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Comparison of the Total Cost of Various Designs of Rc Columns

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ABSTRACT: *Provisions of Indian (IS 456: 2000), European (EC2 - 1992) and American (ACI 318) codes of practice for the design of RC columns have been critically studied. As per the recommendations of Indian, European and American codes of practice, RC rectangular columns have been designed adopting limit state method for all designs. The total cost of columns has been calculated and is compared using bar chart. It is found that the total cost of the column is less when Indian code of practice is adopted.*
Keywords: *Biaxial bending, lateral ties, limit state design, RC rectangular columns, uniaxial bending.*

I. INTRODUCTION

Design of a reinforced concrete structure is not easily reduced to a science, since it implies functional and aesthetic factors, as well as technical and economic ones. Design is a matter of talent, technical knowledge and imagination. As of today, a reinforced concrete structure should satisfy the requirements of safety or reliability, serviceability, durability, economy and aesthetics. Comparison of various building code requirements reveals significant differences between practices adopted by various countries. In this paper, RC rectangular columns have been designed as per the following three codes of practice and the total cost is compared.

- **"*Indian Standard* Plain and Reinforced Concrete – Code of Practice IS: 456: 2000"**
- **"Manual for the design of reinforced concrete building structures to EC2 – 1992"**
- **"ACI 318: Building Code Requirements for Reinforced Concrete (ACI 318 - 95) and Commentary (ACI 318R – 95)"**

II. CRITICAL PARAMETERS FOR THE DESIGN OF RC COLUMNS AS PER THE THREE CODES OF PRACTICE

The Indian and European codes of practice follow SI units whereas the American code of practice follows FPS units. The following are the critical parameters for the design of columns;

PARAMETERS	**IS 456:2000**	**EC2:2000**	**ACI-318**
Slenderness ratio	$\frac{l_{ex}}{b}$ *or* $\frac{l_{ey}}{D}$	$\left(\frac{l_e}{D}\right) crit = 7.21(2 - \frac{M_1}{M_2})$	$\frac{kl_{eff}}{r}$
Condition for compression members	Slenderness ratio <12 – short column >12 – long column	Slenderness ratio $>\frac{l_e}{D}$ - short column $<\frac{l_e}{D}$ - long column	Slenderness ratio <22 – short column >22 – long column
Co-ordinates for interaction curve	$\frac{P_u}{f_{ck}\,bD}$ and $\frac{M_u}{f_{ck}\,bD^2}$	$\frac{P_u}{f_{ck}\,bD}$ and $\frac{M_u}{f_{ck}\,bD^2}$	$\frac{P_u}{f_{ck}\,A_g}$ and $\frac{M_u}{f_{ck}\,A_g D}$
Area of tension reinforcement(A_{st})	$\frac{\rho bD}{100}$	$\frac{\rho bD f_{ck}}{f_y}$	ρA_g
Diameter of Lateral Ties	Should not be less than i) dia of main bar/4 ii) 6mm whichever is less.	Should not be less than i) dia of main bar/4 ii) 6mm whichever is less.	Should not be less than 0.3inch
Spacing of lateral ties	Should not be greater than i) 16xdia of main bar ii) 300mm whichever is less	Should not be greater than i) 12xdia of ties ii) least dimension of column iii) 300mm whichever is less	Should not be greater than i) 16xdia of main bar ii) 48xdia of ties iii) 16inch
Check for biaxial bending	$(\frac{M_{ux}}{M_{ux\,1}})^{\propto_n} + (\frac{M_{uy}}{M_{uy\,1}})^{\propto_n} \leq 1$	$(\frac{M_{ux}}{M_{ux\,1}})^{\propto_n} + (\frac{M_{uy}}{M_{uy\,1}})^{\propto_n} \leq 1$	$P_n > P_u$ Where, $\frac{1}{P_n} = \frac{1}{P_{nx}} + \frac{1}{P_{ny}} - \frac{1}{P_0}$

Values for design of columns with uniaxial bending:

Size of the column = 300 x 500mm
Unsupported length of column = 3m
Ultimate uniaxial bending = 200kNm
Varying ultimate loads = 1000kN, 1200kN and 1500kN

Values for design of columns with biaxial bending:

Size of the column = 400 x 600mm
Unsupported length of column = 3m
Ultimate moment at major axis = 120kNm
Ultimate moment at minor axis = 90 kNm
Grade of concrete – M25 and grade of steel – Fe500

By using the above parameters, the design of RC rectangular columns with uniaxial and biaxial bending have been carried out for the above values and the results are given below.

III. RESULTS AND DISCUSSIONS:

3.1 RESULTS FOR RC RECTANGULAR COLUMNS WITH UNIAXIAL BENDING:

The results for the design of RC rectangular columns with uniaxial bending to carry ultimate loads of 1000kN, 1200kN and 1500kN are tabulated.

