NEAR EAST UNIVERSITY

INSTITUTE OF GRADUATE STUDIES

DEPARTMENT OF CIVIL ENGINEERING

COMPARATIVE ANALYSIS OF RC FRAMED RESIDENTIAL BUILDING DESIGNED ACCORDING TO BAEL 91/99 AND EC2 IN IVORY COAST

M.Sc. THESIS

KPIE JANVIER DE THALES ADJE

Nicosia

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Approval

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Declaration

I hereby declare that all information, documents, analysis, and results in this thesis have been collected and presented according to the academic rules and ethical guidelines of the Institute of Graduate Studies, Near East University. I also declare that as required by these rules and conduct, I have fully cited and referenced information and data that are not original to this study.

Adje Kpie Janvier De Thales

08/06/2023

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Abstract

COMPARATIVE ANALYSIS OF RC FRAMED RESIDENTIAL BUILDING DESIGNED ACCORDING TO BAEL 91/99 AND EC2 IN IVORY COAST

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ABSTRACT

This investigation provides a comparative assessment of a pair of building design codes such as BAEL 91/99 and EC2, which were founded in 2010. In order to enable a comparison between the codes, a specific location and the most common residential frame model were selected. In this investigation, a reinforced concrete frame building of the regular plan is analyzed for low, mid and rise structures. The moment resisting frame (MRF) model is performed using Autodesk Robot Structural Analysis Professional 2020.

The aim of this analysis is to scrutinize the differences between the two codes and explore the variation in the results obtained from the BAEL 91/99 and EC 2 of a regular RC frame residential building with solid and hollow slab in Abidjan. The results obtained from the analysis are presented in the form of bending moments and axial forces for selected beams and columns for two different codes.

Keywords: MRF, BAEL 91/99, EC2, solid slab, hollow slab, Autodesk Robot Structural Analysis Professional 2020.

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List of Abbreviations

BA: Béton armé

BAEL: Béton Armé aux Etats Limites

EC2: Eurocode 2

GEO: failure or excessive deformation of the ground

ULS: Ultimate Limit State

EQU: Static Equilibrium

MRF: Moment Resisting Frame

MRF+HS: Moment Resisting Frame with Hollow Slab

MRF+SS: Moment Resisting Frame with Solid Slab

NF P 06-001: Norme Française

SLS: Serviceability Limit State

STR: internal failure or excessive deformation of the structure or structural elements

RC: Reinforced concrete

LIST OF SYMBOLS

EC1 & EC2

***A**: Accidental action*

***A**: Cross sectional area*

A_c: Cross sectional area of concrete

A_p: Area of a prestressing tendon or tendons

A_s: Cross sectional area of reinforcement

$A_{s,min}$: Minimum cross sectional area of reinforcement

A_{sw}: Cross sectional area of shear reinforcement

c_{minb}: Minimum cover with respect to adhesion

c_{mindur}: Minimum cover

DL: Dead load

D_{Ed}: Fatigue damage factor

d_g: Largest nominal maximum aggregate size

E: Effect of action

e: Eccentricity

E_c: $E_{c(28)}$ Tangent modulus of elasticity of normal weight concrete

σ_c : Compressive stress in concrete

$E_{c,eff}$: Effective modulus of elasticity of concrete

E_{cd}: Design value of modulus of elasticity of concrete

E_{cm}: Secant modulus of elasticity of concrete

$E_c(t)$: Tangent modulus of elasticity of normal weight concrete at a stress of

E_s: Design value of modulus of elasticity of reinforcing steel

EI: Bending stiffness

F: Action

F_d: Design value of an action

F_k: Characteristic value of an action

f_e: Compressive strength of concrete

f_{cd}: Design value of concrete compressive strength

f_{ek}: Characteristic compressive cylinder strength of concrete at 28 days

f_{ern}: Mean value of concrete cylinder compressive strength

f_{etk}: Characteristic axial tensile strength of concrete

f_{etm}: Mean value of axial tensile strength of concrete

$f_{O,2k}$: Characteristic 0,2% proof-stress of reinforcement

f_t: Tensile strength of reinforcement

f_{tk}: Characteristic tensile strength of reinforcement

f_y: Yield strength of reinforcement

f_{yd}: Design yield strength of reinforcement

f_{yk}: Characteristic yield strength of reinforcement

f_{ywd}: Design yield of shear reinforcement

h: Height

i: radius of gyration of a straight section (uncracked concrete)

K: Coefficient; Factor

G_k: Characteristic permanent action

I: Second moment of area of concrete section

LL: Live load

L_o: Buckling length

M: Bending moment

M_{Ed}: Design value of the applied internal bending moment

N: Axial force

N_{Ed}: Design value of the applied axial force (tension or compression)

P_o: Initial force at the active end of the tendon immediately after stressing

Q_k: Characteristic variable action

Q_{fat}: Characteristic fatigue load

R: Resistance

r: Radius

S: Internal forces and moments

S: First moment of area

T: Torsional moment

t: Thickness

t_o: The age of concrete at the time of loading

T_{Ed}: Design value of the applied torsional moment

V: Shear force

V_{Ed}: Design value of the applied shear force

1/r: Curvature at a particular section

u: Perimeter of concrete cross-section, having area Ac

u, v, w: Components of the displacement of a point

x: Neutral axis depth

x,y,z: Coordinates

z: Lever arm of internal forces

α: Angle; ratio

β: Angle; ratio; coefficient

γ: Partial factor

γ_A: Partial factor for accidental actions A

γ_C: Partial factor for concrete

γ_F: Partial factor for actions, F

$\gamma_{F,fat}$: Partial factor for fatigue actions

$\gamma_{G,fat}$: Partial factor for fatigue of concrete

γ_G: Partial factor for permanent actions, G

γ_m: Partial factor for a material property, taking account of uncertainties in the material property itself

v: Poison ratio

δ: Increment/redistribution ratio

ξ: Reduction factor/distribution coefficient

ε_c: Con1pressive strain in the concrete

ε_{c1}: Compressive strain in the concrete at the peak stress fc

ε_{cu}: Ultimate compressive strain in the concrete

θ: Angle

λ: Slenderness ratio

μ: Coefficient of friction between the tendons and their ducts

v: Strength reduction factor for concrete cracked in shear

ع: Ratio of bond strength of prestressing and reinforcing steel

ρ : Oven-dry density of concrete in kg/m3

ρ_{1000}: Value of relaxation loss (in 0/0), at 1000 hours after tensioning and at a mean temperature of 20°C

ρ_t: Reinforcement ratio for longitudinal reinforcement

ρ_w: Reinforcement ratio for shear reinforcement

σ_c: Compressive stress in the concrete

σ_{cu}: Compressive stress in the concrete at the ultimate compressive strain ε_{cu}

t: Torsional shear stress

ϕ_n: Equivalent diameter of a bundle of reinforcing bars

$\varphi(t,t_0)$: Creep coefficient, defining creep between times tend to related to

elastic

deformation at 28 days

$\varphi(\infty,t_0)$: Final value of creep coefficient

ψ: Factors defining representative values of variable actions

ψ_0: for combination values

ψ_1: for frequent values

ψ_2: for quasi-permanent values

Δc_{de} : execution deviation - 10mm;

$\Delta c_{dur,st}$: reduction of minimum cover for use of stainless steel.

BAEL 91/99

As: Cross sectional area of reinforcement

$\mathbf{A_{s,min}}$: minimum cross sectional area of reinforcement

$\mathbf{A_{sw}}$: Cross sectional area of shear reinforcement

$\mathbf{B_{r}}$: Reduced section of a column

$\mathbf{D_{g}}$: Maximum aggregate size

d: Usable height

$\mathbf{E_{cd}}$: Modulus of elasticity of concrete

$\mathbf{E_{c,eff}}$: Tangent modulus of elasticity of the concrete

$\mathbf{E_{s}}$: Modulus of elasticity of steel

$\mathbf{F_{bd}}$: Adhesion limit stress

$\mathbf{F_{ck}}$: Characteristic compressive strength of concrete at 28 days.

$\mathbf{F_{cm}}$: Average compressive strength of concrete at 28 days.

$\mathbf{f_{ed}}$: Design strength of steel

$\mathbf{f_{tj}}$: Conventional concrete tensile strength at j days.

$\mathbf{F_{yd}}$: Design resistance of reinforcement

$\mathbf{F_{yk}}$: Yield strength of steels

$\mathbf{F_{bu}}$: Design compressive strength of concrete

$\mathbf{G_{k}}$ dead load

$\mathbf{G_{max}}$: all the unfavourable permanent actions;

$\mathbf{G_{min}}$: set of favourable permanent actions

$\mathbf{Q_{1}}$: basic variable

$\mathbf{Q_{i}}$: live load

I: Second moment of area of concrete section

L: Length

l_{brqd}: Required anchorage length

L_f: Buckling length

I_1: Moment of inertia of the reduced homogeneous section

L_{eff}: Effective span of beam

L_n: Effective span between supports

M_o: Maximum isostatic moment in span

M_{oed}: First-order cracking moment at ULS taking into account geometric imperfections.

M_{umax}: Maximum moment in span or on support

M_{oeqp}: First order service moment under the quasi-permanent combination

M_{ed}: Ultimate bending moment

Mser: bending moment at limit state of service

M: Bending moment

M_{Ed}: Design value of the applied internal bending moment

N: Axial force

n: Relative normal effort

N_b: Buckling load evaluated using the nominal stiffness method

N_{Ed}: Design value of the applied axial force (tension or compression)

Po: Initial force at the active end of the tendon immediately after stressing

S: Internal forces and moments (solicitations)

T: Torsional moment

T_{Ed}: Design value of the applied torsional moment

s_{tmax}: Maximum spacing of transverse reinforcement courses

st: Spacing of transverse reinforcement courses

$s_{maxslabs}$: Spacing of reinforcement in bending of a slab

$\mathbf{s_o}$: Initial spacing of web reinforcement for the caquot method

$\mathbf{V_{rd,s}}$: Design shear force that can be supported by a shear force element working at the yield point

$\mathbf{V_u}$: Shear force at ULS

$\mathbf{V_{rd,max}}$: Maximum design shear force that can be supported without causing the crushing of the connecting rods

$\mathbf{V_{rd,c}}$: Design resisting shear force of a member without reinforcement

$\boldsymbol{\gamma_s}$: Safety factor affecting the design strength of the steel

$\boldsymbol{\gamma_b}$: Safety factor affecting the design strength of concrete

Qi : Nominal value;

$\boldsymbol{\psi_{0i}Q_i}$: Combination value ;

$\boldsymbol{\psi_{1i}Q_i}$: Frequent value ;

$\boldsymbol{\psi_{2i}Q_i}$: Quasi-permanent value ;

CHAPTER I

Introduction

Depending on the geographical position, the environmental conditions, and certain realities faced by every country, building codes have been developed accordingly. It is clear that the environmental realities in African and European countries are not the same. For instance; there is no snow and earthquake in some of the French-speaking West Africa countries especially in Ivory Coast. It implies that the load's calculation pattern will be different.

French speaking West Africa is a federation of eight French colonial territories in such as Senegal, Mauritania, Guinea, Mali, Benin, Burkina Faso, Ivory Coast and Niger. After the colonization, these countries have adopted the French rules and regulations in all the aspects of the society and the construction areas as well. In 1906, the first regulation was published based on a calculation method known as admissible stresses.

Throughout the history, the French building standard has been modified and improved several times. In fact, the first building standard was in 1906. It was a circular that has been replaced by Rules BA 45 then BA 60, BA 68, BAEL 80, BAEL 83 and finally BAEL 91. The application of the BAEL 83 rules has been necessary since January 1, 1985, the date on which the previous CCBA 68 rules were repealed after a period of coexistence. The systematic use of BAEL 83 has revealed a few imperfections sufficient to justify a revision to reach BAEL 91 which again was improved to obtain BAEL 91 modified 99 or BAEL 91/99 (Béton armé aux états limites) . This new text, notably introduces the consideration of high-performance concretes (HPC), with a compressive strength of up to 60 mega Pascal (60 MPa).

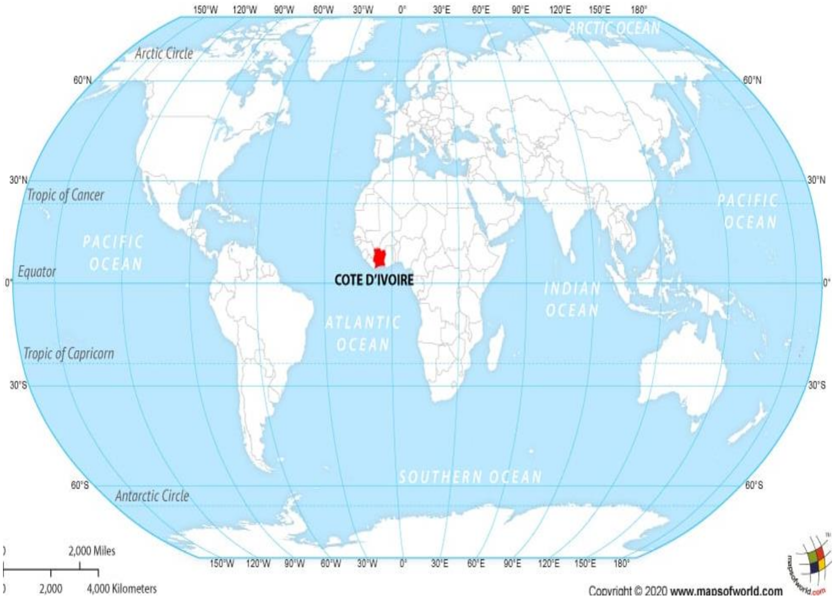
This building standard kept evolving over time until it finally got to the Euro codes rules are being used now.

Since Côte d'Ivoire is a French colonial heritage, it is therefore subjected to the same building code scenario. It is a one of the West African countries with a total land area of 322 462 km² with seaside resorts, tropical forests and. Abidjan, on the Atlantic coast, is the main country's urban center.

A case study is chosen in Abidjan. Abidjan has a total population of 8,392,719.

Figure 1

Ivory Coast on the world Map

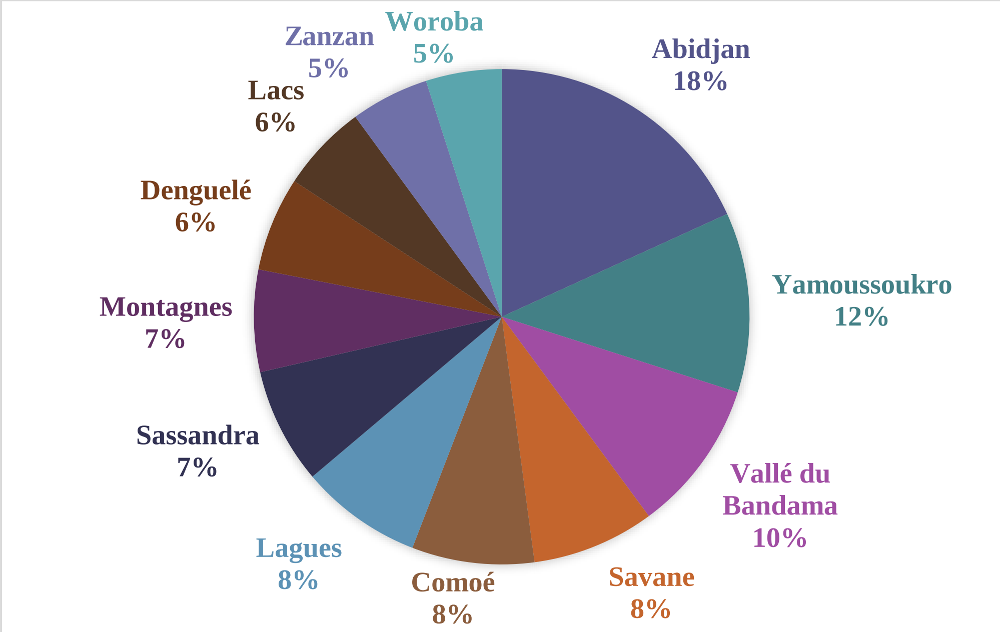


(https://owl.purdue.edu/owl/research_and_citation/apa_style/apa_formatting_and_style_guide/apa_tables_and_figures.html).

Tragically, no current logical building data that passes on current circumstance in Abidjan is available. The data gotten within the census carried out by the Statistical Institute can be used to assess the overall urban construction.

Figure 2

Total urban constructions in Ivory Coast in 2014



(Ivory Coast government agency)

Statement of Problem

The countries of France and Ivory Coast are known to have had BAEL 91 as the same construction code before France switched to the Eurocodes many years ago. In fact, this standard came to West African countries from Europe. The Eurocode was introduced in March 2010 in order to replace the BAEL 91/99 that was used by France and many European countries. However, until now, the BAEL 91/99 is still in use in French-West African countries. Normally, we should be evolving too, like France and many other countries that are continuously revising their building standards, but we are still stagnant in the same position.

