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Contribution to the Taking into Account of Environmental Factors of Vulnerability of Reinforced Concrete Buildings in the City of Douala-Cameroon

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Abstract

The environment of the city of Douala (humid, porous, sandy-clay soil), plays a determining role on the vulnerability of reinforced concrete constructions, by effects of corrosion of degradations, and destructions of the structures (buildings). Relative Y, the method tree of the causes and the tests pH-metric, granulometric and permeameters , allowed us to seek, to check and to analyze certain environmental factors impacting on the constructions, weakening the concrete and pari cochet , the resistance and the durability of the buildings. To this end, the pH tests of groundwater, springs and industrial discharges, containing chloride ions (Cl-), sulphates and carbon dioxides from heavy rainfall and flooding, attack by an electrochemical mechanism the reinforcement and framework of the constructions. Thus, the results obtained from the tests, demonstrate how the dangerous acids present in water, penetrate into the reinforced concrete to destroy it. The resulting chemical reaction of hydration absorbs the water and swells the concrete to reach the steel, weakening it and destroying the protective film (passivation). The action of water on concrete is declined by absorption, hydrolysis, dissolution, solvation and crystallization. Also, the corrosion rate of materials remaining strongly inherent to the high humidity and PH level ≤ 6, directly influencing the electrical resistivity conductivity and diffusion of oxygen and carbon dioxide in concrete.

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As such, the relative humidity (RH) or high water content in concrete and the environment of the site receiving the construction project, produces permeability decreasing effects in the presence of oxygen. These effects contribute to stimulate and increase the corrosion process. Because, water, soil and industrial pollutants, affect the works Given, that it is demonstrated that a quasi-permanent moisture content ≥ 55% in a porous material such as concrete, leads to the loss of 20 to 30% of its cohesion. Hence, the various forms of degradation and loss of loads suffered by the constructions. To this end, the binder content, mineral additives and the water/cement ratio (W/C), are to be considered for the evaluation, resistance and durability of the constructions. Also, most of the methods used to determine the permeability of porous materials are based on Darcy's law. This is because, in its basic form, the fluid flows through a disc-shaped sample under a pressure gradient. Consequently, in addition to the requirement of carrying out geotechnical studies of materials and soil in accordance with the standards of construction and urban planning, pH metric tests are necessary for the effective consideration of environmental factors to achieve the resilience and durability of reinforced concrete structures. It will be in particular: (i) to identify and analyze the impacts of water and soil on reinforced concrete constructions; (ii) to verify and analyze the compliance of the said constructions with the geotechnical and urban planning standards (realization of geotechnical studies and the use of adequate quality materials and qualified manpower); (iii) to contribute to the considerable reduction of the vulnerability of the works to the attacks of the sulphates , for a better safety and durability of the constructions.

Keywords: Climate disturbance; Vulnerability; Corrosion; Collapse; Resilience.

1. Introduction

The city of Douala, the economic capital and gateway to Cameroon by sea, is geographically located at the bottom of the Gulf of Guinea. It consists of a relief characterized by its flatness on the right bank, associated with the presence of creeks, mangroves and swamps. Its climate is humid with high rainfall and receiving heavy rainfall favored by its location on the edge of the sea. Also, its sandy-clayey and humid soil, impacts on the vulnerability of reinforced concrete constructions, in view of corrosion attacks from mineral salts and acids contained in the water. Similarly, urban sprawl and the anarchic occupation of the land taking place at the cost of major embankment work on non-built up areas, favor the construction of structures that do not comply with urban planning and construction standards [1, 12]. Hence the deplorable consequences of the damage and collapse suffered by the buildings.

1.1. Context

The relief and soil characteristics of the city of Douala (wet, porous, sandy-clayey) play a major role in the vulnerability of buildings. Because, the floods resulting from the saline and asphalted waters of the sea, attack by an electrochemical mechanism of corrosion, the framework of the buildings exposed to the acids, contained in the water, thus favoring the fragility of the constructions. From where, the degradations, the bursting of the concrete and the rupture of steel, thus involving the loss of the loads and the collapses [36] . Since, the resulting chemical reaction, absorbs and swells the concrete to reach the steel, then creating the rust causing corrosion and the rupture of this base metal.

To this end, the identification and appropriate analysis of the environmental factors of vulnerability of the works remain essential.

1.2. Issue

Findings of cracking, damage and deformation of reinforced concrete structures, require analyzes and appropriate solution approaches to address them [36]. Related to this, the soil of the city of Douala, made up of sandy-clay granular formations with a high humidity rate, remains exposed to frequent attacks by destructive chemical agents. These include chloride ions (Cl-), anions (So4), magnesium sulphates (MgSO4), and carbon dioxide, present in water and destroying reinforced concrete through corrosion mechanisms. These attack, destabilize the works by the pressure of the ground and the destruction of the constituents of the concrete such as: Alite (C3S), Belite (C2S), Tricalcium Aluminate (C3A) and Tetracalcium Ferrite Aluminate (C4AF) [9, 13,1] . To this end, the verification of the conformity of the structures with the standards of construction and town planning with a view to their resistance and their durability remains essential. It is in this respect that the particularity of the environment of the city of Douala is to be questioned. Hence, the problem of our research work, helping to limit the disastrous consequences suffered by constructions, in the face of environmental and climatic constraints

1.3. Objectives

1.3.1 General objective

-Search for resilient and adaptive solutions to limit the environmental impacts of vulnerability of reinforced concrete constructions in the city of Douala

1.3.2 Specific Objectives

1. *Identify and analyze the impacts of water and soil on reinforced concrete constructions.*
2. *check and analyze the conformity of constructions with the appropriate geotechnical standards;*
3. *Contribute to the reduction of attacks on structures by sulphates for the safety and durability of constructions.*

1.4. Assumptions

1. Identification and analysis of the impacts of water and soil on reinforced concrete constructions, allow adaptation to limit the occurrence of deplorable consequences;
2. Carrying out geotechnical studies of the soil and materials in accordance with construction standards, allows for better resilience and durability of buildings ;
3. The contribution to the safety and durability of reinforced concrete structures makes it possible to limit the degradation and corrosion of materials.

2. Chemical process of concrete degradation

The vulnerability of buildings remains a process for determining the extent of the damage and taking advantage of any opportunities to react and deal with the consequences or recover from the damage suffered. Because, the phenomenon of climatic disturbances with its corollaries of increases in episodes of precipitation and heavy flooding, have a considerable impact on structures (buildings) [2]. Given that the vulnerability of constructions is observed when one of its components simultaneously undergoes the two recognized aspects of exposure and sensitivity.

For this purpose, it is appropriate that the structural reinforced concrete be analyzed beforehand, taking into account all the environmental aspects that affect its hydration, degradation and destruction. Several studies demonstrate the evolution of the pH in view of heavy precipitation and rainwater becoming more and more acidic, and in the presence of chemical substances contained in the ambient air.

The process of chemical actions and its effects on the reinforcements of reinforced concrete is therefore due to the attacks of deterioration of the steel, favored by humidity [19, 20, 21] .

