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Analysis and Design of Two- Way Ribbed Slabs According to Different Codes (Comparative Study)

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Abstract: A building's reinforced concrete two-way ribbed slab is a crucial structural component. International building standards like ACI 318-14, BS 8110-97, Eurocode 2, and CSA - A23.3-04 may be utilised to design a slab that is both safe and cost-effective. The research covered here is a comparative analysis of several codes with the goal of identifying the best cost-effective or optimum code. The programmes "ETABS 2018" and "CSi Detail 18" are utilised for this purpose. Comparisons are made across four criteria: deflection, concrete volume, steel reinforcement weight, and cost. Concrete volume and steel reinforcement weight are calculated with the help of the software's dedicated quantity surveying capability. Soon after planning and contrasting. It was discovered that the EU code results in the highest total cost because it requires the most steel reinforcement and yields the least deflection, while the BS code results in the lowest total cost because it yields the least steel reinforcement and yields the least deflection.

Keywords: ACI 318-14, BS 8110-9, Eurocode 2, CSA - A23.3-04, ETABS.

1. INTRODUCTION

In buildings, across walkways, and even over bridges, slabs are the structural parts responsible for bearing the added dead and living loads. Flat slabs, slabs with drop panels, two-way solid slabs, one-way solid slabs, joist slabs, and waffle slab systems are used primarily to resist high loads or to minimize the slab thickness and the internal forces in the slab and to limit the slab deflection when there are large spans. A waffle slab, also known as a concrete rib slab, is a kind of reinforced concrete slab with ribs running in opposite directions on the bottom. A waffle slab's top is level, but its underneath is a joist-created grid. The grid is created when moulds are taken off of the set concrete. With greater spans and larger weights in mind, this building was built to last.Due to its stiffness, this design is ideal for vibration-sensitive structures including hospitals, labs, and factories. Buildings with large open areas, such as theatres and railway stations, also benefit from its utilisation. Depending on the scope of the project and the amount of concrete required, waffle slabs might wind up being less costly to create than their less complex counterparts, despite the fact that their composition requires more labor-intensive formwork. This was shown to be the case (Prasad, et al., 2005). [5] . Most buildings' structural plans are developed according to regional or global standards. These aid the engineer in his or her evaluation of the whole structural plan, analysis, and design processes. Codes of practice are frameworks for resolving concerns about safety and usability in structural engineering design, and are essentially instructions developed by experienced engineers and teams of specialists. All of these design rules have the same overarching goal—to ensure that buildings are safe and cost-effective to build—but they may use somewhat different guiding concepts, methods, and assumptions to get there. In a recent study (Ghusen Al-Kafria, 2018), [6]. ACI 318-14, BS 8110-97, Eurocode 2, and CSA - A23.3-04 will all be analysed and compared in this research. The purpose of this study is to compare these two-way ribbed slab (waffle slab) building regulations based on deflection, concrete volume, weight of steel reinforcement utilised, and cost.

2. PROJECT DESCRIPTION

The buildings structure selected for this study is a proposed of one-story building .The column sections are (60 cm x 60 cm), (70 cm x 70 cm), (90 cm x 90 cm) and beam sections are (40 cm x 80 cm) ,(60 cm x120 cm), (80 cm x160 cm) for slabs size (10 m x 10 m), (15 m x 15 m), (20 m x 20 m) respectively as shown in figure(1), figure (2) and figure (3) .The materials properties that used in the building, compressive strength of concrete, fc is taken as 25 MPa. The yield strength for main reinforcing bars, fy is taken as 420 MPa, the super dead load (SD) is calculated as 1.68 kN/m2 and the live load (LL) is taken as 4 kN/m2. Dead load(self-weight) is calculated by program for each slab system are analyzed and designed based on four codes: ACI, BS,CSA and EU.

