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COMPARATIVE STUDY OF SHEAR OF REINFORCED CONCRETE ELEMENTS ACCORDING TO ACI – EUROCODE – CBA CODES

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Abstract –This research project focuses on a comparative study between three codes, the American code ACI 318-08, European standards EUROCODE 2 and the Algerian code CBA.93. In this comparative study, we analyze the different parameters affected the shear of steel bars reinforced concrete structures highlighting the concordance points between the three codes considered and the difference in their approach respectively. The comparative study investigates the following points such as concrete and steel properties, load combinations, and design approaches of the shear resistance of reinforced concrete. The results obtained permit to conclude with proposed suggestions as a contribution for an eventual revision of the Algerian code CBA.

Keywords – ACI, EUROCODES, CBA, Comparative Study, Shear Strength, Reinforced Concrete.

I. INTRODUCTION

The first reinforced concrete structure was designed in 1855 by Joseph Lambot. Since then, this material has spread strongly in the field of construction [1]. Reinforced concrete is a complex material, constituted from two materials: concrete and steel, arranged in the manner to give economical and resistance structure [2].

We call concrete: the mixture in suitable proportions of aggregates (sand, gravel, etc.), hydraulic binder (cement), water. Reinforced concrete is the material obtained by adding steel bars to the concrete. These steel bars are usually called reinforcements. In the combination of concrete and steel, concrete resists compressive forces and steel resists tensile forces and possibly compressive forces if the concrete is not sufficient to take all the compressive forces that exist [3]. A construction will be called reinforced concrete if both materials participate in the strength of the whole [4]. This study consists to analyze the shear behavior of reinforced concrete elements according to the American Concrete Institute code ACI, the European standards EUROCODE, and the Algerian concrete code CBA93. This comparative study permits to highlight the concordances and differences between these three codes in terms of design approaches of the shear resistance of reinforced concrete sections. The results of this comparison will constitute a database for a possible revision of the Algerian concrete code CBA 93.

II. Comparison of shear strength approaches of sections according to ACI, EUROCODE and CBA

II.1 Physical and mechanical properties

A) Concrete

Table 1: Comparison of physical and mechanical properties of concrete

	According to ACI Code	According to EUROCODE	According to CBA Code
Density	2155/2555Kg/m³	The code indicated no value.	2500Kg/m³
Coefficient of thermal expansion	The code indicated no value.	10x10⁻⁶/°C	10x10⁻⁶/°C
Characteristic Compressive Resistance	For : $f_c' \leq 35\ MPa$ Max : $f_{cr}' = f_c' + 1.34\ S_s$ $f_{cr}' = f_c' + 2.33\ S_s - 3.5$ For : $f_c' > 35\ MPa$ Max : $f_{cr}' = f_c' + 1.34 S_s$ $f_{cr}' = 0{,}9\ f_c' + 2.33\ S_s$ For: $fc' > 35\ MPa$ and a number of trials S_s Less than 15: $f_{cr}' = 1{,}1\ f_c' + 5$	$f_{cm}(t) = \beta_{cc}(t).f_{cm}$ For S = 025 (Resistance class Cement CEM 32.5R, CEM 42,5 N) $\beta_{cc} = \exp\left\{0{,}25\left[1 - \left(\frac{28}{t}\right)^{\frac{1}{2}}\right]\right\}$ **(article 3.1.2, (1) Page 26 EN 1992-1-1:2004)**	$f_{cj} = \frac{j}{4{,}76 + 0{,}83j}.f_{c28}\ if\ f_{c28} \leq 40MPa$ $f_{cj} = \frac{j}{1{,}40 + 0{,}95j}.f_{c28}\ if\ f_{c28} > 40MPa$ **(Article A.2.1.1.1, CBA 93)**
Characteristic resistance to traction	$f_{ct} \approx 6{,}7\sqrt{f_c'}(enPsi)$ $f_{ct} \approx 0{,}56\sqrt{f_c'}(enMPa)$ For normal concrete.	$f_{ctm}(t) = (\beta_{cc}(t))^{\alpha}.f_{ctm}$ $\alpha = 1$ For $t < 28$ $\alpha = 2/3$ For $t \geq 28$ f_{ctm} = depends on t (Annex I)	$f_{tj} = 0{,}6 + 0{,}06\ f_{cj}$ Just for $f_{ct} < 60MPa$. **Article A.2.1.1.2, CBA93**
Longitudinal deformation modulus	$E_c = \gamma_c^{1.5}.43\sqrt{f_c'}.10^{-3}$ $E_c = 4730\sqrt{f_c'}$ (Normal density concrete) Example $\gamma_b = 2500Kg/m3$ $f_c' = 25MPa$ $E_c = 23650\ MPa$ **(article 8.5.1; Page 318-107 ACI 318M-08)**	$E_{cm}(t) = (f_{cm}(t)/f_{cm})^{0.3}.E_{cm}$ $E_{cm}(t)$ et $f_{cm}(t)$ depends on time (Annex I). E_{cm} et f_{cm} these are the values determined at 28 days. • Example : Normal density concrete (t=28j) f_{cm} = 25MPa : $E_c = 31000MPa$	$E_{ij} = 11000\ (f_j)^{1/3}$ Example : Normal Density Concrete : $f_{cj} = 25MPa$ $E_c = 32164{,}2\ MPa$ **(Article A.2.1.2.1, CBA 93)**
Long term deformations – Shrinkage	The ACI code gives no Value.	$\varepsilon_{cs} = \varepsilon_{cd} + \varepsilon_a$ $\varepsilon_{ca}(t) = \beta_{as}(t).\varepsilon_{ca}(\infty)$ $\varepsilon_{cd}(t) = \beta_{ds}(t,ts).Kh.\ \varepsilon_{cd0}$ $\varepsilon_{ca}(\infty) = 2.5(f_{ck} - 10).10^{-6}$ $\beta_{as}(t) = 1 - \exp(-0.2\ t^{0.5})$ $\beta_{ds}(t,ts) = [\frac{t-t_s}{t.t_s} + 0.04\sqrt{h_0^3}]$	$\varepsilon_t = 2.10^{-4}$ (Humid climate) $\varepsilon_t = 3.10^{-4}$ (Mild climate) $\varepsilon_t = 4.10^{-4}$ (Hot and dry climate). $\varepsilon_t = 5.10^{-4}$ (Very dry climate)
Long term deformations – Creep	The ACI code gives no Value.	$\varepsilon_{cc}(\infty,t_0) = \varphi(\infty,t_0).\left(\frac{\sigma_c}{E_c}\right)$ $\sigma_c > 0{,}45\ f_{ck}(t_0)$ t_0 : the age of the concrete at the time of chargement. $E_c = 1{,}05\ E_{cm}$	$E_{vj} = \frac{E_{ij}}{3} = 3700\sqrt[3]{f_c'}$ $\varepsilon_{totale} = \varepsilon_{ij} + \varepsilon_{fl}$ $\varepsilon_{tot} = \frac{\sigma_{ij}}{E_{ij}}(1 + \emptyset f(t))$