Thus, water, gas and cement hydrates contribute to the mechanisms of modification of the chemical and physical properties of concrete, starting at time (td), depending on the concrete/reinforcement behavior. From where, the formation of certain expansive layers at the origin of the constraints on the concrete. Finally, the third step is at time (tc), which corresponds to the occurrence of cracks, indicating the disappearance of the passivation layer following the drop in pH (basic solution = pH >7) [22] .

Non-compliance with construction standards by property developers, project owners and players in the building industry, are thus effects and chains of training causing all forms of cracking, degradation, deformation, instabilities, and load breaks. To this end, these causes of chemical degradation of concrete remain of an alkali-silica and alkali-carbonate order and result from several processes in particular:

1- bringing the concrete surface into contact with the aggressive solution;

2- the penetration of SO_4 anions, by diffusion limited to a superficial zone;

3- the occasional reaction of sulphate ions with anhydrous (C_3A) or hydrated aluminates (C_4AH_x and $C_3ACaSO_4H_{12}$);

4- cracking due to ettringite crystallization pressures ;

5- accentuation of sulphate penetration through cracks;

6- the progression of the attack following a degradation front whose thickness gradually widens over time;

7-the more or less complete destruction of the concrete.

- Sodium Sulfate Attack Case

1)- Formation of secondary gypsum or ettringite :

Ca(OH)2+Na2SO4+2H2O+CaSO4+2H2O+2NaOH;

2)- Formation of secondary ettringite , from residual anhydrous C3A:

C3A+3CaSO4+2H2O+26H2O+C3A+3CaSO4+32H2O;

3)- Formation from hydrated aluminates (monosulfoaluminate):

C3A+CasO4+ 18H2O+ 2Ca(OH)2 +2SO4+12H2O+C3A+3CaSO4+32H2O;

- Magnesium sulfate (MgSO4) attack cases :

Ca(OH)2 +MgSO4+CaSO4+ Mg(OH)2

Mg(OH)2 : brucite characterized by low solubility and low PH [36].

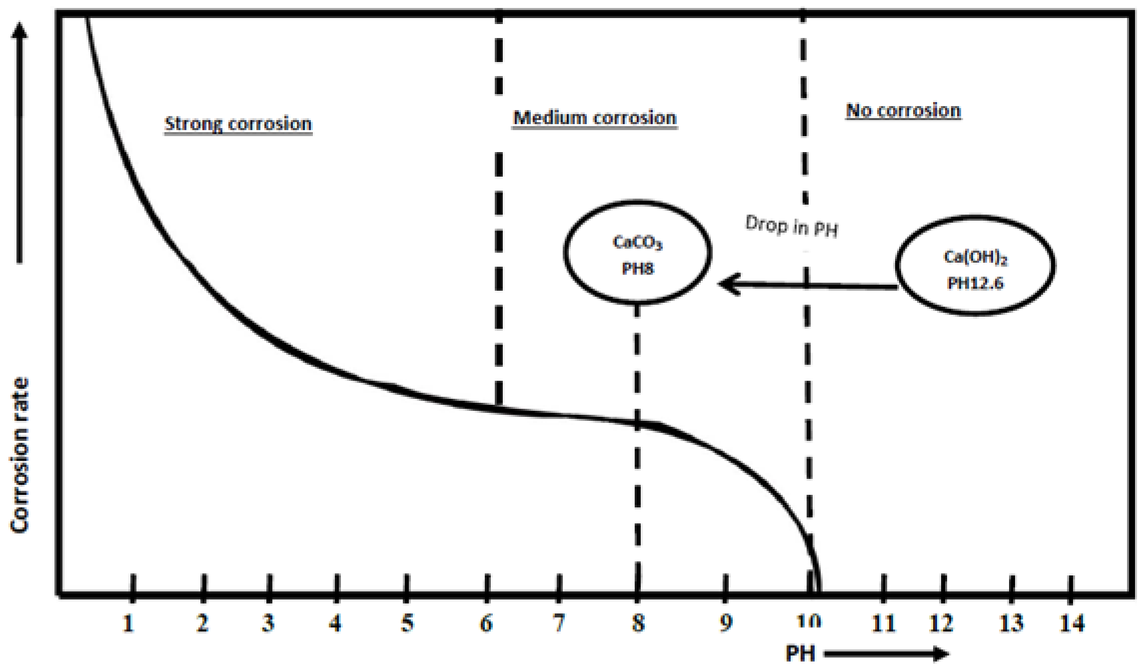

Figure 1: Steel corrosion rate as a function of the pH of the interstitial solution in the concrete [40].