TABLE 3.1.1: AS PER IS 456:2000

ULTIMATE LOAD, Pu (kN)	1000		1200		1500	
DESCRIPTION	MAIN BARS	TIE BARS	MAIN BARS	TIE BARS	MAIN BARS	TIE BARS
Diameter (mm)	25	8mm@ 300mm c/c	28	8mm@ 300mm c/c	32	8mm@ 300mm c/c
No. of bars	4	11	4	11	4	11
Length of a single bar (m)	3	1.48	3	1.48	3	1.48
Total length (m)	12	16.28	12	16.28	12	16.28
Weight of a bar (kg/m)	3.858	0.395	4.839	0.395	6.32	0.395
Total weight (kg)	46.296	6.43	58.06	6.43	75.84	6.43
Total weight (N)	369.3		473.95		637.62	
Cost of steel (Rs.)	1635		2590		3201	
Cost of concrete (Rs.)	2025		2025		2025	
Total cost of the column (Rs.)	**3660**		**4615**		**5226**	

TABLE 3.1.2: AS PER EC2 - 1992

ULTIMATE LOAD, Pu (kN)	1000		1200		1500	
DESCRIPTION	MAIN BARS	TIE BARS	MAIN BARS	TIE BARS	MAIN BARS	TIE BARS
Diameter (mm)	16	8mm @ 95mm c/c	20	8mm @ 95mm c/c	32	8mm @ 95mm c/c
No. of bars	4	32	4	32	4	32
Length of a single bar (m)	3	1.48	3	1.48	3	1.48
Total length (m)	12	47.36	12	47.36	12	47.36
Weight of a bar (kg/m)	1.58	0.395	4.469	0.395	6.32	0.395
Total weight (kg)	18.96	18.7	48.33	18.7	75.84	18.7
Total weight (N)	517.06		632.43		800.78	
Cost of steel (Rs.)	2216		2844		3826	
Cost of concrete (Rs.)	2025		2025		2025	
Total cost of the column (Rs.)	**4241**		**4869**		**5851**	

TABLE 3.1.3: AS PER ACI-318

ULTIMATE LOAD, Pu (kN)	1000		1200		1500	
DESCRIPTION	MAIN BARS	TIE BARS	MAIN BARS	TIE BARS	MAIN BARS	TIE BARS
Diameter (mm)	12.7	9.5m@ 200mm c/c	22.22	9.5mm@ 355mm c/c	25.4	9.5mm@ 406mm c/c
No. of bars	4	16	4	9	4	8
Length of a single bar (m)	3	1.48	3	1.48	3	1.48
Total length (m)	12	23.68	12	13.32	12	11.84
Weight of a bar (kg/m)	0.995	0.56	3.05	0.56	3.982	0.56
Total weight (kg)	11.95	13.26	36.57	7.46	47.78	6.63
Total weight (N)	547.2		731.78		853.58	
Cost of steel (Rs.)	3102		3795		4841	
Cost of concrete (Rs.)	2025		2025		2025	
Total cost of the column (Rs.)	**5127**		**5820**		**6866**	

3.2 RESULTS FOR THE DESIGN OF RC RECTANGULAR COLUMNS WITH BIAXIAL BENDING:
The results for the design of RC rectangular columns with biaxial bending to carry axial loads of 1600kN, 1800kN and 2000kN are tabulated.

TABLE 3.2.1: AS PER IS456:2000

ULTIMATE LOAD, Pu (kN)	1600		1800		2000	
DESCRIPTION	MAIN BARS	TIE BARS	MAIN BARS	TIE BARS	MAIN BARS	TIE BARS
Diameter (mm)	20	8mm @ 300mm c/c	25	8mm @ 300mm c/c	28	8mm @ 300mm c/c
No. of bars	8	11	8	11	8	11
Length of a single bar (m)	3	1.48	3	1.48	3	1.48
Total length (m)	24	16.28	24	16.28	24	16.28
Weight of a bar (kg/m)	2.469	0.395	3.856	0.395	4.84	0.395
Total weight (kg)	59.26	6.43	92.59	6.43	116.16	6.43
Total weight (N)	555.35		764.82		1091.5	
Cost of steel (Rs.)	3332		4589		6549	
Cost of concrete (Rs.)	3240		3240		3240	
Total cost of the column (Rs.)	**6572**		**7829**		**9789**	

TABLE 3.2.2: AS PER EC2:1992

ULTIMATE LOAD, Pu (kN)	1600		1800		2000	
DESCRIPTION	MAIN BARS	TIE BARS	MAIN BARS	TIE BARS	MAIN BARS	TIE BARS
Diameter (mm)	16	8mm @ 95mm c/c	20	8mm @ 95mm c/c	25	8mm @ 95mm c/c
No. of bars	8	32	8	32	8	32
Length of a single bar (m)	3	1.48	3	1.48	3	1.48
Total length (m)	24	47.36	24	47.36	24	47.36
Weight of a bar (kg/m)	1.58	0.395	2.47	0.395	3.858	0.395
Total weight (kg)	37.92	18.71	59.28	18.71	92.59	18.71
Total weight (N)	644.19		971.05		1202.19	
Cost of steel (Rs.)	3865		5824		6763	
Cost of concrete (Rs.)	3240		3240		3240	

