



## **THE AFRICAN CONCRETE CODE**

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**ABSTRACT:** This paper poses the important question of whether there is a real need for another international code for the design of concrete structures in Africa. Concrete is an international material that knows no boundaries or continents. Then why would an underdeveloped continent such as Africa need a concrete code? Can a continent without much significant research base in concrete develop a design code? This paper will attempt to answer these questions. In so doing the paper presents a brief review of the basic significant differences and special features of the continent that would require special attention when it comes to design of concrete structures in this region of the world. The lack of suitable materials for concrete making, workmanship quality control and the prevailing environmental conditions in the continent of Africa require developing a special standard that could account for these specific problems. The paper also addresses the most significant differences of the current international codes such as the ACI-318 and EC-02 that hinder their use successfully and effectively beyond their national origins. These codes, however, can be used as reference codes for the new code.

It is concluded that in order to put the concrete industry in this region on the right track, it is essential to develop a regional code similar to the American, European and Asian codes. This will not only facilitate engineering construction activities within the continent, but it will also enhance education, research and concrete practice in the region. The new code should reflect the regional and national particularities on several levels namely; educational, technological, social, environmental and economical levels.

## INTRODUCTION

The most important question one would pose in this present situation of economic renaissance for the vast forgotten African continent is, do we really need another code for concrete structures? Currently, world over there are several concrete codes of practice to guide design, construction and maintenance; some of these codes have been with us for almost a century. The ACI-318 code, British standards, CEB-Fib Model code on the international level, whereas, on the regional level, we have the South African Code, Algerian code, Egyptian code and many others. Many countries in the region which do not have their own code have been using these international codes. In fact, some of these countries are using several codes with varying assessment and performance requirements at the same time, sometimes in the same project. Moreover, most of the local codes are in reality adopted and adapted from the well known international standards. For example, the South African code is based on the European standards, the Egyptian code is based on the American standards and the Algerian code is based on French standards. Then, why do we need a unified regional code for concrete practice in this region? The answer to this question is quite difficult. One would argue that because there are so many codes in one region with similar circumstances would dictate the necessity for one uniform standard. It makes some sense that a continent such as Africa with similar conditions and levels of development would require a standard which closely reflect its particularities. The issue is more complex and needs rigorous analysis. In fact, the most logical second question would be, can the professionals in Africa even with the cooperation with the international community draft a code to be put side by side with these giant international well established codes in the concrete design and construction. Is it going to be accepted by the international community in general and the concrete professions in Africa in particular? Does Africa possess the inertia, critical mass, scientific background, experience, research base and experts to carry on this task? The following paragraphs would attempt to answer some important aspects of these fundamental questions.



## **AN APPRAISAL OF THE VAST AND VARIED CONINENT OF AFRICA**

The vast continent of Africa with 53 nations, 750 million people, with the highest population growth, with an area of more than 30 million km<sup>2</sup>, with the longest river, with diversified natural resources looks forward at the beginning of the twentieth century for real development in all fronts. Africa needs to apply technology wisely, needs to comprehend the lessons of its predecessors examples in Europe, America and more recently in Asia. As per an estimate by 2050 more than 75% of the African population will live in urban areas. To meet and serve these frequent and far reaching changes, large quantities of materials are required for construction of shelters and infrastructures. Concrete due to obvious reasons lends itself as the only feasible material capable of meeting these needs. In general, the developing countries are consuming about one third of the concrete produced annually world wide, although these countries make up 85 % of the world population. If the consumption trends and over consumptive life style being followed in the industrialized countries are to be imitated in the developing countries, the world will become unsustainable. The amount of materials needed for decent living is unimaginable. There is a clear need to address this matter and to find alternatives to current consumption practices so that the world can be sustainable and material consumption and waste minimized. Concrete being the most important material of construction worldwide plays a predominant role in any society. In fact, concrete consumption is a real indicator of social progress and development in any country. There is a clear need for a design code that would consider these material limitations and sustainability constraints.

If Africa is to develop its infrastructure to support its future economic growth, an increase in concrete consumption will follow. With the unification of Africa both on the economic and political front, African union 1999, there is real need to establish and develop one regional standard in the concrete industry to facilitate and accelerate this economic development.

