TECHNICAL CONTRADICTIONS IN THE EUROPEAN NORM EN 206 FOR CONCRETE DURABILITY

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ABSTRACT: In the EN 206, for each environmental exposure class recommendations are given in terms of water-cement ratio (*w/c*) , air content, cement factor, and strength class. The following aspects are examined in the present paper:

a) difficulties in the practical application of the norm;
b) contradictions between *w/c* and compressive strength;
c) incongruities between the environmental aggression levels and the corresponding durability requirements.

Keywords: durability, water-cement ratio, compressive strength, air content.

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INTRODUCTION

In a previous paper (1) the preliminary Euroopean Norm prEN206 (2) on concrete was critically examined for the durability criteria containing technical incongruities and contradiction.The purpose of the present paper is to examine critically the durability criteria as proposed in the final European Standard EN 206 (3) in form of tables defining the exposure classes for each environmental action and the relevant technical limits recommended for concrete composition and strength class. For this purpose the original tables of the European Standard EN 206 were segmented and re-arranged in the present paper for a better comparison of the exposure classes with the recommended limits.

DEFINITION OF THE EXPOSURE CLASSES

Table 1 shows the six environmental exposure classes and the corresponding designations (*XO*, *XC*, *XD*, *XS*, *XF*, and *XA*).

Table 1 - Exposure classes

CLASS DESIGNATION:	DESCRIPTION OF THE ENVIRONMENT:	No. of sub-classes
XO	No risk of corrosion (inside buildings with very low air humidity)	1
XC	Corrosion of the reinforcement induced by carbonation	4
XD	Corrosion of the reinforcement induced by chlorides other than from sea water	3
XS	Corrosion of the reinforcement induced by chlorides from sea water	3
XF	Freeze-thaw attack with or without de-icing agents	4
XA	Chemical attack	3

In the following sections each environmental exposure class - except *XO* - will be segmented in the corresponding sub-classes and combined with the technical limits required for durable concrete in terms of maximum water-cement ratio (*w/c*), minimum 28-characteristic compressive strength (strength class), and minimum air volume if any. The exposure class *XO* is not discussed in the present paper because it deals with non aggressive environments (inside buildings with very low air humidity) for which no limit is recommended by EN 206 in terms of either *w/c* or strength class for durability purposes. This does not exclude that high strength concrete can be specified and used for structural purposes in inside buildings belonging to the exposure class *XO*.

Exposure Class XC: Corrosion of the Reinforcement Induced by Carbonation

Four sub-classes (*XC1*, *XC2*, *XC3*, and *XC4*) are identified (Table 2) for each humidity level of the environment: dry (*XC1*); wet, rarely dry (*XC2*); moderate humidity (*XC3*); cyclic wet and dry (*XC4*). For each exposure sub-class, examples of structures are also provided in order to help the users of this norm in identifying the concrete structure (foundation, concrete sheltered from rain, etc.) typically exposed to the specific environment. Moreover, for each sub-class a limit to maximum *w/c*, minimum strength class and minimum cement content are given in order to reduce the risk of corrosion of the metallic reinforcement promoted by carbonation.

The authors of the present paper completely agree with the assumption that the steel corrosion promoted by carbonation depends on the humidity level of the environment as well as on the porosity of the cement matrix determined by the *w/c* adopted for the concrete mixture. However, several critical observations can be made to the solution of this problem as presented by EN 206.

a) The sub-class *XC1* (Table 2) and the class *XO* (Table 1) are both related to dry inside buildings the only difference being the humidity of the air which is "*low*" or "*very low*" respectively. How can the users of the norm distinguish between these two levels of humidity?