1°-Density: the EUROCODE (Article 11.1.1, (4) EN1992-1-1:2004) does not indicate any value, but the ACI code (Article R2.2 ACI 318-08) gives an interval that limits the density with a small difference from that given by the CBA code (Article A.3.1.2.1, CBA93) as indicated in Table 1.

2°-Coefficient of thermal expansion: the ACI code does not indicate any value while the EUROCODE (Article 3.1.3, (5) EN1992-1-1:2004) and CBA code (Article A.3.1.3.3, CBA93) indicate the same value of 10×10^{-6}/°C, as shown in Table 1.

3°- Compressive strength: This resistance has almost different empirical expressions for the three codes (Table 1). The calculation is based on the number of tests according to ACI code (article 5.3.3.2 ACI 318-08). EUROCODE (article 3.1.2, (1) EN1992-1- 1:2004) requires a formula based on the cement strength class used; however, the CBA (Article A.2.1.1.1, CBA 93) recommends two formulas determining the strength as a function of the concrete age and the value of the compressive strength f_{c28}.

4°-Tensile strength: Note that both the ACI (Article 8.6; R8 ACI 318-08) and CBA (Article A.2.1.1.2, CBA93) codes present empirical formulas, for the calculation of the tensile strength of concrete, depending on the compressive strength of concrete. Although the EUROCODE (Article 3.1.8 EN1992-1-1:2004) requires a formula which depends on the compressive strength of concrete and the cement strength class used.

5°-Longitudinal deformation modulus: From the empirical formulas proposed by the three codes as shown in Table 1, it can be seen that they are based on the compressive strength value. Although, the modulus of elasticity according to the ACI code depends on the concrete density, thus it can be seen that the elasticity modulus value of the EUROCODE and CBA is higher than that obtained from the ACI code.

6°- Long term deformations

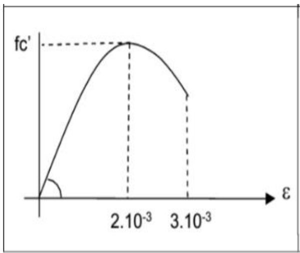
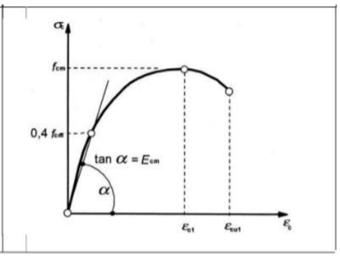
a-Shrinkage: For shortening coefficients, it is difficult to compare them because these coefficients have different terms (see Table 1). Nevertheless, we try to compare them between EUROCODE and CBA code because the ACI code (Article 9.2.3 ACI 318-08) does not give any value. The EUROCODE (Article 3.1.4,(2) EN1992-1-1:2004) suggests a relationship depending on factors that are a function of time, and relative humidity. However, the CBA code proposes values depending of the region climate in Algeria.

b-Creep: The ACI code does not indicate any creep value, while the two codes EUROCODE and CBA require creep expressions that are based on the same theoretical basis depending on the concrete elasticity modulus, the concrete compressive strength as well as the time as shown in Table 1. Except that the EUROCODE adopts a relationship depends on stress applied to concrete, the concrete strength class, and the creep coefficient which depends on the time and the environmental conditions.

7°-Poisson's ratio: From Table 1, it can be seen that the concrete Poisson's ratio values recommended by the EUROCODE (Article 3.1.3, (4) EN1992-1-1:2004) and the CBA code (Article A.2.1.3 CBA 93) are similar. However, it seems that the ACI code does not give any value.