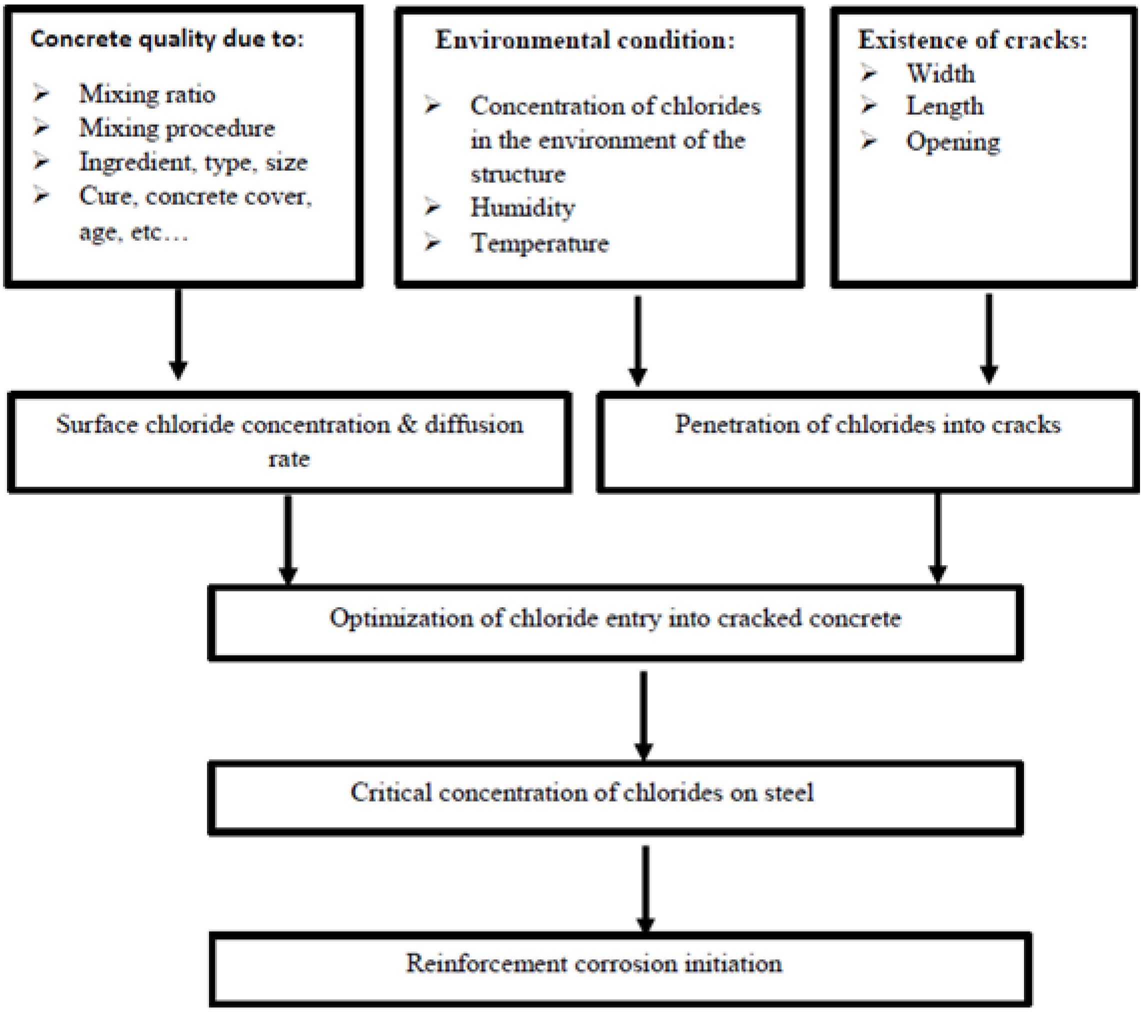

Figure 2: Diagram of attacks on structures by chlorides via cracks or porosity in the concrete [46].

2.1. Corrosion by chloride ions

Corrosion is a gradual, progressive transformation of steel into iron oxide by an oxidation-reduction mechanism. It occurs when the pH drops below 7, under conditions considered normal. Thus, the penetration of chloride ions within a cementitious matrix can cause enormous damage to the structure, which can lead to the destruction and ruin of the structure. Because, when the chloride ions penetrate at the level of the surface of the corroded reinforcement in sufficient quantity, they cause physico-chemical modifications on the surface thereof. Then, the initiation of corrosion will begin, which will thus reach the steels, through the open porosity of the concrete cover. The chloride ions will thus cause the destruction of the passivation layer. Hence, corrosion by dissolution of the steel. Because, the more the steel corrodes, the more the stress becomes important to the tensile strength of the coating, causing cracks and accelerating the penetration of aggressive destructive agents. However, the presence of chlorides and other mineral salts (NaCl) and carbon dioxide destroy the protective film of the steel and trigger oxidation-reduction. This process creates rust which causes corrosion of the base metal which is steel. [36]. For this purpose, three main fluids penetrate the concrete to weaken it. These are: water containing aggressive chloride ions, carbon dioxide and oxygen which move in several ways in the concrete.Two types of sources of attacks on concrete are also distinguished: attacks by external sulphates present in the environment of the concrete, formed from the layers of gypsum and secondary ettringite, as well as thaumasite from the exposed surface to sulfates.

As well as, internal sulphate attacks from the minerals that make up the concrete itself such as: Alite (C3S), Belite (C2S), Tricalcium Aluminate (C3A), and Tetracalcium Alumino Ferrite (C4AF) , from its preparation. The degradation of concrete by sulphates is therefore due to expansion phenomena, in relation to the crystallization of secondary ettringite , different from the primary and obtained from the hydration of portlandite cement by reaction of gypsum. However, the formation of secondary gypsum results from the substitution reaction between portlandite and sodium sulphate, but also from calcium aluminates in cement, or from remains of Anhydrous C3A (C3A+3CaSO4+2H2O+24-26H2O+ C3ACaSO4 H3O-32), either also from hydrated tetracalcium aluminate (C3AH13) or calcium monosulfoaluminate C3ASO4H12, or also emanating from tetracalcium alumino ferrite .

Also, the swelling of the solid resulting from the reactions between sodium chlorides, magnesium chlorides, portlandite and calcium chloride in contact with the tricalcium aluminate of the cement (C3A), make it possible to form Friedel's salt.

On the other hand, carbonation emanates from the action of atmospheric carbon dioxide (CO2) on the concrete. It penetrates the concrete and dissolves in the interstitial solution, then reacts with portlandite Ca (OH2) and hydrates (CSH). The reaction produced, causes the reduction of the PH of the interstitial solution of the concrete (acidity). To this end, the high rate of humidity, the temperature, the chemical pollution of the waters in the presence of ions and the industrial discharges (pollutants) thus affect the durability of the works. Related to this, the vulnerability of reinforced concrete to corrosion is the result of attacks by chloride ions and carbonation (carbonic acid H2CO3, formed in water by the effects of solvation of carbon dioxide CO2), coming from the air. in high rate, contained in groundwater, and soil [36].

2.2. Water Impacts

The severity of the impacts of water from climate disturbances on the vulnerability of buildings depends on the occurrence of a hazard (degree of surprise or unprecedented character of intensity, magnitude, exposure and sensitivity), backed by the environmental constraints, and characteristics of the ground receiving the construction project [8, 9]. Because, the action of water on the concrete is declined according to a varied process such as absorption, hydrolysis, dissolution, solvation and crystallization. This is why the destruction of the cementitious material comes mainly from the attack of aggressive agents existing in the environment, in water and soil content, but especially from the concentration of sulphates in contact with water. This is why it should be noted that water in a particular way plays the role of the electrolytic medium on the reinforcements of reinforced concrete constructions. This is therefore a determining parameter in the corrosion process. Since, the corrosion rate strongly depends on high humidity and PH which directly influence electrical resistivity conductivity and oxygen diffusion. Since, when the water content increases in the concrete, several effects occur such as: the decrease in oxygen permeability with high impact, contributing to stimulate the corrosion process. As such, several authors have demonstrated the existence of a relative humidity, critical of the order of RH 60%

in concrete, with the presence of aggressive destructive chemical agents, such as soluble salts such as: perchlora , acetals , halides and others… which are the cause of chemical degradation in reinforced concrete structures, corrosive on reinforcement and in the constituent elements of steel . Also, the water infiltrating into the ground, is charged with SO_4^{2-} ions, in contact with the soil or embankments containing sulphates. As such, the presence of humidity thus allows the combustion gas (coal, various fuels) to oxidize, emitting very aggressive sulfuric acid.

Also, it has been shown that so-called "acid" rainwater whose pH can go down to 4, and sometimes less, is very dangerous and aggressive. It is therefore indicated that the presence of rains in relation to environmental pollution, caused by sulfur oxides SO_x , of industrial or domestic origins, represent around 1/3 of the sulfur oxides contained in the atmosphere, lead to the formation very hygroscopic sulfuric acid, condensing into droplets and containing heavy metals (mercury, lead, silver, cadmium), and other sulphates such as ammonium and sodium [36] . Similarly, the oxides of azodes (NO_x) present in the atmosphere are transformed into nitric acid, allowing acid rain to cause degradation, following a complex process, causing dissolutions due to sulfuric and carbonic acids, but also expansions crystallization of salts, such as gypsum (dirt on facades) or etstringitus . We note that hydrochloric and nitric acids are strong mineral acids by reaction with the heat of the cement, and create calcium chloride $CaCl_2$ and calcium nitrate $(NO_3)_2Ca$, considered as very harmful and aggressive soluble salts. Also, sulfuric acids H_2SO_4, produced during the oxidation of hydrogen sulphide from sewerage networks or by condensation effects from atmospheric SO_2, are recognized as doubly aggressive, by the quality of the acidity and the anion SO_4^{2-}, contributing to the formation of expansive salts such as ettringite or gypsum [36].