Table 2 - Exposure class XC: Corrosion of the reinforcements induced by carbonation*

Class designation:	Environment description:	Examples where exposure classes may occur:	Max. W/C	Minimum strength class**	Min. cement content (kg/m^3)
XC1	Dry or permanently wet	• Inside building with low air humidity	0.65	20/25	260
XC2	Wet, rarely dry	• Water retaining structures • Foundations	0.60	25/30	280
XC3	Moderate humidity	• Inside building with moderate/high air humidity • External structures sheltered from rain	0.55	30/37	280
XC4	Cyclic wet and dry	• External structures exposed to rain water	0.50	30/37	300

*this may not be the case if there is barrier between the concrete and its environment

**cylinder/cube concrete strength class (N/mm^2) based on cement of strength class 32.5

b) According to EN 206, for a simple concrete structure such as a small house (not exposed to aggressive environments such as sea water, freezing-thawing or chemical attack), five different concrete mixtures should be placed (Fig. 1): one for the very dry inside building *XO* without any limit to *w/c*; a second concrete for the dry inside building (*XC1* with a maximum *w/c* of 0.65); a third mixture for the foundation (*XC2* with a maximum *w/c* of

0.60); a fourth concrete for the external patio "*sheltered from rain*" or "*inside building with moderate/high air humidity*" (*XC3* with a *w/c* not higher than 0.55); and a fifth concrete mixture for the external structures exposed to sun and rain water (*XC4* with a maximum *w/c* of 0.50). This really seems to be very confusing since, according to EN 206, the job-site of this small house should be transformed in a sort of sophisticated laboratory where different truck-mixers will cross each other to feed the concrete mixtures to be placed in the wall of the kitchen or the beam in the sitting room. This confusion will result in a full rejection of these recommendations on behalf of architects, civil engineers and contractors.

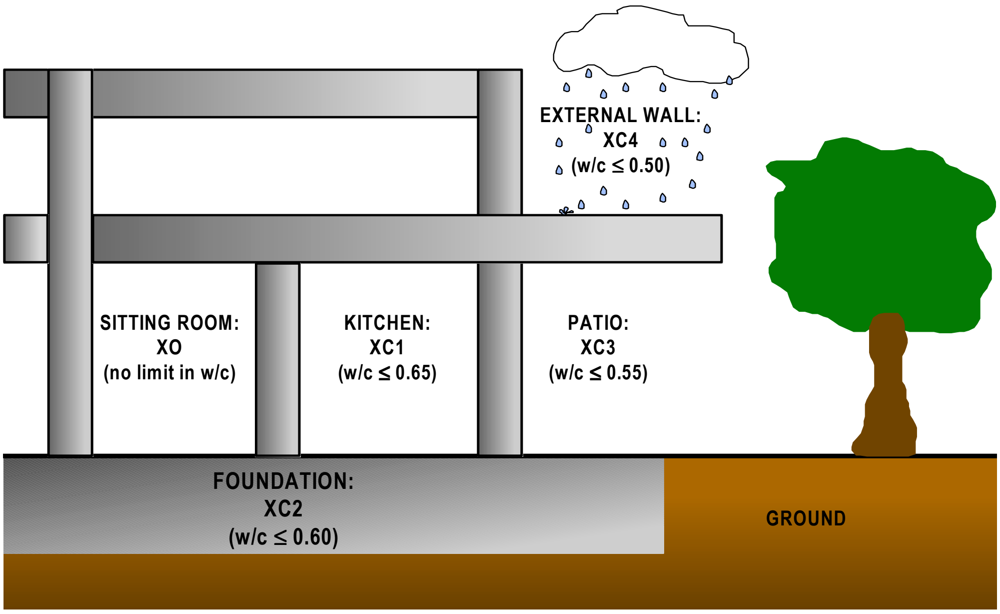

Figure 1 Example of different concrete mixtures which should be adopted in small house according to EN 206.

c) According to EN 206, all the above recommendations might not be taken into account when the surface of the concrete structures is protected from carbonation by an adequate *barrier* (see * in Table 2). Is a lime-based masonry mortar sufficiently protective from carbonation? Or we need a ceramic tile covering? No answer to these questions for the willing users of this norm.

