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Comparative Study of Reinforced Concrete Design Norms (BAEL91, BS8110 and Eurocode 2) on the Design of a two Span Beam in Cameroon

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ABSTRACT

This research compares the beam longitudinal reinforcement areas required by different international design norms or design provisions that deals with the design of reinforced concrete structures namely the French norms: Bétons Armée aux Etats Limites' (BAEL) 91 revised in 99, the British standards BS8110 and the Eurocode 2(EC2) as used with the Frech national annex (NF EN 1992-1) and the British national annex (BS EN 1992-1). The aim of this research was to determine which code or norms provides the most safe and economic design in Cameroon. From literature, the study first gathered information on the design criteria and beam analysis from the different international norms as well as on the properties of steel reinforcement bars and concrete. The study adopted a continuous beam of 2 spans for the design. Concrete grade 20/25 and 12mm diameter bars were chosen. The yield strength of reinforcing steel, the density of reinforced concrete and the effective depth (d) depended on the requirements of each code. The area of tensile reinforcement obtained by EC2 (both France and Britain National annex) is smaller than that of BAEL 91 and BS8110 at support and at spans as well. This shows that Eurocode 2 results in more economical areas of reinforcement steel bars than when designing with BAEL 91 or BS8110. Since Eurocode 2 results in smaller required steel reinforcement areas, this decreases the steel reinforcing bars congestion in a structural member. The BEAL91 has the highest required steel reinforcement area due to its lower yield strength amongst all the other codes under study. The study recommends that Cameroon should as a matter of urgency draw up her national annex and starts the full implementation of Eurocode 2 in order to enjoy its manifold benefits.

Key words: Economical Design, Eurocode 2, International Design Codes, Reinforced Concrete, Steel Reinforcement area.

I. INTRODUCTION

Reinforced concrete is a combination of two dissimilar but complementary materials, namely concrete and steel [1]. By providing steel bars predominantly in those zones within a concrete member which will be subjected to tensile stresses, a structural material can be produced which is both strong in compression and in tension [2]. Despite the availability of international codes in Cameroon, the collapse of some buildings in Yaoundé and Douala has been attributed to problems of structural design amongst other causes [3]. Concrete should therefore be well designed as it fails when it cannot provide the required strength to support its designed load [4].

Reinforced concrete structures are normally designed in accordance with the recommendations given in standards or design codes [5]. Codes provide the essential data and standards in analyzing and designing the structure from strength and economical point of view [6]. Codes vary from one nation to the other because what is approved by one nation may not necessarily be approved in another nation. National building codes have been formulated in different countries to lay down guidelines for the design and construction of structures [7]. According Izhar and Reena [8], codes serve the following purposes: they ensure structural stability/safety by specifying certain minimum design requirements. They make the task of a designer rather simple by making available results in the form of tables and charts. They ensure a consistency in procedures adopted by the various designers in the country. They protect the design against structural failures that are caused by improper site construction practices.

The use of different design methods and codes will definitely bring about different results in structural analysis and design leading to variability in behavior, costs and durability of structures [9]. It is, always, the duty of the structural engineer to provide designs that would lead to optimum performance and economy by employing the most efficient design method in accordance with a relevant design code available so as to satisfy the client's requirements [10].

Since different countries follow different methodologies in building design thus there are many design codes that are built across the world [8]. Cameroon does not yet have a reinforced concrete design code of her own and so far the country has been using many international design codes from many countries. From the building permit applications files of the last twenty years in the Bamenda city council (BCC) alone, structural analysis reveal that norms of France, British, United States of America, India, and Eurocodes have been used by engineers in the design of reinforced concrete structures in the country.

Boudebous [11] recommends the use of Eurocode against the BAEL91 code because of the lower steel reinforcement requirements, which leads to cheaper construction while still maintaining safety. Nwoji and Ugwu [9] affirms that Eurocodes are more technologically advanced than BS 8110 and will continue to enjoy more advancement, and adds that they are more flexible and safer and more economical, easier to use and provides more economical sections.

In this study comparison will be made between various codes or norms used in Cameroon such as the French norms: Bétons Armée aux Etats Limites'- BAEL91 (11]; British Standards -BS 8110 [12]; the Eurocode 2 based on the French national annex NF EN 1992-1 [13] and the British national annex BS EN 1992-1 [14]. The choice to compare the areas of reinforcing steel for these selected codes is guided by the fact that in the past years, Bétons Armée aux Etats Limites' (BAEL91) and British Standards (BS 8110) have been the norms taught in technical high schools and other higher institutions in Cameroon,. The Eurocode 2 based on the French national annex NF EN 1992-1 [13] has been used to teach in some civil engineering schools in the country and ANOR [15] of Cameroon quality standards organization recommends the use of Eurocodes in Cameroon to be use alongside the French national annexes. Eurocode 2 based on the British national annex BS EN 1992-1 [14] has also been used to teach students of the Bachelor of Technology Programs in some institutions in Cameroon.