2.3. Ground constraints

The characteristics and constraints of the soil of the city of Douala, which is predominantly porous, wet, sandy-clayey, with a low bearing capacity (0.63Mpa-1.10m), impact on the vulnerability of buildings and do not allow optimal infiltration of water. Since the low permeability of the soil creates the instability of constructions due to fatigue and pressure (clay, sand, humidity), especially with the insufficient depth of the foundations observed in the construction sites of the city. To this end, the components of resistance and durability of the constructions become fragile (degree of resistance to gravitational forces, load-bearing elements), etc., causing the destruction of the structure. Several scientists reveal that some cities can also suffer from effects related to the abnormal behavior of the ground (landslide, landslide, earthquake, etc.), causing collapses, as was the case in Logbessou - Douala in the recent past . and at Lombock Island in 2016, where buildings collapsed due to ground liquefaction phenomena, destabilizing structures [1, 9].

Some buildings are therefore likely to suffer serious material damage, and expose their occupants to considerable harm such as deterioration, deformation and subsidence. Since the building no longer offers a controlled, livable and secure indoor and outdoor environment for its operators. Hence, the requirement for constructions to comply with the appropriate standards (carrying out geotechnical studies, respecting the Master Plan for Town Planning and Land Use).

3. Research methodology

Our approach is based on methods with descriptive and quantitative approaches, of statistical counting of constructions having undergone effects of vulnerability (deformations, degradations, loss of loads). To this end, the collection of data, the documentary analyzes and the mapping of the study areas, enabled us to use the cause tree method and carried out certain pH-metric and granulometric tests, to seek the sources and environmental causes of vulnerability of constructions, to achieve lasting solutions to the problem posed by our subject. After investigations carried out on 200 samples of buildings in the city of Douala, only 81 have the building permit and have carried out studies geotechnics and generally great heights (R+1, R+2,….R+6…). On the other hand, 194 do not have one. However, 89 responses obtained from the technicians interviewed say that they know nothing about the conformity of the works for which they are responsible. Here presented as below, the results of the compliance survey of a sample of constructions:

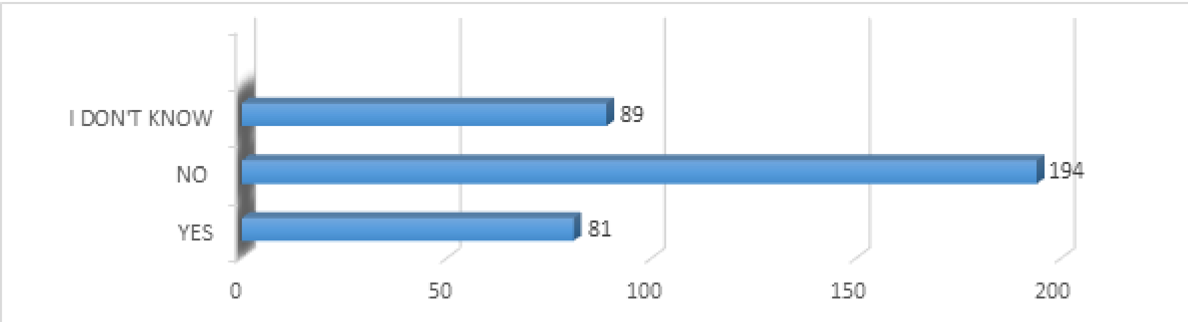

Figure 3: Results of construction compliance surveys in the city of Douala.

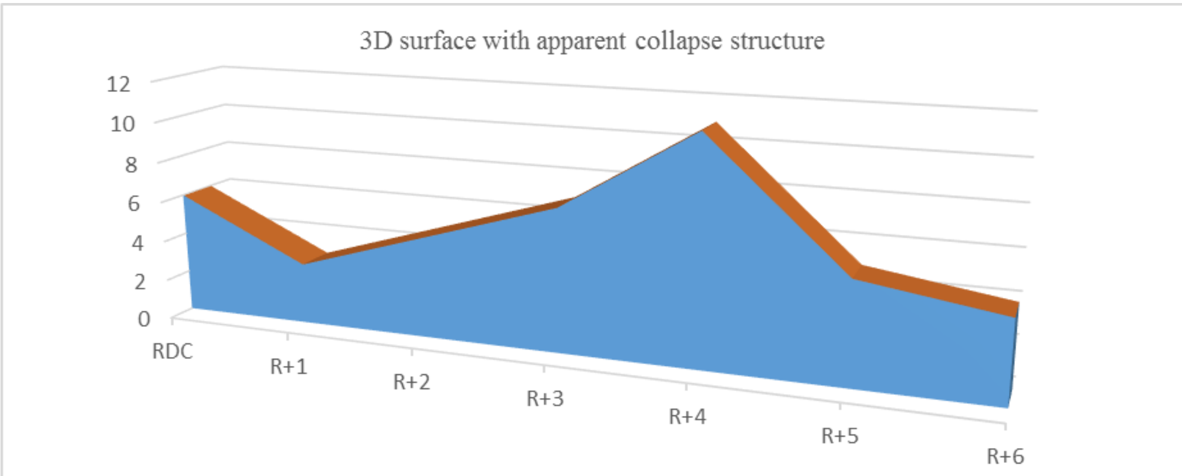

Figure 4: 3D surface modeling of the apparent structure of the type of collapsed constructions Years 2006-2016 / 2019-2021.

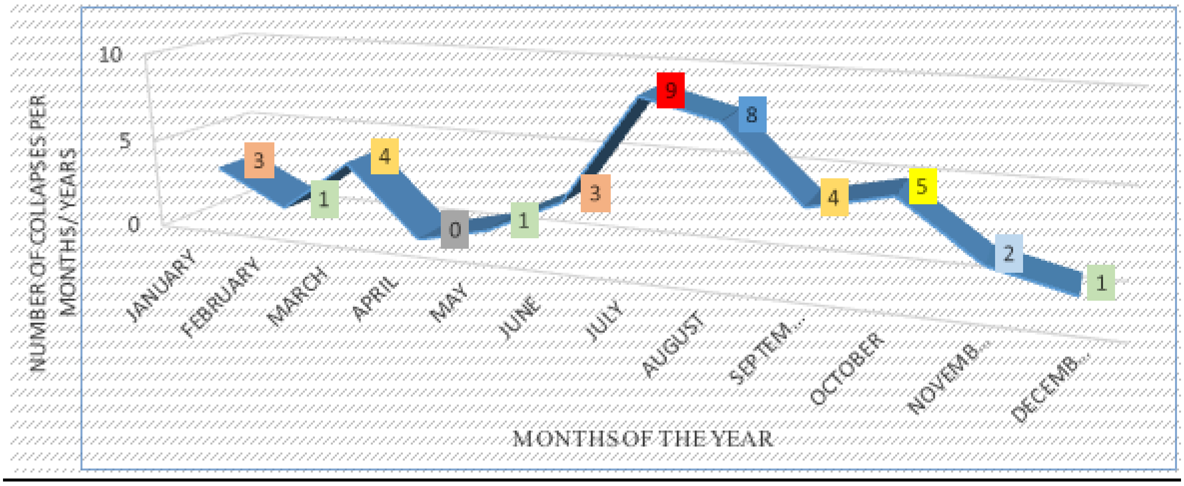

Figure 5: Stacked curves of monthly collapses Years 2006-2016/ 2019-2021.