Purpose of the Study

For the next five years, the government of Cote d'Ivoire has planned major structuring projects, particularly in the sectors of infrastructure, security, transport, mining, energy, hydrocarbons, and industry, improving the quality of life and the environment, tourism, and the basic social sectors, with a view to deep and lasting socio-economic transformation. In the field of housing, the government is planning the construction of 150,000 social housing units by 2025, the acceleration of housing construction, the development of the local building materials industry, and the restructuring of precarious neighborhoods and strategic urban areas in Abidjan. To achieve its objectives, the government relies on foreign companies. Consequently, we notice a strong presence of French companies since colonial times, which have the majority of the projects.

The reason for considering this study is that, firstly, it is to be expected that over the coming years, the new standard will be applicable for most of the work in West African countries. That means we will be more likely to shift from the BAEL to the Euro code. Therefore, structural engineers in West African countries, especially in Ivory Coast, should understand the differences in approaches to calculation that exist between the two codes and the similarities, if any, before they are officially used in West Africa.

Secondly, since realities in Cote d’Ivoire and Europe are not the same, this study will appreciate the new regulation's contribution. Locate the difficulties of its applications, detect the possible flaws of the old regulation, and at the end, deduce its future in our country. This study may help prepare us for a better transition from BAEL to Eurocode or awaken African engineers to elaborating our own building design code.

The aim of this study is to explore the variation in the outcomes from the BAEL 91/99 and EC 2 of a regular RC frame residential building with a solid and hollow slab in Abidjan using Autodesk Robot Structural Analysis Professional 2020.

To establish a comparative evaluation between two design codes:

- BAEL 91/99
- EC2

To investigate moment-resisting frame with solid slab (MRF+SS) and hollow slab (MRF+HS) low-rise to mid-rise RC framed structures,

To explore the variation in the outcomes.

To verify axial forces and bending moments for selected columns and beams respectively according to codes mentioned above.

Significance of the Study

This study will prepare French-speaking West Africa countries for a better transition from the BAEL to Eurocode.

- Understand the difference between both standards in detail.
- Lacking the current knowledge
- Specify the method to be used
- Objectives of the study
- Results and discussions

Research Questions

The proposal problem statement is:

- What is the difference between the BAEL 91/ 99 and the EC2?
- What are the different approaches that exist in both codes?
- How each standard are built-in the form and substance?
- What is the difference in the process of analysis and design scheme?
- What are the applied safety requirements of both codes?
- What is the difference in loads (live and dead) intensities?
- The above questions are the doubtful points in the mind of the Engineers in French speaking West Africa countries.

Limitations

This research is limited to RC frame without shear wall and to a set of structural software. In fact, BEAL 91/99 is not found in all the structural designing software. On the other hand, seismic loads and wind loads, are not taken under consideration based on the geographical position of Abidjan (Ivory Coast). As a result, the designed system is suitable for Abidjan, Ivory. To apply these results to another location, the corresponding loads (wind loads, and seismic loads) should be determined according to the area’s conditions, and then modify the structural models accordingly.

CHAPTER II

Literature Review

During the study, a literature review related to the comparison between BAEL 91/99 and EC2 was performed. It is important to note that few articles have been published in this regard. Articles and papers are reviewed in this part.

Related Researches

Mr Metz Marie Laure (2008), “Comparaison BAEL 91,99 / EC 2 et modélisation PS92 / EC 8 appliquée à un établissement hospitalier”. This study revealed that the more economical code is based on the structural elements subjected to the study. For instance, the steel area obtained from the BAEL is more economical than the Eurocode for the beams where EC2 requires a larger section of reinforcement to be extended beyond the support (5.14cm² against 3.98 cm² for the BAEL 91/99). This represents a 29% increase in section reinforcements. For the end steel, there is a difference of 21% of the reinforcement section, the EC2 being less favourable.

For the slabs, the determination of the reinforcements according to the small span and the edge anchoring, the BAEL 91/99 is more favourable than EC2. This represents a difference of about 20% for the reinforcements longitudinal and 10% for shore anchoring.

For slabs in on direction the reinforcement section following the long span is lower for EC2, in effect it is obtained by multiplying the reinforcements by 20%¨contrary to the BAEL the coefficient is 25%. For slabs in both directions, it should be noted that if the seismic provisions are taken into account, the BAEL is more favourable than the EC2.

Hanane Bentouhami, (2012), “Comparison BAEL 91/99 and EC2 and implementation of a tool for dimensioning of reinforced concrete to EC 2” In this study, the difference between the two codes have been used for the implementation of a new software using EC2. The difference has been made only theoretically. Ferrail, EffAdd, Ferrmax, ANSYS have been used for the design of the software.

This study has shown that there are differences between the two regulations from the mechanical characteristics of the materials (diagrams) point of view but also of the calculation methods, particularly for continuous beams and columns. The results are relatively close or not between the two regulations depending on the elements studied. CBS-Pro and ROBOT software have been used for the design.

According to the authors << it is even allowed to think that the more explicit consideration of the requirement of sustainability in projects foreseen by Eurocode 2 can lead to a reduction costs, which however could only be detected after an overall assessment >>.

Marcellin K. (2017). “Comparative study between BAEL 91/99 and the Euro codes: example of the Moada framework bridge, thesis in international institute of water and environmental engineering”.
It result that the reinforcement section obtained according to the Eurocode design is lower than that obtained with the BAEL91/99 design. This difference is mainly due to the differences noted in the calculation assumptions and in certain calculation formulas using Robot Structural Analysis 2015.

Guy Roger A. and Kouandete Valery D. (2018), “ Comparison of Eurocode 2 and BAEL 91,99 for Industrial RC Buildings in Benin- Cotonu”. The main purpose is to investigate the differences caused by the use of different codes for the design of building-pharmacy. The results obtained from the study using RDM 6 software calculate the internal solicitations have been compared to each other.

CHAPTER III
Methodology

This chapter display information on the case study, deals with the modelling of the structures , and explores the variations in the outcomes gain with the two building codes.

Case Study

The area of the study is Abidjan city in Côte d'Ivoire that commonly known as Ivory Coast, a country in West part of Africa, on the Gulf of Guinea (North Atlantic Ocean) is between Liberia and Ghana. Mali and Burkina Faso are its northern borders. Abidjan city contains ten major districts and it is Côte d'Ivoire's largest city and economic capital as shown in Figure 3. It is located at the seaside and has the West Africa's biggest port. The RC frame under this study will be designed according to two building codes.

The building plan within the scope of this study is inspired by an existing building in Northern Cyprus. The plan will be subject to two codes such as BAEL 91/99 and EC2.

Ivory Coast seismicity state

The seismicity of Ivory Coast is generally considered low to moderate. The country is located in West Africa and is situated on the stable African continental plate, which is not directly located near any major tectonic plate boundaries.

Fortunately, according to Ivory Coast government institute, the country is been in a zone considered to have very low earthquake magnitude. Therefore, the zone under the study is characterized by low seismicity. For this reason, designers do not consider earthquake loads in the design of structures. According to the history, the most significant earthquake in the area occurred on 26 June 1985, with a magnitude of 4.9 Mw.

In general, seismic activity in West Africa is lower compared to regions near plate boundaries, such as the East African Rift or the Mediterranean. The majority of earthquakes in the region are of low magnitude (below Mw 5.0) and often go unnoticed by the local population.

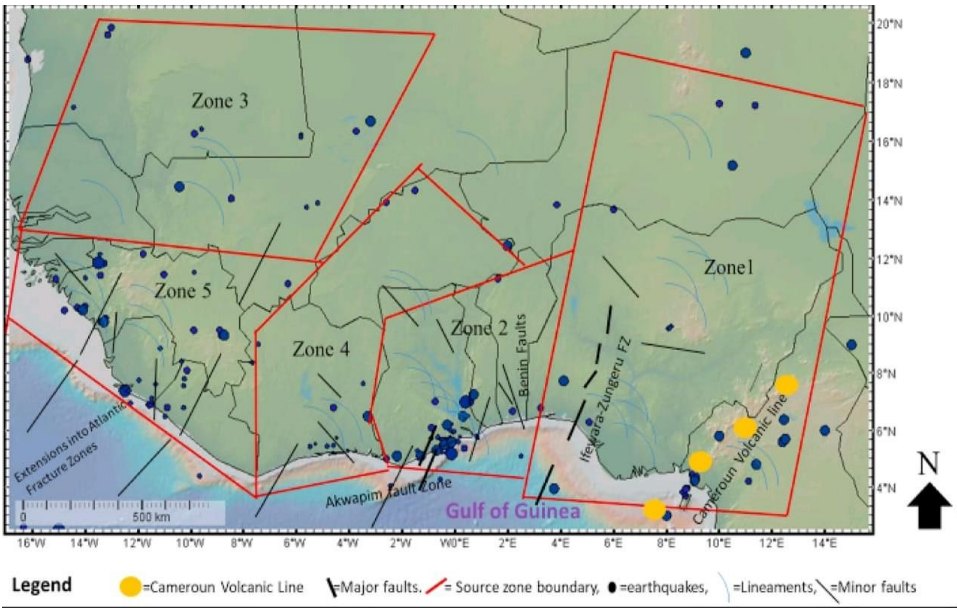
Figure 3

Abidjan and its districts

(https://owl.purdue.edu/owl/research_and_citation/apa_style/apa_formatting_and_style_guide/apa_tables_and_figures.html).

Figure 4

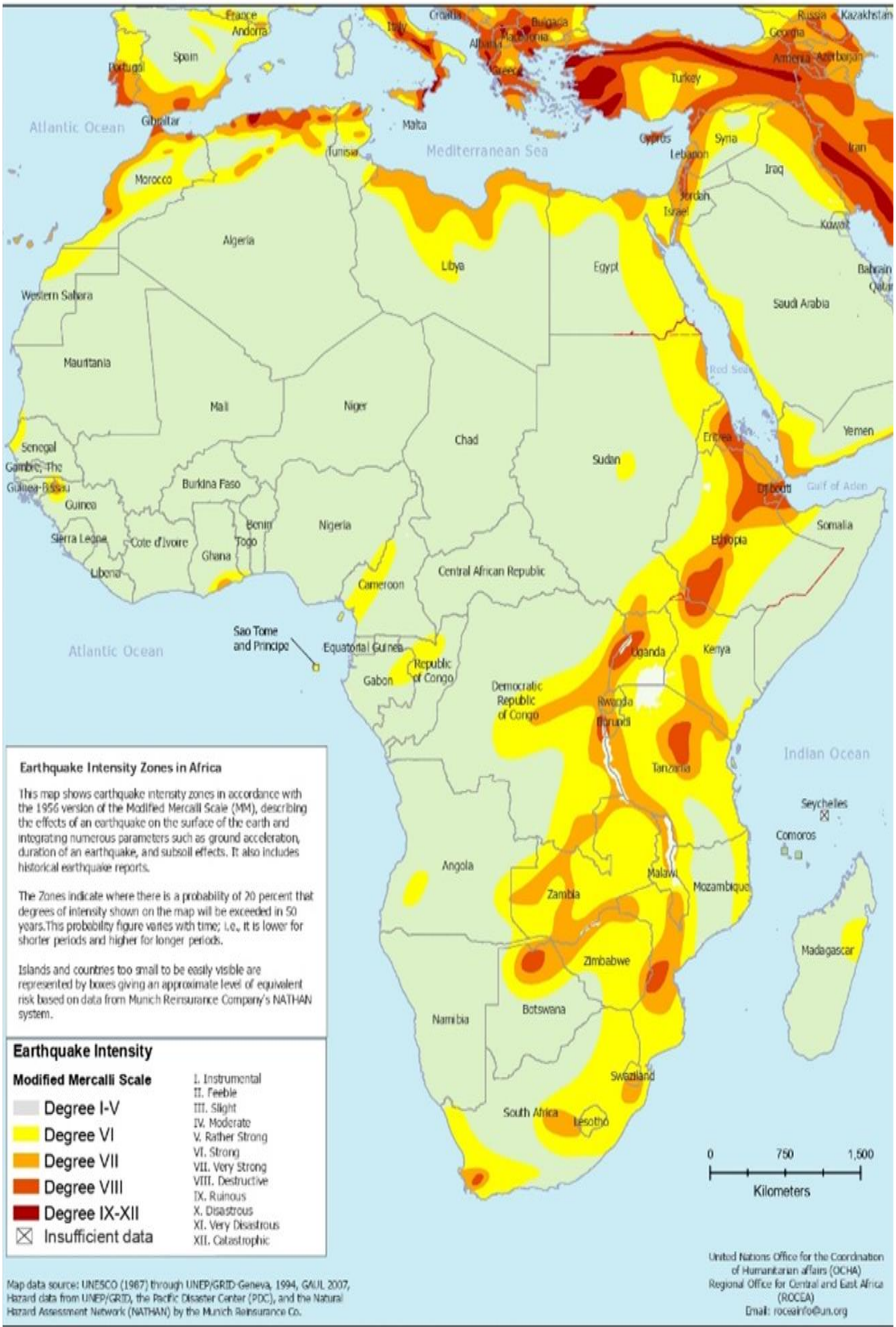
Seismicity and seismic assessment in West Africa



(https://www.sciencedirect.com/science/article/abs/pii/S1464343X21002065)

Figure 5

OCHA Regional Office Central and East Africa Earthquake Risk in Africa: Mercalli Scale. Issued: December 2007.



(https://reliefweb.int/map/ethiopia/earthquake-risk-africa-modified-mercalli-scale-december-2007)

Modelling of RC Framed Structures

This is a design study, dimensioning by the two regulations BAEL 91/99 and EC2, and calculation of a G+4 building, for residential use. This building contains an accessible terrace.

Total length L: 21.75 m

Total width B: 14.95 m

Ground floor height h: 3 m

Current story height: 3 m

Total height: 12 m

Types of soil: sandy-clayey sediments

The allowable soil stress: 1.3 bars.

From the seismic point of view, the land is located in zone 4.

Allowable bearing pressure :	150 kN/m²
Modulus of subgrade reaction:	20000 kN/m³
Concrete density:	25 kN/m³
Building Importance factor:	1
Type of foundation:	Single footing
Intended purpose:	Residential
Concrete class:	25MP
Steel class:	400 MPa

Two types of RC buildings were modelled and analysed in this part, namely:

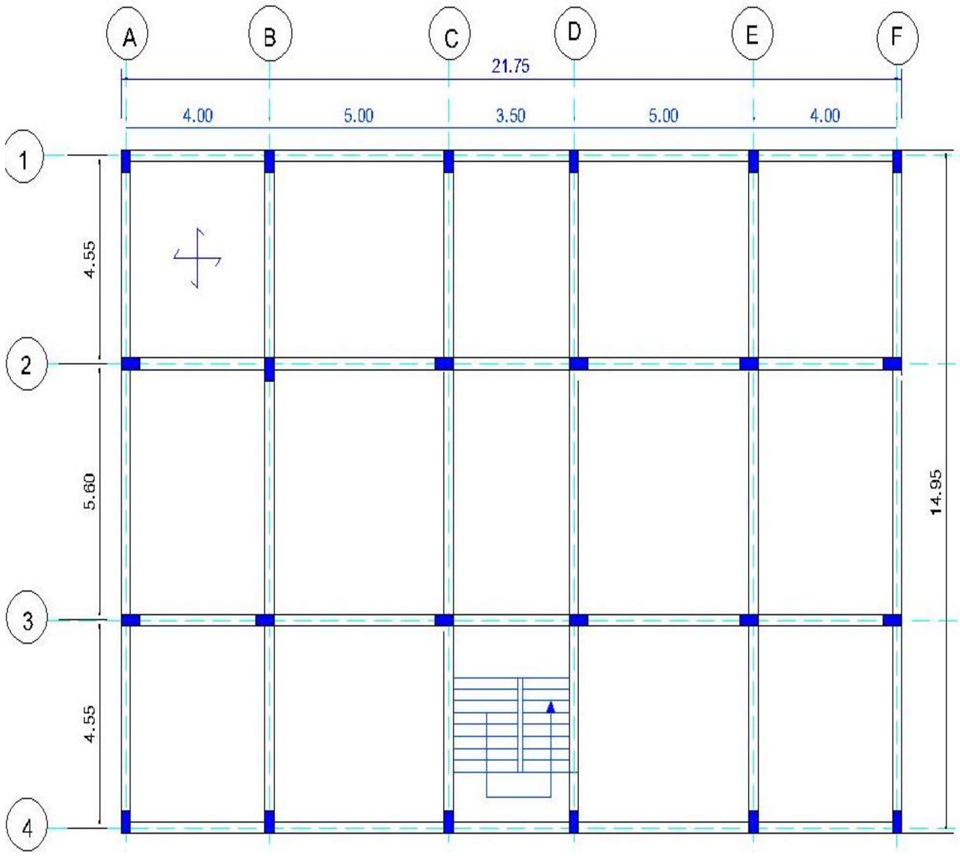
- Four-story moment-resisting frame with solid slab (MRF+SS) regular form analysis.
- Four-story moment-resisting frame with hollow slab (MRF+HS) regular form analysis.

