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COMPARISON OF REINFORCED CONCRETE MEMBER DESIGN METHODS OF VARIOUS COUNTRIES

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ABSTRACT

Different countries have variety of geographical, topographical and climatic conditions. Some countries have their own guidelines for the design of structures and some are depended on other countries for laying down the guidelines. Design codes are the most important and basic tools for structural design engineers. The diversity of codal provisions for countries worldwide leads to the problem when engineers have to move from one country to other. Thus knowledge of main features commonalities and differences of the various code of practice is necessary to form a common platform for structural design throughout the world. The comparison between these building codes will help to form a most effective and economical building design. Comparison is made between various reinforced concrete codes such as European code, Indian code, American code, British code and Canadian code. This paper constitutes comparative study of different codal provisions for beam, column and slab design parameters. Further, analytical study is done by keeping loads and load factors constant to bring out the clear difference in their design approach for beam and column.

Key words: Beam Design, Column Design, Structure Design Codes.

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1. INTRODUCTION

Design codes of different countries provide engineers with parameters and procedures for the design of the various structural elements such as beams, columns, slabs, footing etc. Different countries have formulated their own codes for laying down the guidelines for the design and construction of structures. These codes came into the picture after a collaborative effort of highly experienced structural engineers, construction engineers, academicians and other eminent fellows of respective areas. These codes are revised periodically based on current research and trends (e.g. IS456: 1978 and IS456:2000). Codes serve the following objectives/purposes:

They ensure structural stability and thus the safety by specifying certain minimum design requirements. They make the task of a designer rather simple by making available results in the form of tables and charts. They ensure a consistency in procedures adopted by the various designers in the country. They protect the design against structural failures that are caused by improper site construction practices i.e. codes have legal sanctity and one can have a stand on the basis of these design codes. There are numerous research works done related to the comparison between different countries building design codes.The Comparison of wind loads calculated by fifteen different codes and standards, for low, medium and high-rise buildings(John Holmes, Yukio Tamura, Prem Krishna ,2009)[12]The study of main contributing factors which lead to poor performance of structure during an earthquake has been done using Eurocode, IBC and IS 1893:2002(Vinit Dhanvijay, 2015)[13].Design of reinforced concrete structure with various international codes from the economical point of view has been done(Labani Nandi, 2014)[14].A comparative study of strength design requirements of ACI-318, BS8110 and Eurocode2 has been done(Ali Abdul Hussein Jawad, 2006)[15].Comparison of reinforced beams design has been done using BS8110 and Eurocode2(Chee Khoon Ng, 2006)[16]. Comparison of reinforced concrete designs has been done based on ACI 318 and BS8110 codes(Sami W.Tabsh,2013)[17].Comparison of actions(loads) and resistances(strength) has been done using USA, Europe and Egypt codes(Mourad M. Bakhoum, 2015)[18].

Since different countries follow different methodologies in building design thus there are many design codes that are built across the world. Comparison between these building codes will help to form a most effective and economical building design. Comparison will be made between various codes such as European code, Indian code, American code, British and Canadian code of design of buildings in terms of beam design, column design and slab design.

1.1. Research Objective

The main aim of this research is to view the difference in design procedure for different elements of the RC structure such as beam, column and slab adopted by European code, Indian code, American code, British code and Canadian code. Apart from comparative study, analytical study is carried out using STAAD Pro V8i software to bring out reinforcement differences present in different codes for same loads.

2. COMPARITIVE STUDY OF VARIOUS CODES

In this work a comparative study of the design parameters of the various elements of a building such as beam, slab and column is done by using different countries RC building design codes. The various codes studied are IS 456:2000, BS 8110, EC2, ACI 318 and A23.3.

The differences between important parameters are noted and are represented in form of tables.

2.1. Load Combinations

Various loads may act on a structure simultaneously; load combinations should be evaluated to determine the most severe conditions for design. These load combinations vary from one country code to another country code, depending on the various factors such as physic of people, weather conditions, material properties etc. The difference in load combinations for different countries is given in table1.