3.1. Particle size test by sieving

The test consists of a dry and wet sieving, in application of the NFP 94-056 standard, making it possible to determine the weight percentages of the different families of grains, which the soil constitutes. The dry way is a dried sample sieving and the wet way sieving is to take the dried sample but after washing.

Then, the sample of the aggregate must take into account the formula: 200D≤ P≤ 600 , where D (mm) is the mesh of the largest sieve of the series and P(g) , the weight of the material to be sampled. Sieving ends when the residues do not vary by more than 1% between two vibration sequences. And the results obtained are represented by a granulometric curve, with the abscissa openings of the sieves on a logarithmic scale, and the ordinates the percentages of cumulative refusals or cumulative sieves , on an arithmetic scale. From where, the drawing of the curve in a continuous way without passing by all the Points.

•Procedure:

- Assemble the sieve column in decreasing order of mesh size, adding the cover and the bottom
- Pour the dry material into the sieve column
- Shake this column mechanically
- Take the sieves one by one, starting with the one with the largest opening, adapting a bottom and a lid
- Manually agitate each sieve until the sieve oversize does not vary by more than 1% by mass per minute of sieving.
- Pour the sieve collected at the bottom onto the immediately lower sieve
- Determine the mass of the refusal of each sieve in this way

- Follow the operation until determining the mass of the residue contained in the bottom of the sieve column

•Check the validity of the granulometric analysis imposed by Standard NF EN 933-1 (difference between the sum of the masses of refusal and sieves and the initial mass, etc.).

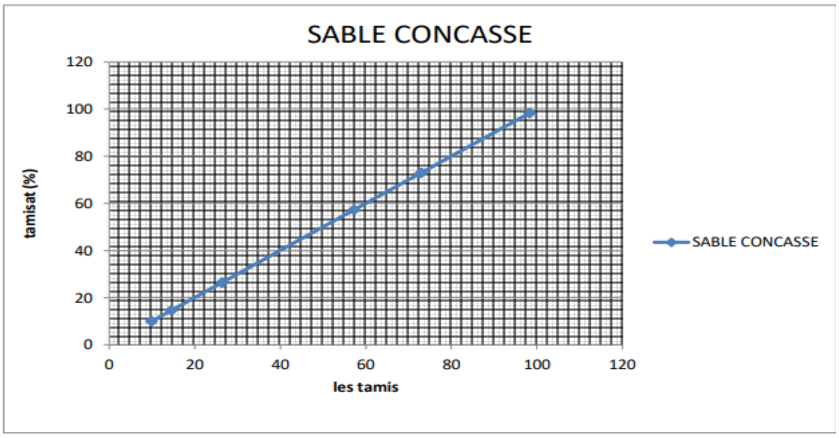

Figure 6: particle size analysis of crushed sand.

Table 1: Particle size analysis of crushed sand.

Sieve (mm)	Weight of empty sieves (g)	Weight of sieves+sand	Sand rejection	Cumulative rejection	Cumulative rejection %	Cumulative sieve
5	0.623	0.627	0.004	0.004	0.266	99.73
2.5	0.596	0.718	0.122	0.126	8.4	91.6
1.25	0.507	1.443	0.936	1.062	70.8	29.2
0.63	0.500	0.662	0.162	1.224	81.6	18.4
0.315	0.470	0.648	0.178	1.402	93.46	6.54
0.160	0.281	0.345	0.064	1.466	97.73	2.27
0.08	0.276	0.305	0.029	1.495	99.6	0.4
Fond	0.454	0.459	0.005	1.500	100	0

•Cleanliness of the sands:

The cleanliness of sand is assessed via a test called "sand equivalent" (Standard NF EN 933-8). This test consists of giving an indication of the importance of the impurities (clay, dust, organic matter, etc.) contained in the sands. These impurities have a negative influence on the adhesion between the grains of sand and the cement, which leads to a drop in the mechanical strength of concretes and mortars. According to

method of measurement, the sand equivalent is designated by ESV for the equivalent of sand at sight and by ESP for the equivalent of sand at the piston.

ES V = (H 2 /H 1) x 100%.

H 2: height of clean sand determined visually

ES P = (H' 2 /H 1) x100%

H' 2: height of clean sand determined at the Piston

H 1: clean sand height + imputed height

Table 2: Cleanliness classes according to sand equivalent values.

ESV at sight (%)	**Piston ES (%)**	**Sand quality**
PVC< 65	**ES *< 60***	**Clay sand** : Do not use
65 ≤ PVC <75	**60 ≤ *ES <70***	**Slightly clayey sand:** Admissible for ordinary concrete with high risk of shrinkage
75 ≤ *PVC <85*	**70 ≤ *ES <80***	**Clean sand** : Suitable for high quality concrete
PVC ≥85	**SE ≥ 80**	**Very clean sand:** Almost total absence of fine clay

Table 3: Cleanliness of crushed sand studied.

	H1 (cm)	**H2(cm)**	**H'2(cm)**	**ESV %**	**ESP%**
Trial1	**12.8**	**8.8**	**7.8**	**68.75**	**60.33**
Trial2	**12.7**	**8.9**	**8**	**70.07**	**62.99**
Trial3	**13.1**	**9.3**	**8.2**	**70.99**	**62.59**

Results

- The crushed sand gives an equivalent of visual sand > 65%, and that of the piston > 60%, which confirms that this sand is a slightly clayey property admissible for common concretes with a high risk of shrinkage.

3.2. Darcy's law

Darcy (1856) proposed a law of fluid flow in a porous medium with the following assumptions:

- flow forces are due to viscosity (inertial forces are neglected);

-the porous medium is completely saturated with a single fluid phase;

- the fluid flows are assumed to be laminar;

- the fluid has no physico-chemical interaction with the material.

In the last hypothesis, the fluid is assumed to have no interaction with the porous medium, but this is not the case for water in cementitious materials. Loosveldt showed that there was a good correlation between gas permeability and ethanol permeability corrected by the Klinkenberg effect on mortar dried at 60°C until stabilization of the mass. However, water permeability is at least one order of magnitude less than ethanol permeability [59]. The intrinsic permeability K (m2) is defined according to Darcy's law which is written:

$$Q = \frac{K}{\mu} A \frac{dp}{dx}$$

When the fluid flowing through the material is water, another quantity denoted Kw is used , called the "water permeability coefficient". We then express the apparent speed of water ua (ratio between the volume flow and the apparent section of the material) and we introduce the hydraulic gradient:

$$\frac{dh}{dx} \left(\frac{dp}{dx} = \frac{dh \rho_{eau} g}{dx}\right)$$

where ρ water is the density of water).

