Scientific Research Publishing

Open Journal of Civil Engineering, 2023, 13, 25-34
https://www.scirp.org/journal/ojce
ISSN Online: 2164-3172
ISSN Print: 2164-3164

Impact of Non-Compliance of Exposure Classes in Reinforced Concrete Structures

Serigne Touba Thiam[1], Mouhamed Lamine Chérif Aidara[2], Alinté Diatta[3]

[1]Graduate School of Sustainable Development and Society, Iba Der Thiam University, Thies, Senegal
[2]Department of Geology, Faculty of Science and Technology, Cheikh Anta DIOP University of Dakar, Dakar, Senegal
[3]Pan-African Polytechnic Institute of Dakar, Dakar, Senegal
Email: stouba.thiam@univ-thies.sn

How to cite this paper: Touba Thiam, S., Aidara, M.L.C. and Diatta, A. (2023) Impact of Non-Compliance of Exposure Classes in Reinforced Concrete Structures. *Open Journal of Civil Engineering*, **13**, 25-34.
https://doi.org/10.4236/ojce.2023.131002

Received: December 23, 2022
Accepted: March 5, 2023
Published: March 8, 2023

Abstract

From the National Agency for the Organization and Construction of Infrastructures (ANOCI) program to the Emerging Senegal Plan (PSE), construction in Senegal has improved considerably. However, deficiencies remain in the specification of materials used mainly in hydraulic concrete. They are generally related to the specification of aggregates for alkali reactivity and the choice of exposure classes specified in NF EN 206-1. The purpose of this article is to study the incidence of non-compliance with exposure classes in reinforced concrete structures. To carry out this study, surveys were carried out at several sites (districts) in Dakar (Cité Avion, Touba Ouakam, Cité Asecna, Cité Batrain, Cité Comico, Cité Assemblée and Terme Sud) in order to collect information on the formulation and implementation methods used. The comparison of the various readings carried out made it possible to deduce conclusions and to give recommendations when using standard NF EN 206-1.

Keywords

Common Exposure Classes, Specific Exposure Classes, Concrete, Alkali-Reaction

1. Introduction

The construction sector has experienced a real boom in Senegal in recent years. This sector of construction has established itself in a real dynamic of growth. Construction activity remained dynamic in 2016 with a 13.3% increase in its value added in volume, after 15.5% in 2015 [1] [2] [3]. Unfortunately, this sector is nowadays, shaken, by a series of disasters (very advanced of 20 buildings of

Maristes housing under threat of demolition after less than 15 years of reception, collapses, repetition of construction defects are the subject of the report reporting 976 buildings threatening ruins in 2018 and 197 in 2019 making 166 victims including 15 dead [4]. Dakar is the most affected area with a higher rate of urbanization (48%) resulting in a significant concentration of building works. The latter are mainly made with concrete, 190 m^3 of which are poured every second in the world, or 6 billion m^3 per year [5]. This makes it the most used manufactured material in the world but unfortunately suffers from significant environmental-specific degradation or it is implemented. To remedy this problem, countries such as France, Belgium, Switzerland, the United Kingdom, etc. after several researches on certain pathologies identified on concrete, have established standards namely: NBN EN 206-1: 2001 (for Belgium), NF EN 206-1: 2004 (for France) to specify the different classes of concrete exposure and to minimize damage in concrete structures [6] [7]. This study aims after having exposed the different classes of concrete according to their exposure, to collect information on the source of supply for the construction sites (aggregates; water; cement); the control of the manufacture and the control of the implementation and the resistance and to give remarks and orientations when the use of the standard NF EN 206-1 in Senegal.

2. Classes of Exposure Classes for Concrete

They include common exposure classes and specific exposure classes:

2.1. Common Exposure Classes

They correspond to the exhibitions most frequently encountered in buildings and civil engineering works [7].

X0: No risk of corrosion or attack (freeze/thaw, abrasion, chemical attack):

This class may concern only unreinforced or weakly reinforced concrete with a coating of at least 5 cm. Example of work covered by class X0: Wall of refend that can be realized in concrete blocks but poured in place because re-entering in a formwork rotation (**Figure 1**).