II.2. Actual stress-strain diagram

Table 2: Comparison of actual stress-strain diagram of concrete.

According to ACI	According to EUROCODE
	

According to the CBA code
The code does not indicate any actual concrete stress-deformation diagram.

About actual concrete stress-strain diagram, the CBA code does not indicate any diagram.

Nevertheless, for those recommended by the ACI code (Article R10.2.6 ACI 318-08) and EUROCODE (EN 1992-1-1:2004), we can noted that they exhibit the same appearance shape which reflects the non-linear concrete behavior as shown in Table 2. According to the ACI code, the deformation corresponding to the maximum stress that can be supported by the compressed concrete, is equal to 2.10^{-3} for most concretes. While, the EUROCODE relates the deformation ε_{cl} corresponding to the maximum stress to the concrete strength class [5].

B) Steel

Table 3: Comparison of physical and mechanical properties of steel

	According to ACI Code	According to EUROCODE	According to the CBA code
Type of steel	- Grade 40 ($f_y = 276MPa$) - Grade 50 ($f_y = 345MPa$) - Grade 60 ($f_y = 414MPa$) - Grade 75 ($f_y = 517MPa$) - Grade 80 ($f_y = 552MPa$) - Grade 100 ($f_y = 690MPa$) - Grade 120 ($f_y = 827MPa$)	$f_{yk} = 400$ à $600\ MPa$ (Article 3.2.2, (3), Page 36 EN 1992-1-1:2004)	- High Adhesion : - (HA) F_eE400 ($f_e = 400MPa$), F_eE500 ($f_e = 500MPa$). - Smooth Round : (RL) F_eE215 ($f_e = 215MPa$), F_eE235($f_e 235MPa$)
Density	The Code does not indicate any value	$\gamma_a = 7850\ Kg/m^3$	The Code does not indicate any value
coefficient of thermal expansion	The three codes do not indicate any value		
modulus of elasticity	E_S =2. $10^5 MPa$		
Poisson's ratio	The three codes do not indicate any value		

1°- Steel type: From Table 3, the both EUROCODE (Article 3.2.2,(3) EN1992-1-1:2004) and CBA code require a classification whose yield limits are almost similar. However, the ACI code suggests several classes.

2°-Density: Regarding this properties, the both ACI and CBA codes do not indicate any value. However, the EUROCODE suggests a value equal to 7850 kg/m³.

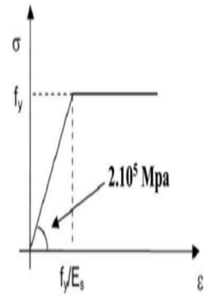
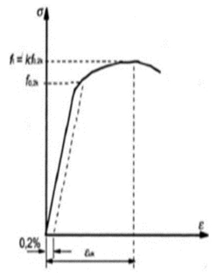
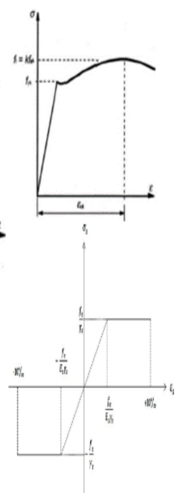
3°-Coefficient of thermal expansion: From Table 3, the three codes do not indicate any value.

4°-Modulus of elasticity: The elasticity modulus values of steel according to the three codes are similar as shown in Table 3.

5°-Poisson's ratio: About this ratio, the three codes do not specify any value.

Stress-deformation diagram

Table 4: Comparison of stress-deformation diagrams of steel:

According to ACI Code	**According to EUROCODE**	**According to CBA Code**
		

-Based on the two simplified stress- deformation diagrams of steel suggested by the ACI code (article R10.2.4 ACI 318-08) and the CBA code (Article A.2.2.2, CBA93) as shown in Table 4, it can be observed that the two diagrams exhibit the same appearance shape. Except for EUROCODE (Article3.2.4,(2) EN1992-1-1:2004), which suggests two diagrams, one for Hot Profile and the second for Cold Profile. The CBA code limits the steel elongation to 10‰.

II.3 Permissible stresses

A) Concrete

Table 5: Comparison of permissible concrete stresses

According to ACI Code	According to EUROCODE	According to CBA Code
$0.85f_c'$	ULS : fcd = $\alpha_{cc}\, f_{ck}/\gamma_c$	ULS : fbu=$0.85 f_{c28}/\theta\gamma$
	SLS σ_c= 0.6 fc28	SLS σ_{bc} =0.6 fc28

From Table 5, it is noted that the checking of stresses in concrete according to the ACI code is done without specifying the nature of the limit state. However, the EUROCODE and the CBA code check the concrete compressive stresses in ultimate limit states (ULS) and service limit states (SLS).