Total cost of the column (Rs.)	**7105**	**9064**	**10003**

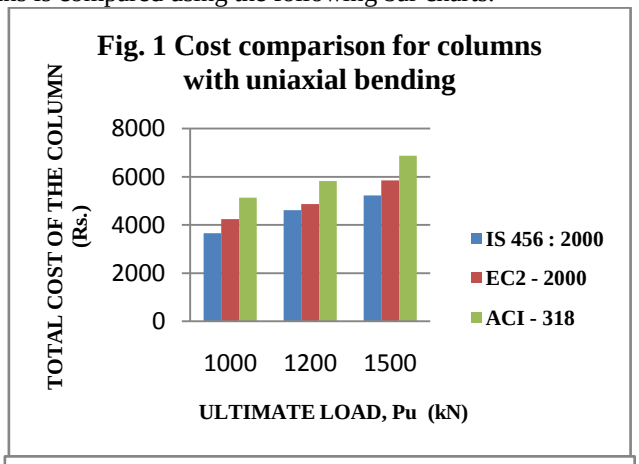
TABLE 3.2.3: AS PER ACI-318

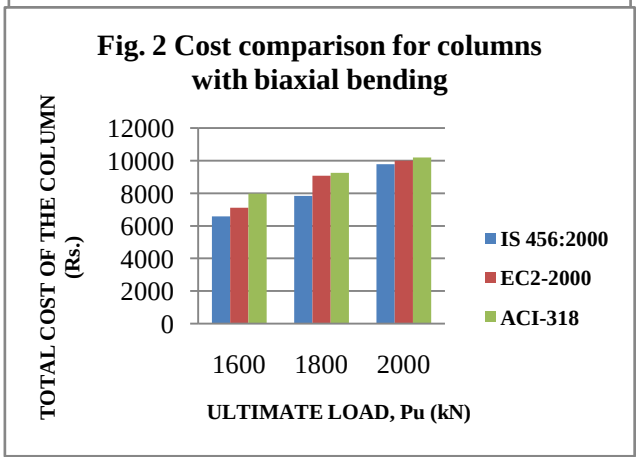
ULTIMATE LOAD, Pu (kN)	1600		1800		2000	
DESCRIPTION	MAIN BARS	TIE BARS	MAIN BARS	TIE BARS	MAIN BARS	TIE BARS
Diameter (mm)	22.22	9.5mm@ 355mm c/c	25.4	9.5mm@ 406mm c/c	28.57	9.5mm@ 406mm c/c
No. of bars	8	9	8	8	8	8
Length of a single bar (m)	3	1.48	3	1.48	3	1.48
Total length (m)	24	13.32	24	11.84	24	11.84
Weight of a bar (kg/m)	3.05	0.56	3.98	0.56	5.04	0.56
Total weight (kg)	73.14	7.46	95.52	6.63	120.9	6.63
Total weight (N)	790.41		1001.74		1274.12	
Cost of steel (Rs.)	4742		6010		6945	
Cost of concrete (Rs.)	3240		3240		3240	
Total cost of the column (Rs.)	**7982**		**9250**		**10185**	

The volume of concrete for the columns with uniaxial bending is **0.45 m³** which is same for all the columns carrying different ultimate loads.

The volume of concrete for the columns with biaxial bending is **0.72 m³** which is same for all the columns carrying different ultimate loads.

The total cost of the columns is compared using the following bar charts.





IV. CONCLUSIONS ON THE DESIGN OF COLUMNS:

- The required volume of concrete is same for all the columns carrying different ultimate loads.
- The weight of steel required is the highest for all the columns when designed as per ACI code. This is mainly due to the number of main bars and the spacing to be provided for lateral reinforcement.
- The total cost of the column is less if designed as per Indian standards when compared to European and American standards and is more if American code is adopted.

LIST OF SYMBOLS:

A_g	- Gross area of the section	M_{ux}	-Ultimate moment at major axis
A_{st}	-Area of tension reinforcement	M_{uy}	-Ultimate moment at minor axis
B	-Width of the column	P_u	-Ultimate load
D	-Overall depth of the column	P_{ux}	-Ultimate load at major axis
D	-Effective depth of the column	P_{uy}	-Ultimate load at minor axis
d´	-Clear cover of the column	P_n	-Axial capacity of the column
f_{ck}	-Characteristic compressive strength of concrete	P_o	-Axial load on the member
f_y	-Characteristic compressive strength of steel	R	-Radius of gyration = 0.3D
K	-Effective length factor = 0.8	V_u	-Ultimate shear force
l_{eff}	-Effective length of the column	□	-Strength reduction factor
l_{ex}	-Effective length in respect of the major axis	P	-Percentage of reinforcement
l_{ey}	-Effective length in respect of the minor axis	□$_n$	Exponent which is based on Pu/Puz
M_u	-Ultimate bending moment		

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