d) Since it is not possible to determine the *w/c* really adopted for a concrete mixture, the 28-compressive strength can be a useful and simple method to check whether or not the actual *w/c* is out of the prescribed limit. This assumption is based on the relationship between *w/c* and compressive strength for a given cement strength class (for instance 32.5): the lower the *w/c*, the higher the concrete compressive strength. This assumption is in general respected in EN 206 with some not understandable exceptions. One of these is shown in Table 2: by changing the exposure sub-class from *XC3* and *XC4*, the maximum *w/c* is reduced from 0.55 to 0.50 but the minimum concrete strength class (in terms of 28-day cube compressive strength) is left at the same level (37 N/mm^2). **Why?** A possible answer could be ralated to the different cement content (300 vs. 280 kg/m^3) for *XC3* and *XC4*. But according to the basic principles of concrete science and technology the compressive strength is related to the *w/c* and not to the cement content.

Exposure class XD: Corrosion of the reinforcement induced by chlorides other than sea water

There are three sub-classes for each humidity level of the class *XD*: moderate humidity (*XD1*); wet, rarely dry (*XD2*); cyclic wet and dry (*XD3*). All these sub-classes (Table 3) refer to concrete structures exposed to chlorides other than from sea water (see section 2.3), and including chlorides from de-icing salts but without freezing-thawing (for instance slabs of internal car park in winter time). There is some difficulty in understanding the reason why two different environmental sub-classes (*XD1* and *XD2*) were proposed ("*moderate humidity*" versus "*wet, rarely*

Table 3 - Exposure class XD: Corrosion of the reinforcements induced by chlorides other than from sea water

Class designation:	Environment description:	Examples where exposure classes may occur:	Max. W/C	Minimum strength class*	Min. cement content (kg/m^3)
XD1	Moderate humidity	• Structures exposed to direct spray containing chlorides	0.55	30/37	300
XD2	Wet, rarely dry	• Swimming pools • Structures exposed to industrial waters with Cl^-	0.55	30/37	300
XD3	Cyclic wet and dry	• Parts of bridges • Pavements • Car park slabs	0.45	35/45	320

*cylinder/cube concrete strength class (N/mm^2) based on cement of strength class 32.5

rarely dry") with the same limits in terms of *w/c*, strength class and cement content (0.55, 37 N/mm^2 and 300 kg/m^3 respectively). Moreover, for concrete structures in exposure classes *XC4* (Table 2) and *XD2* (Table 3) the minimum strength class is the same (37 N/mm^2) but there are different *w/c* requirements (0.50 and 0.55 respectively).**Why?**

Exposure class XS: Corrosion of the reinforcement induced by chlorides from sea water

Table 4 shows the three different environmental exposures as far as the consequences of the corrosion, induced by sea water, are concerned: *XS1* for structures near to the coast exposed to airborne salt; *XS2* for submerged parts of marine structures; *XS3* for tidal, splash and spray zones for semi-immersed parts of marine structures where oxygen can feed the reinforcement corrosion more effectively than in the corresponding submerged structures. However, from a practical point of view it is very difficult to manage a job site where two concrete mixtures should be placed for the same structure of a marine work: one mixture with exposure sub-class *XS2* for that part of the structure which is fully submerged, and an other mixture with exposure sub-class *XS3* for that part of the structure in the tidal zone. However, after distinguishing the submerged part of the structure (*XS2*) from that at the tidal zone (*XS3*) one must adopt the same strength class (45 N/mm^2) related to the same *w/c* (0.45) but with a different cement content (320 versus 340 kg/m^3). This is very surprising since, all other things being the same (type of cement, aggregate, slump level, etc.), it is very

Table 4 - Exposure class XS: Corrosion of the reinforcements induced by chlorides from sea water

Class designation:	Environment description:	Examples where exposure classes may occur:	Max. W/C	Minimum strength class*	Min. cement content (kg/m^3)
XS1	Exposed to airborne salt but not in direct contact with sea water	• Structures near to or on the cost	0.50	30/37	300
XS2	Submerged	• Parts of marine structures	0.45	35/45	320
XS3	Total, splash, and spray zones	• Parts of marine structures	0.45	35/45	340

*cylinder/cube concrete strength class (N/mm^2) based on cement of strength class 32.5

difficult to understand how concretes with two different cement contents (320 and 340 kg/m^3) can attain the same strength level (45 N/mm^2) by adopting the same *w/c* (0.45). This seems to contradict the basic and experiential knowledge in concrete technology.