Up to date, structural calculations included in the building permit documents and submitted to the Bamenda city council show that, about 80% still use the Betons armee a l' etat limit (BAEL) code, 15% use the British Standards (BS 8110); 4% use the eurocode 2 based on the French national annex (NF EN 1992-1) and only about 1% employed the eurocode 2 based on the British national annex (BS EN 1992-1). When compared, some design codes will surely have advantages over others. This research compares the beam reinforcement required by different international design norms such as the French norms (Bétons Armée aux Etats Limites' (BAEL) 91), British Standards BS8110 and the Eurocodes as used in the national annexes of France and Britain with the aim of determining which code provides the most safe and economic design. The study adopted a continuous beam of 2 spans for the design.

2 BASIC INFORMATION

2.1 **Background Information of BAEL**

In France, it was in 1906, that the first national circular containing the rules for designing reinforced concrete structures was issued. This circular of 20th October 1906 laid the first technical bases for reinforced concrete to be admitted as a classical construction material and the method used was based on the Working Stress Method also known as the Allowable Stress Design Method (ASD). The ASD method was later replaced by the 'Beton Armee or BA' BA45 rules followed by the BA60, CCBA68. In 1980 reinforced concrete design in France switched to the Limit states design. The design of reinforced concrete for limit states rules in France are found in the code of practice "BAEL (Béton Armé aux États Limites)" meaning Limit states design of reinforced concrete. The first Limit states design of reinforced concrete rules in France was in 1980 and the standards name was BAEL80. The 1980 code was revised in 1983 and named BAEL83 and the revised 1983 code was used up to 1990. The last edition of BAEL was in 1991 named BAEL91 and this was revised in 1999.

2.2 **Background Information of British Standards for the design of concrete structures**

Mu'azu, Onundi and Ocholi [16] reported that before the Second World War, recommendations for the design of reinforced and prestressed concrete had been published in the UK in a Code of Practice prepared by the Department of Scientific and Industrial Research (DSIR) which was issued in 1934, and in the Building By-laws of the London County Council of 1938. After the war, the DSIR Code was revised and became the British Standard Code of Practice, CP 114, in 1948. CP 114 [17] was titled 'Structural Use of Reinforced and Prestressed Concrete' and CP 114 was based on permissible working stress condition CP 114 Part 1. (1968). This code was revised in 1965 incorporating new findings from research and performance of the code.

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CP 114 was superseded in 1972 by CP110 [18]. The Structural Use of Reinforced Concrete in the series of reinforced concrete codes which is based on new design philosophy (limit state design) although the use of CP 114 was still valid. CP110 [18] introduced separate partial safety factors on loads (γf) and materials (γm). 'Limit state design' was not just a change in calculation format, the intention was that variations in loads, materials and member strengths would be analyzed statistically and then probability theory would be used to calculate new, more rational values for design loads and partial safety factors CP110 in 1972. In August 1985 and1997 the CP 110 was replace by BS 8110 which is also based on the limit state design format. BS 8110 is basically a review of CP 110 because when CP 110 was first published it was not well accepted and ran parallel for 12years with its predecessor the CP 114 [17].

2.3 Background Information to Eurocode 2: 1992: Design of Concrete Structures (EC2)

The Eurocode was officially adopted as the new design standard for European member nations on March 31, 2010. EC2 is meant to unify design philosophies and make civil engineers productive across all of Europe [9]. Eurocode 2 is the one design code for all concrete structures in France, the UK and Europe. EN 1992-1-1 for example was published in December 2004 and the National Annex in UK was published in December 2005, making it possible to use in the UK. The standard was developed to bring reinforced concrete design up to date. Eurocode 2 has to be used in conjunction with: Eurocode 0 or EN1990 Basis of design; Eurocode 1 or EN1991 Actions on structures**;** Eurocode 7 or EN 1997, Geotechnical design and Eurocode 8 or EN 1998 Seismic design. When referring to Eurocode 2, it refers to BS EN 1992 in the United Kingdom and NF EN 1992 in France. Eurocode 2 EN1992 deals with the Design of Concrete Structures and it has four parts namely**:** EN1992-2-1: General rules and rules for buildings, EN1992-2-2: General rules in structural fire design EN1992-2-3: Concrete bridges. EN1992-2-4: Liquid retaining and containing structures BS EN 1992 (2005).

Eurocodes are intended for use in conjunction with national application documents (NADs) as an alternative to national codes such as BS8110-1997, BAEL 91 revised in 1999 for a number of reasons. Users are expected to derive their own formulae or use published guidance, design and local construction practices, standard and quality of local building materials, climatic conditions, and human behavior to structures among other factors differ from country to country due to different conditions. For instance, the weight of a roof might be different in Cameroon from the one in the UK because of snow BS EN 1992:2005. EN 1992-1 (called Eurocode 2 or EC2) for the design of concrete structures

3. RESEARCH METHODOLOGY

The methodology on the one hand looks at the level of implementation of Eurocode 2 in Cameroon and on the other hand the design procedures of the two spans beam.