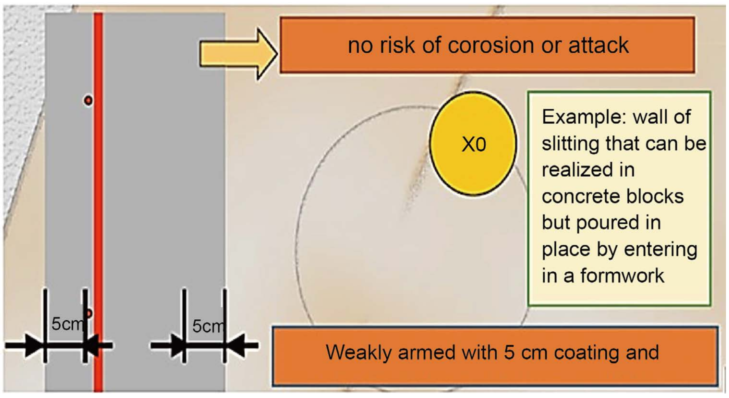

Figure 1. Illustration of structures affected by the concrete XO exposure class [8].

XC: Carbonation induced corrosion:

These classes apply to concrete containing reinforcements and exposed to air and moisture. Moisture conditions can be considered as a reflection of ambient humidity, unless there is a barrier between the concrete and its environment. Moisture conditions define the following four exposure classes:

XC1: Continuously dry or wet;

XC2: Wet rarely dry;

XC3: Moderate humidity;

XC4: Alternating humidity and drying.

For structures, concrete exposed to air in outdoor atmospheres are classified in exhibition class XC4.

Example of structures covered by class XC: Concrete structures containing reinforcements and exposed to air and humidity, exterior walls (XC1/XC3/XC4) and interiors (XC1), floors (XC1), external walls. (XC1), armed foundations (XC1/XC2) (**Figure 2**).

XF: Freeze/thaw attack with or without de-icing agent:

These classes apply when concrete is subjected to a significant attack due to freeze/thaw cycles while wet. Thus we have the following classes:

XF1: Low water saturation without developing agent;

XF2: Low water saturation without a de-activating agent;

XF3: High water saturation without developing agent;

XF4: High water saturation without developing agent.

Example of structures affected by class XF: Reinforced concrete structures exposed to a significant attack due to freeze/thaw cycles, external walls (XF1), external walls (XF1), external paving (XF2 or XF4) (**Figure 3**).

2.2. Specific Exposure Classes

These classes concern structures exposed to seawater, chlorides or chemically aggressive media [7].

XS: Chloride-induced corrosion in seawater:

These classes apply when concrete, containing embedded reinforcements or

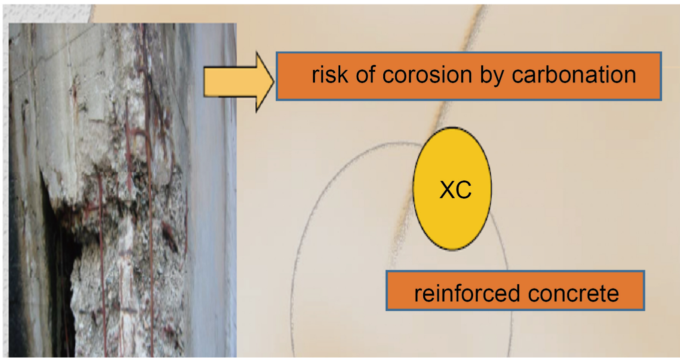

Figure 2. Illustration of the structures concerned by class XC of concrete [8].

metal parts, is subjected to chlorides in seawater or to the action of air carrying sea salt. The different exposure classes are:

XS1: Exposed to air carrying sea salt but not in direct contact with seawater. This class is to be used for structures less than 1 km from the coast;

XS2: Permanently submerged;

XS3: Areas of marling, areas of projection or spray.

Examples of structures covered by class XS: Reinforced concrete structures exposed to marine chlorides such as exterior paving (XS1 or XS2), exterior walls (XS1 or XS2), reinforced concrete structures permanently submerged in seawater (XS2), tidal area and area subjected to projections or spray (XS3) (**Figure 4**).

XD: Chloride-induced corrosion of a non-marine origin.