Exposure class XF: Freeze-thaw attack

Theoretically the freezing-thawing effect may be more severe in slabs than in vertical surfaces due to the direct rain exposure and then to the higher water saturation before freezing. However, from a practical point of view, it is very difficult to organize the placing of different concrete mixtures in horizontal and vertical surfaces of the same work. For instance, piers, abutments, beams and decks in the same bridge, should be manufactured by using different concretes depending on the specific exposure sub-class (Table 5):

- *w/c* ≤ 0.55 without entrained air for vertical surfaces exposed to rain and freezing (*XF1*);
- *w/c* ≤ 0.55 with at least 4% by volume of entrained air for vertical surfaces as above but exposed to airborne deicing salts (*XF2*);
- *w/c* ≤ 0.50 with 4% of entrained air for horizontal surfaces exposed to freezing without deicing salts (*XF3*);
- *w/c* ≤ 0.45 with 4% of entrained air for horizontal surfaces exposed to freezing and direct spray of deicing salts (*XF4*).

Even in this exposure class (Table 5) there are some technical contradictions between maximum *w/c* and minimum strength class. For instance, the different maximum *w/c* which should be adopted in concrete mixtures for exposure sub-classes *XF3* and *XF4* (0.50 and 0.45 respectively) does not agree with the same minimum strength class (37 N/mm^2) for both the mixtures at equal entrained air (≥ 4%). Moreover, in the exposure class *XF3* (max. w/c =

0.50 and min. air volume = 4%) the strength class is the same (37 N/mm^2) as that of exposure class *XC4* (Table 2) where the same *w/c* ratio should be adopted *in the absence of entrained air*. A cube strength class of 30 N/mm^2 for the air-entrained concrete in exposure class *XF3* would be more adequate than 37 N/mm^2 (Table 5) in order to remove these contradictions.

However, all the above comments appear to be of negligible concern when compared with the confusion arising from the recommended limits for the same structure in exposure classes *XC* or *XF*. Think for instance about a reinforced concrete wall in two different environments, both characterized by wet-dry cycles the only difference being the absence or the presence of freezing-thawing cycles in winter time: the exposure sub-class should be *XC4* for the wall in Rome and *XF0* for the same wall in Stockholm. Accordingly, the *w/c* of the concrete should be 0.50 (Table 2) for a wall in Rome and 0.55 (Table 5) for the corresponding wall in Stockholm both without air-entrainment. So, the more severe exposure in Stockholm (wetting-drying cycles+freezing-thawing cycles) would require a less restrictive requirement in terms of *w/c* than the less severe exposure in Rome (wetting-drying cycles without freezing-thawing cycles).

Table 5 - Exposure class XF: Freeze-thaw attack

Class designation:	Environment description:	Examples where exposure classes may occur:	Max. W/C	Minimum strength class*	Min. cement content (kg/m^3)	Min. air volume (%)
XF1	Moderate water saturation, without deicing salts	• Vertical surfaces exposed to rain and freezing	0.55	30/37	300	-
XF2	Moderate water saturation, with deicing salts	• Vertical surfaces of road structure exposed to freezing and airborne deicing salts	0.55	25/30	300	4
XF3	High water saturation, without deicing salts	• Horizontal surfaces exposed to rain and freezing	0.50	30/37	320	4
XF4	High water saturation, with deicing salts	• Horizontal surfaces of road structures and vertical surfaces exposed to direct spray of deicing salts	0.45	30/37	340	4

