controls constitutes the reference condition, with unitary value.

Factor D-E: indoor/outdoor environment

Actually, the method distinguishes the two factors, respectively related to the quality of the outdoor environment and of the indoor environment. In the current study, though, in reference to UNI 11104, which allows for the definition of internal and external actions for reinforced concrete works, what in general surrounds the element in the reinforced concrete structure must necessarily be considered as environmental condition. Then, it is necessary to refer to an only factor D-E, surrounding environment, and for it the sub-factor D/E.1 can be classified:

D/E.1 Class of environmental exposition: UNI 11104 code defines different classes of environmental exposition for 6 possible causes of decay, describing the corresponding environmental conditions and relating them to the risk of decay of the concrete. Finally, on prospect 4, in function of the class of environmental exposition, the norm individuates the conditions to respect, especially in reference to: maximum W/C ratio, minimum class of strength, minimum cement content, and minimum air content. The fulfillment of these prescriptions constitutes the condition of reference for the unitary value.

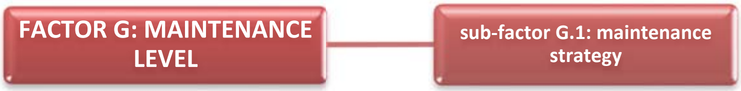
Factor F: in-use condition.

This generally takes into account the typology of use and the typology of users regarding the component. Specifically, in the structures in reinforced concrete durability is mostly influenced by the typology of use and so by the destination of use, rather than by the typology of users involved. Then, considering the low incidence represented by the typology of users on the decay of performances, the factor can be articulated in the following single sub-factor:

F.1 Class of use: in the aim of a correct and objective evaluation, it is possible to refer to the paragraph §2.4.2 of NTC '08 "*classes of use*", where a classification of the structures in seismic zones is suggested, in order to evaluate their period of reference. This classification seems to be appropriate in the examined case, as constructions are classified in a crescent order of danger for the users and the environment, and consequently of crescent exposition to the risk of usury. The classification has, as it is acknowledged, 4 classes (I, II, III, IV). The mid-normal condition can be represented by class II (ex. residential building), and the unitary value is attributed to it.

Factor G: maintenance level.

It considers the influence of maintenance on the duration of the component, and it is one of the most important aspects for the durability of the structures in reinforced concrete. In particular, it is opportune to identify the sub-factor reported below:



<u>G.1 Maintenance strategy:</u> it is about finding the maintenance strategy that will be carried out on the component considered, on the basis of the available information. In particular, with reference to the definitions of the UNI 9910, UNI 10147 and UNI 10366 codes, and to the main typologies of maintenance listed here (preventive and corrective) the condition of reference with unitary value is the mixed strategy, represented by a mix of the two.

4. Conclusions

In relation to the reference conditions that have been found in the previous paragraph, which correspond to quality levels defined as mid-normal, the possible different conditions have been examined in depth. As a consequence, on the basis of legislative prescriptions and of the scientific literature, the attribution of values that are higher or lower than unity, respectively if the analyzed conditions represent improving or worsening situations compared to the reference conditions, has been hypothesized, as it can be observed in the summarizing chart in Fig. 2.
The work that was synthetically illustrated here focused its attention on the structural reinforced concrete elements, and suggests hypothesis for the in-depth examination of the arguments related to the widely contested issue of the subjectivity in the attribution of values to the corrective factors.
The proposition, to be extended to the other components of the building system, after validations and in-depth studies, and through experimental applications, could constitute a useful document for designers in the aim of the individuation of the aspects that mostly influence durability, according to legislation.
It seems eventually appropriate to highlight that the legislative obligations on the maintenance plan force designers to make important and delicate evaluations on structures (specifically reinforced concrete ones): the reference is, in particular, not just to the Code of Public Contracts, but mainly to NTC ’08, that force the structural designer to compose this document, though its content and structure haven’t been defined by this D.M. yet. Then, it is necessary to provide appropriate instruments for the evaluation of the performance decay of structures, in order to avoid that the predictions on chronology and technology that characterizes the maintenance plan keep being entrusted to software that, unavoidably, formulates the very same propositions for every context in the world.

FACTOR	**SUB-FACTOR**	VALUE ESTIMATION		
		<1	=1	>1
Factor A: Quality of component	Cement	Portland Mixed	Portland blend	Blast furnace Portland pozzolan
	Water	% chlorides and	0,5 < % chloride and	% chloride and

		sulphate > 1 Humus substances in suspension > 2 g/l	sulphate < 1 1,5 g/l < humus substances in suspension < 2 g/l	sulphate < 0,5 Humus substances in suspension < 1,5 g/l
	Aggregate	0,05 < % chlorides content 0,2 < % sulphate content	0,025 < % chlorides content < 0,05 0,1 < % sulphate content < 0,2	% chlorides content < 0,025 % sulphate content < 0,1
	Mechanical resistance	<C25/30	C25/30	>C25/30
Factor B: Quality of design	Component protection (vertical elements)	No thermal insulation, covered with lowly waterproofing material and non-cement plaster	No thermal insulation, covered with waterproofing material and cement plaster	Thermal insulation
	Components protection (Horizontal elements)	No protection	Protection with waterproofing layer	Protection with insulation and waterproofing
	Concrete cover width	$c < c_{nom}$	$c = c_{nom}$	$c > c_{nom}$
Factor C: Work execution level	Pouring procedures	1 or 2 prescriptions fulfilled	3 prescriptions fulfilled	4 prescriptions fulfilled
	Vibration and compression	No respect of the indications in the Guidelines of the High Council of Public Works	Respect of the indications in the Guidelines of the High Council of Public Works	-
	Seasoning	1 or 2 prescriptions fulfilled	3 prescriptions fulfilled	4 prescriptions fulfilled
	Dismantling	No respect of the indications in the Guidelines of the High Council of Public Works	Respect of the indications in the Guidelines of the High Council of Public Works	-
	Tests	No tests	A Type or B Type Tests Probing	-
Factor D-E: Indoor and outdoor environment	Class of environmental exposition	No respect of the indications in Prospect 4 UNI 11104	Respect of the indications in Prospect 4 UNI 11104	Improving conditions in comparison to the indications in Prospect 4 UNI 11104
Factor F: In-use condition	Class of use	Class III and IV	Class II	Class I
Factor G: Maintenance level	Maintenance strategy	Corrective maintenance	Mixed maintenance (preventive and corrective)	Only preventive maintenance

Fig. 2 – Summarizing table of the values to confer to sub-factors

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18. UNI EN 12504-1:2009 - Prove sul calcestruzzo nelle strutture.
19. UNI EN 12504-3:2005 - Prove sul calcestruzzo nelle strutture.
20. UNI EN 12390 (parti 1-8):2002 Prova sul calcestruzzo indurito
21. UNI 9910:1991 Terminologia sulla fidatezza e sulla qualità del servizio.
22. UNI EN 10147:2002 - Manutenzione, terminologia.
23. UNI 10366:2007 – Manutenzione. Criteri di progettazione della manutenzione
24. UNI EN 12350:2001 Prove sul calcestruzzo fresco: Campionamento, Prova di abbassamento al cono, Prova VéBé, Indice di compattabilità, Prova di spandimento alla tavola a scosse, massa volumica, Contenuto d’aria - metodo per pressione.
25. UNI-EN 13670 – 1:2001 Esecuzione delle opere in calcestruzzo – Requisiti comuni.