B) Steel

Table 6: Comparison of Steel Allowable Stresses

According to ACI code	According to EUROCODE	According to CBA Code
The code does not indicate any value **(page 4, TN331_ACI_floor_design_040509).**	σ_s= 0.8 f_{yk} cracking no limit	ULS : σst = fe /γs
		SLS : - Minimal harmful cracking (MHC) - Harmful cracking (HC): $\overline{\sigma_{st}}$ = min(2/3 f_e ; 110(ηftj)1/2) **(article A.4.5.3.3., CBA93)** Very Harmful cracking (VHC): $\overline{\sigma_{st}}$ = min (0,5 f_e ; 90 (ηftj)1/2)

II.4 Load Combinations

From Table 7 and 8, it can be seen that combinations of actions are based on the same theoretical foundation according to the three codes studied. These combinations are versus dead, live and accidental (seismic) loads, temperature, snow, wind, and other loads. However, the load factors of dead and live loads at ULS in the EUROCODE and CBA codes are similar and different than those of the ACI code. In general, the latter underestimates the dead load factor and overestimates that of live loads compared to the EUROCODE and CBA code.

Table 7: Comparison of load combinations at ultimate limit states (ULS)

According to ACI Article C9.2(Page 318-403 ACI 318-08)	According to L'Eurocode2 Article 2.3(Page 8; YANNICK.SIEFFERT "Le Béton armé selon L'Eurocode2")
✓ Combinations taking into account the pressure action ✓ of a liquid and the imposed deformations: U = 1.4 (D+F) U = 1.2 (D+F+T) + 1.6(L+H) + 0.5 (S ou L ou R) ✓ Accidental Combinations : U = 1.2D + 1.6(S ou L ou R) + γ_L.L U = 1.2D + 1.6(S ou L ou R) + 0.8W U = 1.2D + 0.5(S ou L ou R) + γ_L.L + β_W.W U = 0.9D + β_W.W + 1.6H U = 0.9D + β_W.W U = 1.2D + 0.2S + γ_L.L + α_E.E U = 0.9D + α_E.E + 1.6H U = 0.9D + α_E.E l'article C9.2(Page 318-403 ACI 318-08) With: γ_L = 1 in the case of car parks in a public square and the surfaces or L > 490Kg/m². γ_L = 0.5 in other cases. β_W = 1.6 If W is reduced by a direction factor, if not β_W = 1.3. α_E = 1.4 If E is based on the service level of the seismic force, if not α_E = 1. ✓ Example of permanent load combination G=30KN/ml, ✓ and operating Q = 10KN/ml of an ✓ isostatic girder: 1,2G + 1,6Q = (1,2 x 30) + (1,6 x 10) = 52 KN/ml.	✓ Fundamental Combinations : $\sum \gamma_{Gj.sup} \cdot G_{Kj.sup} + \sum \gamma_{Gj.inf} \cdot G_{Kj.inf} + \gamma_{Q.1} \cdot Q_{K.1} + \sum \gamma_{Q6} \cdot \Psi_{0.i} \cdot Q_{K.i}$ With : $G_{kj.sup}$ and $G_{kj.inf}$ are permanent actions of different origin. Values of γ_{Gj} and γ_{Q6} are summarized . ✓ Accidental Combinations : $\sum G_{Kj} + A_d + \Psi_{1.1}(ou\ \Psi_{2.1}).Q_{K.1} + \sum \Psi_{2.i}.Q_{K.1}$ $\Psi_{1.1} et\ \Psi_{2.1}$ With : $\Psi_{1.1} et\ \Psi_{2.1}$ Depends on the project accidental situation. A_d : representative value of the accidental action. G = 30KN/ml, and operating Q = 10KN/ml of an isostatic beam: 1,35G + 1,5Q = (1,35 x 30) + (1,5 x 10) = 55,5KN/ml.
According To CBA Code Article A.3.3.2.2, CBA93	
✓ Accidental Combinations: ✓ Accidental Combinations:	$1,35\ G_{max} + G_{min} + \gamma_{Q1}.Q_1 + \sum 1,3\ \Psi_{0i} Q_i$ $1,35\ G_{max} + G_{min} + \gamma_{Q1}.Q_1 + \sum 1,3\ \Psi_{0i} Q_i$

Table 8: Comparison of load combinations at service limit states (SLS)

According to ACI code Article C9.3(Page 318-403 ACI 318-08)	According to EUROCODE
✓ Combinations taking into account the pressure action of a liquid and Imposed deformations: U=D+F U=D+H+F+L+T U = D + H + F + (S ou Lrou R) U = D + H + F + 0.75(L + T) + 0.75(S ou Lrou R) ✓ Accidental combinations: U = D + H + F + (W ou 0.7E) U = D + H + F + 0,75(W + 0.7E) + 0.75L+ 0.75(S ou Lrou R) U = 0.6D + W + H	✓ Characteristic combination: ∑ Gk,j+ Qk,1+ ∑ ψ0,i.Qk,i Article 2.4(YANNICK.SIEFFERT "Le Béto armé selon L'Eurocode2")
According To CBA Code article A.3.3.3, CBA93	
Gmax+ Gmin + Q1+∑ Ψ0i.Qi	