Data Collection Procedure

The plan under this study is an existing plan in Cyprus; this plan will be subjected to some modifications and design to the BAEL and EC2. The three-dimensional (3D) analysis is performed under moment resisting frame analysis. In this study, for selected columns and beams respectively under different parameters proposed by the above-mentioned codes axial forces and bending moments will be compared.

Figure 6

Floor plan for G+4 story moment-resisting frame residential building



Dimensions of structural elements

Table 1

Layout of *slab*

No storey	type of slab	Thickness (mm)	slab Description
G+4	solid/hollow	160	Slab carrying internal walls

Table 2

Layout of Beams

No storey	Beam	Dimensions (mm)	Type of carrying
G+4	B	450x250	walls

Table 3

Layout column

No storey	Column	b(mm)	b (mm)
G+4	C	250	500

Load combinations

Load combinations in structural design codes, such as BAEL 91/99 and EC2, specify the combinations of different types of loads that need to be considered when designing structures. The overview of load combinations in BAEL 91/99 and EC2 are given below in Table 4.

Table 4

Load combinations

Combination	BAEL 91/99	EC1
DL and LL	1.35 DL+1.5 LL	1.35 DL+1.5 LL
DL + LL	DL + 1.5LL	DL + 1.5LL
DL + LL+ W	1.35DL + 1,50LL + W DL+1.5LL+W DL +1.5W+ 1.3 +ψ0 LL 1.35DL+1.5W+1.35ψ0 LL	1.35DL + 1.5LL + 0.9 W DL + 1.5 LL + 0.9 W DL + 1.05 LL + 1.5 W 1.35 DL + 1.05 LL + 1.5 W

Design of G+4 Residential Building

Here are displayed the findings based on the analysis of the structure.

Method used

Moment-resisting frame could be a rectilinear gathering of columns and beams, with the beam rigidly associated to the columns. Moment resisting frame comprises columns, beams and the rigidity between them. In this structural system the stiffness of the columns and beams are trusted to resist the lateral and gravity loads.

The resistance to lateral forces is due to the rigid frame action, which is the progress of shear force and bending moment in the frame members and joints. By virtue of the connections of rigid beam–column, a moment frame can not displace sideway without bending the columns or beams depending on the geometry of the connection. The bending rigidity and strength of the members of the frame is consequently the predominant source of lateral stiffness and strength for the whole frame.

Moment resisting frame has a greater architectural versatility compare to other structural system such us bracing and shear walls system because openings or open spaces are not obstructed by bracing elements.

Moment resisting frame can be made of reinforced concrete or steel.

Robot Structural Analysis

The RC building is analyzed and designed using the Robot Structural software program 2020.

Robot software is a proficient and progress basic stack investigation computer program that confirms code compliance and employments BIM-integrated workflows to trade information with Revit. Robot Basic Investigation can moreover offer assistance to make more flexible, constructible plans that are precise, facilitated, and associated to BIM.

Autodesk Robot Structural Analysis is a professional level software provides engineers with advanced building simulation and analysis abilities for large, complex structural modelling. Part of the Digital Prototyping solution, this software offers a smooth workflow, helping engineers to more quickly perform simulation and analysis on a variety of structures

The software gives engineers a good platform to quickly execute simulation and analysis of different kind of structures by providing a smooth workflow. The open API (application programming interface) contributes to the development of a scalable, country-specific analysis solution for large and complicated structures. Printouts can be generated directly from printout composition or using Microsoft Word editor HTML format.

Modelling using Autodesk Robot Structural Analysis Professional 2020

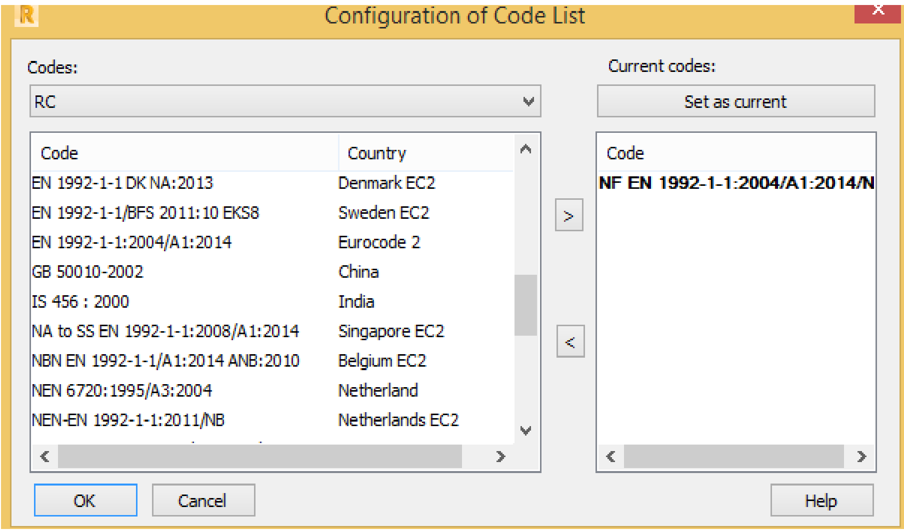
Model initialization

This work consists of modelling the plan, which has started by the structural design: positioning of structural element (columns, beams and slabs) including their dimensions.

Autodesk Robot Structural Analysis Professional 2020 present many Euro codes 2 as per European countries such us UK EC2, Denmark EC2, Sweden EC2, Singapore EC2, Belgium EC2, Netherland EC2, Norway EC2, Poland EC2, Finland EC2, Romania EC2, Italy EC2 and France EC2. This list shows that not all European countries use the same Eurocode instead; the code has been fitted to each of them according to their needs as shown below.

Figure 7

Building Codes



In this study, the unit and the design codes chosen are the following: Metric as unit and BAEL 91/99 as design code with DTU 13:12 the geotechnical annex code and EC2 and the French annex codes.

Figure 8

Units and other specifications

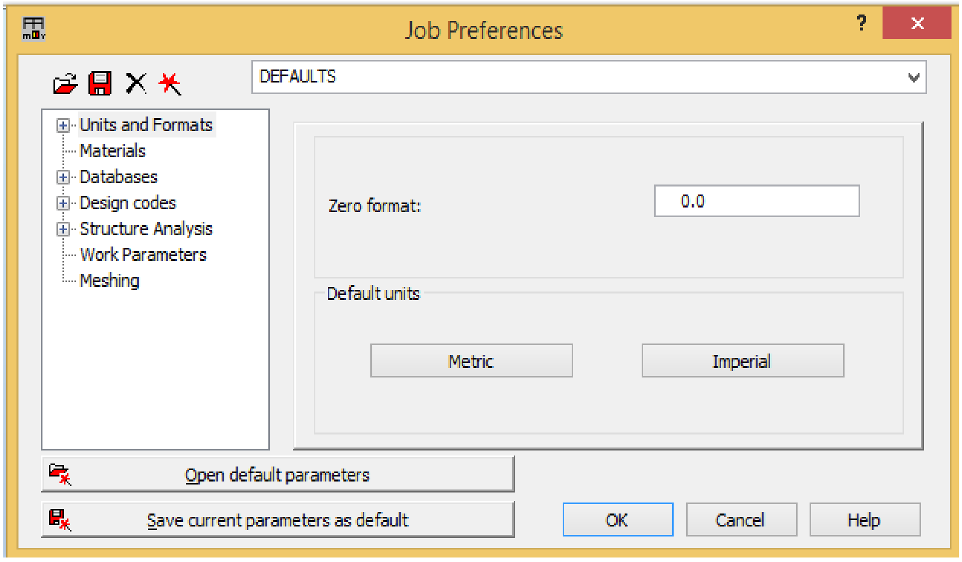


Figure 9

International code, EC2

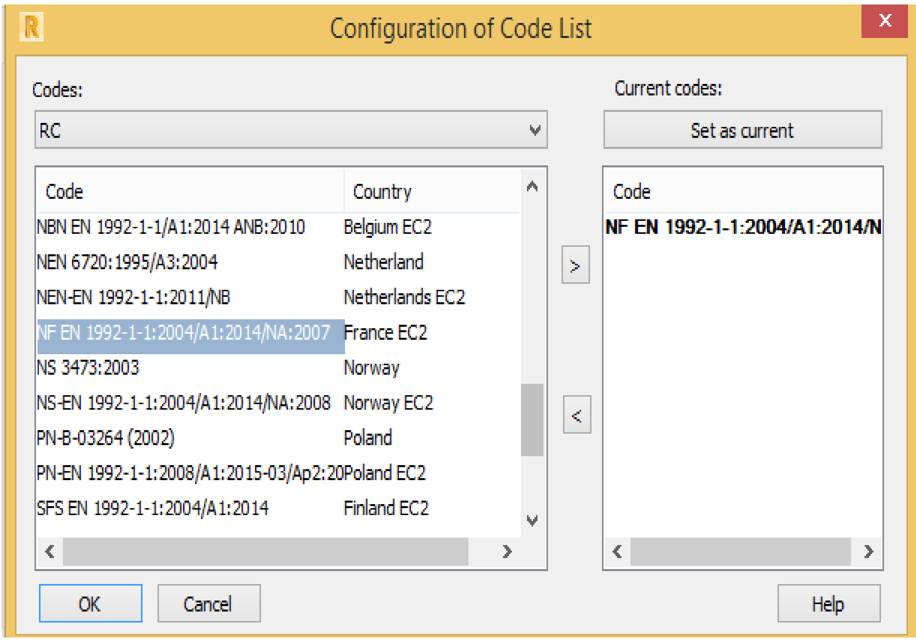
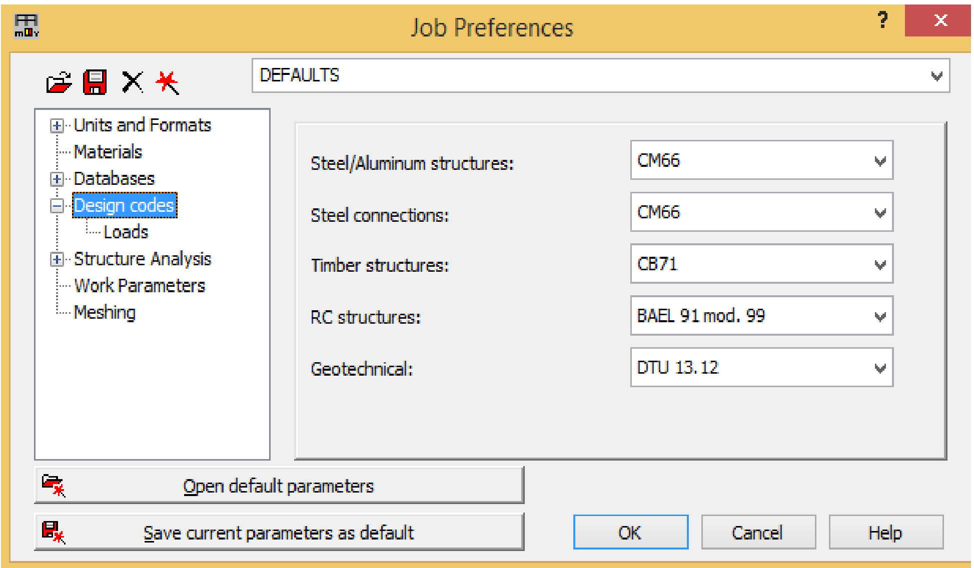


Figure 10

Design Codes



Material properties

The picture below shows the sizing of the different structural elements columns, beams and slabs. The dimensions are given as input to the software. It show the materials properties generated by the software itself.