3.1 Level of implementation of Eurocode 2 in Cameroon

This is carried out by investigating the implementation of Eurocode 2 in the curriculum of some twenty seven (27) civil engineering schools and in the structural analysis documents for building permit of some sixty one (61) building projects sites in Cameroon in the past two years

3.2 Design method

The method used for design is that of limit state philosophy for design. The limit state design method is the recommended method in BAEL91, BS 8110 and Eurocode 2 codes. The main purpose of this work is to compare the beam reinforcement areas required by different international codes namely: French code BAEL 91, British code BS8110 and the Euro codes 2 as used in the national annexes of France and also Britain with the aim of determining which code provides the most economic design.

3.3 comparative studies

The methodology involves comparisons of design criteria, materials properties and the areas of steel reinforcement required by the different international design code. The results will be discussed and followed by a conclusion.

3.3.1 Comparison of Design criteria and beam analysis for the different international codes

For every international code, the study compares the appellations and symbols used in each code for loads and bending moments, it also looks at the load combinations as well as the effective depth formula considered for the different international codes as in table 1. Table 1 presents the corresponding numerical values

3.3.2 Comparisons of Material (concrete and steel) Properties

For every international code, the study compares the appellations and symbols, gives values for the 28 days characteristics strength of concrete, standard specimen used, maximum grade of concrete, design strength of concrete, the reduction coefficient in

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bending and the partial coefficient of the concrete strength. Next is the characteristic strength for high yield steel, partial coefficient of the steel strength, design strength of steel, ductility and diameters of reinforcement defined.

3.3.3 Comparisons of Area of steel reinforcement required

For every international code, the study compares the appellations and symbols, gives values for, the verification of crushing strength of concrete, Alpha, the lever arm and the area of steel reinforcement required

3.4 Beam to design

The beam adopted for this study a continuous beam of 2 spans with typical span length of 7m between axis in the X-direction of the floor and carries loads by the shorter sides of 3.5 m between the load carrying beams in the Y-direction of the floor. This study is from the 15cm thick one way solid floor of a dancing hall with corresponding live loads of 5KN/ m^2 applicable to all the codes. The breadth of the web of the beam is 20cm and the overall depth is 50cm. The characteristic strength of concrete is 20/25 mPa and 12mm diameter bars are chosen. Characteristic yield strength of reinforcing steel, the density of reinforced concrete and the effective depth (d) depends on the requirements of each code. NF EN 1990 [20] and NF EN1991 [21] have been used for the design parameters.

4. RESULTS AND DISCUSSIONS

4.1 State of implementation of the Eurocodes in Cameroon

In Cameroon, it is the Standards and Quality Agency (ANOR) that is responsible for issuing building regulations for housing. This body is responsible for the development and certification of Standards as well as certification and assessment of compliance with the Standards. ANOR has recommended the Eurocodes as the standard for reinforced concrete design in Cameroon ANOR (2018). The Eurocodes were adopted in Cameroon without the relevant corresponding National Annexes. For this reason, ANOR has recommended to use the French national annex to Eurocode.

4.1.1 Design norms in curriculums in some civil engineering schools in Cameroon

Table 1 Various design norms taught in some schools across Cameroon in the past two years

S/N	Institution	Code Used in Teaching
1	GTTTC Mbengwi	BAEL
2	GTTTC Njikejem	BAEL
3	ENIAT SOA	BAEL
4	ENIAT Douala	BAEL
5	ENIAT Bafoussam	BAEL
6	High school programs under the CGCE board	BAEL
7	High school programs under the BACC board	BAEL
8	ENSET Douala	BAEL
9	ENSET Kumba	BS8110
10	ENSET Bambili	BAEL
11	ENSET Ebolowa	BAEL
12	National Advanced School of Engineering, Yaounde	BAEL
13	National Advanced School of Engineering, Douala	Eurocode 2
14	National Advanced School of Engineering, Bamenda	BAEL
15	Institute Universitaire de la Cote BTS/ HND programs	BAEL
16	Institute Universitaire de la Cote Degree program	Eurocode 2
17	Institute Universitaire SIANTOU BTS/ HND program	BAEL
18	Institute Universitaire SIANTOU Degree program	Eurocode 2
19	National polytechnic University Institute Bamenda	BAEL
20	HIBUMS Polytechnics Bamenda	BAEL
21	HARVARDS Polytechnics Bamenda	BAEL
22	ISSAB Polytechnics Bafoussam	BAEL
23	Institute Universitaire TCHOUNANG Bafoussam	BAEL
24	Catholic University Bamenda	BAEL
25	National Advanced School of Public Works Yaounde	Eurocode 2
26	IUT Bandjoun	BAEL
27	HND/ B.TECH Academic Organ of the University of Bamenda	BAEL
Summary		
	Total percentage that uses BAEL	81.5%
	Total percentage that uses BS8110	3.70 %
	Total percentage that uses Eurocode 2	14.8%

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Table 1 presents the results of codes usage in the teaching of design of reinforced concrete structures in some schools in Cameroon. 85.5% of the schools are still using Betons Armee A L'etat Limite (BAEL) in the curriculum, 1.64% are using British Standard number 8110 (BS8110) in the teaching meanwhile, 14.80% of the schools considered in this investigation have adjusted their curriculum to the use of Eurocode 2 in the teaching of reinforced concrete structures. This shows that the level of implementation of Eurocode 2 is still low in school curriculum in Cameroon. Therefore the majority of civil engineering schools in Cameroon are still using out dated codes that have not been revised since the year 2000 a situation that hinders this country not to enjoy the flexibility of Eurocde 2 to a greater extent.