II.5 Comparison of shear strengths according to CBA, EUROCODE, ACI codes

Table 9 compares the shear strength expressions of a

				CBA	EUROCODE	ACI
Shear stress				$T = \frac{V_u}{b_d}$	$T = \frac{V_{Ed}}{b_d}$	$T = \frac{V_u}{b_d}$
Justifications of beams under shear stresses	Justification of the concrete	Straight reinforcements $\alpha = 90°$	MHC	$\pi_U \leq \min(0,2 \frac{f_{cj}}{\gamma_b}; 5MPa)$	$V_{Rd,c} = \max(C_{Rd,c}.K\ (100\ \rho_1 f_{cK})^{\frac{1}{3}}$ $K_1.\sigma_\varphi.b_w.d$ $V_{Rd,s} = \frac{A_{sw}}{s}.z.f_{ywd}.cot\theta$	$V_{max} = 0,17\sqrt{f_c'}.b_w.d + 0,66\sqrt{f_c'}.b_w.d$
			HC or VHC	$\pi_U \leq \min(0,15 \frac{f_{cj}}{\gamma_b}; 4MPa)$		
		Straight reinforcements α = 45°		$\pi_U \leq \min(0,27 \frac{f_{cj}}{\gamma_b}; 7MPa)$		
		45° < α < 90°		Linear interpolation		
	Steel justification	area of shear reinforcement		$\frac{A_t}{b_0 S_t} \geq \frac{\gamma_s(\tau_u - 0,3 f_{tj} K)}{0,9 f_e(cos\alpha + sin\alpha)}$ $\frac{A_t f_e}{b_0 S_t} \geq 0,4MPa$ (article A.5.1, 23 CBA 93)	Si $V_{Ed} \leq V_{Rd} = \min(V_{Rd,s}; V_{Rd,max})$ $\frac{A_{sw}}{S} \geq \frac{V_{Ed}}{Z.f_{ywd}\ (cot\theta + cot\alpha).s}$ (Article 9.2.2; S. Multon (2012) béton armé ,Eurocode 2)	Si $V_u > 0,5\ \Phi V_c$ $\frac{A_v}{s} = \frac{V_u - \Phi.V_c}{\Phi f_{yt}\ d\ (sin\alpha + cos\alpha)}$ For α = 90° $\frac{A_v}{s} = \frac{V_u - \Phi.V_c}{\Phi f_{yt}\ d}$ (Article 11.4.7.1 11.4.7.2 ACI 318-08)
		shear reinforcement spacing		$S_t \leq \min(0,9d; 40cm)$ (article A.5.1, 22 CBA 93)	$S_t \leq S_{t,max} = Min\ (0,75d; 60cm)$ $S_1 \leq S_{1,max} = 0,75d(1 + Cot\ \alpha)$ (Article 9.2.2; S. Multon (2012) béton armé, Eurocode 2)	S≤ $S_{max} = Min\ (0,5d; 60cm)$ (Article 11.4.6.3 ACI 318-08)

reinforced concrete cross-section according to the ACI, EUROCODE and CBA codes.

It should be noted that according to the three codes, CBA (article A.5.1, 1 CBA 93), EUROCODE (Multon, 2012) and ACI (Article11.2.2 ACI 318 M-08**)**, the shear stress is based on the same theoretical foundation which is the shear force applied to the beam cross-section.

-The shear strength expression according to three codes is based on the same theoretical basis, i.e., the ultimate shear force should be less than the sum of the resistant forces of concrete and steel. Although, the Eurocode neglects the contribution of the compressed concrete in the calculation of the shear reinforcement.

-According to both ACI and CBA codes, the formulas used to evaluate the shear strength of concrete are generally based on the concrete compressive strength and the useful cross-section of concrete. In addition, the CBA code involves in the shear strength evaluation two other parameters such as the type of cracking and the inclination of the shear reinforcement.

Contrary to the ACI code which gives no direct indication on the influence of cracking, but it penalizes the resistant force V_n by a reduction factor

Ø=0.75. For the calculation of shear reinforcement, both CBA and ACI codes involve the concrete contribution to shear strength. However, the CBA code limits this contribution by the concrete area state (concreting recovery or not) and the effort type by the introduction of the K coefficient.

- According to the three codes, the maximum shear reinforcements spacing depends on the effective height (d) of the concrete cross-section. Nevertheless, the ACI code underestimates the maximum spacing which is 0.5d compared to that of the Eurocode and CBA estimated to 0.75d and 0.9d, respectively.

III - NUMERICAL APPLICATION

Consider a column having a square cross-section of 500 x 500 mm^2 dimensions subjected to shear loads as shown in Figure 1.

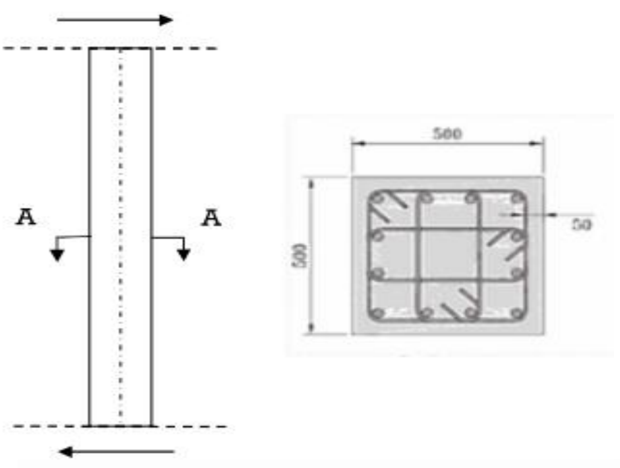


Figure 1: Column subjected to shear force

The objective of this numerical application is to determine the shear reinforcement of this column according to the three codes CBA, EUROCODE, ACI.