Table 1 Comparison of load combinations for various countries

Country	Load combinations
IS 456	1.5 (D + L) 1.2 (D + L ± W) 1.5 (D ± W) 0.9 D ± 1.5 W
ACI 318	1.4D 1.2D+1.6L+0.5Lr 1.2D+1.6Lr+(L OR 0.8W) 1.2D+1.6W+1.0L+0.5Lr 0.9D+1.6W
BS8100	1.4*D*+1.6*L* 1.4*D*+1.4*W* 1.0*D*+1.4*W* 1.2*D*+1.2*L*+1.2*W*
CSA	1.4D 1.25D+1.5L 1.25D+1.4W 1.0D+1.0E
EC 2	1.35D+1.5L 1.0D+1.5W 1.35D+1.5L+0.9W

2.2. Beam Parameters

The various critical parameters use for beam design such as span to depth ratio, maximum or minimum tensile steel, minimum shear reinforcement and spacing are studied using different codes and the difference is represented in the table2.

Table 2 Beam parameters for different countries codes

Parameters	IS 456	BS 8110	EC 2	ACI 318	A23.3
L/d ratio Cantilever Simply supported continuous	 7 20 26	 7 20 26	ρ=1.5% | ρ=0.5% 6 | 8 14 | 20 18 | 26(end) 20 | 30(int)	 8 16 18.5(end) 21(interior)	 8 16 18(end) 21(interior)
Mini. Tensile for flexure $\frac{Ast}{bwd}$	$\frac{0.85}{fy}$	0.8(fy=250N/mm^2) 0.45(fy=460N/mm^2)	$\frac{0.26fctm}{fy} \geq 0.0013$	$\frac{0.25fc'}{fy}$ or $\frac{0.224\sqrt{fck}}{fy} \geq \frac{1.4}{fy}$	$\frac{0.2fc'}{fy}$ or $\frac{0.18\sqrt{fck}}{fy}$
Maxi. tensile steel for flexure	0.04bD	0.04bD	0.04bD	Net tensile strain in extreme tensile steel≥0.005	Tension reinforcement limited to satisfy $\frac{c}{d} \leq \frac{700}{700+fy}$
Maximum shear reinforce-ment $\frac{As}{bwSv}$	$\frac{0.4}{0.87fy}$	$\frac{0.4}{0.95fyv}$ when 0.5Vc<V<Vc+0.4 $\frac{V-Vc}{0.95fyv}$ When Vc+0.4<V<0.8$\sqrt{fcu}$or5 N/mm^2	$\frac{0.08\sqrt{fck}}{fy}$ When applied shear is less than shear strength of concrete	$\frac{0.9\sqrt{fck}}{16fy} \geq \frac{0.33}{fy}$ When applied shear is greater than 0.58concrete strength $\frac{0.062\sqrt{fc'}}{fyt} \geq \frac{0.32}{fyt}$	$\frac{0.054\sqrt{fck}}{fy}$ or $\frac{0.06\sqrt{fc'}}{fy}$ When applied shear is greater than concrete strength
Spacing of mini. spacing	0.75d≤300mm	0.75d Should not be greater than d	0.75d≤600mm	0.5d≤6 00mm and 0.25d≤300mm when, Vs>$\frac{bwd\sqrt{fc}}{3}$	0.63d≤600mm 0.32d≤300mm When, Vu>$\frac{\varnothing cfcbwd}{8}$

2.3. Column Parameters

The various important parameters required for column design such as slenderness ratio, condition for short column, axial load calculation formula, maximum or minimum longitudinal reinforcement, diameter and spacing of lateral ties are studied and the difference is represented in table3.