Classes apply when concrete, containing embedded reinforcements or metal parts, is subjected to water other than marine water, containing chlorides, including vehicle-driven de-icing salts. The different exposure classes are (**Figure 5**):

XD1: Moderate humidity;

XD2: Wet, rarely dry;

XD3: Alternating humidity and drying.

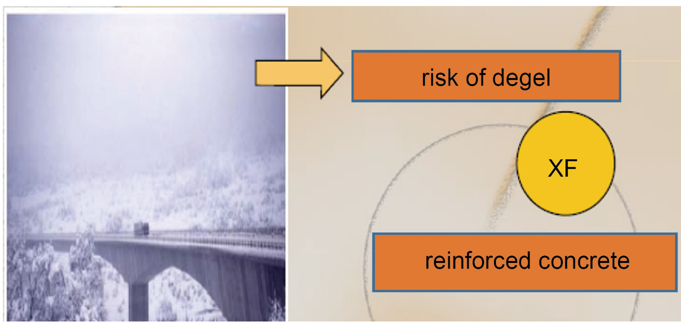

Figure 3. Illustration of structures affected by concrete class XF [8].

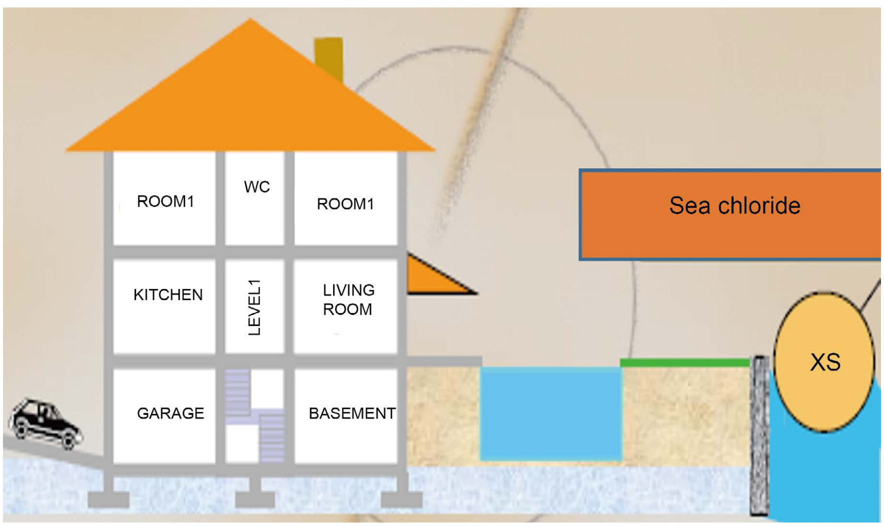

Figure 4. Illustration of structures affected by concrete class XS [8].

Examples of works covered by Class XD: Reinforced concrete works exposed to non-marine chlorides, sails and pool concrete slabs (XD2), covered car park ramps and slabs (XD3) (NF EN 206-1, 2004) (**Figure 5**).

XA: Chemical attack

These classes apply when concrete is exposed to chemical attacks, occurring in natural soil, surface water or groundwater:

XA1: Low chemical aggression environment;

XA2: Environment of moderate chemical aggression;

XA3: Highly chemical aggressive environment.

Examples of structures covered by class XA: Reinforced concrete structures exposed to chemical aggressions: foundations in urban environments (habitat foundations) and in agricultural environments such as manure pits, manure storage areas, silage areas and milking parlour (NF EN 206-1, 2004) (**Figure 6**).