Figure 11

Columns and beams sections

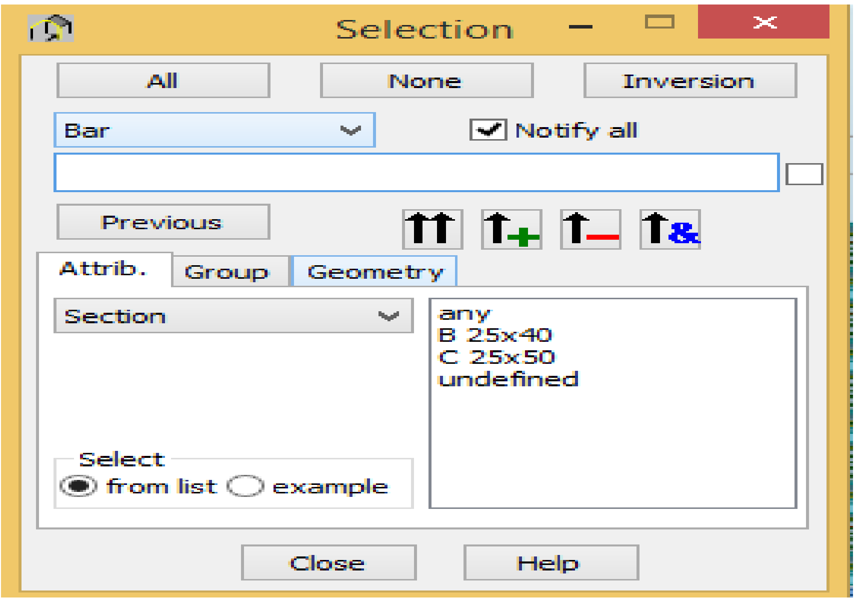


Figure 12

Solid slab

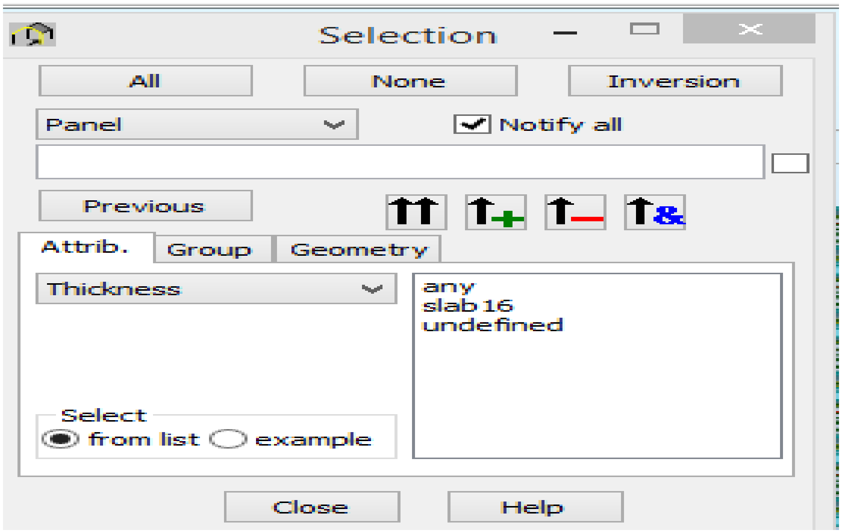


Figure 13

Hollow slab properties

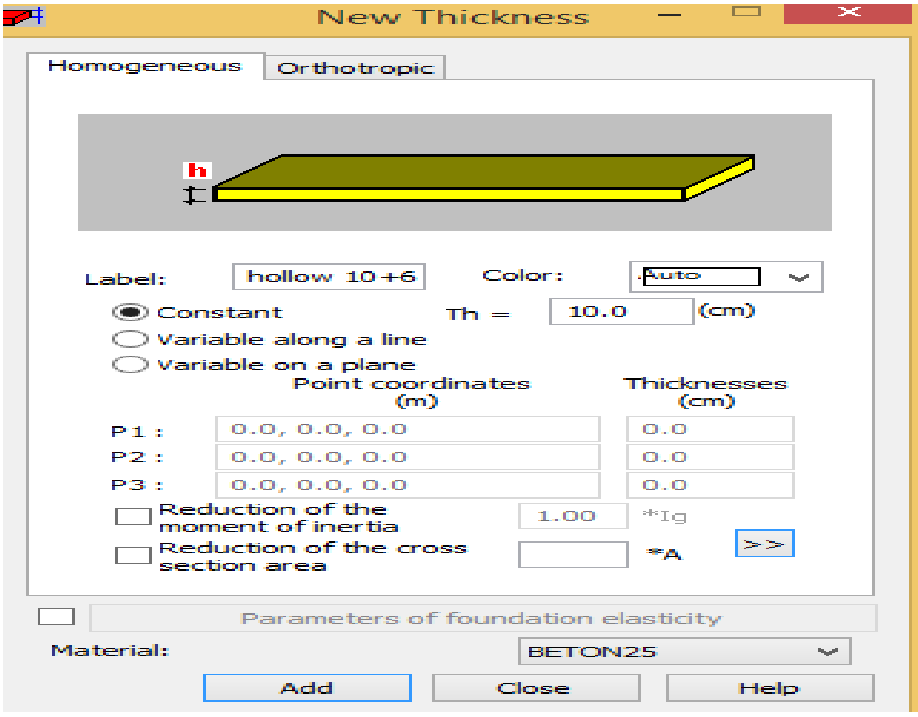


Figure 14

Steel properties

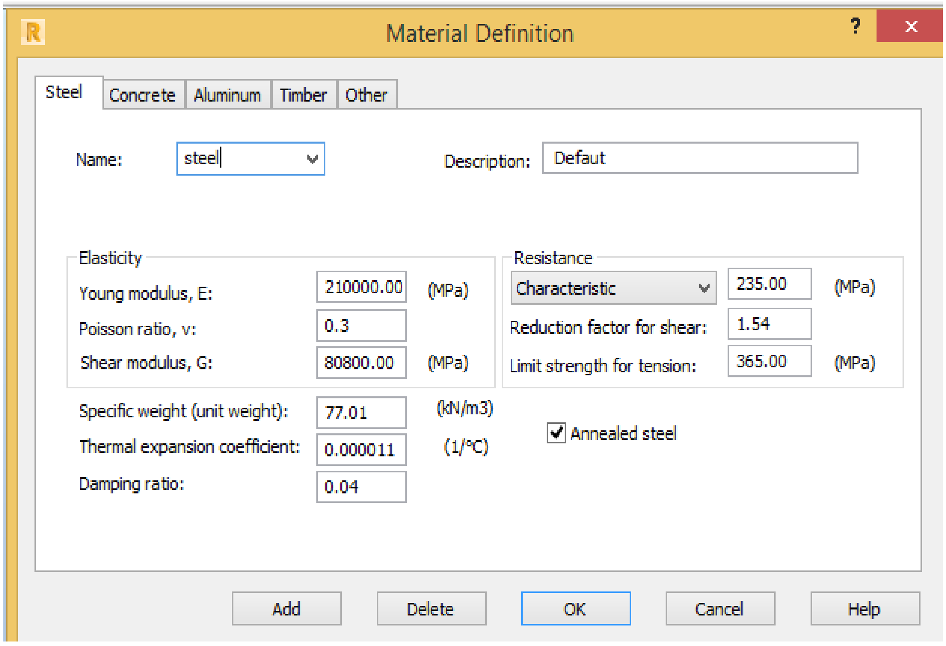
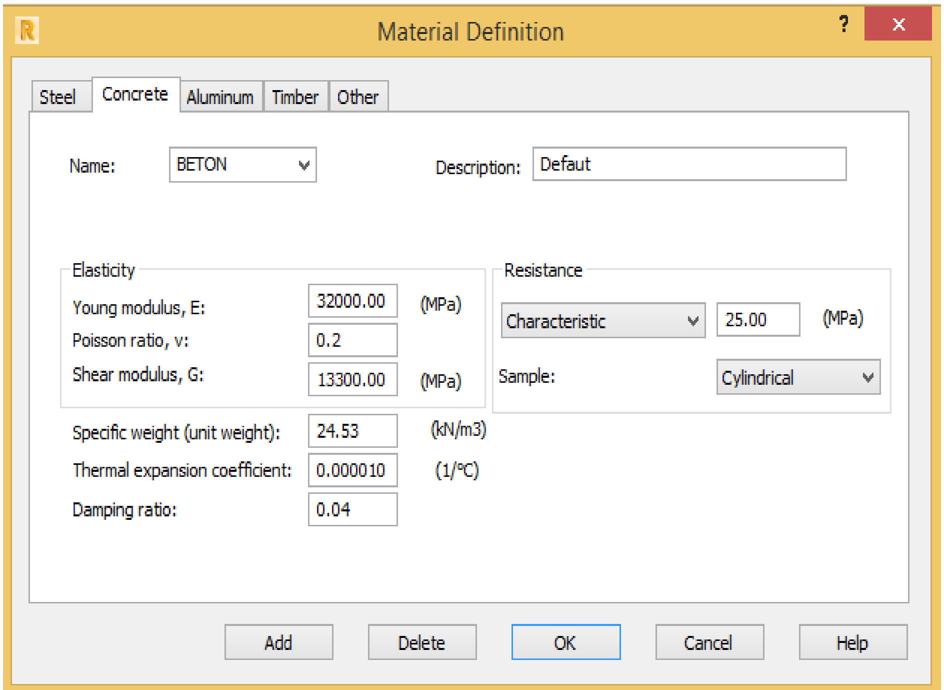


Figure 15

Concrete properties



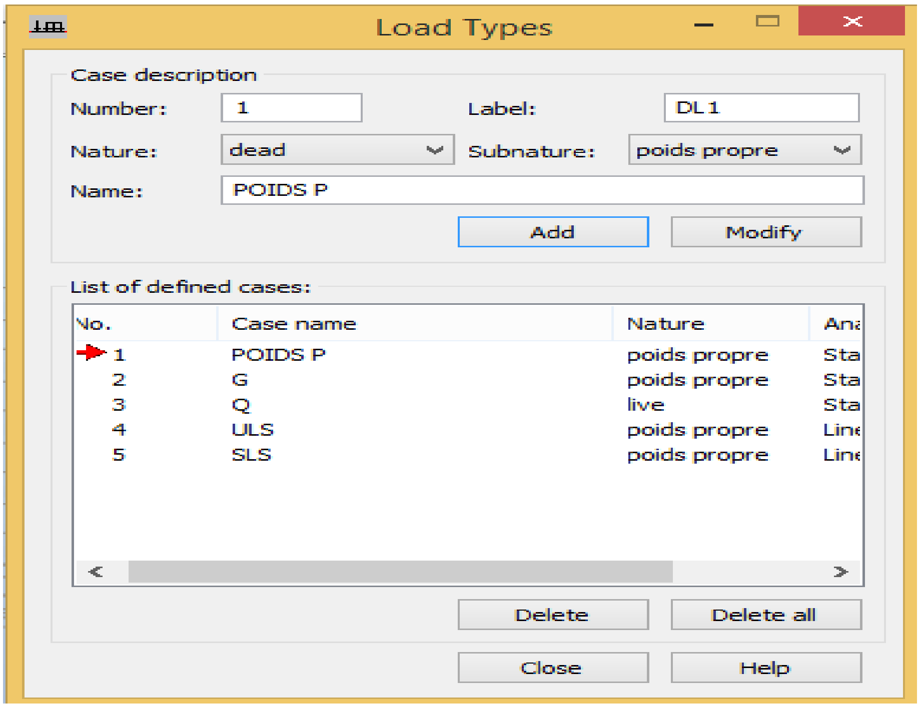
Loading

The permanent loads such as beams, columns and slabs are designed according to their critical values. In this study, due to the low wind load intensity in the area subjected to the study the wind load is not considered in the design.

The self-weight of the structural elements are computed automatically by software Robot according to their unit weights. Moreover, weights of covering elements and walls, which depends, of the materials chosen are included in the calculations.

Figure 16

Load types



Manual combinations have been used for the load case code combination for both BAEL91/99 and EC2.

Figure 17

Types of Combinations

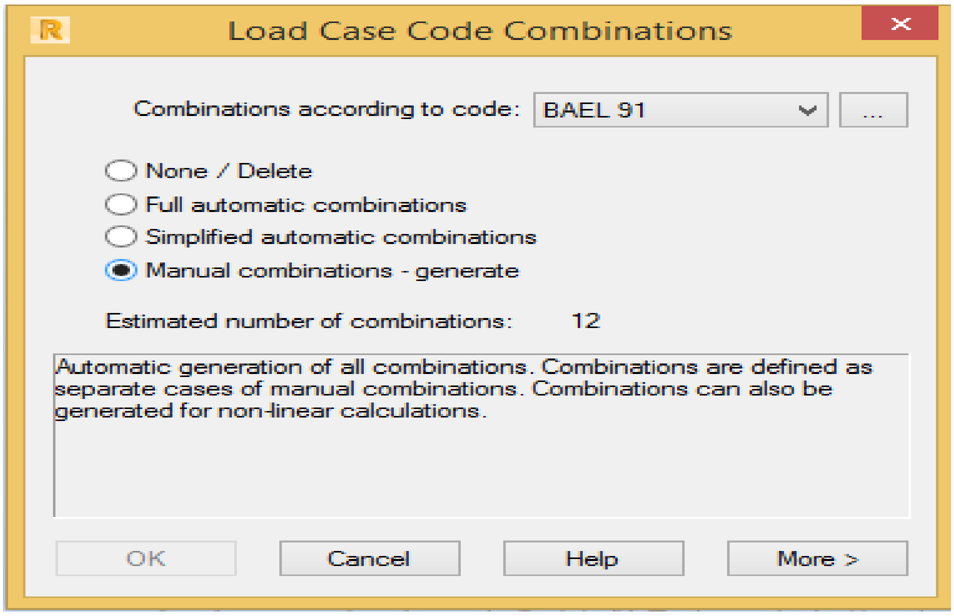
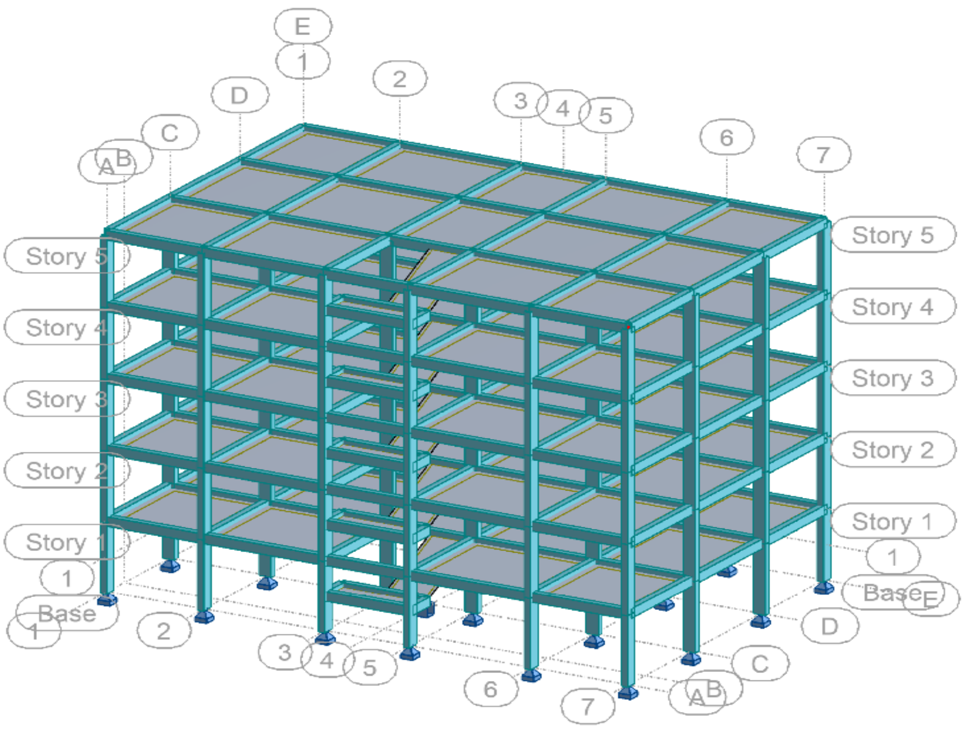


Figure 18

3D view of G+4 residential building



CHAPTER IV

Design codes

A comparative analysis of reinforced concrete framed residential building designed according to the BAEL 91/99 (French concrete design code) and EC2 (European concrete design code) would involve the examination of various aspects of the design process, including design methodologies, material properties, structural analysis, and design provisions. Here is a brief overview of these aspects for comparison:

Partial factors

Partial factors allowing to cover the uncertainties and to determine the design actions and resistances are defined as follows:

Table 5.

Partial factors for materials BAEL

Design situation		γ_b (Concrete)	γ_s (Steel)
ULS	Persistent/Transient	**1,5**	**1,15**
	Accidental	**1,15**	**1,0**
SLS		**1,0**	**1,0**

Table 6.

Partial factors for materials Eurocode 2

Design situation		γ_C (Concrete)	γ_S (Steel)
ULS	Persistent/Transient	1.5	1.15
	Accidental	1.2	1.0
SLS		1.0	1.0

The two tables above show two changes, γ_b becomes γ_C with 'c' for 'Concrete' et $\gamma_{b,\ \text{accidental}}$ passes from 1.15 to 1.2.
These changes are noteworthy: γ_b therefore becomes γ_C with 'c' for 'Concrete' and γ_b, with 'b' 'Béton' accidentel goes from 1.15 to 1.2.

It is important to show how concrete and steel materials are addressed in the two regulations and their differences.

Regulation requirements for materials: concrete- BAEL

Compressive strength
The compressive strength of concrete at 28-day based on A 2.1.111, is called the required characteristic value and is noted f_{c28}.

Compressive strength at 28 days: f_{c28}
Strength at day j: f_{cj}

At more than 28 days $f_{cj} = f_{c28}$

At less than 28 days, the following law is accepted:

$$f_{cj} = \boldsymbol{j}/(\boldsymbol{a}+\boldsymbol{bj}) f_{c28}$$

With $f_{c28} \leq 40$ MPa ; a =4,76 et b = 0,83

All designs must be based on a specified characteristic strength that is obtained during execution.
The scope of application of the BAEL 91/99 rules applies to concretes up to 80 MPa.
On the building sites, the concretes frequently used are concretes having slump test of 10 cm.

Tensile strength

$$f_{tj} = 0{,}6 + 0{,}06\, f_{cj}$$

Design resistance: $f_{bu} = \frac{0.85\, fcj}{\gamma b}$

Others characteristics

Poisson's ratio
- v = 0.2 in uncracked section
- v = 0 in cracked section

Density: ρ = 25000 kg/m² or ρ = 24.5 kN/m3

Strain modulus:
Instantaneous modulus of elasticity

$$E_{ij} = 11000\ 3\sqrt{fc}\mathrm{j}$$

Modulus of delayed elasticity $Ev\mathrm{j} = 3700\ 3\sqrt{fc}\mathrm{j}$

Stress strain diagram
BAEL 91/99 presents two possible diagrams:

Figure 19

Parabola-rectangle diagram of concrete

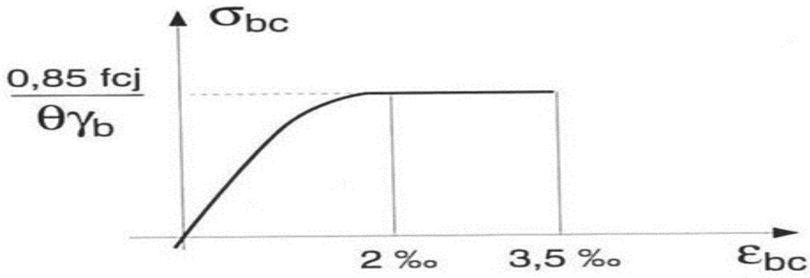
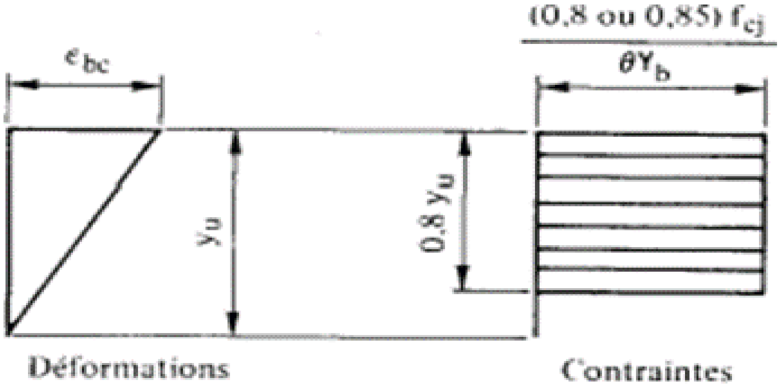


Figure 20

Simplified rectangular diagram



(From design code BAEL 91,99)

Regulation requirements for materials: concrete - EC2

Compressive strength

In EC 2, the compressive strength is determined either on cylindrical or cubic specimens according to EN 206-1.

EC2 allows the use of concrete from 12 to 90 MPa cylinder strength. This is noted: f_{ck} = Compressive strength at 28 days.