Table 3 Different parameters for column

Parameters	IS 456	BS 8110	EC 2	ACI 318	A 23.3
Slenderness ratio	$\frac{lex}{D}$ or $\frac{ley}{B}$	$\frac{lex}{h}$ or $\frac{ley}{b}$	$\frac{lo}{i}$	$\frac{kleff}{r}$	$\frac{klu}{r}$
Condition for compression member (short column)	$\frac{lex}{D}$ and $\frac{ley}{B}$<12	$\frac{lex}{h}$and $\frac{ley}{b}$<15(braced) $\frac{lex}{h}$and $\frac{ley}{b}$<10 (unbraced)	$\frac{lo}{i}$<limiting value of slenderness ratio	$\frac{klu}{r}\leq 40$ Short column	$\frac{klu}{r}\leq$34-12($\frac{M1}{M2}$) (for non sway frames) $\frac{klu}{r}\leq 22$ (sway frames)
Ultimate axial load for short columns	Pu=0.4fck. Ac+0.67fy Asc	Pn=0.8[0.85fc'($Ag-Ast$)+$Astfy$]	Pu=0.57fckAc+0.87fy kAs	P=0.4fcu(Ag−Asc)+0.8$Ascfy$	Pro =α1φc fc'($Ag - Ast -$ $At- Ap$) +φs fy Ast +φaFy A $t-$ fpr Ap

Longitudinal reinforceme-nt Mini. Max.	0.008Ag 0.06Ag	0.004Ag 0.06Ag	As(min)=$\frac{0.10N_{ED}}{fyd}$ or0.002Ac(whichever is greater) As(max)=0.04Ac(outside lap location) =0.08Ac(at lap)	0.004Ag 0.01Ag	0.01Ag 0.08Ag
Dia. of lateral ties	Should not be greater than 1)dia. of main bar/4 2)6 mm(whichever is less)	1) Atleast one quarter of the largest longitudinal bar size 2) 8 mm	Should not be less than 1)Dia of main bar/4 2) 6 mm (whichever is less)	Should not be less than 1)10mm for longitudinal bars of 32mm dia. or smaller 2)13mm for dia. of longitudinal bar larger than 32mm	Calculated from Interaction diagram
Spacing of lateral ties	Should not be greater than 1)16×dia of main bar 2)300mm (whichever is less)	Maxi. 12×dia of smaller longitudinal bar	Should not be greater than 1)20×dia of ties 2)Least dimension of column 3)400 mm(whichever is less)	Should not be greater than 1)16×dia of main bar 2)48×dia of ties 3)least lateral dimension of column	Should not be greater than 1)16×dia of smallest long. Bar 2) 48×dia of ties 3)least lateral dimension of column 4)300 mm

2.4. Slab Parameters

The various important parameters for slab design such as criteria for one way slab, span to effective depth ratio, minimum reinforcement are studied and is represented in table 4.

Table 4 Different parameters for slab

<table>
<tr><th>Parameters</th><th>IS 456</th><th>BS 8110</th><th colspan="3">EC 2</th><th>ACI 318</th><th>A 23.3</th></tr>
<tr><td>Criteria for one way or two way slab</td><td>$\frac{ly}{lx}$>2
One way slab</td><td>$\frac{ly}{lx}\geq 2$
One way slab</td><td colspan="3">$\frac{ly}{lx}$>2
One way slab</td><td>$\frac{ly}{lx}\geq 2$
One way slab</td><td>$\frac{ly}{lx}\geq 2$
One way slab</td></tr>
<tr><td rowspan="5">$\frac{span}{effective\ depth}$</td><td rowspan="5">Cantilever =7
SS=35
Continuous=40