## **AN OVERVIEW OF CONCRETE CONSUMPTION IN AFRICA**

Portland cement remains the main indicator of concrete consumption worldwide. From an economical viewpoint, it seems that there is no real alternative to Portland cement as a binder for concrete structures. With the projected growth of the concrete consumption, a corresponding increase in cement production is expected. In some of the European countries, Portland cement has been replaced completely by blended neat cement. In the United States, however, only 20 percent of cement used is blended cement. However, Portland cement, as we know it will be with us for a long time to come especially in our region. Cement being the most important ingredient for making concrete is now produced in many countries. Table 1 shows the cement production for industrialized and developing countries alike. China by far is the leading cement producer, the United States of America ranks third in cement production after Japan. Presently, India ranks as the fourth world cement producing country. Cement production is estimated to reach 2 billion tons annually. Production and consumption of cement is an indicator of the concrete industrial activities. Under developed countries in the sub-Sahara region such as Uganda for example suffers from shortage of cement. Its annual consumption is only about half a million-ton.. In these African countries, labor is relatively cheap as against material which constitute 75 percent of construction cost against only 40 percent in the developed world. Therefore, concrete codes that are based on the concept of cheap materials and high labor cost will be inappropriate to be used in these regions. Also, Capital and foreign exchange are limited in many developing countries, thus restricting imported goods such as steel reinforcing. The amount of steel reinforcement specified in any code would play a predominant factor in the economy of these countries. Table 2, which shows the cement consumption per capita per year in Africa, gives a good indication of the infrastructure development in the continent. The northern and the southern regions being the most developed compared to the rest of Africa. The average per capita cement consumption in Africa is well below world average. This consumption is expected to increase in

the years to come.

**Table 1. Regional cement consumption (Million Tones), Source World Cement**

Area	Year 2000	Percentage	Year 2005	Percentage
Asia	932	58.1 %	1082	59.3 %
Europe	393	24.5 %	432	23.7 %
South America	118	7.3 %	142	7.8 %
North America	92	5.7 %	92	5.0 %
Africa	71	4.4 %	77	4.2 %
Total	1606	100 %	1825	100 %

**Table 2. Per capita Cement consumption in Africa**

Country	kg/capita	Country	kg/capita
Libya	674	Senegal	132
Tunisia	449	Ghana	97
Egypt	325	Benin	80
Algeria	280	Sudan	57
South Africa	268	Tanzania	39
Morocco	256	Congo	38
Namibia	153	Kenya	37
Gabon	150	Nigeria	36
Swaziland	144	Cameron	35

### **NATURE OF CONCRETE KNOWLEDGE AND BUILDING CODES**

The practice of engineering as a profession is, by its very nature based on knowledge. This knowledge comes from research and experience gained in practice. Codes are written based on knowledge and experience of local origin. Concrete codes are based on experience and experiments reflecting the educational, economical, technological and social welfare concerns of a society. Therefore, codes can be a powerful means of collecting and disseminating knowledge. This knowledge is translated into minimum requirements to provide the public with safety and enhance public economy. The American code for example, the

most widely known, is based on needs and requirements of the American construction industry at large. The European codes are local in nature; the unification of Europe has made it possible to draft the new European code for Europe. EC-02 code is based on the European experience. More recently the Asians have drafted a new Model code for Asia to reflect the Asian experience and to help facilitate their emergence on the economical level.(1,2,3). Codes are developed with key principles in mind, such as providing:

- Adequate structural safety and ductility
- Adequate durability and structural integrity
- Acceptable performance at service load levels
- Acceptable construction and maintenance cost

### **CONCEPT OF STRUCTURAL SAFETY RELATED TO STRENGTH**

The main objective of structural design is to produce a safe and serviceable structure, which can be constructed conveniently. It is expected to provide high probability of survival under anticipated loads and which can be constructed at acceptable cost. The building code should be able to guide a structural engineer to produce such a structure. Safety, therefore, is the most important objective of any code. The code should also provide adequate safety not only against collapse but also against unserviceable structures. Most codes follow a more deterministic approach with a rational probabilistic basis.(2)

The partial safety factors in the design codes should result in acceptable probabilities of failure at a reasonable cost. Also, the structure must have a high probability of remaining serviceable under anticipated service loads. This is now accomplished by using the “limit state” approach”. The structure is checked at ultimate limit state and serviceability limit state. In practice the structure is designed for the ultimate limit state and checked for the service

limit state. Variation in concrete strength and quality control change from one place to another. Applying a single factor would be inappropriate for all situations and locations. Partial safety factors would be more appropriate, for good quality concrete or acceptable level concrete if the quality of concrete is questionable. In addition, in many African countries, steel and cement are imported from abroad. Labor cost in these countries is much cheaper than developed countries. Therefore, design and construction practices adapted in developed countries which aim to minimize cost of labor at the expense of using more materials may not yield economical designs in African poor countries.(4)