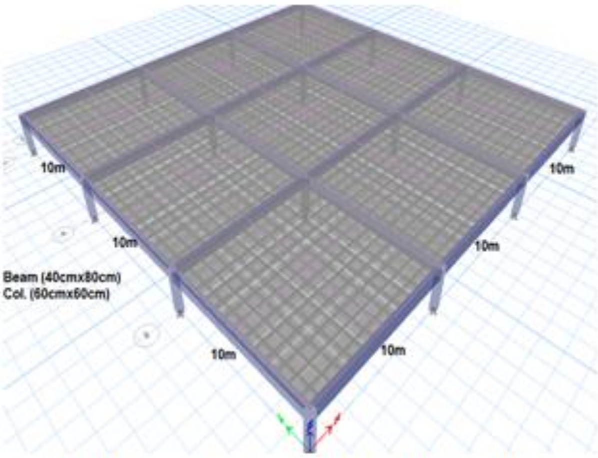

FIGURE 1. 3D-View show building with one story for slab size(10mx10m)

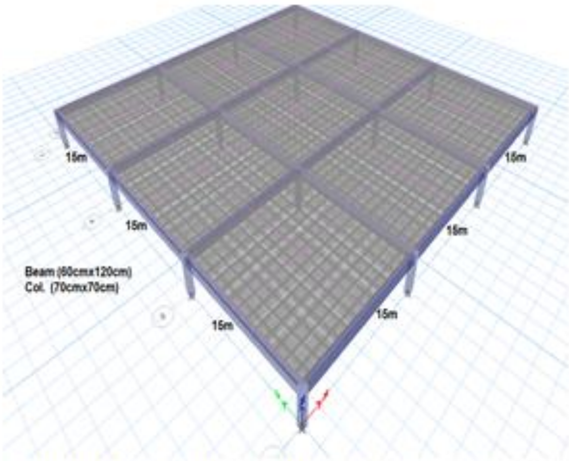

FIGURE 2. 3D-View show Building with one story for Slab Size (15mx15m)

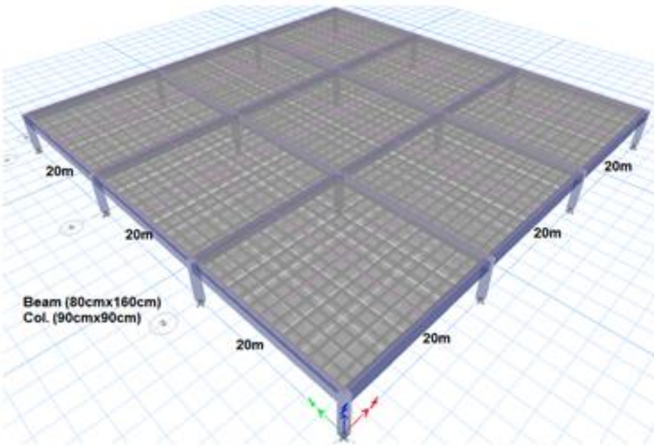

FIGURE 3. :3D-View show Building with one story for Slab Size(20mx20m)

2.1 Building Codes Requirements For Two-Way Ribbed Slab:

ACI-318M-14

- Minimum Rib width 100 mm (ACI8.8.1.2)
- Overall depth of Ribs ≤ 3.5 Min Width (ACI8.8.1)
- Clear spacing between Ribs shall not exceed 750 mm (ACI8.8.1.4)
- Slab thickness over fillers= Max 1/12 clear distance between ribs and 50 mm. (ACI-8.8.2.1.1).

BS-8110-1:1997

- Spaced at centers not exceeding 1.5 m (BS3.6.1.3)
- Width of Ribs ≥100mm
- Overall depth of ribs not exceeding 4 (Width of Ribs)
- Minimum thickness of slab= 50mm or one-tenth of clear distance between ribs. (BS-3.6.1 Table 3.17)

CSA - A23.3-04

- Minimum Rib width 100 mm. (CSA-10.4.1)
- Maximum Rib depth 3.5 times the minimum width of Rib.
- Maximum clear distance between Ribs 800 mm.
- Minimum slab thickness1/12 of the clear distance between ribs, but not less than 50 mm.

Eurocode2-Part 1-1(2004)

- Ribs Spacing does not exceed 1500 mm. (Eu-5.3.1)
- Depth of the Ribs below the flange does not exceed 4 times its width.
- Depth of the flange is at least 1/10 of the clear distance between Ribs or 50 mm whichever is the greater.
- Transverse Ribs are provided at a clear spacing not exceeding 10 time the overall depth of the slab.