The average compressive strength at d-days at t age and an average temperature of 20° and a cure performed according to EN 12390, we have:

$f_{cm}(t) = (\alpha_{cc}(t))^{\alpha}\ f_{cm}$

with f_{cm} being the average strength at 28 days and

$\alpha_{cc}(t) = \exp\left(s\left(1- (28/t)^{1/2}\right)\right)$

α_{cc}(t): a coefficient which depends on the age of the concrete *t*
The compressive strength value is $Fcd = \alpha_{cc}\frac{fck}{\gamma c}$

γc : concrete partial safety factor.
: a coefficient taking account of long-term impacts on the tensile strength and of unfavourable impacts, resulting from the way the load is applied

α_{cc} = 1 (year)

Tensile strength:

The tensile strength value f_{ctd} $f_{ctd} = \alpha_{ct}\ \frac{fctk.0.05}{\gamma c}$

α_{ct} = 1 (Year)

γc : concrete partial safety factor.
: a coefficient taking account of long-term impacts on the tensile strength and of unfavourable impact, coming about from the way the load is applied.

Others characteristics

Poisson's ratio
- v = 0.2 uncracked concrete
- v = 0 cracked concrete

Instantaneous modulus of deformation $E_{cm} = \frac{f_{cm}}{22[10]^{0.3}}$

Tangent modulus of elasticity 1 for long-term deformations: the Eurocode takes a value depending on each project by introducing the SLS moment due to quasi-permanent loads MEd,i-$perm$ and the design moment MEd:

$E_{c,\mathrm{eff}} = \frac{Ecm}{1 + \varphi(\infty,t0)}$: Module of elasticity tangent effective 1

$Ec = \frac{Ecm}{1 + \varphi e}$ with $\varphi_e = (\infty, t0)\ \frac{MEd,quasi-perm}{MEd}$

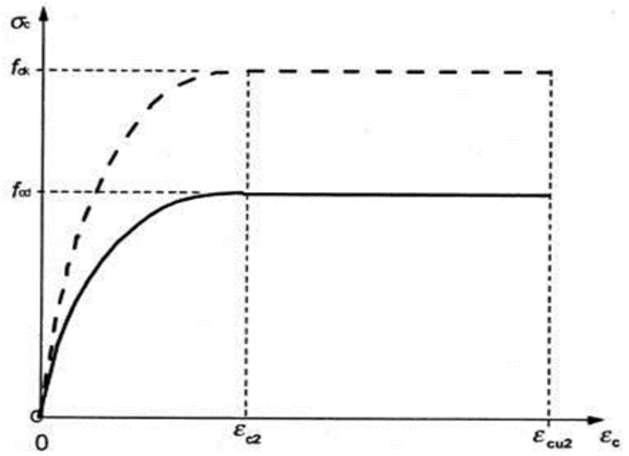
(∞, t0): represents the coefficient of creep which can be calculated either utilising the curves.

Stress-strain diagrams

Sections can be calculated using one of the following three stress-strain relationships:

Figure 21

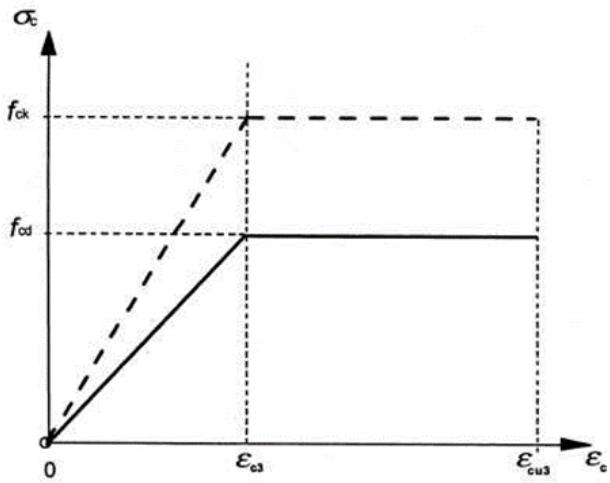
diagram of concrete parabola-rectangle under compression



(From BS EN 1992-1-1:2004 EN 1992-1-1:2004 (E) figure 3.3)

Figure 22

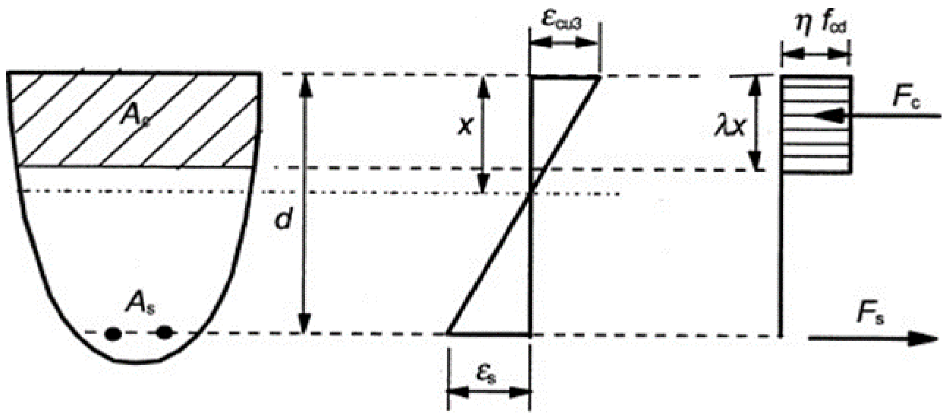
Bi-linear stress-strain relation EC2



(From BS EN 1992-1-1:2004 EN 1992-1-1:2004 (E) figure 3.4)

Figure 23

Rectangular stress distribution EC2



(From BS EN 1992-1-1:2004 EN 1992-1-1:2004 (E) figure 3.5)

Reinforcement – BAEL

Mechanical properties

Characteristic resistance
Yield limit defining the steel grade: fe

Design resistance: $F_{ed} = fe/\gamma s$

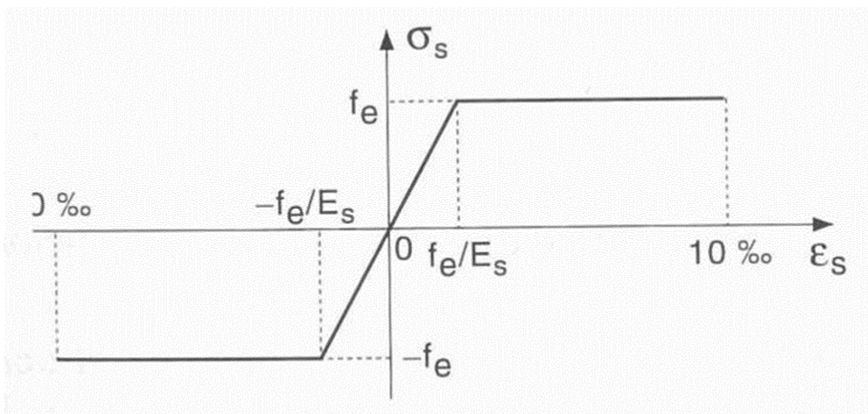
Longitudinal Modulus of Elasticity Es = 200 000 MPa

Stress-strain diagram

The considered diagram for the purposes of the calculation is conventionally defined as follows: Diagram with horizontal level.

Figure 24

Steel Stress strain diagram-BAEL



(From BEAL 91,99, A.2.2,2 diagramme déformations-contraintes)

Concrete Cover - BAEL

The cover calculated with the BAEL depends only on the geometry of the element.

The BAEL9/99 defines the 3 degrees of harmfulness of the openings of cracks according to the characteristics of exposure of a construction compared to its environment as well as the situation of a construction element compared to the envelope of this one.

- Case of extremely damaging cracking: Cracking is considered to be very harmful when the elements in use are exposed to an aggressive environment (sea water, marine atmosphere such as salt spray and mist, very pure water, gases or particularly corrosive soils) or else must provide a seal.

- Case of detrimental cracking: Cracking is considered detrimental when the elements in question are exposed to bad weather or to condensation or can be alternately submerged and emerged in fresh water.

- Case of cracking with little detriment: The cracking is considered as little detrimental in the other cases.

Therefore, the cover of any reinforcement is at least equal to:

- 5 cm for structures at sea or exposed to salt spray or fog, as well as for structures exposed to very aggressive atmospheres;

- 3 cm for walls, cased or not, which are subjected (or are likely to be) to aggressive actions, or bad weather, or condensation, or even, having regard to the destination of the works, in contact with a liquid ;

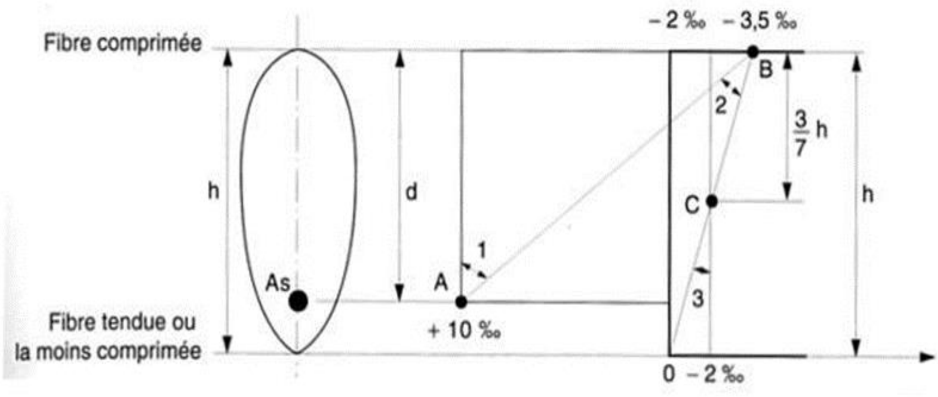
- 1 cm for walls, which would be located in, covered and closed premises and which would not be exposed to condensation.

Diagrams of the limit deformations of the section – BAEL

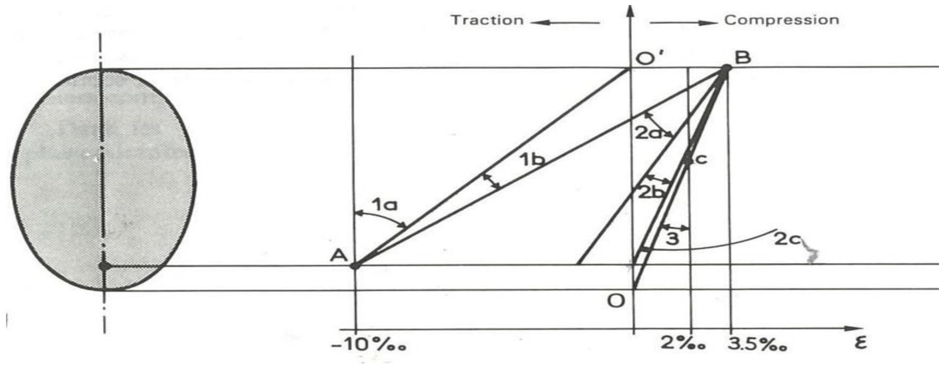
Depending on the stresses, the distribution and the section of the reinforcements, the section failure can take place in different ways, by simple compression that leads the concrete to crush, to the exhaustion of the resistance of all the tensile reinforcement, via simple or compound bending. These different cases are gathered in a single diagram representing the deformation of the section in the ultimate state.

Figure 25

Diagrams of the limit deformations of the section



(From BAEL 91,99 section A.4.3.3)



Pivot A : $s_s = s_{su}$ = 10 ‰

• Domain 1a: represents simple tension or compound bending with tension in which the whole section is tense. The corresponding deformation diagrams are straight lines passing through A. Concrete does not intervene.

• Domain 1b: represents simple or compound bending with neutral axis inside the section. The strength of concrete is not exhausted with $0 \leq s_b \leq 3.5‰$. The straight line representative of the deformations revolves around point A.

Pivot B: $S_b = S_{bu}$ = 3. 5 ‰

The three domains 2a, 2b and 2c represent simple or compound bending with neutral axis inside the section but the ultimate shortening of the concrete is reached. Their characteristic lines revolve around point B.

• Domain 2a: the elastic limit of the steel is reached or exceeded with

$S_{ed} = \frac{fed}{Es} \leq s_s \leq 10$ ‰

Domain 2b : steels are strained to a stress below the limit
of elasticity with

$$s_s < S_{ed} = f_{ed}/E_s$$

• Domain 2c: The steels are compressed, while the extreme fibers of the section are still tense.

Pivot C : $sb = sb1 = 2$ ‰

Domain 3 corresponds to compound bending with compression or to simple compression, for which the entire section is compressed.

Reinforcement – EC2

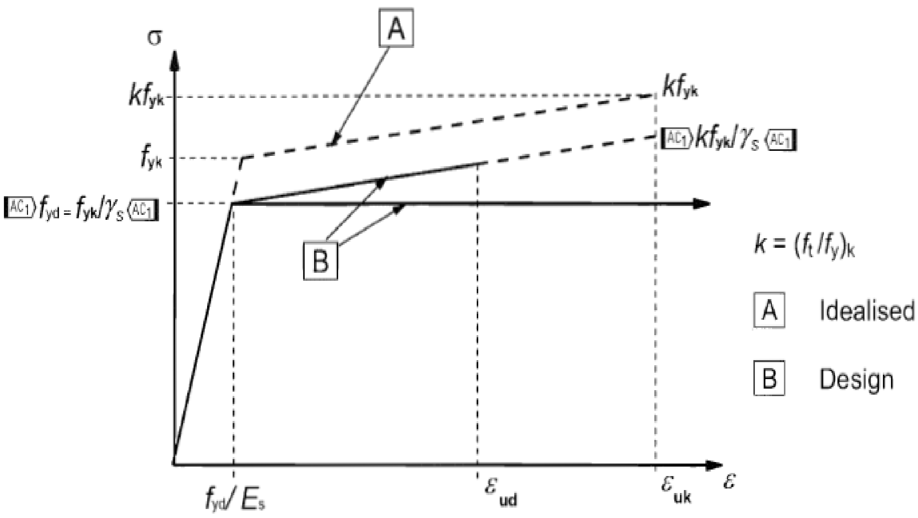
Characteristic resistance
Yield strength defining the steel grade: f_{yk} ou $f_{0.2k}$
Tensile strength: f_t $\qquad F_{yd} = f_{yk}/\gamma_s$

Longitudinal Modulus of Elasticity $Es = 200\ 000\ MPa$

Stress-strain diagram

Figure 26

Stress-strain diagram inclined



(From EC2 design stress-strain diagram for reinforced steel for compression and tension.)

- Inclined upper branch, with strain limit equal to ε_{ud} = 0.9 S_{uk} , and maximum stress equal to kf_{yk}/γ_s for s_{uk} with $k = (f_t/f_y)$k.

The values of ε_{ud} and k [2] depend on the class of reinforcement.

- Horizontal upper branch, without limit for steel deformation

Concrete cover EC2

In EC2, the cover of the reinforcements does not depend on the dimension of the element but on the structural class1 and the exposure conditions, which favours high-strength concretes.
The EC 2 recommendations for cover are innovative. They aim, based on the NF EN 206-1 standard, to optimize the durability of the structures in a relevant way.

The determination of the cover value must take into account:

- The exposure class in which the structure (or part of the structure) is located,
- The expected duration of use of the project,
- The strength class of the concrete,
- The type of quality control systems implemented to ensure the regularity of concrete performance,
- The type of reinforcement (carbon steel, stainless steel), control of the positioning of the reinforcements.

The value of the cover can thus be optimized in particular:

- If a concrete with a compressive strength class more than the reference class (defined by the exposure class) is chosen,
- Whether there is a system for checking the regularity of the performance of the concrete and controlling the positioning of the reinforcements.
- The nominal cover must be indicated on the plans. It is described as the minimum cover c_{min} plus a calculation margin for execution tolerances Δ_{cdev}:

$$c_{nom} = c_{min} + \Delta c_{dev}$$

Minimum cover, c_{min}

Minimum concrete cover, c_{min}, is provided to guarantee:

- The safe transmission of bond forces.
- Protect of the steel against corrosion.
- (EN 1992-1-2) n satisfactory fire resistance.

$$c_{min} = Max\ \{c_{min,}; c_{min,dur} + \Delta c_{dur,\gamma} - \Delta c_{dur,st} - \Delta c_{dur,add}\ ; 10mm\}$$

c_{minb}: minimum cover with respect to adhesion - diameter of the bar or bundle;
c_{mindur} : minimum cover with respect to environmental conditions – table 4.1 and 4.2;
$\Delta_{cd}e$: execution deviation - 10mm;
$\Delta_{cdur,st}$: minimum cover reduction using stainless steel.
$\Delta_{cdur,}$: additive safety element.
$\Delta_{cdur,add}$: minimum cover reduction using additional protection.

The process of determining the cover of the reinforcements in each part of the structure comprises the following eight steps:

- 1st step: consideration of exposure classes

- 2nd step: Choice of structural class: Current buildings and civil engineering structures are designed for a project use life of 50 years, which amounts to an S4 class.