### **CONCEPT OF STRUCTURAL INTEGRITY RELATED TO DURABILITY**

Compressive strength of concrete is not a good indicator of concrete durability. This being a test result, it can not account for construction practice, such as placing, compaction and curing. Therefore, a major concern of using the existing international codes directly is the way each code deals with the durability problem in concrete to ensure structural integrity. ACI-318 for example deals with this matter in a general way. EC-02 code which is based on CEB-fib model code is more specific. In ACI 318-05, only two classes of exposures are identified as exterior and interior with limitations on crack widths for these conditions. Durability, according to this code, is achieved by limiting the water to cement ratio and specifying concrete compressive strength. Also ACI code gives some limitations on chloride content of concrete. Euro code on the other hand, elaborates on the issue of durability by specifying different exposure conditions leading to risk on structural integrity. Suggesting appropriate concrete strength, water cement ratio, cover, and curing regimes to be followed, but sets no limit on chemicals in concrete. In brief, African region has long relied on foreign codes which were developed for different climatic conditions and construction practices. In the Sahara region of Africa combination of high temperature, dry winds, low precipitation leads to plastic shrinkage, drying shrinkage and



thermal cracking. Also an increase in temperature leads to increase in water demand leading to lower strength and lower durability. African climate is arid or tropical in general. Temperatures reach 50 degrees in Sahara in the day time and drops to zero at night, where in the tropical areas it reaches around 40 degrees with wet hot summers and relative humidity of 90% in the middle of Africa. In Alaziza near Tripoli the highest temperature world wide was recorded (58 degree centigrade). In addition to these environmental effects, concrete constituent materials contain poorly graded aggregate and sand that in many cases are not suitable for concrete making. Therefore, workmanship, quality control and the prevailing environmental conditions in the continent of Africa require developing a special standard that could account for these specific problems. (6,7) In summary, emphasis of the code for hot weather concreting in Africa must be based on durability design that should satisfy the following requirements:

- Minimum cement content
- Additional cementing materials (fly ash, slag, silica fume etc.)
- Mandatory curing practice
- Minimum compressive strength
- High durability
- Maximum concrete cover
- Minimum water cement ratio (maximum 0.50)
- Limit on chloride and sulfates contents
- Mandatory quality control

### **AN OVERVIEW OF INTERNATIONAL REFERENCE CODES**

There is a need to base the new code on the existing codes of practice. These codes are well established and have been in use for some time. The choice between these codes however, is quite difficult. This is so because these codes are based on different approaches and basically local experiences and experiments.

The most important and widely used two international code documents now a days are, European Committee for standardization for design of concrete structures (EC-2) and the American Concrete Institute Building Code Requirements for structural Concrete ACI-318-05 and Commentary 318-05. These documents when compared show significant differences in many situations. The ACI code, for example, which is based on the ultimate strength design method, until recently still considers the working stress design method as another alternative method. Only in the last edition of the code ACI-318-02, the controversial decision to drop this method was taken. On the other hand, the European code is based on the Limit state design method for interim period. The margin of safety as related to imposed loads and reduction capacity material factors are quite different between these codes. Table.3 shows the load factors for several codes where these difference are apparent. Obviously, the safety factors inherent in these codes are selected on the basis of quality control of concrete based on western standards.

In addition, the ACI code has been changing at a rapid pace lately every three years. One of the recent significant changes in the ACI-318-05 code is the inclusion of a new method and approach to the design of flexural members. Instead of using the well established concept of balanced reinforcement ratio and maximum reinforcement ratio, the code uses the new concept of limit strain approach. But the code on other aspects is still unclear in dealing with durability and serviceability requirements. The new changes in the code have a sweeping effect on the educational and construction industry on the international level. Indeed it is difficult for many countries, especially in this part of the world, where change is slow, to follow these unwarranted and fast changes.

More specifically the following is a brief comparison of the way the ACI-318 and EC2 codes deal with some important design parameters related to design of concrete structures(5).