Dimensions of Slabs and Check it with limitations for Codes3-1

A- For Slab Size 10 m x 10 m

Check ACI-318M-14 Requirements:

$\mathrm{bw} = 150\mathrm{mm} \geq 100\mathrm{mm}\ \mathrm{O.K}$

$\mathrm{h} = 500\mathrm{mm} \leq (3.5\ \mathrm{bw} = 525\mathrm{mm})\mathrm{O.K}$

$\mathrm{lc} = 700\mathrm{mm} \leq 750\mathrm{mm}\ \mathrm{O.K}$

$$\mathrm{hf} = 100\mathrm{mm} > \max\left(\frac{\mathrm{lc}}{12} = \frac{700}{12} = 60\mathrm{mm}, 50\mathrm{mm}\right)$$

Section dimensions are satisfied the ACI- limitation

Check BS-8110-1:1997. Requirements:

$\mathrm{bw} = 150\mathrm{mm} \geq 100\mathrm{mm}\ \mathrm{O.K}$

$\mathrm{h} = 500\mathrm{mm} \leq (4\ \mathrm{bw} = 600\mathrm{mm})\mathrm{O.K}$

$\mathrm{lc} = 800\mathrm{mm} \leq 1500\mathrm{mm}\ \mathrm{O.K}$

$$\mathrm{hf} = 100\mathrm{mm} \geq \max\left(\frac{\mathrm{lc}}{10} = \frac{800}{10} = 80\mathrm{mm}, 50\mathrm{mm}\right)\ \ \mathrm{O.K}$$

Section dimensions are satisfied the BS- code limitation

Check CSA - A23.3-04 Requirements:

$bw = 150mm \geq 100mm\ O.K$

$h = 500mm \leq (3.5\ bw = 525mm)O.K$

$lc = 750mm \leq 800mm\ O.K$

$hf = 100mm \geq max\left(\frac{lc}{12} = \frac{750}{12} = 65mm, 50mm\right)\ O.K$

Section dimensions are satisfied the CSA- code limitation

Check Eurocode2-Part 1-1(2004) Requirements:

$bw = 150mm \geq 100mm\ O.K$

$h = 500mm \leq (4\ bw = 600mm) O.K$

$lc = 850mm \leq 1500mm\ O.K$

$hf = 100mm \geq max\left(\frac{lc}{10} = \frac{850}{10} = 85mm, 50mm\right)\ O.K$

Section dimensions are satisfied the Eurocode limitation

B- For slab size 15mx15m:

Check ACI-318M-14 Requirements:

$bw = 200mm \geq 100mm\ O.K$

$h = 600mm \leq (3.5\ bw = 700mm) O.K$

$lc = 750mm \leq 750mm\ O.K$

$hf = 200mm > max\left(\frac{lc}{12} = \frac{750}{12} = 65mm, 50mm\right)$

Section dimensions are satisfied the ACI- code limitation

Check BS-8110-1:1997. Requirements:

$bw = 200mm \geq 100mm\ O.K$

$h = 600mm \leq (4\ bw = 800mm) O.K$

$lc = 900mm \leq 1500mm\ O.K$

$hf = 200mm \geq max\left(\frac{lc}{10} = \frac{900}{10} = 90mm, 50mm\right)\ O.K$

Section dimensions are satisfied the BS- code limitation

Check CSA - A23.3-04 Requirements:

$bw = 200mm \geq 100mm\ O.K$

$h = 600mm \leq (3.5\ bw = 700mm) O.K$

$lc = 800mm \leq 800mm\ O.K$

$hf = 200mm \geq max\left(\frac{lc}{12} = \frac{800}{12} = 70mm, 50mm\right)\ O.K$

Section dimensions are satisfied the CSA- code limitation

Check Eurocode2-Part 1-1(2004). Requirements:

$bw = 200mm \geq 100mm\ O.K$

$h = 600mm \leq (4\ bw = 800mm) O.K$

$lc = 900mm \leq 1500mm\ O.K$

$hf = 200mm \geq max\left(\frac{lc}{10} = \frac{900}{10} = 90mm, 50mm\right)\ O.K$