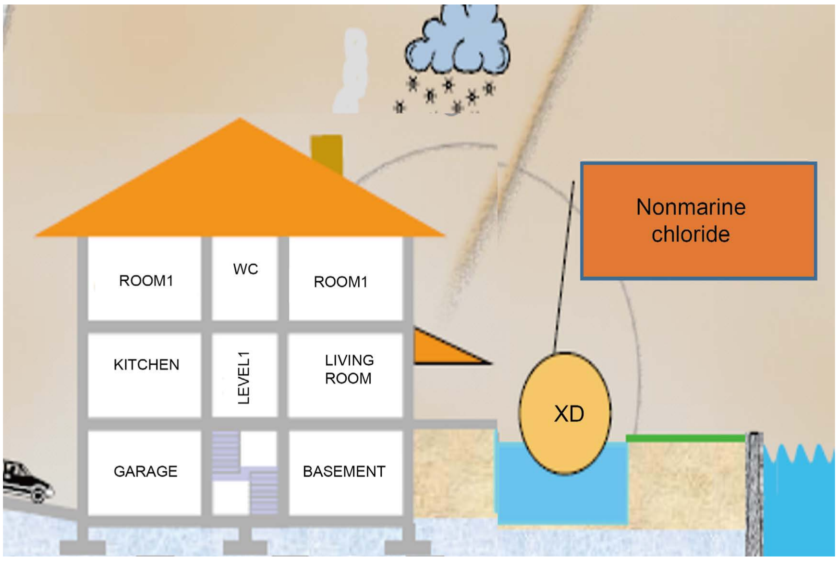

Figure 5. Illustration of the structures concerned by class XD of concrete [8].

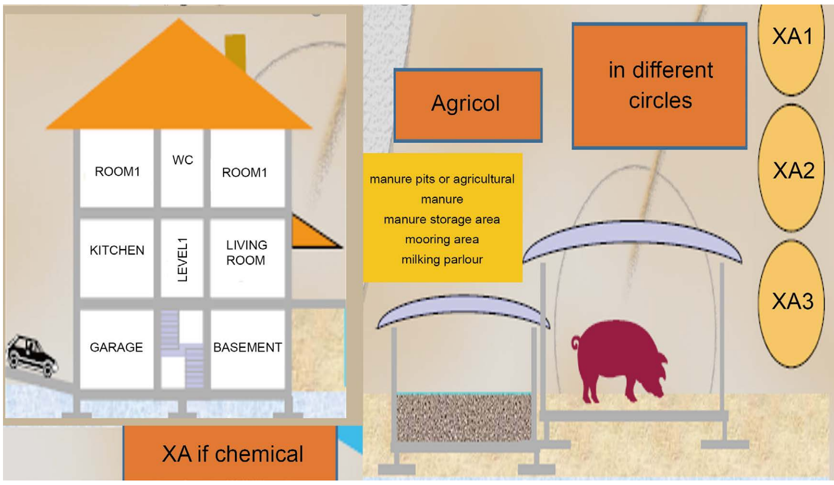

Figure 6. Illustration of structures affected by concrete XA class [8].

3. NF EN 206-1 Standards

The NF EN 206-1 standard is the culmination of 20 years of European standardization work by the TC 104 of the European Committee for Standardization (CEN). After the publication in 1990 of the European pre-standard ENV 206, the member countries published national standards based on this experimental European pre-standard, as was the case in France with the standard XP P18-305 (having submitted 11 exposure classes).

In 2004, NF EN 206-1 was published in France to replace the old experimental standard XP P 18-305, concerning the manufacture of structural concrete.

The standard NF EN 206-1 (with 18 exposure classes) with its National Annex has become, since 2005, the normative basis for all structural concrete. This standard became NF EN 206-1/ CN in December 2012 (**Figure 7**).

NF EN 206-1 is part of a global normative context that includes:

- component standards: concrete aggregates (NF EN 12620 andXP P 18-545), common cements (NF EN 197-1), concrete additives, additions (EN 450-1), (NF EN 934-2) and mixing water (NF EN 1008);
- Fresh concrete test standards (EN 12350 series) and hardened concrete standards (EN 12390 series);
- design standards (Eurocodes) in particular the NF EN 1992 or Eurocode concrete (EC 2) series;
- building performance standards (NF P 18-201: DTU 21);
- technical design rules and CCTG booklets (Paper 65, SNCF booklet, etc.).

b. Concrete affected and excluded by the standard

Concretes governed by the standard

The standard NF EN 206-1 applies to structural concretes, whether ready-to-use concretes or concretes made on site by the user of concrete, for use in buildings and civil engineering works. The standard is applicable for concretes used in factory prefabricated structural products and covered by a standard, the special conditions of application are defined in NF EN 13369 (**Figure 8**).