4.1.2 Design norms used in structural analysis

Table 2 Design norms used for structural calculations from sixty one building projects sites

SUMMARY			
S/N	Code name	Number	Percentages
1	Number of structural analysis that used BAEL	54	88.5%
2	Number of structural analysis that used Eurocode 2	01	1.64%
3	Number of structural analysis that used BS8110	06	9.8%

Table 2 presents the results of codes usage in the design of reinforced concrete from 61 project sites investigated using the Engineer's structural analysis documents for each project. Amongst the structural analysis results, 88.5% implemented the Betons Armee a L'etat Limite (BAEL), 9.8% used the British Standard number 8110 (BS8110) and 1.64% used the Eurocode 2 design norms. The results shows that the use of BAEL is still the Dominant code of practice used by designers and many are yet to design with Eurocode 2. The danger of still using BAEL or BS8110 is that the codes have not witnessed any update since the year 2000 despite new emerging technologies, materials and field experience.

4.2 Design Criteria, Beam Analysis, Design and Discussions

4.2.1 Design criteria and beam analysis

Table 3 Comparison of Design criteria and beam analysis

Criteria	**French code (BAEL 91)**	**British Standard (BS8110)**	**EUROCODE 2 NF EN**	**EUROCODE 2 BS EN**
			France	**Britain**
Live loads (Q)	Exploitation loads, Q	Characteristic imposed load, Qk	Characteristic variable action, Qk	Characteristic variable action, Qk
Density of concrete for dead loads (G)	Permanent Loads, G	Characteristic dead load, Gk	Characteristic permanent action, Gk	Characteristic permanent action, Gk
Load combination	1.35G +1.5Q	1.4Gk +1.6Qk	1.35Gk +1.5Qk	1.35Gk +1.5Qk
Bending moment at spans	Ultimate bending moment Mu	Bending moment , M	Internal moment M_{Ed}	Internal moment M_{Ed}
Bending moment at interior support	Ultimate bending moment Mu	Bending moment, M	Internal moment M_{Ed}	Internal moment M_{Ed}
Effective depth	d=0.9h	d=h-cover- half bar diameter- stirrup diameter	d=0.9h	d=h-cover- formwork deviation- half bar diameter- stirrup diameter

From table 3, changes have been noticed in terminology of design criteria Loads as used in BAEL91 and BS8110 becomes Actions in EC2. Also the different appellations such as exploitation loads as used in BAEL91, imposed loads as used in BS8110 have been replaced by the common name Characteristic variable action, Qk as used in EC2. Permanent loads as used in BAEL91 and dead loads as used in BS8110 have been replaced by the common name Characteristic permanent action, Gk. Ultimate bending moment as used in BAEL91, and bending moment as used in BS8110 have been replaced by the common name internal moment $M_{Ed.}$ The load combination used in the codes is provided in Table 3. The BAEL91 and the EC2 application in France and Britain have the same factors of load combination 1.35Gk +1.5Qk of while the British BS8110 has different and higher factors of load combination of 1.4Gk +1.6Qk.

4.2.2 Structural analysis of the beam

In order to know the bending moments that are in equilibrium with the design loads for the required loading combinations acting on the beam under study, structural analysis of the beam was carried out resulting in the bending moment diagram in figure 1.

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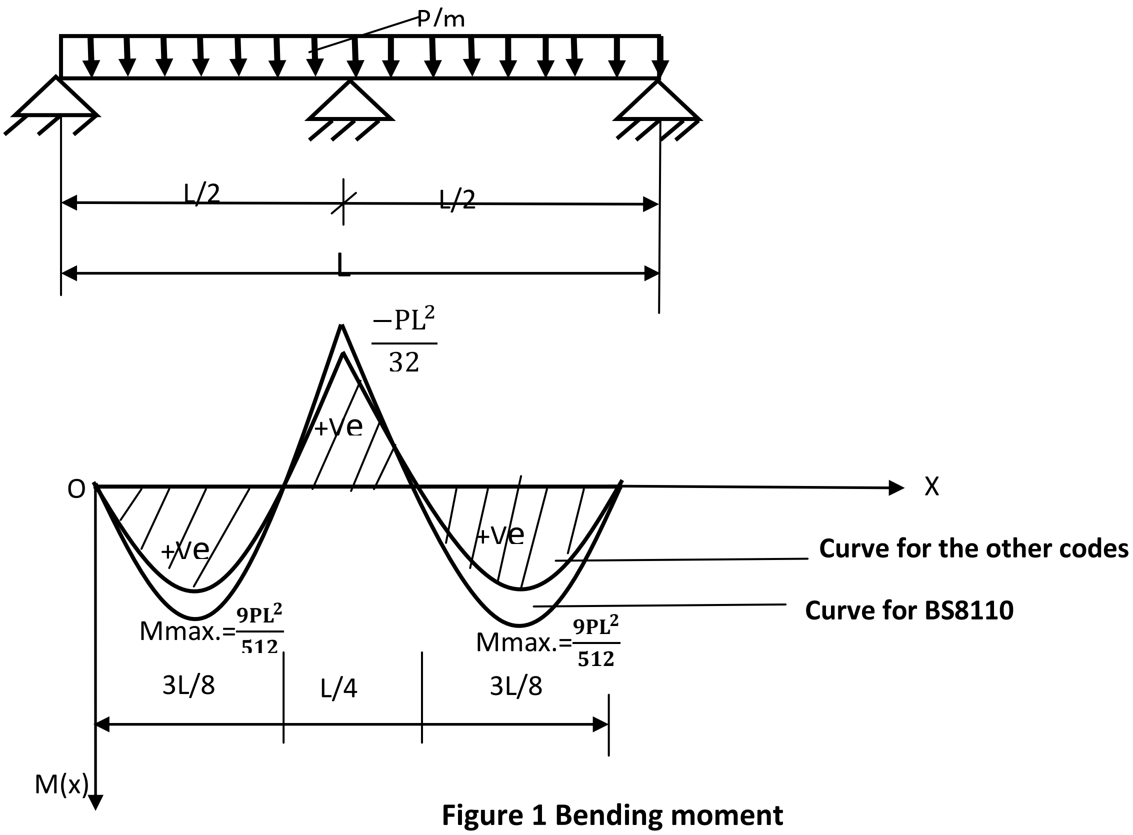