The relationship can be written:

$$u_a = \frac{Q}{A} = \frac{k \rho_{eau} g}{\mu_{eau}} \cdot \frac{dh}{dx} = K_w \frac{dh}{dx}$$

K_w is defined by the relationship:

$$K_w = \frac{k \rho_{eau} g}{\mu_{eau}}$$

The permeability coefficient K_w is homogeneous at a speed and is expressed in m/s. It is no longer an intrinsic quantity since it depends on the material, but also on the characteristics of the water. From the definition of K_w , it can be shown that a permeability of 1 m 2, corresponds to a permeability coefficient of 107m/s at 20°C [55].

Most of the methods used to determine the permeability of porous materials are based on Darcy's law. In the basic form of this law, fluid flows through a disk-shaped sample under a pressure gradient. However, all of these procedures are based on the same principle of applying hydraulic pressure to one end of a cylindrical sample and measuring the steady-state percolation rate. Since from the percolation rate and the dimensions of the sample, one can determine the permeability coefficient (K_w).

According to studies by Jensen in 1988, there are three main modes for measuring the water permeability of concrete through several permeameter -type devices such as: (i)-Measurement of flow through saturated concrete; (ii)-Measuring the penetration of water into the concrete; (iii)- the study of the drop of a pressure applied in the concrete; (iv)- the study of the drop in pressure applied to a concrete specimen.

The table below presents the values of the permeability coefficient of a cement paste at different ages for a W/C ratio of 0.7

Table 4: Coefficient reduction permeability of a cement paste for a W/C ratio of 0.7. [55].

Age (days)	**Permeability coefficient**
Costs	2x10-6
5	4x10-10
6	1x10-10
8	4x10-11
13	5x10-12
24	1x10-12
final	6x10-13

It is therefore established that:

-The water permeability coefficient decreases with the W/C ratio, For cement pastes of the same degree of hydration, the permeability decreases when the cement dosage increases, i.e. when the W/C ratio decreases.

- Hydration of concrete exposed to atmospheric air can be prevented and segmentation of capillary porosity can be interrupted even for low W/C ratio.

-To obtain a good concrete, its composition must be studied, followed by a correct implementation in a suitable environment, especially during the first days of hardening.

3.3. Six (6) cell permeameter

This testing device allows six concrete samples to be carried at a time. The reading of the water flow elapsed for each test specimen is ensured on cells (six cells) made of glass with a capacity of 1.5 l of water each. The specimens are held in place by a manual clamping system. The test specimens which can be used are cylinders with a diameter of 160 mm and of variable height. The experimental technique is based on the flow of water, i.e. the water passes through the concrete specimen under the effect of an applied pressure [55]. The components of the device are:

-Six slots for placing specimens with a fixing system.

- Silicone seals at the top and bottom.

- A pressure regulator.

- six graduated cells with a capacity of 1500 ml for placing water and reading the flow of water flowing out.

- Automatic air compressor with 10 bar capacity.

✓ **Results of the Pareto chart of effects**

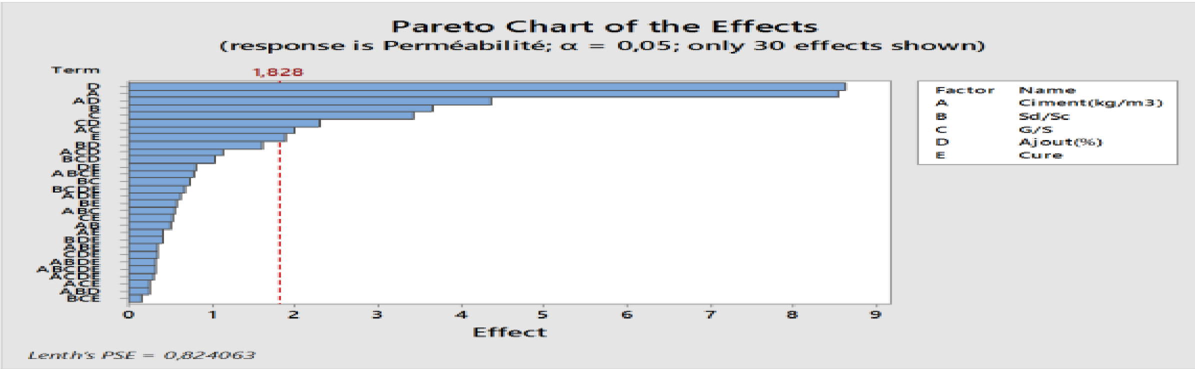

Figure 7: Results of the Pareto diagram of effects.

Looking at the red line passing through 5 factors and 3 interactions of 2 factors, indicates that all the factors are influential.

The determining factors of permeability are: 1) D: the percentage of addition; 2) A: the cement dosage; 3) AD: the interaction of cement dosage and percentage addition. 4)

B: the SD/SC ratio; 5) C: the G/S ratio; 6) CD: the G/S ratio interaction and the percentage of addition; 7) AC: the interaction of cement dosage and G/S ratio; 8) E: the cure

3.4. PH-metric test of water in the study areas of the city of Douala

The determination of the pH value of water according to the International Standard ISO 10523:2008(F), is of paramount importance for use and according to many types of sampling to be taken. Carrying out tests with a pH meter also complies with other known references such as: ISO 3696; ISO 5667-3. Waters whose pH values are considered high or low, are directly or indirectly recognized as toxic and dangerous for its use and the environment. The pH is a useful parameter for evaluating the corrosive properties of a structure and its environment.

✓ **Test apparatus**

1-Resealable flat-bottomed sample bottle , made of polyethylene or glass, eg laboratory bottle as specified in ISO 4796-2, designation 100 WS. The type of cap used should allow all air to be excluded from the sample bottle;

2-Device for measuring temperature, allowing measurement with a total uncertainty not exceeding 0.5°C. It is preferable to use the temperature probe;

3-Thermometer with a graduation of 0.5°C.

4-Temperature probe, separate or integrated in the pH electrode, for example Pt 100, Pt 1000 or with negative temperature coefficient. Temperature measurement deviations due to the device must be corrected against a calibrated thermometer.

5-The pH meter provides the following means of adjustment:

a) pH electrode zero point (or offset voltage);

b) slope of the pH electrode;

c) pH electrode temperature;

d) input resistance > 1012 W.

It must be possible to change the display of the pH meter to read either the pH value or the voltage (pH reading on the pH meter must be 0.01 or greater).

6-Glass electrode and reference electrode. The zero point of the measuring chain for glass electrodes should not deviate by more than Δ pH = 0.5 (manufacturer's declared value) from the nominal value of the pH electrode. The value of the practical slope must be at least equal to 95% of the theoretical slope. Use electrodes with electrolyte solutions and a flow rate of 0.1 ml/day to 2 ml/day as reference electrodes.

7-Agitator, operating with minimal gas exchange between test portion and air.

The pH value can change rapidly as a result of chemical, physical or biological processes in the water sample. For this reason, it is advisable to measure the pH value immediately at the sampling point. If this is not possible, take a water sample in a sample bottle. When filling the sample bottle, avoid gas exchange, for example the release of carbon dioxide, between the sample and the surrounding air. Completely fill the bottle and cap it, avoiding the formation of bubbles. Keep samples refrigerated (2°C to 8°C) and in the dark during transport and storage (ISO 5667-3). When samples are measured in the laboratory, check the potential influences of transport and storage on the pH value of the samples to be analyzed. Pay particular attention to sampling strategies for certain types of water matrices.