Concrete outside the scope of the standard

This standard does not apply to concrete that is not structural (filler concrete, curb concrete, cleanliness concrete, etc.) as well as to special concrete such as aerated concrete, foam concrete, cavernous concrete, refractory concrete, concretes with non-metallic aggregates or concretes with a density of less than 800 kg/m^3 (**Figure 9**).

4. Application of NF EN 206-1 to Senegal

a. Site Survey or Information Collection:

Field investigations focused on Category A, B and C sites.

To specify, the sites of:

category A are constructions of two floors maximum on ground floor or basement, single-detached houses, semi-detached, in small number;

Figure 7. Evolution of standard NF EN 206-1.

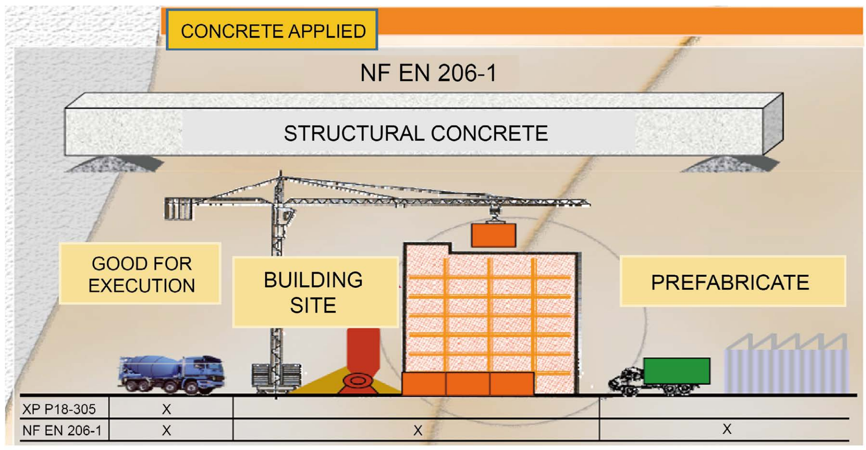

Figure 8. Illustration of the concretes concerned by standard NF EN 206-1 [8].

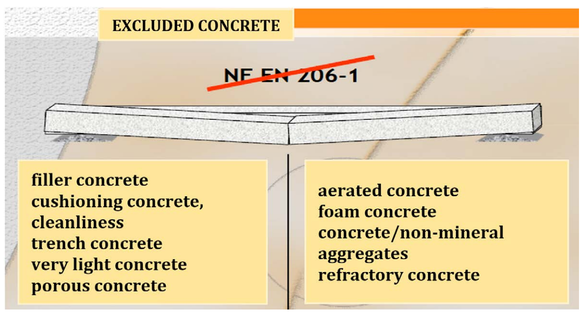

Figure 9. Illustration of concretes excluded by standard NF EN 206-1 [8].

Category B are buildings up to 16 levels, a large pavilion or industrial construction with a concrete volume of up to 5000 m^3;

Category C are buildings up to 16 levels.

Sampling:

Projects of category A:

These sites are most often spotted in the Dakar neighbourhoods and most of these buildings are run by master masons and entrepreneurs in the informal sector. During my visits, I identified thirty (30) sites in the municipality of Ouakam (Table 1).

Source of concrete supply:

The remarks made here are:

- Concrete Manufacturing: The concrete used in this category of workings is usually mixed or mixed manually in a basin dug on the ground and made waterproof with concrete by means of shovels (this is concrete made on site).

Table 1. Category A Projects.

District Name	Number of construction sites visits
1—Cité Avion	6
2—Touba Ouakam	6
3—Cité Asecna	5
4—Cité Batrain	5
5—Cité Comico	4
6—Cité Assemblée	2
7—Terme Sud	2

- Implementation of concrete on site: The already kneaded concrete is poured into buckets and then conveyed by the pulley-rope system to the workpieces to be poured.
- Concrete control: There was a complete lack of control over the concrete (no compression tests on the designed concrete).

Projects of category B and C:

These sites, most often found in the major arteries of Dakar, are generally under the direction of large construction companies. During my visits, I identified thirty (30) sites in some areas of Dakar (**Table 2**).