For high strength deformed bars of grade 415, the values given above multiplied by 0.8</td><td rowspan="5">Cantilever=7
SS=20
Continuous=26
End span=23</td><td>type</td><td>ρ=1.5%</td><td>ρ=0.5 %</td><td rowspan="5">Cantilever=10
SS=20
One end cont.=24
Both ends cont.=28</td><td rowspan="5">Cantilever=10
SS=20
One end cont.=24
Both end cont.=28</td></tr>
<tr><td>cantilever</td><td>6</td><td>8</td></tr>
<tr><td>SS</td><td>14</td><td>20</td></tr>
<tr><td>one way cont. or two way spanning cont. over one long side</td><td>18</td><td>26</td></tr>
<tr><td>One way or two way spanning slab</td><td>20</td><td>30</td></tr>
</table>

Minimum reinforce-ent	Mild steel reinforcement in either direction should not be less than equal to 0.15% For high strength deformed bars or welded wire fabric should not be less tha equal to 0.12%	For mild steel in both directions $\frac{0.24bh}{100}$ For high yield steel(460MPa) $\frac{0.13bh}{100}$	Asmin=$\frac{0.26fck\ btd}{fyk}$ But not less than 0.0013btd Asmax=0.04Ac Secondary transverse reinforcement of not less than 20%of the principal reinforcement should be provided in one way slab.	Not less than 0.0014Ac	0.002Ag in each direction

3. DATA USED AND MODELING

The model adopted for this study is a G+10 office building. Building is analysed and designed according to different countries codes by using Staad Pro V8i software by keeping the parameters such as cross- section of beam, column and slab same for each code, grade of steel is taken as Fe415 and concrete grade is taken as M30 for each code and also the loads such as dead load, live load and wind loads are taken according to Indian standards so that comparison can be done on common points. Comparison graphs for main reinforcement of beam, shear reinforcement i.e. stirrups for the beam, longitudinal reinforcement for columns and longitudinal and transverse reinforcement of slab is plotted by taking the average values of each element such as the beam, column and slab on each floor(1 member is selected on each floor)

The design data for the building include:

Height of each floor including ground floor= 3.65m each.

Thus total height of building = 40.15m

Floor finish= 1.0 KN/m^2

Assumed wind speed= 50m/sec

Beam cross section=350mm*400mm

Column cross section=500mm*600mm

Thickness of slab=150mm

Boundary walls= 230 mm thick masonry walls

Partition walls=115mm thick masonry walls

Parapet walls=115mm thick masonry walls with height 1.25m

Density of reinforced concrete=25KN/m^3

Density of masonry wall= 20 KN/m^3

Compressive strength of concrete=30MPa

Grade of steel=Fe415

Terrain category 2

Return period= 50 years

Mean probable design life of structure= 50 years

Flat terrain

Load combinations:

1.2DL+1.2LL+.2W

1.5DL+1.5W

1.5DL+LL

LOAD CALCULATIONS:

1) dead load calculations:

Main wall load=0.23*3.65*20= 16.8 KN/m

Partition wall load= 0.115*3.65*20=8.4KN/m

Parapet wall load=0.115*1.25*20=2.9KN/m

Slab dead load= (25*0.125+1) KN/m^2

2) Live load= 4.0KN/m^2 at each floor

3) WIND LOAD CALCULATIONS:

AS PER IS 875 PART 3

HEIGHT	K1	K2	K3	Design wind velocity(m/sec)=VbK1.K2.K3	Design wind pressure(N/m^2)$Pz = 0.6.Vz^2$
3	1	0.98	1	49	1440.60
6	1	0.98	1	49	1440.60
9	1	0.98	1	49	1440.60
12	1	0.996	1	49.8	1488.03
15	1	1.020	1	51	1560.60
18	1	1.038	1	51.9	1616.17
21	1	1.055	1	52.75	1669.54
24	1	1.070	1	53.5	1717.35
27	1	1.085	1	54.25	1765.84
30	1	1.100	1	55	1815.00
33	1	1.108	1	55.38	1839.83
36	1	1.115	1	55.75	1864.84
39	1	1.122	1	56.13	1890.00
42	1	1.130	1	56.50	1915.35