✓ **Operating mode**

1- Prepare the calibration buffer solutions;

2- Choose the buffer solutions so that the expected measurement of the sample is between the values of the two buffers. Because, the buffers must reach the same temperature, for a good reading of pH. Pour approximately 30ml of each of the buffers (10.01; 7.00 and 4.01) into separate 50ml beakers;

3- When a pH electrode that does not have an internal temperature probe is used, immerse a temperature probe in the test solution.

4- For the measurements, prepare the glass and the reference electrode or the combined pH electrode;

5- Switch on the measuring device;

6- Measure the temperature of the buffer and the sample solutions and that the buffer and the sample have the same temperature. If there is no temperature probe, set the device to the measurement temperature, using the pH values of the buffer solutions indicated on the respective certificates, according to the existing temperature;

7- Calibrate the two-point pH electrode using buffer solutions of the expected range of pH values (two-point calibration);

8- Adjust the devices manually from the determined data;

9- Immerse the pH electrode and the temperature probe in the first buffer, generally the one at pH 7, which is used to adjust the zero point. Then stir to avoid the enrichment of the potassium chloride caused by the leakage of the reference electrodes near the glass electrode;

10- Switch off the stirrer and start the calibration procedure on the measuring device. The automatic devices independently identify the stability of the measurement, keep this value and set the zero point;

11- When manually adjustable devices are used, initially set the zero point to pH7. Then, Rinse the pH electrode and the temperature probe carefully before, between and after the measurements using demineralised water, then in the rinsing beaker of pH 10.01 buffer;

12- Immerse the pH electrode in the second buffer solution and shake. Turn off the stirrer and begin the calibration procedure for the second buffer on the meter. The automatic devices independently identify the stability of the measurement and maintain this value by adjusting the slope. Adjust the slope so that the pH value of the second buffer is reached, for devices with manual adjustment;

13- Check the result of the adjustment of the pH electrode on two new samples of the buffer solutions. Measurements shall not deviate more than 0.03 from the relevant set point. Otherwise, repeat the procedure and replace the pH electrode if necessary. Then record the zero point and the slope of the pH electrode, as well as the measurement temperature. If information is needed regarding the condition of the pH electrode for a wide pH range;

14- Measure the samples under the same conditions as during the calibration. When changing solutions, rinse the pH electrode and measuring vessel with distilled or deionized water and, if possible, with the next solution to be measured. Then repeat the procedure with other subsamples, if appropriate.

✓ **pH Calculation Mode**

To calculate the pH of strong acids and bases you need: 1-For a strong acid pH: pH = -log C; 2-For a strong base: pH=14+ log C. They are valid for concentrations >10-7 mol/L; 3-For weak acid: pH= ½ pKa - ½ log C; 4-For a weak base: pH =7+ ½ pKa +½ log; 5- pH=1/2(pKa1+pKa2).

Table 5: Results of pH metric tests in the study areas of the city of Douala.

No.	**Period**	**pH**	**Nature Trials / areas**
01	Jan 2023	5.9	Borehole water / Ndokotti
02	February 2022	4.6	Borehole water / Bonapriso
03	August 2022	5.3	Borehole water / Bassa
04	October	6.00	Borehole water Industrial Zone
05	September	4.6	Spring water / Dakar
06	September 2022	4.6	Spring water / Ndokotti
07	December 2022	4.1	Borehole water / Logpom
08	December 2022	4.95	Borehole water / Bekoko
09	December 2022	4.4	Borehole water / Bonanjo
10	January 2021	4.3	Borehole water / Yassa
11	Jan 2021	4.8	Borehole water / Bessengue
12	October 2021	6.94	Discharge water / Bassa
13	February 2021	4.6	Borehole water / Makepe
14	June 2021	4.4	Borehole water / Cité-Sic
15	August 2021	3.4	Borehole water / Bonaloka
16	October 2021	3.9	Borehole water / PK12
17	December 2021	4.5	Borehole water / Makepe - Missoké
18	January 2020	7.2	Discharge water / Bassa
19	June 2020	7.4	Discharge water/port area
20	August 2020	5.6	Borehole water / Mboppi
22	Dec 2020	6.4	Borehole water / Bonaberi
23	January 2019	4.5	Borehole water / Akwa
24	February 2019	3.9	Borehole water / Ndogbong
25	October 2019	4.5	Borehole water / Logbessou

Source: *Hydrac-Cameroon Laboratory / Douala*

- The tree of causes makes it possible to establish and observe the correlations between the various causes and scenarios contributing to the impacts of vulnerability of the constructions

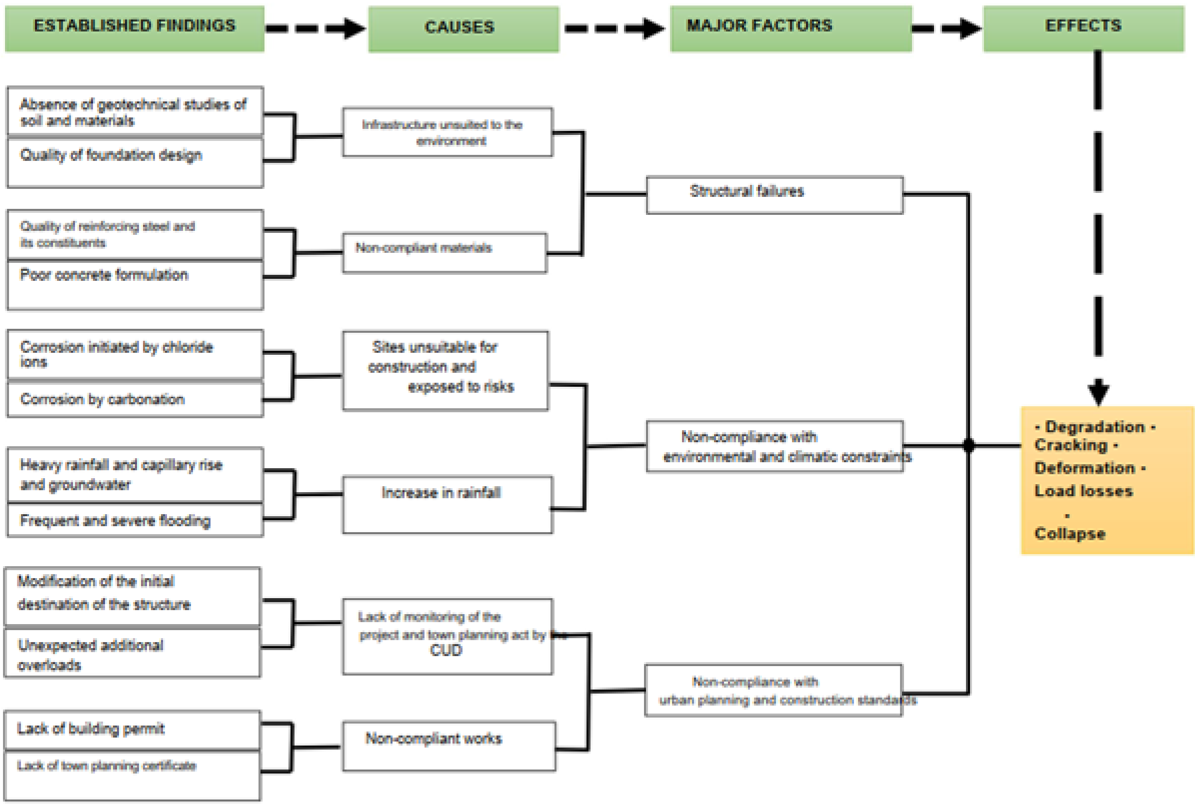

Figure 8: Cause tree.