Section dimensions are satisfied the Eurocode limitation

C- For slab size 20mx20m

Check ACI-318M-14. Requirements:

$bw = 250mm \geq 100mm\ O.K$

$h = 875mm \leq (3.5\ bw = 875mm) O.K$

$lc = 750mm \leq 750mm\ O.K$

$$hf\ = 200mm > max\left(\frac{lc}{12} = \frac{750}{12} = 65mm, 50mm\right)$$

Section dimensions are satisfied the ACI- code limitation

Check BS-8110-1:1997. requirements:

$bw = 250mm \geq 100mm\ O.K$

$h = 875mm \leq (4\ bw = 1000mm) O.K$

$lc = 900mm \leq 1500mm\ O.K$

$$hf\ = 200mm \geq max\left(\frac{lc}{10} = \frac{900}{10} = 90mm, 50mm\right)\ O.K$$

Section dimensions are satisfied the BS- code limitation

Check CSA - A23.3-04 requirements:

$bw = 250mm \geq 100mm\ O.K$

$h = 875mm \leq (3.5\ bw = 875mm) O.K$

$lc = 800mm \leq 800mm\ O.K$

$$hf\ = 200mm \geq max\left(\frac{lc}{12} = \frac{800}{12} = 70mm, 50mm\right)\ O.K$$

Section dimensions are satisfied the CSA- code limitation

Check Eurocode2-Part 1-1(2004). Requirements:

$bw = 250mm \geq 100mm\ O.K$

$h = 875mm \leq (4\ bw = 1000mm) O.K$

$lc = 1000mm \leq 1500mm\ O.K$

$$hf\ = 200mm \geq max\left(\frac{lc}{10} = \frac{1000}{10} = 100mm, 50mm\right)\ O.K$$

Section dimensions are satisfied the Eurocode limitation

3. RESULTS OF SOFTWARE ETABS ANALYSIS

TABLE 1. Maximum deflection, bending moment, torsion and shear force values for slab size 10m x 10 m

ITEM	*CODE- TYPE*			
	ACI 318M-14	***BS 81101:1997***	***CSA A23.3-04***	***Eurocode2***
Maximum bending strip moment (kN.m)	+297.6	+270.7	+283.6	+250.5
	-559	-509.6	-533.3	-472
Shear force (kN)	294	267.5	280.2	264.5
Torsion (kN.m)	2.979	2.91	2.94	2.7
Deflection (mm)	5.552	5.488	5.521	5.257

TABLE 2. Maximum deflection, bending moment, torsion and shear force values for slab size 15 m x 15 m.

ITEM	CODE TYPE			
	ACI 318M-14	***BS 81101:1997***	***CSA A23.3-04***	***Eurocode2***
Maximum bending strip moment (kN.m)	+1180.9	+1041.7	+1129.65	+1026.41
	-2144.4	-1897.3	-2057.2	-1834.8
Shear Force (kN)	822.6	722.1	788.9	703.5
Torsion (kN.m)	23.24	30.06	23.5	22.9
Deflection (mm)	15.940	15.225	15.888	15.205

TABLE 3. Maximum deflection, bending moment, torsion and shear force values for slab size 20 m x 20 m.

ITEM	CODE- TYPE			
	ACI 318M-14	***BS 81101:1997***	***CSA A23.3-04***	***Eurocode2***
Maximum bending strip moment (kN.m)	+4820.9	+4210.3	+4599.3	+3752.8
	-8790.5	-7719.8	-8402.3	-6905.1
Shear force (kN)	2686	2356	2566.25	2106.42
Torsion (kN.m)	61.3	62.2	61.98	59.443
Deflection (mm)	25.150	24.522	24.938	23.332

From tables 1–3 that show variations in parameters such as maximum strip bending moment, shear force, torsion and deflection for slabs with different size notice that maximum strip bending moment , shear force and deflection in ACI are the largest for all slabs with different sizes, followed by CSA and BS on the other hand, these parameters in EU are the least for all slab sizes compared to other codes, while torsion in BS is the largest for all slab sizes except slab (10m x10m), followed by CSA and ACI. On the other hand, torsion in EU is the least for these slabs.