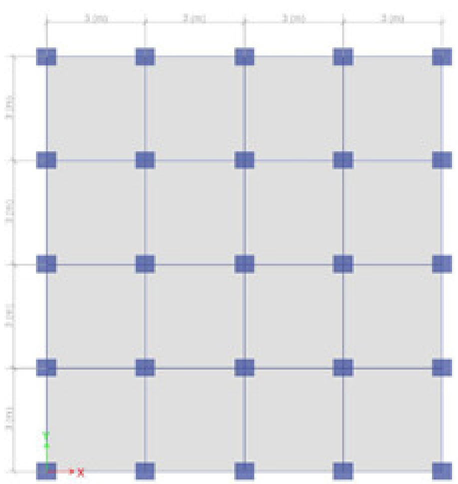

Figure 1 Building plan

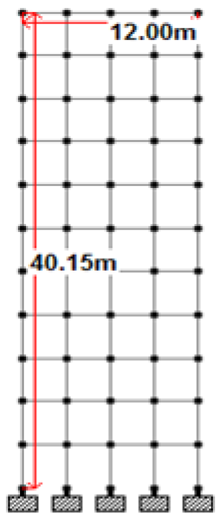

Figure 2 Building elevation

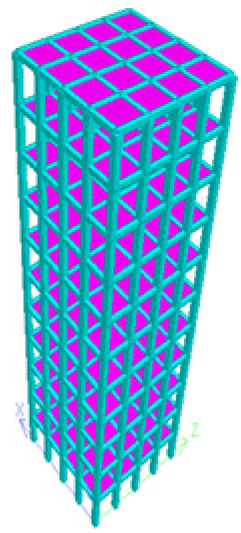

Figure 3 Building 3D Model

4. RESULTS AND CONCLUSION

Staad results for different codes are analyzed and the difference of average tensile reinforcement for beam, average shear reinforcement for beams, average of longitudinal reinforcement for column and average for longitudinal and transverse reinforcement for slab is represented in for of graphs. The difference in average tensile reinforcement for beam is represented in figure 4.

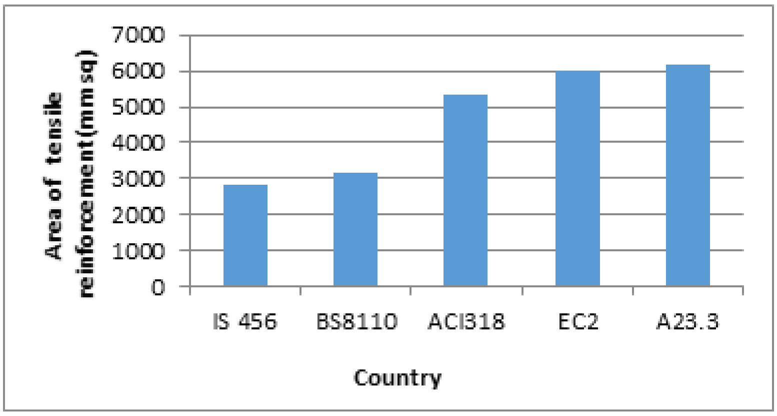

Figure 4 Variation in tensile reinforcement of beam for various codes on average basis

The difference in average shear reinforcement of beam for different countries is represented in figure 5.

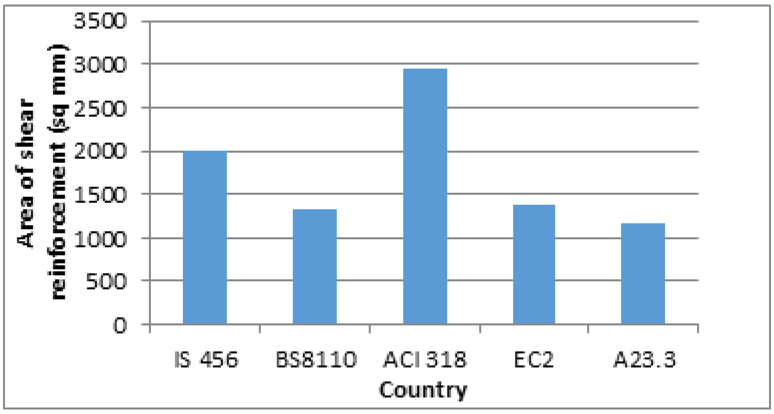

Figure 5 Variation in shear reinforcement of beam for various codes on average basis

The difference between the average longitudinal reinforcement in column for different countries code is represented in figure 6.