4. Results and discussions

Environmental factors such as climate, water, soil, chemical substances (CO2, Cl-, Fe, Mg, NH4+...), and certain inappropriate and poor quality materials (steel, cement, aggregates) affect reinforced concrete structures. To this end, it has been shown that a quasi-permanent humidity level ≥ 55% in a porous material such as concrete leads to the loss of 20 to 30% of its cohesion . This thus denotes the quality of the corrosion attacks and the pH of the waters analyzed in the study areas. In this respect, the causal tree method and the granulometry and pH-metric tests in accordance with international standards for construction and town planning and that of the ISO 10523:2008(F) standard, establishing that certain materials (steels , cement, aggregates), unsuitable and of poor quality in a humid environment with water content in intact or disturbed soil of the site, carries a very high risk of degradation. Because, the presence of chemical and aggressive substances of concrete and steel contained in water such as chloride ions, carbon dioxide, acids, and soluble salts (perchlora, acetephales ...) , require to delay for a consideration in the realization of the works. In this respect, the auscultation applied to the high-rise building of types R+2, 3.6… and more, collapsed, made it possible to raise the low quality of the concrete (average, 15.86 Mpa) from where, the fragility of the deterioration and the rate of corrosion after the passage of water (heavy rainfall, flooding).

Corrosion of materials thus remains a result of lack of control, negligence in monitoring and formulation of concrete in compliance with appropriate construction and urban planning standards. Therefore, the binder content, the mineral additives and the Water/Cement (W/C) ratio are to be considered for the evaluation of the resistance and durability of constructions.

Related thereto, water whose pH values are considered high or low, are dangerous for its use and the environment of the site receiving the work. By the way, the pH remains a very useful parameter for the evaluation of the corrosive properties of structures (concrete/steel). The pH values resulting from measurements of rainwater, drinking water, surface and underground water, as well as wastewater and industrial discharges and those of liquid sludge or sewage water, respect the normative range, with a strength ionic less than I = 0.3 mol/kg (conductivity: $\gamma 25°C < 2000$ mS /m) of solvent and in the temperature range of 0°C to 50°C. Also, the pH value logarithm in base 10 of the molar activity ratio of hydrogen ions (αH) is multiplied by −1.

pH= -lg αH = - lg(^{m}H γH /m°) where :

αH is the relative activity (molality) of hydrogen ions;

γH is the molal activity factor of hydrogen ions at mH ;

mH is the molality, in moles per kilogram, of the hydrogen ions;

m ° is the reference molality.

pH is measured on a scale of 0 to 14, but a measurement of 7 indicates the neutrality of water. We note, that the gases (carbon dioxide released or dissolved in the sample), affect the pH value. Related to this, rainwater (meteorite) remains naturally acidic with a pH of 5-5.6. Because it absorbs carbon dioxide and the gases present in the air, combining with oxygen to form carbon (very dangerous) at the origin of the corrosion, degradation and destruction of reinforced concrete.

In summary, water, soil and polluting industrial discharges affect structures with macroscopic consequences, reactions of swelling, cracking, falling and loss of the mechanical characteristics of concrete.

This therefore strongly indicates the quality of the attacks and the rate of corrosion. Thus, the use of quality materials, compliance with standards, predictions of the evolution of water penetration into the concrete with the effects of degradation and corrosion of the structures affected, as well as the periodic evaluation the efficiency of maintenance operations, remain essential for an effective adaptation and resilience of constructions, in the face of the environmental and varied constraints of the day in the city of Douala.

Table 6: Main construction vulnerability factors in the city of Douala.

MAIN FACTORS	CAUSES AND ORIGINS	FINDINGS MADE
ENVIRONMENTAL, CLIMATE AND NORMATIVE CONSTRAINTS	**Humidity Exposure Frame**	-Corrosion initiated by chlorides - Corrosion initiated by carbonations. -High humidity. -Sandy clay soil
	Rainfall	- Frequent flooding. - Capillary rising water. - Superficiality of the water table.
	Marshy sites and non-buildable areas	- Punching of surface soles; -Unsuitable soil backfilling -Differential settlement of the foundations
	Poor quality of materials	-Poor quality of the constituents and of the reinforcing steel. - Failure to master the standards for obtaining and using construction materials
	Unsuitable infrastructure	- Lack of building permit - Absence of geotechnical studies of the soil / or failure to respect the results obtained. - Absence of pH metric water tests - Lump-sum choice and poor sizing of the foundations. -Unexpected overloads of additional floors - Illegal modifications and extensions of the destination of the works

5. Conclusion and perspectives

The soil of the city of Douala, made up of sandy-clay granular formations, with a high humidity rate subject to high rainfall with a saturation level of 99% with rising water tables, contributes to the degradation of the reinforcements, causing deplorable consequences for reinforced concrete constructions. Because, heavy rainfall and flooding in general, impact on constructions by an electrochemical corrosion mechanism that attacks concrete and steel. These waters, infiltrating into the ground, are charged with SO4 2- ions and penetrate into the concrete. Since, the presence of humidity allows the combustion gas to oxidize to emit very aggressive sulfuric acid. Similarly, the chloride ions found in the inter-granular spaces of the concrete, penetrate from the outside inwards to destroy the passivation layer protecting the steel and create the rust at the origin of the corrosion of the metal of base. Hence, its degradation, deformation and rupture. To this end, the contact of the concrete with the aggressive solution, creates a specific reaction of the sulphate ions with the tricalcium aluminates (C3A) or hydrates (C4AHx and C3ACASO4H12), making it possible to form dirt and cracks, to then destroy the materials by bursting. concrete. Thus, the performance of granulometric, pH- metric and Non-Destructive Testing tests to determine the quality of concrete structures and the evaluation of the compressive strength of structures through the digital Sclerometer (standard EN 12504-2 ASTMC 305M) remains essential. It is for this reason that the tree of causes method allowed us to research the various environmental causes of vulnerability on the constructions, while determining the pH values of the analyzed waters. This contributed to the determination of the acidity and alkalinity of the waters of the environment of the sites receiving the works.

As demonstrated by the scientist Ernest MBOTE in his work : " the neglect of preliminary studies of the soil serving as substratum and the failure to take into account its physical, chemical and mechanical characteristics, justify 73% of the failure of constructions in reinforced concrete in sub-Saharan Africa". As such, the analysis of the pH value as well as the geotechnical tests of the soil in accordance with the related standards (NFP 94-500, study missions) are essential. Also, the implementation of joint, effective actions for monitoring the establishment and construction of works by the Decentralized Local Authorities and the partner Administrations concerned, would contribute to a better practice of the process of adaptability and resilience of constructions.

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