Figure 1 Bending moment

The bending moment diagram on figure 1, shows that, the bending or internal moment at the support and at the spans of BS8110 is higher than that of the other codes in this study. This is as a result of the higher factors in the load combination of BS8110.

4.2.3 Loads, bending moments and effective depth

Table 4 Comparison of loads, bending moments and effective depth

ITEMS	BAEL 91	BS8110	NF EN 1992	BS EN 1992
	Concrete			
28 days strength of concrete	Fc28 20 mPa	Fcu 25 mPa	Fck 20/25 mPa	Fck 20/25 mPa
Standard specimen used	Cylinder of height 30cm and diameter of 15cm	Cube sample of 15cmx15cmx15cm	Cylinder of height 30cm and diameter of 15cm	Cylinder of height 30cm and diameter of 15cm
Maximum grade of concrete	40 mPa.	50 mPa	C90/105 MPa	C90/105 MPa
Design strength of concrete	Fbu= 0.85 fc28/γ_b 11.33 mPa	0.67fcu/ γ_m 11.16 mPa	Fcd =0.85 fc28/γ_b 11.33 mPa	Fcd =0.85 fc28/γ_b 11.33 mPa
The reduction coefficient α in bending	0.85	0.67	0.85	0.85
Partial coefficient of the concrete γ_b or $\gamma_{m\ or\ \gamma c}$	1.5	1.5	1.5	1.5
	Reinforcing steel			
Characteristic strength for high yield steel	Fe= 400 mPa	Fy=460 mPa	Fyk=500 mPa	Fyk=500 mPa
Partial coefficient of the steel strength γ_s or γ_m	$\gamma_{s=1.15}$	$\gamma m_{=1.15}$	$\gamma_{s=1.15}$	$\gamma_{s=1.15}$
Design strength of steel	Fsu = fe /γ_s 348 mPa	Fy/γ_m 400.2 mPa	Fyd = fe /γ_s 435 mPa	Fyd = fe /γ_s 435 mPa
Ductility	No information	No information	Class B	Class B
Diameters of reinforcement defined	6,8,10,12,14,16, 20,25,32,40	6,8,10,12,16, 20,25,32,40	6,8,10,12,14,16, 20,25,32,40	6,8,10,12,16, 20,25,32,40

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From table 4, the BS8110 uses a lower value ρ=24kN /m^3 for the density of concrete meanwhile BAEL91 and EC2 implements ρ=25kN /m^3 leading to slightly higher service dead actions. The bending moment of BS8110 is higher because of her higher factors of load combination than every other code in this study. The effective depth for both BEAL91 and French National Application of EC2 is same meanwhile the British national application of the EC2 varies.

4.2.4 Comparisons of Material (concrete and steel) Properties

From table 4, the design value of concrete compressive strength in BAEL is denoted as Fbu, in Eurocode 2 (NF EN 1992.1.1 and BS EN 1992.1.1), it is denoted as Fcd. The design value of concrete compressive strength and the corresponding characteristic value given in BAEL is Fbu= $\alpha fc28/\gamma_b$ meanwhile in BS8110 it is given as $\alpha fcu/\gamma_m$ and in Eurocode 2 (NF EN 1992.1.1 and BS EN 1992.1.1) it is given as Fcd = $\alpha fck/\gamma_b$. γ_b or γ_m represents partial coefficient of the concrete strength, which is 1.5 for the permanent and the transient condition, and α represents the reduction coefficient considering the long-term effect and adverse effect to concrete, for compressive and bending condition this factor should equal 0.85 meanwhile in BS8110 this factor is equal 0.67. In BAEL91 and EC2 national applications in France and Britain, the formula of the characteristic strength of concrete is based on the design of cylindrical concrete strength after 28 days and denoted Fc28 while using BAEL91 and Fck while using EC2. While using BS 8110 the characteristic strength of concrete is based on the design of cube concrete strength after 28 days and denoted Fcu. By estimation, the strength of the cylinder is 80% of the cube strength. Hence BS8110 is more conservative than the others in terms of design strength of concrete.