*cylinder/cube concrete strength class (N/mm^2) based on cement of strength class 32.5

Exposure class XA: chemical attack

Table 6 has been rearranged and simplified on the basis of the original table as available in EN 206 for concretes exposed to chemical attack (*XA*) coming from soil or water. This exposure class seems to be the masterpiece of complication in the EN 206 European Standard. For instance, for an underground concrete structure (such as foundation or pipe) the following parameters should be determined:

- sulphate content of the soil to select the corresponding exposure sub-class (*XA1*, *XA2*, *XA3*);
- water permeability to consider whether or not to the environment should be moved into a lower class depending on the specific soil permeability;
- acidity of the soil based on the German Standard test DIN 4030-2 (4) in order to move the exposure sub-class from *XA1* to *XA2* whether the acidity is higher than 20° Baumann Gully in soil with a sulfate content in the range of 2000-3000 mg/kg.

The authors of the present report think that neither design engineers nor architects (even in Germany) will specify such a complicated durability requirement for an underground concrete structure.

CONCLUSIONS

The European Standard EN 206 has been critically reviewed as for the durability criteria of concrete structures. It was segmented and re-arranged to relate the environmental exposure classes with the recommended technical and compositional limits. The main concerns on this norm are expressed in the following conclusions.

1. It is a very complicated norm since too many concrete mixtures should be placed even for a simple work: for instance, 5 different concrete mixtures should be theoretically used to build up a small house in a garden. There is the risk of rejecting this norm by potential users (architects, design engineers, contractors) who not necessarily are concrete technologists or scientists.
2. There are some technical contradictions between the recommended maximum *w/c* and the corresponding minimum compressive strength: for instance for concretes in exposure sub-classes *XC4* and *XD2* the maximum *w/c* should be 0.50 and 0.55 respectively, whereas the same strength class of 37 N/mm^2 would be acceptable at equal cement type and air volume; in exposure classes *XF3* and *XA2* the needed minimum strength class is the same (37 N/mm^2) at equal *w/c*, cement type (I 32.5) and cement content (320 kg/m^3) but with different requirements for the minimum entrained air volume (4% versus 0%).
3. There is some disagreement between exposure classes and the relevant requirements for durability purpose in term of maximum *w/c*: for instance, a concrete wall in the exposure sub-class *XC4* (wetting-drying cycles) needs a lower *w/c* (0.50) than that (0.55) required for the same structure in the more severe exposure sub-class *XF0* where freezing-thawing cycles occur in addition to wetting-drying cycles.

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Table 6 - Exposure class XA: chemical attack in natural soils, ground water, and sea water

Class designation	Environment description*							Max. W/C	Minimum Strength Class ****	Min. Cement content kg/m^3
	SOIL:		WATER:							
	Acidity (Baumann Gully)**	$SO_4^=$ (mg/kg)***	$SO_4^=$ (mg/l)	PH	CO_2 (mg/l)	NH^+_4 (mg/l)	Mg^{++} (mg/l)			
XA1	>200	≥2000 ≤3000	≥200 ≤600	≥6.5 ≤5.5	≥15 ≤40	≥15 ≤30	≥300 ≤1000	0.55	30/37	300
XA2	—	>3000 ≤12000	>600 ≤3000	>5.0 ≤4.5	>10 ≤100	>30 ≤60	>1000 ≤3000	0.50	30/37	320
XA3	—	>12000 ≤24000	>3000 ≤6000	>4.5 ≤4.0	>100	>60 ≤100	>3000	0.45	35/45	360

* When two or more aggressive characteristics lead to the same class, the environment shall be classified into the next higher class.

** To be checked according to the German DIN 4030-2 test

*** Clay soils with a permeability below 10^{-5} m/s may be moved into a lower class

**** Cylinder/Cube concrete strength class (N/mm^2) based on cement strength class 32.5