Exposure classes

EC2 defines 18 classes of environment, divided into 6 parts:
X0: no risk of corrosion or attack;
XC: corrosion induced by carbonation;
XD: corrosion induced by chlorides;
XS: corrosion induced by chlorides present in seawater;
XF: freeze-thaw attack;
XA: chemical attack;

Table 7.

Recommended structural classification

Structural Class							
Criterion	Exposure Class according to Table 4.1						
	X0	XC1	XC2 / XC3	XC4	XD1	XD2 / XS1	XD3 / XS2 / XS3
Design Working Life of 100 years	increase class by 2	increase class by 2	increase class by 2	increase class by 2	increase class by 2	increase class by 2	increase class by 2
Strength Class [1) 2)]	≥ C30/37 reduce class by 1	≥ C30/37 reduce class by 1	≥ C35/45 reduce class by 1	≥ C40/50 reduce class by 1	≥ C40/50 reduce class by 1	≥ C40/50 reduce class by 1	≥ C45/55 reduce class by 1
Member with slab geometry (position of reinforcement not affected by construction process)	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1
Special Quality Control of the concrete production ensured	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1

Table 8.

Minimum cover, c_{min}, values

Environmental Requirement for $c_{min,dur}$ (mm)							
Structural Class	Exposure Class according to Table 4.1						
	X0	XC1	XC2 / XC3	XC4	XD1 / XS1	XD2 / XS2	XD3 / XS3
S1	10	15	20	25	30	35	40
S2	10	15	25	30	35	40	45
S3	10	20	30	35	40	45	50
S4	10	25	35	40	45	50	55
S5	15	30	40	45	50	55	60
S6	20	35	45	50	55	60	65

Table 9.

Values of minimum cover, c_{min}, requirements with regard to durability for reinforcement steel according to EN 10080

Environmental Requirement for $c_{min,dur}$ (mm)							
Structural Class	Exposure Class according to Table 4.1						
	X0	XC1	XC2 / XC3	XC4	XD1 / XS1	XD2 / XS2	XD3 / XS3
S1	10	10	10	15	20	25	30
S2	10	10	15	20	25	30	35
S3	10	10	20	25	30	35	40
S4	10	15	25	30	35	40	45
S5	15	20	30	35	40	45	50
S6	20	25	35	40	45	50	55

Table 10.

Exposure classes related to environmental conditions according to EN 206-1

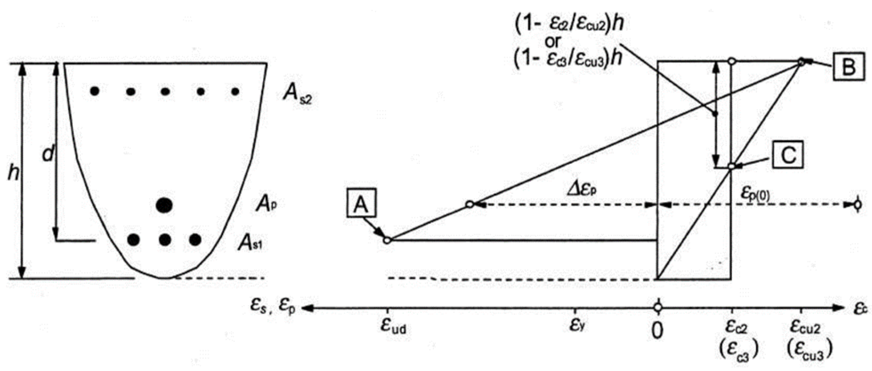
Class designation	Description of the environment	Informative examples where exposure classes may occur
1 No risk of corrosion or attack		
X0	For concrete without reinforcement or embedded metal: all exposures except where there is freeze/thaw, abrasion or chemical attack For concrete with reinforcement or embedded metal: very dry	Concrete inside buildings with very low air humidity
2 Corrosion induced by carbonation		
XC1	Dry or permanently wet	Concrete inside buildings with low air humidity Concrete permanently submerged in water
XC2	Wet, rarely dry	Concrete surfaces subject to long-term water contact Many foundations
XC3	Moderate humidity	Concrete inside buildings with moderate or high air humidity External concrete sheltered from rain
XC4	Cyclic wet and dry	Concrete surfaces subject to water contact, not within exposure class XC2
3 Corrosion induced by chlorides		
XD1	Moderate humidity	Concrete surfaces exposed to airborne chlorides
XD2	Wet, rarely dry	Swimming pools Concrete components exposed to industrial waters containing chlorides
XD3	Cyclic wet and dry	Parts of bridges exposed to spray containing chlorides Pavements Car park slabs
4 Corrosion induced by chlorides from sea water		
XS1	Exposed to airborne salt but not in direct contact with sea water	Structures near to or on the coast
XS2	Permanently submerged	Parts of marine structures
XS3	Tidal, splash and spray zones	Parts of marine structures
5. Freeze/Thaw Attack		
XF1	Moderate water saturation, without de-icing agent	Vertical concrete surfaces exposed to rain and freezing
XF2	Moderate water saturation, with de-icing agent	Vertical concrete surfaces of road structures exposed to freezing and airborne de-icing agents
XF3	High water saturation, without de-icing agents	Horizontal concrete surfaces exposed to rain and freezing
XF4	High water saturation with de-icing agents or sea water	Road and bridge decks exposed to de-icing agents Concrete surfaces exposed to direct spray containing de-icing agents and freezing Splash zone of marine structures exposed to freezing
6. Chemical attack		
XA1	Slightly aggressive chemical environment according to EN 206-1, Table 2	Natural soils and ground water
XA2	Moderately aggressive chemical environment according to EN 206-1, Table 2	Natural soils and ground water
XA3	Highly aggressive chemical environment according to EN 206-1, Table 2	Natural soils and ground water

Diagrams of the limit deformations of the section – EC2

The Eurocode exposes new stress–strain diagrams which were not used at BAEL. This therefore leads to some modifications at the level of the so-called 3-pivot diagram where the limit values of concrete and steel deformations change according to the choices made.

Figure 27

Stress distribution in the ULS – EC2



(From EC2, Possible strain distributions in the ultimate limit state, figure 6.1)

A- reinforcing steel tension strain limit

B - concrete compression strain limit

C - concrete pure compression strain limit

Summary of comparison

The comparison between the two regulations helps to deduce some discrepancies leading to changes in the calculation of the reinforcements:

- Partial coefficient in the case of the Accidental situation,
- Calculation resistance: absence of the 0.85 coefficient for the Eurocode,
- Concrete deformation modulus: this difference generates a modification for the calculation the equivalence coefficient used for sizing at ELS,
- Stress-strain diagrams: the Eurocode presents additional and different diagrams from the BAEL and therefore distinct limit deformation

values. This greatly influences the dimensioning more precisely the calculation at the ULS by a different definition of the pivots.

- The horizontal step diagram for steel is presented in both regulations; however, care should be taken in how it is used. Indeed, the deformation is limited to 10‰ in the BAEL and is not limited in the EC2.

- Another important point to note is the determination of the reinforcement cover, which no longer depends only on the geometry of the element (BAEL) but on its exposure class and the structural class for EC 2.

- The BAEL does not stipulate an exposure class but it indicates the provisions to be taken into account for the protection of reinforcement.

- The Eurocode has given more importance to the sustainability part and more particularly to the classification of environments.

- The coating approach introduced by Eurocode2 is very different from that of BAEL 91/99.

- BAEL 91/99 specifies the characteristic strengths of materials such as concrete and steel, which are used in the design process.

- EC2 provides guidelines for determining the characteristic strength of materials based on statistical analysis and testing

Design methodologies

Design loads BAEL-NF P 06-001

Permanent action - BAEL

The permanent actions are noted G and their intensity is constant or little variable in time or always varies in the same direction tending towards a limit. They are generally introduced in the calculations with their most probable values. When a permanent action is susceptible to significant deviations from its mean, this must be taken into account by introducing a maximum and a minimum value.

Variable action-BAEL

Operational loads, climatic loads -BAEL

Variable actions are noted Q and their intensity varies frequently and significantly over time. The representative values are set according to the intensity, duration of application and nature of the combinations.

- Nominal value Q_i ;

- Combination value $\psi_{0i}Q_i$;

- Frequent value $\psi_{1i}Q_i$;

- Quasi-permanent value $\psi_{2i}Q_i$;

Table 11.

Live loads 1

Nature and destination of the premises	***Live Loads (KN/m²)***
Accommodation in rooms, playrooms, and nurseries.	*1.5*
Collective accommodation (dormitories)	*2.5*
Dining rooms, cafes, canteens (number of Seating places) <100	*25*
Meeting rooms with working tables	*2.5*
Various halls (stations, etc.) where the public can walk.	*4*
Showrooms of less than 50 m²	*2.5*
Showrooms of more than 50 m²	*3.5*
Meeting rooms and places of worship with standing assistance.	*5*
Halls, stands and performance halls, venues and sports with standing places.	*6*
Conference theater halls, amphitheatres, grandstands with seats.	*4*
Community kitchens, not including wholesale Material.	*2.5*
Shops and annexes	*5*
Balconies	*3.5*
Building balconies open to the public	*6*
Loggias	
Lower circulations of buildings	

Table 12.

Live loads 2

Nature and destination of the premises	***Live loads (kN/m^2)***
Residential buildings	
Accommodation including Convertible	***1.5***
Balconies	***3.5***
Stairs (isolated steps excluded, entrance halls)	***2.5***
Non-convertible attics whose use is not planned not normally accessible:	
with floor	***1.0***
without floor	
Part accessible for maintenance:1 kN concentrated at any point of the structural elements or ceiling supports on which one can move.	
Attics proper	***2.5***
Cellar floors	***2.5***
Office buildings Bureaux	
Actual offices	***2.5***
Traffic and stairs	***2.5***
Reception halls	***2.5***
Ticket halls	***4***
School and university	
Classrooms,	***2.5***
Amphitheaters	***2.5***
Collective dormitories	
Workshops, laboratoris heavy equipments	***2.5***
Circulations and stairs	***4***
Libraries,	***4***
meeting rooms	***4***
Collective kitchens	***5***
Hospitals and dispensaries	
Rooms	***1.5***
Internal circulations	***2.5***
Medical technical premises (labor and sugery rooms)	***3.5***

Accidental Action -BAEL

The accidental actions are noted Fa and come from rare phenomena (earthquake, shock).

Design load parameters– BAEL

- G_{max} : all the unfavourable permanent actions;

- G_{min}: set of favourable permanent actions;

- Q_1 : basic variable ;

- Q_i : accompanying variable;

Building categories BAEL

Current constructions

Buildings that normally fall into this category are :

- Buildings used for housing and accommodation;
- Office buildings;
- School buildings;
- Hospital buildings;
- Commercial buildings (stores, boutiques, etc.), excluding storage buildings
- Auditoriums

Industrial buildings

- Industrial buildings (factories, workshops, etc.);
- Warehouses.

Special constructions:

In special constructions, certain parts of the structure can be assimilated to elements of ordinary construction, others to elements of industrial construction, while others fall under the application of general rules.
E.g.: a building with parking spaces for light vehicles, covered by a floor under the roadway.

EC1 Categories of use

Table 13.

Building categories

Category	Specific Use	Example
A	Areas for domestic and residential activities	Rooms in residential buildings and houses; bedrooms and wards in hospitals; bedrooms in hotels and hostels kitchens and toilets.
B	Office areas	
C	Areas where people may congregate (with the exception of areas defined under category A, B, and D[1)])	**C1**: Areas with tables, etc. e.g. areas in schools, cafés, restaurants, dining halls, reading rooms, receptions. **C2**: Areas with fixed seats, e.g. areas in churches, theatres or cinemas, conference rooms, lecture halls, assembly halls, waiting rooms, railway waiting rooms. **C3:** Areas without obstacles for moving people, e.g. areas in museums, exhibition rooms, etc. and access areas in public and administration buildings, hotels, hospitals, railway station forecourts. **C4**: Areas with possible physical activities, e.g. dance halls, gymnastic rooms, stages. **C5**: Areas susceptible to large crowds, e.g. in buildings for public events like concert halls, sports halls including stands, terraces and access areas and railway platforms.
D	Shopping areas	**D1:** Areas in general retail shops **D2**: Areas in department stores

Permanent Actions -EC2

The permanent actions have a continuous duration of application and equal to the life of the structure. They are represented by their characteristic values. If the variations are small, they are assigned a single characteristic value Gk (dead weight or self-weight). If there are uncertainties concerning the value of the permanent action, two characteristic values G_{ksup} and G_{kinf} are defined, which are determined in such a way that the probability that the real value of the action exceeds them is less than 5%. It will be assumed that the distribution function is a Gaussian.

Variable Actions -EC2

The live loads of buildings are caused by the occupation of the premises. Their values are given by the EC1 as shown in table 14 and take into account:

- The normal use that people make of the premises;

- Furniture and mobile objects;

- Vehicles;

The loads include:

- Loads on floors;

- Roof loads;

- Actions due to transport vehicles;

- Special equipment actions;

Table 14.

Design loads

Categories	Live loads (kn/m^2) UDL	Concentrated Loads (kN)
Category A:		
Planchers	1.5-2.0	2.0-3.0
Escaliers	2.0-4.0	2.0-4.0
Balcons	2.5-4.0	2.0-3.0
Category B		
Category C:		
C1	2.0-3.0	3.0-4.0
C2	3.0-4.0	2.5-7.0
C3	3.0-5.0	4.0-7
C4	4.5-5.0	3.5-7
C5	5.0-7.5	3.5-4.5
Category D		
D1	4.0-5.0	3.5-7.0
D2	4.0-5.0	3.5-7.0

Accidental Action -EC2

These are actions of short duration of application but significant magnitude, which are not likely to arise on a given structure during the life of the project. τ_n represents them by a nominal value set by codes or regulations.

Design value of actions -EC2

The design value F_d of an action F can be expressed as:

$$Fd = yf * \psi * Fk$$

With : - Fk: characteristic action's value;

- γ_f: partial coefficient taking the possibility of unfavourable deviations of the action values from the representative values into consideration;

- ψ: coefficient that depends on the load combination and on type of building;

Summary
The values of the live loads for the two regulations are quite close with a larger margin for EC2.

Load Combination

The design approach in BAEL 91/99 focuses on the limit state design method, which considers the ULS and SLS while the EC2, in addition to the limit state design method it emphasizes the partial factor design approach that involves applying partial safety factors to different load and resistance factors.

Ultimate limits state -ELU –BAEL 91/99

Fundamental Combinations

The RC framed buildings were modelled using the load combinations for each code. The various load combinations for both codes are taken into account for the 3D analysis.

$$\Sigma 1.35\ G_{i,\ sup} + 1.5\ Q_1 + \Sigma 1.3\ \psi_{0i} Q$$

Table 15.

Design Load factor

Actions permanentes $1{,}35\ G_{max} + G_{min}$	Actions variables		
	de base $\gamma_{Q1}\ Q_1$	d'accompagnement $1{,}3\ \Psi_{02}\ Q_2$ (1)	d'accompagnement $1{,}3\ \Psi_{03}\ Q_3$ (2)
1,35 G ou G	$1{,}5\ Q_B$	0 ou W ou S_n ou $W + S_n$	0 ou 0,8 T
	1,5 W	0 ou $1{,}3\ \Psi_0\ Q_B$ ou S_n ou $1{,}3\ \Psi_0\ Q_B + S_n$	0 ou 0,8 T
	$1{,}5\ S_n$	0 ou $1{,}3\ \Psi_0\ Q_B$ ou W ou $1{,}3\ \Psi_0\ Q_B + W$	0 ou 0,8 T

- For live loads, the values of ψ_0 are defined in the appendix to standard NF P 06-001; the value of ψ_0 is equal to 0.77 for all premises with the exception of archives and parking for which its value is 0.9.

- When the basic action is snow, for an altitude > 500 m, this value is increased by 10%.