Reinforcement bars provides both tensile and compressive strength to the structure, but also make the structure satisfy the special requirements of deformation properties [22]. The diameters of reinforcement defined in BS8110 codes and Eurocode 2 (BS EN 1992.1.1) are similar, but the strengths are different. The characteristic strength for high yield steel is 460 mPa in BS8110 code and for Eurocode 2 (BS EN 1992.1.1), the characteristic strength for high yield steel is 500 mPa. The diameters of reinforcement defined in BAEL codes and Eurocode 2 (NF EN 1992.1.1) are similar, but the strengths are different. The characteristic strength for high yield steel is 400 mPa in BAEL code and for Eurocode 2 (NF EN 1992.1.1), the characteristic strength for high yield steel is 500 mPa. Diameter 14 steel found in BAEL code and Eurocode 2 (NF EN 1992.1.1) is not recommended in BS8110 code and Eurocode 2 (BS EN 1992.1.1). The symbol for the characteristic yield strength for reinforcement steel is Fe in BAEL, Fy in BS8110 and f_{yk} in Eurocode 2 (NF EN 1992.1.1 and BS EN 1992.1.1). The partial factor of reinforcement γ_s is the same and equal to 1.15 for all the design codes compared here. The design strength of steel for BAEL is the lowest.

The EC2 has introduced the notion of ductility of reinforcing steel besides the yield strength. The old BAEL91 and the BS8110 do not make such provisions. The normal ductility differences are specified as A, B or C. The first two classes A and B are the most common with C most likely for structures that are exposed to low operation temperatures (below -20oC). This ductility ensures that the structural members fail in a ductile manner and every form of brittle failure should is avoided. Ductile failure ensures that steel fails first and sufficient warning is given before collapse. Due to ductile failure and economy, the under-reinforced sections are preferred by designers than over reinforced sections which often lead to brittle failure [23].

4.2.5 Area of steel reinforcement required

Before getting into the determination of the areas of reinforcement, it is important to define and mention the relevance of some design parameters. The parameters for the determination of the area of require steel reinforcement are such as μ or k is used for the verification of crushing strength of concrete, this is carried out in limit states design in order to avoid a situation of over compression of concrete in the compression regions of a structural member. Another parameter is the lever arm (Z). The lever arm is the perpendicular distance between the line of action of the couple forming compression and tensile force in a reinforced concrete section. The lever arm plays a vital role in the calculation of the moment of resistance, the maximum and minimum reinforcement ratios etc. thus influencing the entire design of a reinforced concrete section. The effective depth is also another important parameter. For the design of the longitudinal tension reinforcement, the effective depth (d) of a section is defined as the distance from the extreme concrete fibre in compression to the center of gravity ot the longitudinal tension reinforcement. The effective depth is important as it is used to calculate the required level of reinforcement for an element of a certain thickness to resist a certain bending moment. The guiding parameter for the effective depth should be the concrete cover (c). The concrete cover is the distance between the surface of the reinforcement closest to the nearest concrete surface (including links and stirrups and surface reinforcement where relevant) and the nearest concrete surface. Some norms take the effective depth of tensile reinforcement as 90% of the full depth of the beam though the results obtain will not reflect the minimum concrete cover that satisfy the requirements for bonding, durability and fire rating.

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Table 5 Comparisons of Area of Steel Reinforcement Required