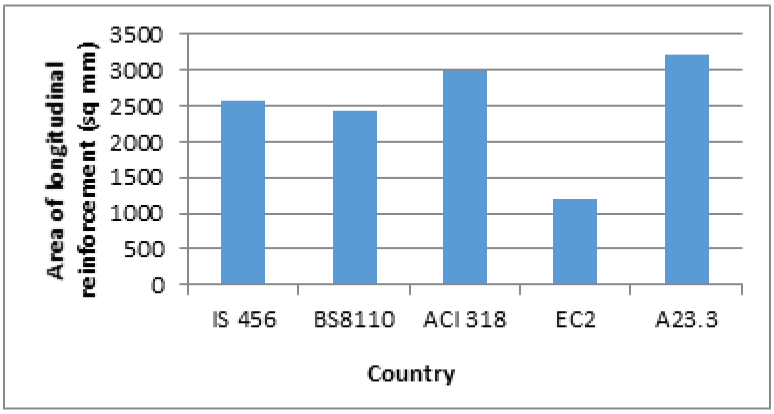

Figure 6 Variation of longitudinal reinforcement in column for various codes on average basis

The difference in longitudinal and transverse reinforcement in of various countries codes slab is represented in figure 7.

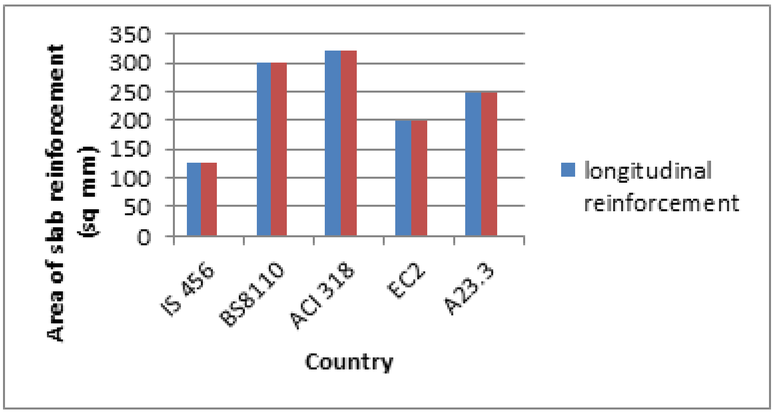

Figure 7 Variation of area of longitudinal and transverse reinforcement of slab for different codes on average basis

5. CONCLUSION

Based on the results of the study it was concluded that flexural reinforcement is least from IS 456:2000 code and maximum for CSA A23.3 by keeping the live load, dead load and wind load same for all codes.

Shear reinforcement for beams is least for IS456:2000 and is maximum for Canadian code. Longitudinal reinforcement for columns is minimum from EC2 and maximum for Canadian code.

Longitudinal and transverse reinforcement for the slab is least for EC2 and maximum for ACI318.

The difference in area of reinforcement is observed due to the difference in stress block diagrams of steel and concrete. This difference is due to difference in maximum strain in steel and concrete taken differently in various codes thus the formulas for calculating area of reinforcement is also different. Since for the combined effect of dead, live and wind load results are varying hence it is not easy to give the exact solution but efforts can be made further in this field to arrive at the best results. Analysis can be done further by using load combinations from different countries code also and noticing the difference and forming factors to transfer one country code to another. This would help design engineers to work in different countries easily.

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