Table 10: Comparison of column shear numerical results according to the 3 codes.

	CBA	EUROCODE	ACI
Data	$f_{c28} =$ 25MPa $f_e =$ 400 MPa Longitudinal reinforcements : 12ϕ30 Stirrups : ϕ10	$f_{ck} =$ 25MPa $f_{yk} =$ 400MPa Longitudinal reinforcements : 12ϕ30 Stirrups : ϕ10	$f_c' =$ 25MPa $f_y =$ 414 MPa Longitudinal reinforcements : 12ϕ30 Stirrups : ϕ10
Concrete cross-section	$b_w.h = 50.50cm^2$	$b_w.h = 50.50cm^2$	$b_w.h = 50.50cm^2$
Shear force	V_Q = 0.2 MN V_G = 0.1 MN	$V_L = 0.2\ MN$ $V_D = 0.1\ MN$	$V_L = 0.2\ MN$ $V_D = 0.1\ MN$
Shear force at ULS	$V_u = 1.35\ V_G + 1.5\ V_Q = 435KN$	$V_u = 1.35V_D + 1.5V_L = 435KN$	$V_u = 1.2V_D + 1.6V_L = 441KN$
Shear reinforcement spacing	15.1 cm	20.4 cm	13.13 cm
Maximum spacing	40 cm	33.75 cm	22.5 cm
Shear stress	$\tau_U = \frac{V_u}{b_0\ d} = 1.93\ MPa$	$\tau_U = \frac{V_u}{b_0\ d} = 1.93\ MPa$	$\tau_U = \frac{V_u}{b_w\ d} = 1.96\ MPa$
Area of shear reinforcement	$4\Phi10 = 3.14\ cm^2$	$4\Phi10 = 3.14\ cm^2$	$4N°10 = 4\ \#\ 3 = 2.84\ cm^2$

Comparison results and discussion:

Table 10 shows that:

- The shear force values calculated at ultimate limit states (ULS) by both the CBA and EUROCODE are similar and slightly lower than that obtained by the ACI code, this low value is due to the dead load factor value adopted by the CBA code (γ_G= 1.5) which is lower than that of the ACI code α_l =1.6.

- The spacing of the shear reinforcements according to the EUROCODE is relatively larger compared to those of the CBA and ACI codes for the same shear reinforcement quantity because the EUROCODE generally adopts a smaller inclination of concrete shear cracks around 27°, in order to optimize the shear reinforcement compared to that adopted by the ACI and CBA codes which is equal to 45°. However, the CBA code overestimates the maximum spacing of the shear reinforcements by 18% and 78% compared to those of EUROCODE and ACI code, respectively. It can be concluded that the ACI code is much safer for the design of shear reinforcement of concrete structures, especially for uncontrolled structures and worksites.

IV -CONCLUSIONS

The objective of this theoretical comparative study is to investigate the shear behavior of reinforced concrete elements according to three codes: American code ACI 318-08, European standards EUROCODE 2 and the Algerian code CBA93. This comparative study allows to draw the following conclusions:

- The design formulas for the three codes are generally based on the same theoretical foundation, and they are generally based on the mechanical properties of both steel and concrete materials.

- The coefficient of thermal expansion of concrete is practically the same according to the three codes.
- The compressive and tensile strength of concrete at d-days according to the three codes are evaluated by empirical expressions.
- The stress-deformation diagrams of concrete (and even those of steel) have the same shape.
- The value of the modulus of elasticity of concrete according to the CBA code is higher than that obtained by the EUROCODE which is in turn higher than that of ACI which depends on the density of concrete. However, values of the modulus of elasticity of steel according to the three codes are similar.
- The Poisson's ratio of concrete is practically the same for the three codes studied.
- The checking of stresses in concrete according to the ACI code is done without specifying the nature of the limit state. However, the EUROCODE and the CBA code check the concrete compressive stresses in ultimate limit states (ULS) and service limit states (SLS).
- To limit harmful cracking in concrete at the service limit state (SLE), the CBA requires limiting stresses in steel by reducing its yield strength value. However, the ACI and EUROCODE do not give any direct conditions on stress in steel, but it controls harmful cracking of concrete by limiting the crack width by providing, generally, a minimum percentage of reinforcement in the concrete cross-section.
- The load combinations according to the three codes are based on the same theoretical foundation. These combinations are versus dead, live and accidental (seismic) loads, temperature, snow, wind, and other loads. However, load factors of dead and live loads at ULS in the EUROCODE and CBA codes are similar and different than those of the ACI code. The latter, generally, underestimates the dead load factor and overestimates that of live loads compared to the EUROCODE and CBA code. The dead load factors are generally 1.35 for EUROCODE and CBA code and 1.2 for ACI code, while those for live loads are 1.5 for EUROCODE and CBA and 1.6 for ACI code.

- For the calculation of shear reinforcement, both CBA and ACI codes involve the concrete contribution to shear strength. However, the CBA code limits this contribution by the concrete area state (concreting recovery or not) and the effort type.