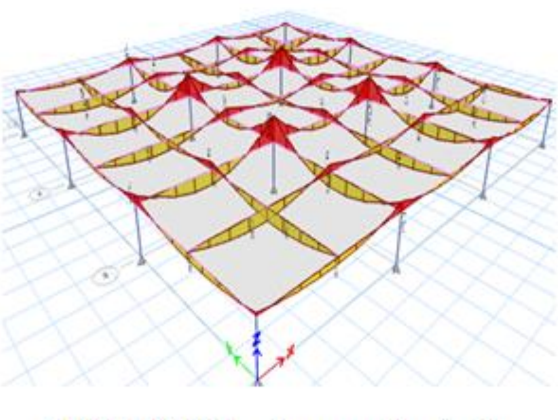

FIGURE 4. 3D-View show moment in each strip

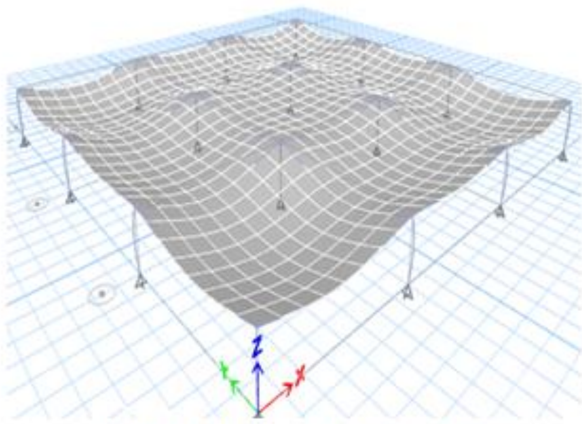

FIGURE 5. 3D-View show deflection shape

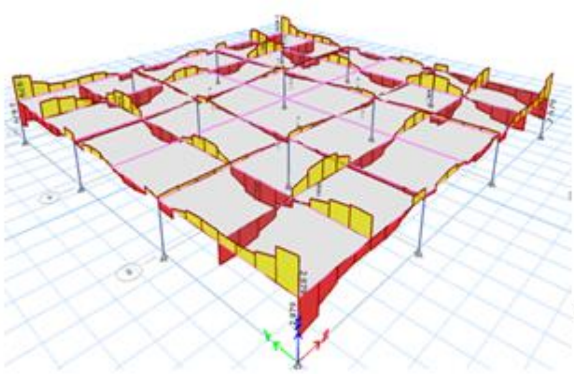

FIGURE 6. 3D-View show torsion in each strip

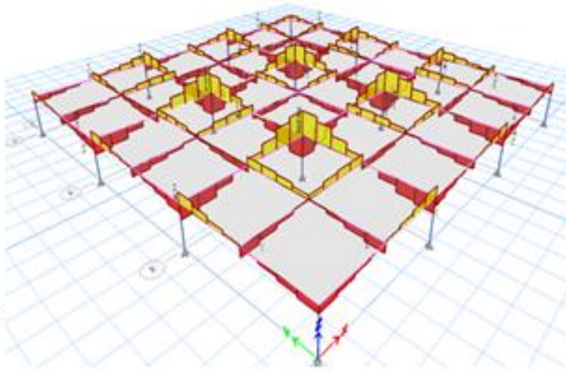

FIGURE 7. 3D-View show shear force in each strip

Table 4. Comparison of slabs based on deflection

Slab Size	Deflection in ACI (mm)	Deflection in BS (mm)	Deflection in EU2 (mm)	Deflection in CSA (mm)
10mx10m	5.552	5.488	5.257	5.521
15mx15m	15.940	15.225	15.205	15.888
20mx20m	25.150	24.522	23.332	24.938

Table (4) shows the values of deflections for slabs of different sizes according to different codes. From this table and its graphical representation in figures 8–10, it can be seen that deflection in ACI is the largest for all slabs with different sizes, followed by CSA then BS on the other hand, deflection in the EU is lowest for all slabs of different sizes; however, all the deflection values for the four codes are within the acceptable range.