Ultimate limits state -ELU –EC2

Fundamental load combinations:

There are several types of ultimate limit states in EC0:

EQU: static equilibrium loss of structure considered as a rigid body;

STR: structural excessive deformation or internal inner or structural elements including footings, piles when the resistance of the building materials of the structure dominates

GEO: the ground excessive deformation or failure, when the resistances of the ground or the rock are significant for the resistance;

✓ For static balance (EQU) (Set A):

For long-lasting or transient project situations: give the following combinations:

Usual coefficients:
$1.10\ G_{kj,sup} + 0.9\ G_{kj,inf} + 1.5\ Q_{k,1} + \sum 1.5\ \Psi_{0,i}\ Q_{k,i}$

Alternating coefficients:
$1.35\ G_{kj,sup} + 1.15\ G_{kj,inf} + 1.5\ Q_{k,1} + \sum 1.5\ \Psi_{0,i}\ Q_{k,i}$

✓ For the resistance of building structures not subject to geotechnical actions (STR) (Set B)

$1.35\ G_{kj,sup} + 1.00\ G_{kj,inf} + 1.5\ Q_{k,1} + \sum 1.5\ \Psi_{0,i}\ Q_{k,i}$

✓ for the resistance of building structures subjected to geotechnical actions (STR/GEO) (Set B):

$1.35\ G_{kj,sup} + 1.00\ G_{kj,inf} + 1.5\ Q_{k,1} + \sum 1.5\ \Psi_{0,i}\ Q_{k,i}$

Calculation stresses with respect to serviceability limit states; SLS
$G_{max} + 1.00\ G_{min} + Q_1 + \sum \Psi_{0,i}\ Q_i$

Design loads with respect to serviceability limit states

BAEL-SLS

Load Combinations to be considered

$G_{max} + G_{min} + Q_1 + \Psi_{0,i}\, Q_i$

• Gmax : the set of unfavorable permanent actions;
• Gmin : the set of favorable permanent actions;
• Q1 : a so-called basic variable share;
• Qi : the other variable actions called accompanying (with i 1)

Table 16.
Comminations actions at SLS

Permanents Actions Gmax + Gmin	*variable Actions*	
	De base Q_1	*D'accompagnement $\psi_{02}\, Q_2$*
G	*Q_B*	*0 or 0.77W ou 0.77 Sn*
	W	*0 or $\psi_0\, Q_B$*
	S_n	*0 or $\psi_0\, Q_B$*

Values of coefficients ψ relating to live loads BAEL- NF P 06-001

The table 22 in the appendix displays the coefficients ψ values relating to live loads: These are the values known as:

Combination: $\psi_{0i}\, Q_i$
Frequent: $\psi_{1i}\, Q_i$
Quasi-permanent: $\psi_{2i}\, Q_i$

EC2- SLS

Unless others specified in EN 1991 to EN 1999, for SLS, 1.0 is taken as partial action factors.

✓ ***In characteristic combination:***

$$G_{kj,sup} + G_{kj,inf} + Q_{k,1} + \sum \Psi_{0,i}\, Q_{k,i}$$

✓ ***In frequent combination :***

$$G_{kj,sup} + G_{kj,inf} + \Psi_{11}\; Q_{k,1} + \sum \Psi_{2,i}\, Q_{k,i}$$

✓ ***In quasi-permanent combination :***

$$G_{kj,sup} + G_{kj,inf} + \Psi_{21}\; Q_{k,1} + \sum \Psi_{2,i}\, Q_{k,i}$$

Values of coefficients ψ relating to live loads EC1

Combination value: $\psi_0 Q_k$,

Frequent value: $\psi_1 Q_k$,

Quasi-permanent value: $\psi_2 Q_k$.

Values of ψ factors

Table 17.

(F1) provides values for the symbols

Load	ψ_0	ψ_1	ψ_2
Imposed loads in buildings, category (see EN 1991-1-1)			
Category A: areas in residential buildings	0,7	0,5	0,3
Category B: office areas	0,7	0,5	0,3
Category C: congregation areas	0,7	0,7	0,3
Category D: shopping areas	0,7	0,7	0,6
Category E: storage areas	1,0	0,9	0,8
Category F: traffic area, vehicle weight ≤ 30 kN	0,7	0,7	0,6
Category G: traffic area, 30 kN < vehicle weight ≤ 160kN	0,7	0,5	0,3
Category H: roofs	0	0	0
Snow loads on buildings (see EN 1991-1-3)*), when			
s_k < 2,75 kN/m^2	0,7	0,4	0,2
s_k ≥ 2,75 kN/m^2	0,7	0,5	0,2
Ice loads **)	0,7	0,3	0
Wind loads on buildings (see EN 1991-1-4)	0,6	0,2	0
Temperature (non-fire) in buildings (see EN 1991-1-5)	0,6	0,5	0

*) Outdoor terraces and balconies ψ_0 = 0 combined with categories A, B, F and G.
Note: In case there are different categories of loads in one building, which cannot clearly be separated into different sections, values for ψ factors giving the most unfavourable effect should be used.
**) Added in the Finnish National Annex

Design provisions

BAEL provides specific design provisions for different structural elements such as columns, beams, slabs and foundations. It includes equations, charts, and tables for design calculations.
EC2 offers comprehensive design provisions for different structural elements, including formulas for determining the design the required reinforcement, detailing requirements and construction considerations.

Structural Analysis

BAEL uses simplified methods for structural analysis, such as static linear analysis to determine member forces and deformations.

EC2 allows for more advanced analysis methods including nonlinear analysis, which considers the behaviour of structures beyond the linear elastic range.

Seismic design

BAEL9/99 has specific provisions for seismic designs, considering the seismicity of the region and assigning seismic zones. It includes additional design requirements for resisting lateral forces due to earthquakes.

EC2 also incorporates seismic design provisions, considering the region's seismicity. It provides guidelines for determining the design seismic action, detailing requirement for seismic resistance, and additional considerations for seismic design.

Summary

There is a difference in the load combinations: there are several types of ULS combinations in the Euro codes depending on whether it is a loss of balance, excessive deformation, soil deformation…
Furthermore, the load combination coefficients are higher for EC0 compared to BAEL9/99 for secondary actions. Indeed, under ELU combinations, the support actions are multiplied by $1.3\text{x}\psi_{0i}$ for the BAEL and by $1.5\text{x}\ \psi_{0i}$ for the EC2.

The coefficients (ψ) values are generally lower than the values of NF P-06-001 which retains $\psi_0 = 0.77$ instead of 0.7 of Eurocode1 for all premises.

At the ULS, and in fundamental combinations, the EC0 provides different load combinations base on the ULS to be verified (EQU, STR or STR/GEO).

EC2 seismic load combinations factors are differently from the two BAEL.
EC2 snow factor is 0.2N while BEAL is 0.1N.
For a building

EC2: G+A+0.2N+0.3Q
BAEL: G+E+0.1N+0.77Q

In general, the load combinations determined by EC2 are more unfavourable than those of BAEL 91/99.

CHAPTER V

Results

This chapter shows the outcomes of these findings comparing to the work done previously.

This chapter presents the obtained results from both BAEL 91/99 and EC2 using MRF model. The results are presented for selected columns and beams in form of axial forces and bending moments.

Selected structural elements are shown on the below figure followed by graphical representation shown in the following figure.

Figure 28

Plan of G+4 residential building

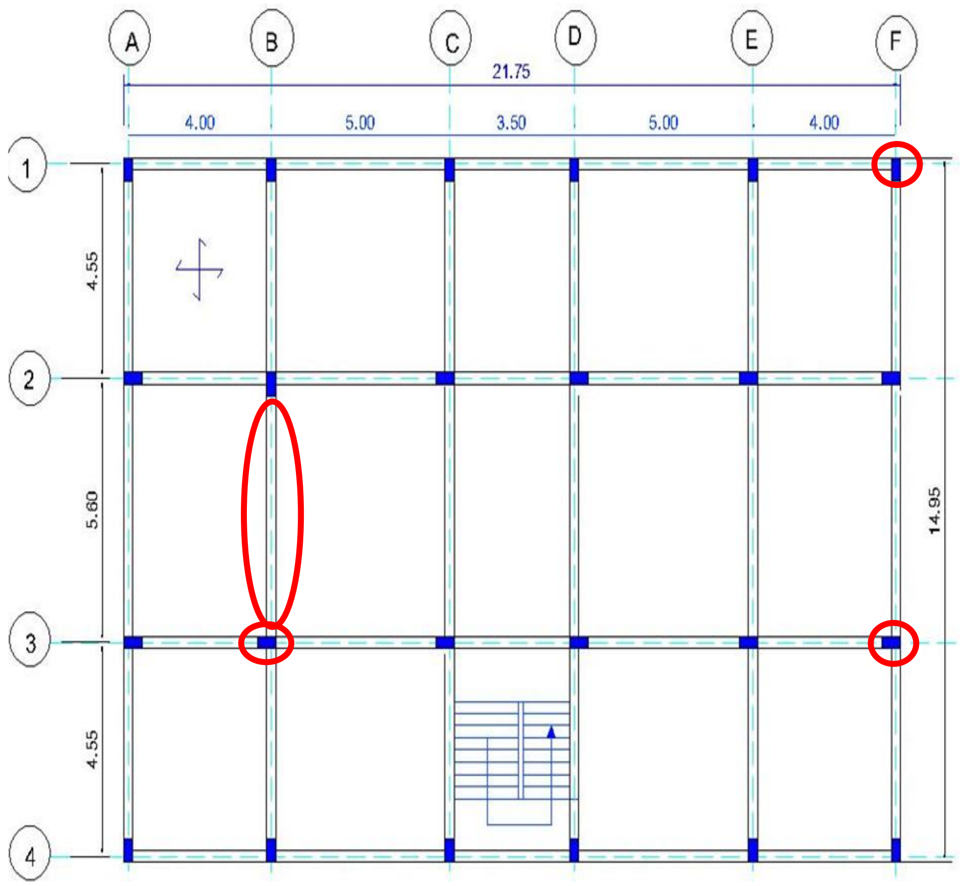


Table 18.

Results from BAEL 91/99

Columns MRF + Hollow slab	Axial force (kN)	Moment (kN.m)
Interior	1378.42	16.39
Exterior	823.76	24.18
Corner	384.82	15.59

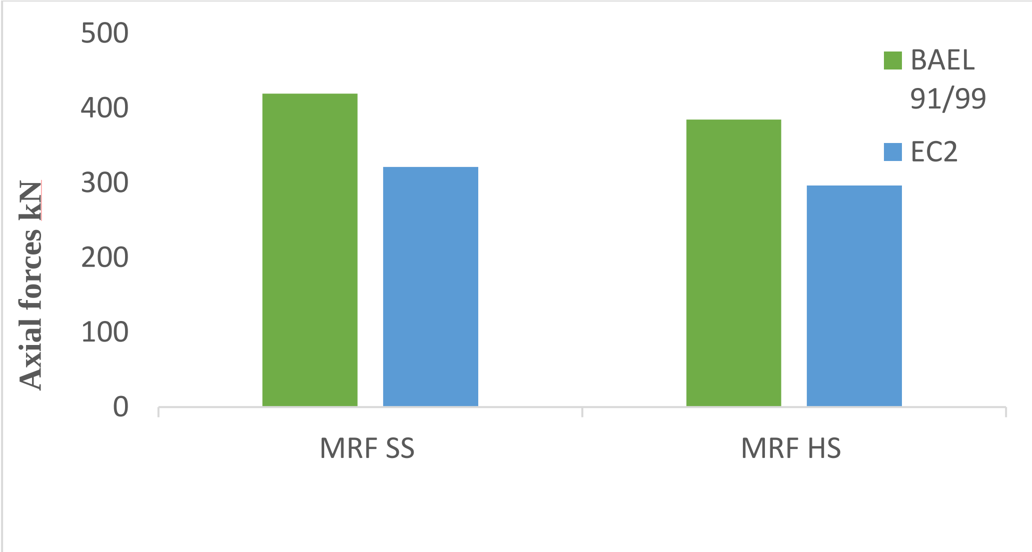
Columns MRF + Solid slab	Axial force (kN)	Moment (kN.m)
Interior	1621.90	14.21
Exterior	923.43	22.59
Corner	419.31	16.25

Axial forces of the selected columns

The axial forces of different columns (exterior, corner and interior) have been analyzed for two types (MRF+SS and MRF+HS) of RC framed structures using the two different codes. Figures 29-30 show the outcome of column axial forces.

Figure 29

Axial forces for corner column



The total axial force for the corner column obtained from BAEL 91/99 4-storey MRF solid slab is 13.21%, higher than that of the EC2. The total axial force for corner column, obtained from BAEL 91/99 4 storey MRF hollow slab is about 13% less than EC2.

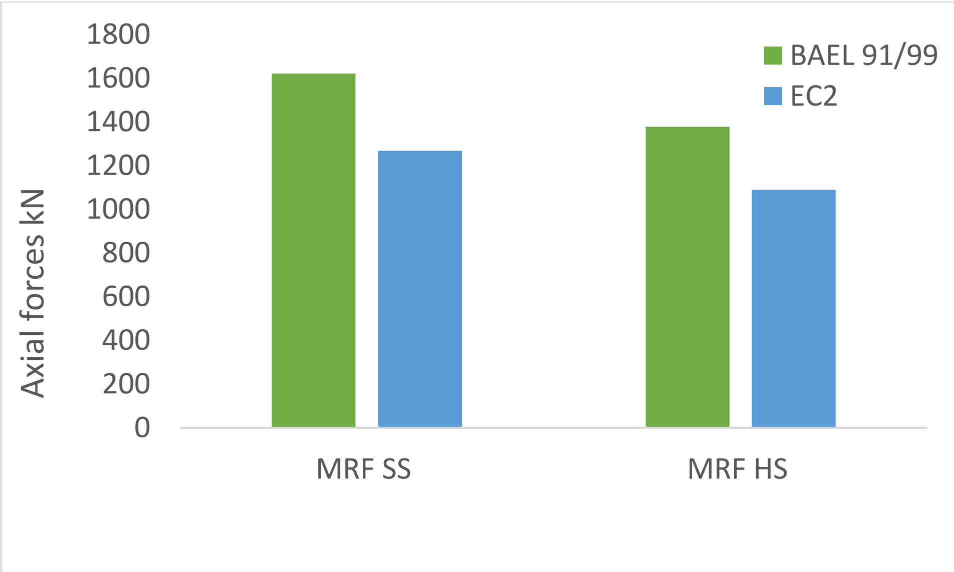
Figure 30

Axial forces for exterior column

The total axial force for the exterior column obtained from BAEL 91/99 4-storey MRF solid slab is 12.71%, higher than that of the EC2. The total axial force for exterior column, obtained from BAEL 91/99 4-storey MRF hollow slab is about 12.19% higher than EC2.

Figure 31

Axial forces for interior column



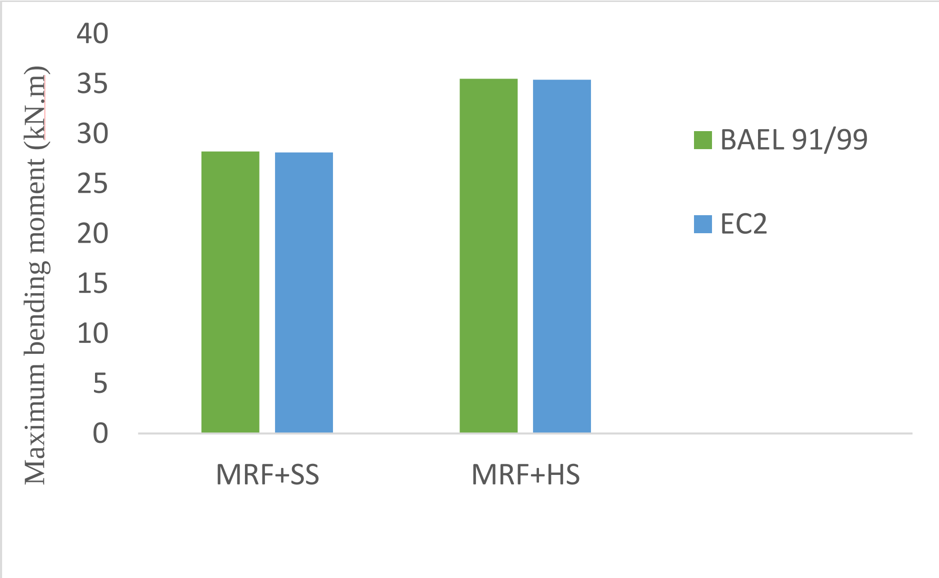
The total axial force for the *interior* column obtained from BAEL 91/99 4-storey MRF solid slab is 12.24%, higher than that of the EC2. The total axial force for exterior column, obtained from BAEL 91/99 4-storey MRF hollow slab is about 11.74% higher than EC2.

Bending Moments in beam

The chosen beams maximum bending moments are analyzed. The analysis is made on the longest beam span under MRF+SS and MRF+HS of RC framed structures using the two codes. Figures 31 shows the results of maximum beams bending moments.

Figure 32

Maximum bending moments (kN.m)



The total bending moment of the longest beams obtained from BAEL 91/99 4-storey MRF solid slab is almost equal to that of the EC2. The total bending moment of the longest beams, obtained from BAEL 91/99 4-storey MRF hollow slab is almost equal to that of EC2.