Table3. Load factors and resistance factors for different codes

Code	Load factor		Strength Reduction factors			Material strength reduction factors	
	Dead	Live	Flexure	Flexure +axial load	Shear	Concrete	Steel
ACI-318-05	1.20	1.60	0.65 to 0.90	0.65 to 90	0.75	-----	----
Euro-2	1.35	1.50	-----	-----	-----	1/1.5	1/1.15
CSA	1.25	1.50	-----	-----	-----	0.65.	0.85
NZS	1.20	1.60	0.85	0.65to 0.85	0.75	-----	-----

**Concrete compressive strength**

The ACI-318-5 has no upper limit on compressive strength of concrete to be used in reinforced concrete structures, while the EC2 code limits compressive strength to 90MPa. ACI limits compressive strength only in some situation in the design equations for example in development length and shear. The EC2 code starts changing expressions when concrete compressive strength reaches 50MPa. These codes also limit the use of concrete strength in certain design expressions. ACI code starts changing some design expressions at concrete compressive strength of 70MPa.

**Load and resistance factors**

The ACI-318 uses strength reduction factors applied to the nominal strength capacity, which varies with the type of action (flexure, shear, axial load) force .The EC code uses partial safety approach with reduction factors applied separately for concrete and steel. Factors are also introduced to account for brittle behavior of high strength concrete in the EC2 code.

**Modulus of Elasticity**

Both ACI-318 and EC02 codes use a secant modulus concept fore the modulus of elasticity of concrete. The definition of the secant modules, however, is different in the two codes. ACI-318 bases the modulus of the specified compressive strength, whereas, the EC-02 code bases the secant modulus on an average compressive strength. ACI-318 gives an expression for the secant modulus of elasticity

defined as the slope of the line drawn from a stress of zero to the compressive stress equal to 0.45 of the compressive strength of concrete. The EC2 code gives a different expression. The secant modulus defined as the slope of the line drawn from zero stress to the compressive stress equal to 0.40 of the compressive strength of concrete.

### **Concrete Tensile Strength**

Tensile strength of concrete determines the cracking load. This is needed to determine the minimum required steel reinforcement in the design of concrete structures in flexure. ACI-318 uses the modulus of rupture to determine the flexural cracking moment while, the EC2 code uses the direct tensile strength as a basic parameter to calculate the tensile strength of concrete. In the absence of direct tensile tests, EC2 provides an expression for the mean tensile strength in terms of compressive strength of concrete

### **Minimum reinforcement for flexure**

The primary role of minimum reinforcement is to provide adequate reserve of strength after cracking to prevent a sudden failure. ACI-318 uses an expression for this minimum value related to both steel strength and to the compressive strength of concrete. EC2 on the other hand, requires that minimum reinforcement for flexure average compressive strength and yield strength of steel. It is noted that the EC2 requires less minimum reinforcement for beams than does ACI-318. Unlike the requirement for EC2, the minimum reinforcement requirements for slabs given by ACI-318 expressions are not a function of concrete strength.

### **Flexure and Axial Load**

EC2 permits the use of several equivalent stress distributions. ACI-318 code for example at strength of above 50MPa predicts significantly higher column capacities than EC2 code for the compression controlled regions.

### **Minimum shear Reinforcement**

The ACI-318 expressions give smaller amounts of steel reinforcement in shear than EC2 for all concrete strengths.

### **Punching (Two way shear)**

The ACI-318 expressions for punching shear depend on column aspect ratios. The critical shear section is taken at  $d/2$  from the face of the column. EC-02 determines the resistance of concrete for punching shear at a critical section located at a distance  $2d$  from the face of the column. EC-2 expressions for low reinforcement ratios give considerably lower punching shear resistance than ACI-318 expressions. At higher ratios of reinforcements, the two codes give similar results. EC2 code provisions account for size effect and longitudinal reinforcement ratios whereas; ACI-318 code does not specify it.

### **Tension and development lengths**

Generally the EC2 expressions give shorter development lengths than the ACI-318 expressions. The ACI-318 limits the value of square root of the compressive strength to a certain value, whereas, the EC2 code cautions the designer of the increasing brittleness of high strength concrete.

It can be concluded from the above discussion that these established codes have significant differences in many aspects. These aspects related to structural safety, durability and economy. It is understood and well established that design codes are continually evolving documents using a consistent philosophy and the latest research results often reflecting the prior state of art and tradition of the country of origin. There are, however, these significant differences in the code philosophies and approaches to design of concrete structures.