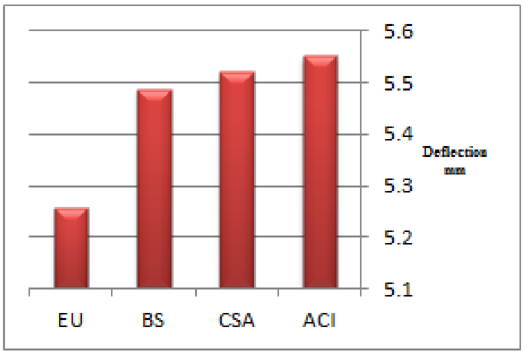

FIGURE 8. Deflection –Codes type diagram for slab size 10mx10m.

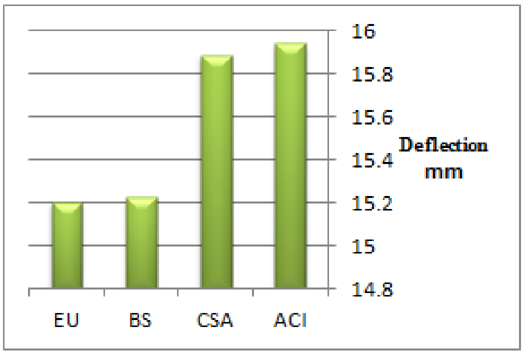

FIGURE 9. Deflection –Codes type diagram for slab size 15mx15m.

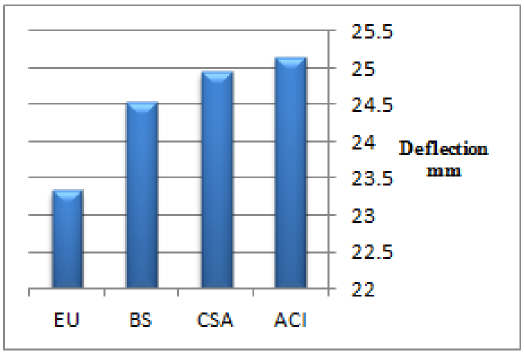

FIGURE 10. Deflection –Codes type diagram for slab size 20mx20m.

TABLE 5. Comparison of slabs based on concrete volume.

ACI			
Total Volume m^3	Slab Size 10mx10m	Slab Size 15mx15m	Slab Size 20mx20m
Slab	227.755	779.4	2070
Beams	134.4	453.6	1075.2
Total	362.155	1233	3145.2
BS			
Slab	212.344	725	1882.5
Beams	134.4	453.6	1075.2
Total	346.744	1178.6	2957.7
EU			
Slab	205.848	725	1783.125
Beams	134.4	453.6	1075.2
Total	340.248	1178.6	2858.325
CSA			
Slab	219.6	759.4	2001.445
Beams	134.4	453.6	1075.2
Total	354	1213	3076.645

Table (5) shows the total amount of concrete volume needed for the construction of beams and slabs for each slab according to different codes from this table and its graphical representation in figures 11–13, it is found that the quantity of concrete according to ACI is larger for all slabs with different sizes than CSA or BS while in the EU it requires a smaller amount of concrete for all slabs with different sizes.