Parameter	French code (BAEL 91)	British Standard (BS8110)	EUROCODE 2 NF EN France	EUROCODE 2 BS EN Britain	Observations
Verification of crushing strength of concrete	μ= $Mu/bd^2fbu \leq 0.186$ 0.15< 0.186 therefore pivot A	K= $M/bd^2fcu \leq 0.156$ 0.065 < 0.156 it is singly reinforced	$\mu u = M_{Ed}/bd^2fcd$ 0.05≤0.15≤0.371 Therefore pivot B and no compression steel is required	$K=MEd/bd^2fck \leq 0.167$ 0.082 < 0.167 it is singly reinforced	**Design using first interior support moments**
Alpha	αu= 1.25 (1-√1-2μ) 0.204	No information	(ulim=0.371) αulim= 1.25 (1-√1-2μlim)= 0,617	No information	
The lever arm Z	Z= d(1-0.4α) 41.328 cm	$Z = d(0.5 + \sqrt{0.25} - k/0.9) \leq 0.95d$ 43.29cm	Zulim= d(1-0.4αulim) 40.9 cm	$Z = d(0.5 + \sqrt{0.25} - k/1.134) \leq 0.95d$ 42.21cm	
Area of steel reinforcement required	$Ast = \frac{Mu}{Zfsu}$ **4.77cm²**	$As = \frac{M}{0.87fyz}$ **4.10cm²**	$Ast = \frac{MEd}{\mathbf{Z}ulimfsu}$ **3.85cm²**	$As = \frac{MEd}{Zfsu}$ **3.76cm²**	
Breadth of flange	b=bw+0.2L= 160mm	bf=bw+0.2L= 160mm	bt=bw+0.2L= 160mm	bf=bw+0.2L= 160mm	**Design using end span moments**
Flange moment	Mtu= b.fbu.ho(d-0.5ho)= 1019.7kNm	Mf =0.45fcu.bf.hf(d-0.5hf)= 1061.10 kNm	M^T_{RD}= bt.fcd.ht(d-0.5ht)= 1019.7kNm	Mf =0.567fck.bf.hf(d-0.5hf)= 1042.37 kNm	
Compare with design moment	Mtu>M section bxh	Mf>Mu Fictive: section bxh	M^T_{RD} >Mu Fictive: section bxh	Mf>Mu Fictive: section bxh	
Verification of crushing strength of concrete	μ= $Mu/bd^2fbu \leq 0.186$ 0.0105< 0.186 therefore pivot A	K= $M/bd^2fcu \leq 0.156$ 0.0045 < 0.156 it is singly reinforced	$\mu u = M_{Ed}/bd2fcd$ =0.0105<0.05 Therefore pivot A and no compression steel is required	$K=MEd/bd^2fck \leq 0.167$ 0.00575< 0.167 it is singly reinforced	
Alpha	αu= 1.25 (1-√1-2μ) =0.0132	No information	αu= 1.25 (1-√1-2μu)=0,0132	No information	
The lever arm Z	Z= d(1-0.4α) 44.76 cm	$Z = d(0.5 + \sqrt{0.25} - k/0.9) \leq 0.95d$ 44.46cm	Zu= d(1-0.4αu) 44.76 cm	$Z = d(0.5 + \sqrt{0.25} - k/1.134) \leq 0.95d$ 43.51cm	
Area of steel reinforcement required	$Ast = \frac{Mu}{Zfsu}$ **2.48 cm²**	$As = \frac{M}{0.87fyz}$ **2.24cm²**	$Ast = \frac{MEd}{\mathbf{Z}ufsu}$ **1.98cm²**	$As = \frac{MEd}{Zfsu}$ **1.92cm²**	

From the given case study which results are on table 5, the design principles are the same for all the codes under study. The formula for effective depth differs between the codes. In France (BAEL91 and NF EN 1992-1 for the design of concrete structures) uses d≤ 90% total depth of beam meanwhile in Britain, BS8110 takes the effective depth as the total depth minus the

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concrete cover and the half diameter of longitudinal steel while NF EN 1992-1 for the design of concrete structures uses the same formula but, further minuses the formwork deviation and the stirrup diameter. The formula for the lever arm differs in the same manner, the formula has alpha in BAEL91 and NF EN1992-1 meanwhile in BS8110 it is different. The limits for verification of crushing strength of concrete also vary within the codes. Since certain parameters differ in the nations implementing the Eurocodes, it means that nationally determined parameters also affect the design with EC2.

The area of tensile reinforcement obtained by EC2 (for both France and Britain) is smaller than that of BAEL 91 and BS8110 at the support and at spans as well. This shows that Eurocode 2 results in more economical than designing with BAEL 91 or BS8110. Since Eurocode 2 results in smaller required reinforcement areas, this decreases the steel reinforcing bars congestion that can result in a structural member. The BEAL91 has the highest required reinforcement area because it also has the lowest yield strength amongst all the other codes under study. This reveals that the lower the yield strength of steel, the greater the area of reinforcement steel required there by resulting in uneconomic design.

5. CONCLUSION

The main conclusions from this study can be summarized as follow:

The introduction of Eurocode has harmonized the factors of loads combination in France (NF EN 1992-1) and Britain (BS EN 1992-1) to 1.35Gk +1.5Qk, also the yield strength of steel has become 500mPa, the strength of concrete is measured from cylindrical specimens. This makes design to be approximately same when using the French (NF EN 1992-1) or the British (BS EN 1992-1) in Cameroon. The bending or internal moment at the support and at the spans of BS8110 is higher than that of the other codes in this study. The is as a result of the higher factors in the load combination of BS8110. The effective depth for both BEAL91 and French National Application of EC2 is same meanwhile the British national application of the EC2 varies. The BS8110 is more conservative than the others in terms of design strength of concrete. The diameters of reinforcement defined in BS8110 codes and Eurocode 2 (BS EN 1992.1.1) are similar, but the strengths are different and this is the same situation between BAEL91 and NF EN 1992.1.1. Diameter 14 steel found in BAEL code and Eurocode 2 (NF EN 1992.1.1) is not recommended in BS8110 code and Eurocode 2 National annex (BS EN 1992.1.1). The EC2 has introduced the notion of ductility of reinforcing steel besides the yield strength meaning that in cases of under reinforcement the structure will hardly undergo brittle failure hence, EC2 ensures more safety to the users of a construction than the BAEL91 and BS8110 codes. Finally results of the comparative study above, the area of tensile reinforcement obtained by EC2 is smaller than that of BAEL 91 and BS8110 at the support and at spans as well. EC 2 therefore results in more economical design than designing with BAEL 91 or BS8110. This also decreases the steel reinforcing bars congestion that can result in a structural member. Therefore this study recommends that designers in Cameroon using BS EN 1992.1.1 should include diameter 14mm steel in their national annex, as diameter 14 reinforcing steel is used throughout Cameroon. Cameroon should as a matter of urgency draw up her national annex and starts the full implementation of Euro code 2 in order to enjoy the manifold benefits of Eurocodes.