One may conclude that it is not possible to use a code written for a specific region and culture directly under different conditions. Application of such codes directly can not bring about the promised safe, durable and economical structures. In fact, this promise has



not been achieved internationally. The durability crisis that is hitting the infrastructures in industrialized world is a vivid example of this condition.

### **INTENDED OBJECTIVES OF THE NEW ANTICIPATED ACC CODE**

Codes from different countries have similar objectives; they have, however, significant differences in their requirements for the design of concrete structures, which make it difficult to apply these codes without considering these differences.

The goal of the African Concrete code is the development of a regional standard that will insure the optimized design objectives for the concrete structures in the continent. These design objectives include safety, serviceability, durability, constructability and service life. Ideally, these objectives have to be fulfilled in accordance with local environment and local practice leading to sustainable concrete practice in the region. To be desirable, the code should reflect the regional and national particularities on several levels. Namely; educational, technological, social, economical and environmental levels. The most important obstacle that will hinder establishing a reliable concrete code for Africa is the lack of concrete research in this area. There is a real need to remedy this situation amongst research centers and universities in the region in cooperation with the international experts in the field.

The anticipated African concrete code needs to document in a comprehensive manner the aspects pertaining to cover the design and construction of structural concrete used in structures of all types. The quality and testing of materials used in construction have to be related to an appropriate standard. Use of the code will be by reference in general building codes of the appropriate authority.

## **NEED FOR BUILDING CODES TO SERVE AS LEGAL DOCUMENTS**

Since the days of Hammurabi, 4000 years ago, the public needed protection and wanted design to be based and governed by rule of law. Structural engineering practice, therefore, must be regulated by the rules of law, because it is directly related to public safety and economy. Building codes when adapted by a certain authority becomes law. When a building code becomes a law, it will be ultimately interpreted by judges. Judges interpretation of the code prevails. Structural engineering, however, is not an exact science. Therefore, any structural design problem will have different solutions and problems can be solved in different ways. Making the practice of structural engineering design a law, implies that each engineering problem has only one unique acceptable solution. In codes, therefore, the authorities involved must be clearly stated. The 2000 International Building Code for example, states clearly the duties and powers of the building officials in enforcing the code and defines the responsibility of each partner. The code wording has to be clear so that even judges who are not engineers will not misinterpret the intent of the committee writing the code. The African concrete code drafting committee has to consider carefully such important issues in writing the code for use in this large and diverse region.

## **FRAMEWORK OF PROPOSED CODE INTERNATIONAL COMMITTEE**

The African concrete code needs to be drafted by an international non-profit non-governmental organization. This organization must be made up of volunteers from all over the world who are interested in the progress and development of Africa. We have the intention to involve all individuals and associations which have the experience and motivation to help in this task. We will cooperate to start drafting the initial code within five years plan. The scientific society of engineers in Tripoli, Libya will play as a focal point for such action. Several symposiums and workshops will be organized



in different African countries in the years ahead to establish a solid base for this work.

### **CONCLUDING REMARKS**

Present state of the art shows that till this day there is no reliable concrete code for the unique prevailing situation covering special areas in Africa. The present paper has highlighted that current international codes are based on experience and experiments largely of local condition relevant to their original country. The paper demonstrates that there is urgent need to incorporate special features of the African continent in a regional code for local concrete practice. Contradiction among international code of practice on several design issues shows that these codes such as ACI-318 which is fast changing is hard to follow and does not necessarily reflect the regional conditions in Africa.

It is obvious that in America and Europe, the material quality, climatic conditions technical level, educational level and economical level are quite different from those in Africa. These differences are reflected in the concrete code in one way or another. Therefore, these codes will not be appropriate for direct use in these developing countries. The safety factors inherent in these codes are selected on the basis of and quality control of concrete based on their standards. These international codes, however, can be used as reference codes for the new code of concrete practice in Africa.

The goal of an ideal African concrete code is the development of a relevant standard to the region which will insure the optimized objectives for design of concrete structures in the vast continent. These design objectives of the intended code need to include safety, serviceability, durability, constructability, and service life. These objectives have to be fulfilled in accordance with local environment and local practice leading to sustainable concrete practice in the region. In short, the appropriate African concrete code should concentrate on achieving a standard, which is



applicable to the continent and acceptable for design practice in African countries.

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