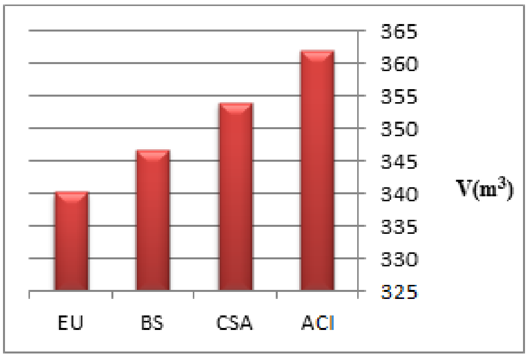

FIGURE 11. Total volume (slab+beam) –Codes type diagram for slab size 10mx10m

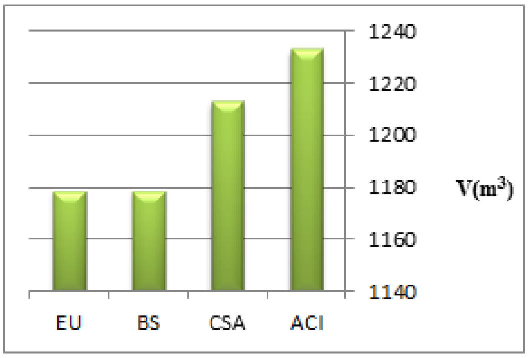

FIGURE 12. Total volume(slab+beam) –Codes type diagram for slab size 15mx15m

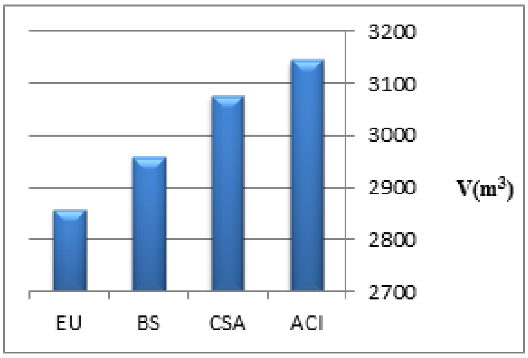

FIGURE 13. Total volume(slab+beam) –Codes type diagram for slab size 20mx20m.

TABLE 6. Comparison of slabs based on weight of steel.

ACI			
Total Steel Weight KG	Slab Size 10mx10m	Slab Size 15mx15m	Slab Size 20mx20m
Slab	3085	9281	14688
Beams	18617	81296	208391
Total	21702	90577	223079
BS			
Slab	1102	4553	11940
Beams	14206	65880	171495
Total	15308	70433	183435
EU			
Slab	1115	5611	9892
Beams	21257	94371	235871
Total	22372	99982	245763
CSA			
Slab	2368	7660	12324
Beams	16995	78911	207336
Total	19363	86571	219660

Table (6) shows the total amount of steel reinforcement needed for beams and slabs for all slabs with different sizes according to different codes from this table and its graphical representation in figures 14–16, it is found that the weight of steel reinforcement according to EU is larger for all slabs with different sizes than ACI or CSA while BS requires a smaller amount of steel reinforcement for all slabs with different sizes.

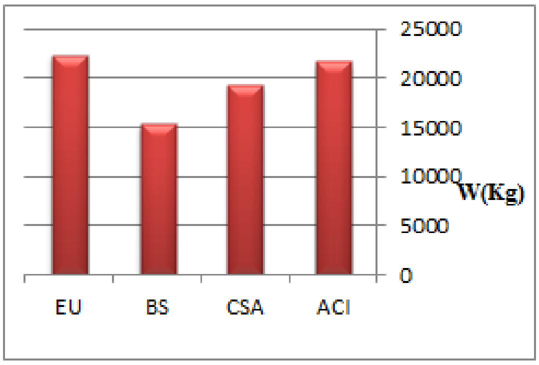

FIGURE 14. Total weight of steel (slab+beam) –Codes type diagram for slab size 10mx10m.

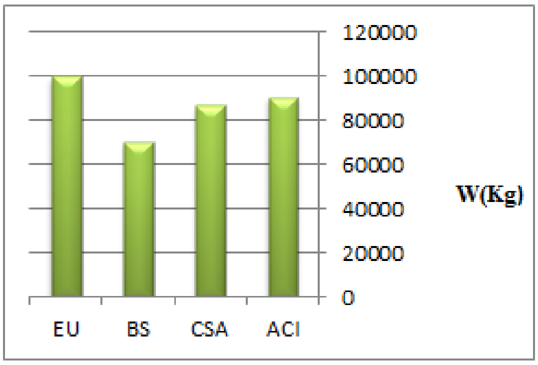

FIGURE 15. Total weight of steel (slab+beam) – Codes type diagram for slab size 15mx15m.

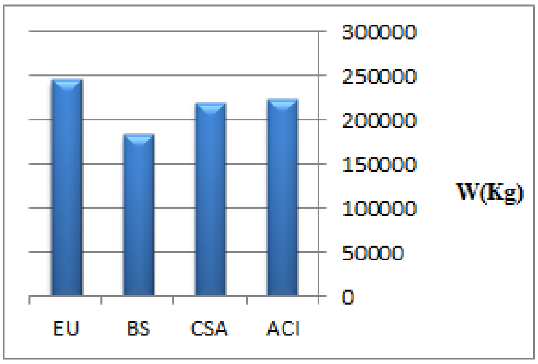

FIGURE 16. Total weight of steel (slab+beam) – Codes type diagram for slab size 20mx20m.