Source of concrete supply:

The remarks made here are:

- Concrete Manufacturing: Concrete, used in this category of workings, for low-volume elements, is usually mixed or mixed with concrete mixers of capacities ranging from 800 to 1000 m^3.
- And as for the pouring of the floors, the companies (customers or prescriber) order the concrete at the level of the concrete plants (producers) charged with the concrete composition according to the requirements of the customer.
- Implementation of concrete on site: The already kneaded concrete is poured into large cylindrical or funnel-shaped metal buckets using cranes (fixed or mobile) or hoists (with a lifting capacity of 1000 kg) before being conveyed to the casting elements.
- And as for the pouring of the floors in hollow bodies or solid slabs, the concrete is conveyed to the slab by trucks equipped with a concrete pump fed by concrete mixer trucks deployed by the concrete plants.
- Control over the concrete: In a different way from Category A workings, a check on the concrete was noted; this was carried out by means of test pieces containing a concrete sample to be tested for compression.

5. Data Analysis and Interpretation

Table 3 thus relates the various remarks on worksites and the conclusions relating to these remarks.

Table 2. B and C categories project.

District	Number of construction sites visits
1—BORAX ENGINEERING	10
2—CDE	2
3—SABLUX HOLDING	3
4—SERTEM	2
5—SARRE CONSTRUCTION	1
6—AKDAR	2
7—BATIX	1
8—CSE	1

Table 3. Data analysis and interpretation.

Category of site	Findings	Conclusions
A	• No concrete mix design; • Lack of characteristic strength check; • Lack of control over the quality of the mixing water (degree of toxicity not determined); • Exposure classes not taken into account.	• Non-compliance with standards (new concrete control guide) • Concrete with highly threatened durability
B et C	For in situ concrete: • No concrete formulation • Compression fracture test (characteristic strength); • Lack of control over the quality of the mixing water (degree of toxicity not determined); • Exposure classes not taken into account.	• Non-compliance with standards (new concrete control guide) • Concrete has sustainability threatened
	For plant concretes: • Concrete MIX DESIGN; • Compression fracture test (characteristic strength); • Lack of control over the quality of the mixing water (degree of toxicity not determined); • Taking into account the XC Exposure Class • Not taking into account XF, XS, XD and XA classes	• Compliance with standards (new concrete control guide) • Concrete has sustainability threatened

6. Conclusions

In these developed points, it is noted on the one hand that there are several types of concrete specific to each task of realization of civil engineering works. And on the other hand, it is noted that there are classes of concrete exposure which reveal to us that for each zone where the work is carried out, concrete capable of withstanding the conditions of these sites must be used.

Exposure classes are also taken into account when determining the level of prevention against GCO (Recommendations 1994) or RSI (Recommendations 2007), where the category of work and the class of exposure are crossed.

By deduction, failure to comply with these classes of exposure of concretes can lead in the long term to significant damages such as: swelling of aggregates, cracks, and collapse, etc., on the work (example: slabs).

Despite these standards which regulate the use of these concretes, some concretes fall outside the norm in the building sector (NF EN 206-1, 2004). These non-standardized concretes have a serious influence on the durability of the structures.

The type of concrete involved in the construction of these structures is subject to high-level requirements that must be met (which is not the case in Senegal: informal construction sector) in order to avoid material breakage (aggregate: gravel).

Compliance with the exposure classes established by NF EN 206-1, 2004 is therefore mandatory in the construction of reinforced concrete, prestressed concrete or non-reinforced concrete structures to avoid the serious consequences that could result.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] L'anoci Devient. Agence Nationale pour l'Organisation et la Construction d'Infrastructures. http://www.xibar.net

[2] PSE. Ministère de l'Economie, du Plan et de la Coopération.

[3] Indice du Chiffre d'Affaires dans la Construction (ICAC). https://www.ansd.sn

[4] Rapport Direction Protection Civile : 225 Bâtiments Effondrés en 2015. https://www.senego.com

[5] Statistiques Mondiales Écologiques. https://www.planetoscope.com

[6] NBN EN 206:2014 ICS : 91.100.30 Concrete and Concrete Products.

[7] NF EN 206-1: 2004 AMD 2 2005. Concrete-PART 1: Specification, Performance, Production and Conformity.

[8] SNBPE National Ready-Mixed Concrete Syndicate.