-For the maximum spacing of the transverse reinforcements, it depends on the effective height of the concrete cross-section according to the three codes.
- The ACI code requires that the minimum diameter of the transverse reinforcement must be 9.5 mm (bar N°10 (≠3)). Whereas, according to the Eurocode and CBA codes, this minimum diameter can reach 6mm.
-The Eurocode suggests a smaller inclination of the concrete shear cracks around 27° in order to optimize the shear reinforcement compared to that recommended by ACI and CBA codes which is equal to 45°.
-The CBA overestimates the maximum spacing of the shear reinforcements by 18% and 78% compared to those of the Eurocode and ACI code, respectively.

-The ACI code is much safer for the design of shear reinforcement of concrete structures, especially for uncontrolled structures and worksites.

V-RECOMMENDATIONS

The results of the comparative shear study according to the three codes ACI, EUROCODE and CBA permit to draw the following recommendations as a contribution for the revision of the Algerian reinforced concrete code (CBA):

- For a good study of civil engineering constructions in a safe and economical way, it is better to have a code that adapts to Algeria country, with taking into account the variation of climatic conditions and soil types that are different from one region to another, inspired from the ACI code.

-The CBA code considers the BAEL code as a reference for all its articles with the exception of the shrinkage values depending on the climate of Algeria. Although, the quality of control of structures and materials in Algerian worksites is far from that of the France, which requires establishing safer formulas inspired from other codes such as the ACI code for the shear strength formulas.

- Establish formulas determining the tensile strength and the elasticity modulus of concrete inspired from those of the ACI code taking into account the density of concrete.

- Establish a formula to design the shear reinforcements inspired from that of the ACI code because of its simplicity and to have safer reinforcements.

REFERENCES

[1] Calcul des Eléments en Béton Armé Aux Etats Limites Cours & Applications - Partie1 faculté d'architecture et de génie civil Polycopié Génie – Civil Université des Sciences et de la Technologie d'Oran Mohamed BOUDIAF.

[2] Dr Ir P. BOERAEVE "Manuel de Calcul de Béton Armé Selon EN1992-1.1" Institut Gramme – Unité Construction 2017.

[3] JEAN FESTA-GEORGES DREUX " Nouveau guide du béton et de ses constituants " Huitième édition 1998.

[4] Support du cours Béton Armé I TEC185Centre Universitaire de Béchar Département de Génie Civil et d'Architecture.

[5] Eurocode 2 : "calcul des structures en béton" (NF EN 1992-1-1).

[6] Design of Reinforced Concrete ACI 318-08 Jack C. McCormac.

[7] Design Paramètres for Longitudinal Bars Beams ACI 318-08.

[8] D.E. ALLEN "Calcul au Etats limites" Archives des publications du CNRC, Digeste de la construction au Canada, janvier 1982.

[9]BRUNO .M "Cours de béton (civ-04-35) " édition hiver2005

[10] C.B.A 93" Règles de conception et de calcul des structures en béton armé".

[11] S. MULTON "Béton armé Eurocode2" Centre de Génie Civil, INSA-Université Paul Sabatier- Toulouse- France 30 Novembre 2012.

[12] ACI 318-08 "Building code requirements for structural concrete".

[13]Technical Note details the requirements of ACI318 -08 for design of concrete floor systems (TN331_ACI_floor_design_040509).

[14] YANNICK SIEFFERT "Le Béton armé selon L'Eurocode2 (2e édition)" éditeur Dunod de Paris, 2010, 2013.

[15] AMERICAN CONCRETE INSTITUTE (2008) Building Code Requirements for Structural Concrete, ACI 318M-08.

LIST OF SYMBOLS

1) Notations of ACI code :

A_c : Area of a section of concrete.

A_s : Area of the tensioned steel.

A_g : the concrete surface only and does not include the void surface

D : Actions due to dead loads.

b : The width of the beam cross-section.

E : Actions due to the earthquake.

E_c : modulus of elasticity of concrete.

E_s : Modulus of elasticity of the reinforcement.

F : Variable load due Pressure of a liquid.

f_c' : Specified compressive strength of concrete.

f_r : concrete fracture modulus.

f_y : Specified yield strength of the reinforcement.

H : Variable load due to thrust of land.

h : height or thickness of beam section

L : Variable operating load.

L_r : Variable load due to the roof.

R : variable rainfall loads.

S : variable snow loads.

W : variable loads due to wind.

γ_c : density of concrete.

ε_s : Deformation of the reinforcement.

λ : coefficient taking into account lightweight concrete.

ρ : unprestressed stretched reinforcement rate, equal to à A_s /b.d.

f_s : the stress or reinforcement closest to the Face stretched to the service limit state.

ρ' : Compressed reinforcement rate, equal to

A_s' /bd.

σ : Effective normal stress.

ϕ : Factor that weighs down type of steel and the value of C and D.

b_w : width of the strip, wall thickness or diameter of the circular cross-section, mm

f_{ct} : average resistance to the rupture of light concrete, MPa,

l_e : Useful buckling length (effective)

l_u : Free length of the column.

K : coefficient depending on the state of connection of the ends of the column.

r : radius of turning

l_d : Tensile development length of a deformed bar, of a deformed metal wire, a reinforcement of smooth or deformed welded metal wire or a prestressed strand in mm.

M_1 : Smaller weighted end moment on a compressive limb, to be considered like positive if the limb is curved in curvature single and negative if it is curved in duplicate curvature N · mm.

M_2 : weighted final moment on the compression member.