TABLE 7. Comparison of slabs based on cost

ACI			
Slab+Beam	Concrete Cost	Steel Cost	Total Cost
10mx10m	25350850	19531800	44882650
15mx15m	86310000	81519300	167829300
20mx20m	220164000	200771100	420935100
BS			
10mx10m	24272080	13777200	38049280
15mx15m	82502000	63389700	145891700
20mx20m	207039000	165091500	372130500
EU			
10mx10m	23817360	20134800	48061300
15mx15m	82502000	89983800	172485800
20mx20m	200082750	221186700	421269450
CSA			
10mx10m	24780000	17426700	42206700
15mx15m	84910000	77913900	162823900
20mx20m	215365150	197694000	413059150

Table (7) shows the final comparison of the combined prices of concrete and steel for all slabs with different sizes according to different codes: For total concrete volume, the price was (70,000) ID per cubic meter and for weight of steel reinforcement, the price was (900,000) ID per 1000 kg (1 tonne), and the total cost was calculated as:

Total Cost = Total Concrete Volume *(70,000) ID +Total Steel Reinforcement *(900,000) ID

From this table and its graphical representation in figures 17–19, it can be seen that **EU** requires the largest price compared to other codes, followed by **ACI** and **CSA** while **BS** requires the least total price for all slabs of different sizes.

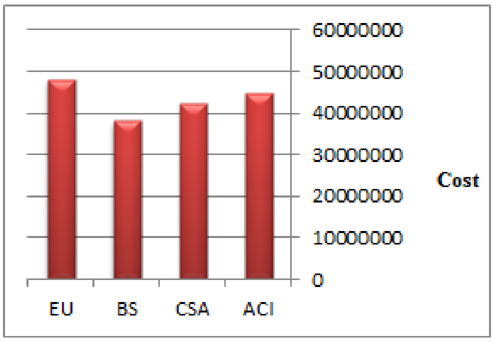

FIGURE 17. Total cost (slab+beam) – Codes type diagram for slab size 10mx10m

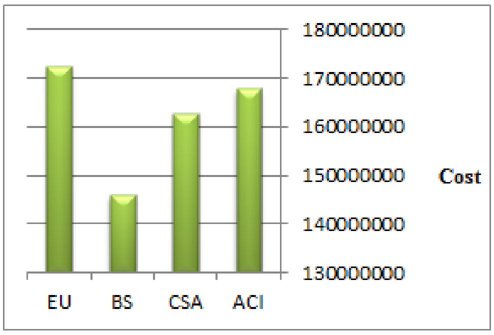

FIGURE 18. Total cost (slab+beam) – Codes type diagram for slab size 15mx15m

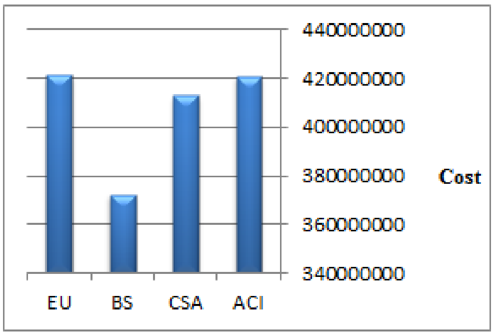

FIGURE 19. Total cost (Slab+Beam) – Codes type diagram for slab size 20mx20m

4. CONCLUSIONS

The ACI code gives the largest amount of concrete volume for all slab sizes, and the CSA and BS codes, the second ones, give a lower amount of concrete volume, while the EU code gives the lowest amount of concrete volume for all slab sizes. The EU code gives the largest amount of steel reinforcement; ACI and CSA are the next two that give the lowest amount of steel reinforcement, while the BS code gives the lowest amount of steel reinforcement for all slab sizes. Based on the total cost, EU gives the largest total cost compared to other codes, with ACI and CSA being the next two that give lower costs, while the BS code leads to the lowest total cost compared to other codes for all slab sizes. The ACI code gives the largest deflection for all slab sizes, CSA and BS are the next two that give lower deflection for all slabs; on the other hand, the EU code gives the lowest deflection for all slabs, and the difference between all codes is not too great.

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