Discussion

Columns designed with BAEL 91/99 regulation have higher axial force values than those designed with EC2. The difference in axial force values between columns designed with BAEL 91/99 regulation and those designed with EC2 (Eurocode 2) can be attributed to several factors. Such as

Material properties: BAEL 91/99 and EC2 might have different assumptions and values for material properties such as concrete and steel. It is been noticed that both codes have different approach in this regard.
About the stress-strain diagrams: the Eurocode presents additional diagrams that differ from the BAEL, and therefore different limit strain values. This has a major impact on design, and more specifically on the ULS calculation, as the pivots are defined differently.

Design methodology: EC2 presents many types of ULS combinations than BAEL 91/99. In addition to that, the values of ψ coefficients relating to live loads in BAEL- NF P 06-001 are higher than those of the EC2 for ULS design.

These variations can impact the strength and behaviour of the columns, resulting in different axial force values during the design process.

The safety factors used in the design of columns may vary between BAEL 91/99 and EC2. In addition to that the safety factors are used to ensure that the structure can withstand unforeseen loads and uncertainties. BAEL 91/99 might employ higher safety factors, leading to higher axial force values.

The values of bending moment of beams designed with BAEL 91/99 and EC2 regulations are almost same with a slight increase for the BAEL 91/99. This may be due to the similarities observed in the SLS load combination in both codes.

CHAPTER VI

Conclusion and Recommendations

The aim of this study was to establish a comparison between BAEL91/99 and the EC2, exploring the variation in the results obtained from the two codes on a regular RC frame residential building with solid slab (MRF+SS) and hollow slab (MRF+HS) low-rise to mid-rise RC framed buildings in Abidjan using Autodesk Robot Structural Analysis Professional 2020.

It is therefore important to compare regulations in terms of both calculation processes and constructive provisions.

For this purpose, we first performed a theoretical comparison of the two regulations and their design arrangements then proceeded to the design of the structural elements. Autodesk Robot Structural Analysis Professional 2020 supports several design codes and standards, including international codes such as Eurocodes, AISC, ACI, and more.

There are differences between the two codes concerning the mechanical characteristics of the materials and loading parameters. The results are relatively similar or not between the two regulations according to the elements studied.

The following conclusions can be observe for the axial force and bending moments:

Axial forces on selected columns

Column axial forces as per BAEL 91/99 for MRF SS is high than those from the EC2, therefore we can say that EC2 code is more favorable than BAEL 91/99.

Column axial forces as per BAEL 91/99 for MRF HS is high than those from the EC2, therefore we can say that EC2 code is more favorable than BAEL 91/99.

Beam bending moments

Beam bending moments as per BAEL 91/99 for MRF SS is equal to those from the EC2; therefore, we can say that EC2 code is more favorable than BAEL 91/99.

Beam bending moments as per BAEL 91/99 for MRF HS is equal to those from the EC2; therefore, according to the results it can be concluded that EC2 code is more favorable than BAEL 91/99.

It is not inherently wrong to use BAEL 91/99 for structural design. BAEL 91/99 is a recognized and accepted design code in Ivory Coast and in all West Africa French speaking countries, and it has been used successfully for numerous projects in the those countries.

However, EC2 provides a unified set of design principles, methods, and safety requirements that can be applied in different countries.

Eurocodes, including EC2, have gained widespread international recognition and acceptance. Many countries outside of Europe have adopted Eurocodes or incorporated their principles into their own design codes. If the project involves collaboration with international stakeholders or requires compliance with international standards, using a widely recognized and accepted design code like EC2 may be advantageous.

It is important to note that software programs are regularly updated and new releases may include support for additional design codes based on market demand, user feedback, and collaboration with industry organisations.

It is difficult to provide a list of all software programs in the field of structural engineering that are known to support the BAEL91/99 design codes.

However it is obvious that software developer may prioritize supporting more widely used international codes that have broader applicability.

At first glance, EC2 appears to be a relatively complex set of rules, but it is nonetheless rich and comprehensive. In fact, our study has already gives some interesting indications: while ensuring a good level of safety, the use of EC2 does not upset the economics of projects. There is even reason to believe that more explicit consideration of the sustainability requirement in EC2 projects can lead to a reduction in costs, which, however, could only be detected after overall an updated assessment.

RECOMMENDATIONS

Confronted with the challenges of globalization and sustainable development we are facing, an unequivocal question is whether we should move to Euro codes standards.

A purely technical in-depth work followed by a financial study on a construction project with the involvement of all actors in the field of building, accompanied by a political will, would give sufficient elements of answer for a future transition towards the latter with our own regional and environmental parameters taken into account through official national annexes.

Integrate the Euro codes in the activities of the design offices in order to master the divergences the divergences that exist between their regulations.

To encourage all the actors of civil engineering in Africa to work for the development of a specific African standard recognized by all African countries and worldwide.

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Appendix A

Table 19.

Hollow slab thickness according to NF P 06-001 de juin 1986

Nature du plancher	Pour une hauteur réelle totale (cm)	Poids surfacique (*) (kN/m^2)
A. Dalles pleines en béton armé	par cm	25
B. Planchers nervurés à poutrelles préfabriquées ou nervures coulées en place, avec entrevous (corps creux) en béton, entre axes : 60 cm.		
- Montages avec table de compression	12 + 4	2,50-2,60
	16 + 4	2,75-2,85
	20 + 4	3,10-3,30
	25 + 5	3,60-4,00
- Montages sans table de compression	16	2,20-2,30
	20	2,60-2,80
	24	2,90-3,10
C. Dito avec entrevous en terre cuite		
- Montages avec table de compression	12 + 4	2,20-2,30
	16 + 4	2,50-2,60
	20 + 4	2,80-3,00
	25 + 5	3,20-3,60
- Montage sans table de compression	16	1,90-2,00
	20	2,20-2,40
	24	2,50-2,70
D. Dito avec entrevous très légers (ex :polystyrène) ou sans entrevous.		
- Montages avec table de compression	12 + 5	1,50-1,70

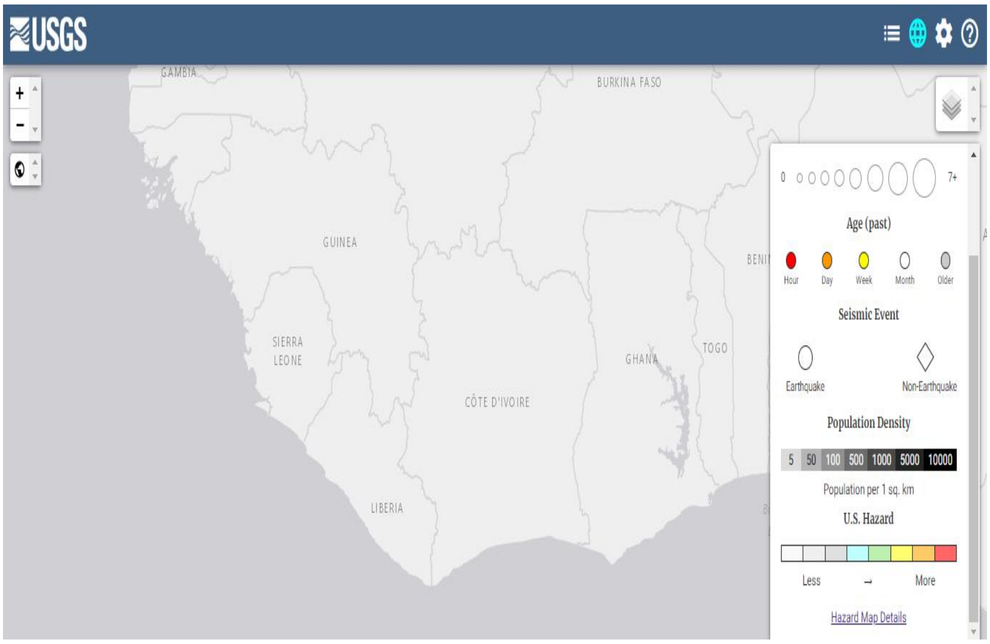
Table 20.

Live Loads according to NF P 06-001 de juin 1986

Nature du local	Valeur de la charge en kN/m^2 (1)
— Hébergement en chambres, salles de jeux et repos des crèches	1,5 **
— Hébergement collectif (dortoirs)	2,5 **
	2.5
— Salles de restaurants, cafés, cantines (nombre de places assises < 100)	2,5 **
— Bureaux proprement dits	2,5 **
— Salles de réunions avec tables de travail	2,5 **
— Halles diverses (gares, etc..) où le public se déplace	4,0 *
— Salles d'exposition de :	
moins de 50 m^2	2,5 *
50 m^2 ou plus	3,5 *
— Salles de réunions et lieux de culte avec assistance debout	5,0
— Salles, tribunes et gradins des lieux de spectacles et de sport avec places debout	6,0
— Salles de théâtre, de conférences, amphithéâtre, tribunes avec sièges	4,0

Figure 33.

Seismicity and seismic assessment in Ivory Coast



(https://earthquake.usgs.gov/earthquakes/map/?extent=2.17477,-733.86475&extent=14.64737,-710.88135)

Table 21.

Values of coefficients ψ

Type of premises	*Coefficients*	
All premises except archives and parkings	*0.77*	ψ_0
Parking lots and archives	*0.90*	
Meeting rooms with seats, various halls, showrooms, classrooms, restaurants, dormitories.	*0.65*	Ψ_1
Archives	*0.90*	
Other premises than above	*0.75*	
Various halls, Meeting rooms, religious places, showrooms, sports halls and stands	*0.25*	Ψ_3
Classrooms, restaurants, dormitories, meeting places	*0.25*	
Archives	*0.8*	
Premises not mentioned above	*0.65*	

Table 22.

Strength and deformation of concrete

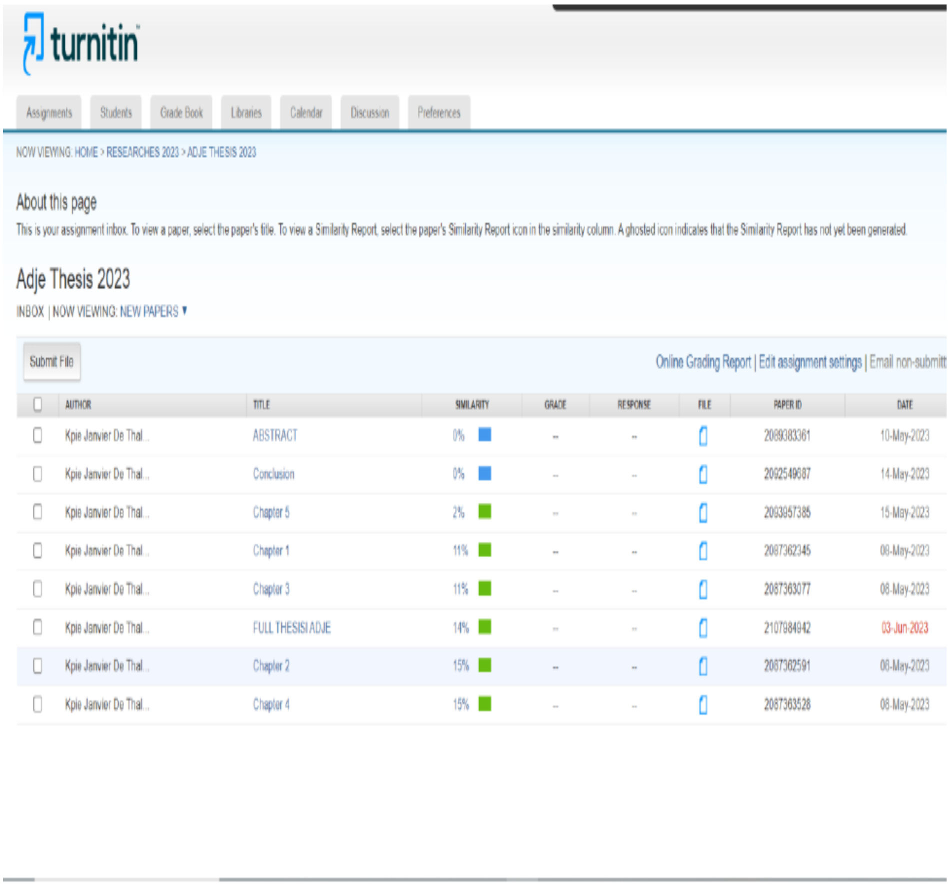
Table 3.1 Strength and deformation characteristics for concrete

	Strength classes for concrete														Analytical relation / Explanation
f_{ck} (MPa)	12	16	20	25	30	35	40	45	50	55	60	70	80	90	
$f_{ck,cube}$ (MPa)	15	20	25	30	37	45	50	55	60	67	75	85	95	105	2.8
f_{cm} (MPa)	20	24	28	33	38	43	48	53	58	63	68	78	88	98	$f_{cm} = f_{ck}+8$(MPa)
f_{ctm} (MPa)	1,6	1,9	2,2	2,6	2,9	3,2	3,5	3,8	4,1	4,2	4,4	4,6	4,8	5,0	$f_{ctm}=0,30\times f_{ck}^{(2/3)}$ ≤C50/60 $f_{ctm}=2,12\cdot\ln(1+(f_{cm}/10))$ > C50/60
$f_{ctk,0,05}$ (MPa)	1,1	1,3	1,5	1,8	2,0	2,2	2,5	2,7	2,9	3,0	3,1	3,2	3,4	3,5	$f_{ctk;0,05} = 0,7\times f_{ctm}$ 5% fractile
$f_{ctk,0,95}$ (MPa)	2,0	2,5	2,9	3,3	3,8	4,2	4,6	4,9	5,3	5,5	5,7	6,0	6,3	6,6	$f_{ctk;0,95} = 1,3\times f_{ctm}$ 95% fractile
E_{cm} (GPa)	27	29	30	31	33	34	35	36	37	38	39	41	42	44	$E_{cm} = 22[(f_{cm})/10]^{0,3}$ (f_{cm} in MPa)
ε_{c1} (‰)	1,8	1,9	2,0	2,1	2,2	2,25	2,3	2,4	2,45	2,5	2,6	2,7	2,8	2,8	see Figure 3.2 ε_{c1} (‰) = $0,7 f_{cm}^{0,31} \leq 2,8$
ε_{cu1} (‰)	3,5									3,2	3,0	2,8	2,8	2,8	see Figure 3.2 for $f_{ck} \geq 50$ Mpa ε_{cu1}(‰)$=2,8+27[(98-f_{cm})/100]^4$
ε_{c2} (‰)	2,0									2,2	2,3	2,4	2,5	2,6	see Figure 3.3 for $f_{ck} \geq 50$ Mpa ε_{c2}(‰)$=2,0+0,085(f_{ck}-50)^{0,53}$
ε_{cu2} (‰)	3,5									3,1	2,9	2,7	2,6	2,6	see Figure 3.3 for $f_{ck} \geq 50$ Mpa ε_{cu2}(‰)$=2,6+35[(90-f_{ck})/100]^4$
n	2,0									1,75	1,6	1,45	1,4	1,4	for $f_{ck} \geq 50$ Mpa $n=1,4+23,4[(90-f_{ck})/100]^4$
ε_{c3} (‰)	1,75									1,8	1,9	2,0	2,2	2,3	see Figure 3.4 for $f_{ck} \geq 50$ Mpa ε_{c3}(‰)$=1,75+0,55[(f_{ck}-50)/40]$
ε_{cu3} (‰)	3,5									3,1	2,9	2,7	2,6	2,6	see Figure 3.4 for $f_{ck} \geq 50$ Mpa ε_{cu3}(‰)$=2,6+35[(90-f_{ck})/100]^4$

BS EN 1992-1-1:2004
EN 1992-1-1:2004 (E)

Appendix B

Similarity Check Report



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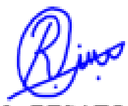
Assoc. Prof. Dr. Rifat Reşatoğlu(Thesis Supervisor)

MSc. Student, Kpie Janvier De Thales Adje

Appendix C
Ethical Certificate



ETHICS LETTER

TO GRADUATE SCHOOL OF APPLIED SCIENCES

REFERENCE: KPIE JANVIER DE THALES ADJE (20206798)

The aforementioned candidate is one of the Master's students in the field of Civil Engineering.

He is working on a thesis under my supervision, entitled "COMPARATIVE ANALYSIS OF RC FRAMED RESIDENTIAL BUILDING DESIGNED ACCORDING TO BAEL 91/99 AND EC2 IN IVORY COAST". The work is based on modeling a regular framed structure. The aim of this analysis is to scrutinize the differences between the two codes and explore the variation in the results obtained from the BAEL 91/99 and EC2 of a regular RC frame residential building with solid and hollow slab in Abidjan city.

The moment resisting frame (MRF) model is performed using Autodesk Robot Structural Analysis Professional 2020.

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Sincerely yours,

Assoc. Prof. Dr. Rifat RESATOGLU

(Supervisor)

Civil Engineering Department,

Faculty of Civil and Environmental Engineering