N_c : Resultant tensile force acting on that part of the concrete section subjected to constraints of traction under the combined effect of service loads and effective prestressing, N.

P_0 : nominal axial force at zero eccentricity, N.

P_u : weighted axial force; to be taken as positive for compression and negative for tension, N.

U : Strength required to withstand weighted loads or at times and forces Related internal.

v_n: nominal shear stress, in MPa.

V_u : cross-section-weighted shear force, N.

V_s : nominal shear strength provided by shear reinforcement, N.

α: defining the orientation of reinforcement.

ϕ: force reduction factor.

r : Radius of turn of cross-section of a compression element, mm.

2) Notations of EUROCODE:

A_s : Area of a steel section.

B : Area of a concrete section.

b_w : Width of the core of T-, I- or L-beams

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

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

E_S : Calculation value of the modulus of elasticity of reinforced concrete steel.

E_b : Modulus of longitudinal deformation of concrete.

E_{fl} : Creep strain modulus.

E_i : Instantaneous deformation module (Eij at the age of j days).

E_V : Deferred deformation module

(Eij for loading applied at the age of j days).

E_q : Earthquake.

F : Force or action in general.

G_k : Characteristic value of a dead load

I : Moment of inertia

L : Length or span.

A_{smin} : Area of minimum reinforcement section

A_{sw}: Area of the shear reinforcement section

A_c: Area of the straight section of concrete

e : Eccentricity

D : Bending chuck diameter

L : Length

γ_A : Partial coefficient relating to shares accidental A

γ_G : Partial coefficient relating to permanent actions G

G_k : value of a dead load

Q_k : Characteristic value of a variable action

b : The width or thickness of a section.

d : Distances from the barycentre of reinforcement stretched (and compressed) respectively to the fibre most compressed extreme.

f_{cd} : Calculation value of the compressive strength of concrete

f_{ck} : Characteristic compressive strength of concrete, measured on cylinder at 28 days.

f_{cm} : Average value of resistance in concrete compression, measured on cylinder

f_{tk} : Characteristic tensile strength of reinforced concrete steel.

f_y : Yield strength of reinforced concrete steel.

f_{yk} : Characteristic yield strength of reinforced concrete steel.

f_{ywd} : Yield strength for calculating sharp force reinforcements

H : Total height of a section of reinforced concrete.

i : Initial or snapshot.

j : Age of j days.

k : Coefficient in general.

η : Coefficient of equivalence between steel and concrete

α_e :is the report E_s/E_{cm}

γ : Partial safety factor defined in the Common Directives.

γ_s: Partial coefficient for reinforced concrete steel

ε : Relative deformation (εb for concrete, εr for concrete removal, ε_s for steel)

ε_{c1} : Relative deformation in compression of concrete at peak stress f_c.

ε_{cu} : Ultimate relative deformation of concrete in compression.

ε_{cd} : Deformation due to drying shrinkage.

ε_{ca} : Deformation due to endogenous shrinkage.

θ : Temperature deviation angular; dimensionless coefficient.

λ : Mechanical slendering of a compressed part.

ν : Poisson coefficient of a concrete structure, dimensionless coefficient.

σ_c : Compressive stress of concrete.

N : Normal effort

N_{Ed} : Calculation value of normal effort acting (tensile or compression)

τ : Torsional tangent stress

ϕ : Diameter of a rebar

ψ: Coefficients defining values representative of variable actions

V_{Ed} : Effort calculation value Acting sharpener

3) Notations of CBA code:

A_S : Total area of reinforcement.

B : Area of a concrete section.

Br : Reduced concrete area.

E : Longitudinal modulus of elasticity.

E_s : Modulus of elasticity of steel

E_v : Deferred deformation module (E_{ij} for loading applied at the age of f_{tj}).

E_{fl} : Creep strain modulus.

F_A : Force or action in general.

G : Dead loads

I : Moment of inertia

L : Length or span.

L_f : Buckling length

N_{ser} : Normal force, at the service limit state

N_u : Normal force at ultimate limit state

Q : Variable action or live loads.

S : Actions due to snow.

S_t : Spacing between transverse reinforcements

T : Temperature

W : Action due to wind.

V_u : Shear effort to calculate service or usage.

b : The width or thickness of the concrete cross-section.

b_0 : Width of the concrete cross-section.

h : Total height of a section of reinforced concrete.

d : Distance between the upper fiber and the lower reinforcements.

f_{bu} : limit constraint of concrete.

f_{cj} : Characteristic compressive strength at d-day.

f_e : Yield strength of steels

f_{tj} : Characteristic tensile strength at d-date

i : radius of the concrete section

u : Perimeter of the concrete section

α : Angle of an armature with the fiber average of a linear part

γ_b : Safety factor of concrete.

γ_i : Load factor

γ_s : Safety factor of steel

ε_{bc} : Relative deformation of concrete

η : Cracking coefficient

λ : Mechanical slendering of a compressed part.

σ_{st}: Permissible tensile stress of steel

ν : Poisson'ratio

ρ : Density of concrete

τ_u: Ultimate shear stress

ψ_i : Coefficients defined in the Common Directives

ϕ: Creep coefficient

$\emptyset_t$: Nominal diameter of shear reinforcement.

$\emptyset_l$: Nominal diameter of longitudinal reinforcement