REFERENCES

1. Victor o Oyenuga (2018) Reinforced concrete design, consultant's approach to Eurocode 2, Third edition, Vasons Concept Consultants LTD, Lagos, Nigeria
2. Chanakya Arya (2009). **Design of structural elements, Concrete, steelwork, masonry and timber designs to British standards and Euro codes**, Third Edition, London: Taylor and Francis 2, Park Square, Milton Park, Abingdon, Oxon OX14 4RN
3. Tchamba, J. C., & Bikoko, T. G. L. J. (2016). Failure and collapse of building structures in the cities of Yaoundé and Douala-Cameroun from 2010 to 2014. Modern Applied Sciences, 10(1), 23-33
4. Nwabueze Michael ANOSIKE (2011) Parameters for good site concrete production management practice in Nigeria, PhD theses, department of building technology, school of environmental sciences, college of science &technology, covenant university, Ota, Nigeria
5. Christopher Ajiboye Fapohunda (2019) **Limit State Design of Reinforced Concrete Structural Elements, First edition , Pẹlikọṣ Publishers,** Department of Civil Engineering, Federal University, Oye-Ekiti, Ekiti State, Nigeria
6. Bano Samreen, Tabish Izhar, Neha Mumtaz (2019) Design of RC member using different building code: a review Civil Engineering Department, Integral University, Lucknow, U.P., India
7. Bakhoum MM, Shafiek HS. (1996) A relative comparison of actions and strength in four concrete building design codes. Basis of design and actions on structures: background and application of Eurocode. Delft: IABSE Colloquium
8. Tabish Izhar and Reena Dagar (2018) Comparison of Reinforced Concrete Member Design Methods of Various Countries, International Journal of Civil Engineering and Technology, 9(4), pp. 637–646. IAEME Publication
9. Nwoji C. U. and A. I. Ugwu (2017) **comparative study of bs 8110 and eurocode 2 in structural design and analysis,** department of civil engineering, university of Nigeria, Nsukka, Enugu state, Nigeria

DOI: 10.31695/IJASRE.2023.9.9.1

10. Boudebous Hadjar (2017) Etude comparative BAEL91/EC2, memoire en Master Académique, structure, génie civil, Faculté des Sciences et de la Technologie, Université Larbi tébessi, Algerie
11. BAEL. 91-99 (2000) Règles techniques de conception et de calcul des ouvrages et constructions en béton armé suivant la méthode des états limites. Eyrolles,.
12. BS 8110. (1985). Structural Use of Concrete. Part 1, British Standard Institution. Her Majesty Bookshop.
13. BS 8110. (1997). Structural Use of Concrete. Part 1, British Standard Institution. Her Majesty Bookshop
14. NF EN 1992-1-1 (2004) Eurocode 2, Annexe Nationale à la: NF EN 1992-1-1, Règles générales et règles pour les bâtiments, AFNOR, France
15. BS EN 1992 (2005), Part 1, General Rules for Buildings, (Eurocode 2). Standard Institution. Her Majesty Bookshop
16. ANOR (2018) National Standards Development Program in Cameroon, Edition de Septembre, diffusion par l'Agence des Normes et de la Qualité B.P.: 14966 Yaoundé – Cameroun
17. N. Mu'azu et al (2018) The Nigerian National Annex to Eurocode as a Prerequisite for complete transition from BS to Eurocode; a view at BS 8110 and Eurocode 2 for Reinforced Concrete Structures. Faculty of Engineering Seminar Series Volume 9 number 1 University of Maiduguri, Nigeria
18. CP 114 Part 1. (1968). The Structural Use of Reinforce and Presstressed Concrete. Part 1. Design, Materials and Workmanship. London: British Standard Institution.
19. CP 110 Part 1. (1972). The Structural Use of Concrete. Part 1. Design, Materials and Workmanship. London: British Standard Institution.
20. NF EN 1990 (2003) Eurocode 0, Annexe Nationale, Bases de calcul des structures, AFNOR France
21. NF EN1991 (2005) Eurocode 1, Annexe Nationale - Calcul des structures en béton - Partie 1-1 : règles générales et règles pour les bâtiments, AFNOR France
22. Yida Guo , Guobin Gong , Chee Chin and Cheng Zhang (2018) Structural design of concrete to EC2 and GB50010-2010: a comparison, MATEC Web of Conferences 175, https://doi.org/10.1051/matecconf/ 175 IFCAE-IOT 2018 01039 01039
23. Whitehead PA, Ibell TJ.(2004) Deformability and ductility in over-reinforced concrete structures, Magazine of Concrete Research, No. 3, 56 pp. 167-77.

DOI: 10.31695/IJASRE.2023.9.9.1