Comparative Analysis of Composite Column Capacity Estimation in International Codes

Sudhir M R[1*], *Arpan* Pradhan[1], and *Beulah* M[1]

[1]Department of Civil Engineering, School of Engineering & Technology, CHRIST (Deemed to Be University), Bangalore, Karnataka, India

Abstract. The primary function of a building, bridge or any structural system is to transmit loads safely from the superstructure to the foundation. The columns play a critical role in this function, and any inaccuracies in load prediction can lead to catastrophic damage. Hence, the evaluation of a column's strength assumes considerable importance. Upon this premise, this research aimed to investigate the strength prediction of M40 grade concrete columns subjected to uniaxial compression loading. The experimental loading capacities of various columns were compared with the evaluated loads as per the Indian Standard code (IS 456:2000), British Standard (BS 8110-1:1997), American Concrete Institute (ACI 318-14) and European Standard (EN 1994-1-1 (2004)). It was observed that the partial safety factors and design philosophies in these codes were different. The experimental results suggested that the load-carrying capacities experimentally determined of the tested columns compare well with the capacities recommended by the IS code and the BS code for columns. In contrast, the other two codes have vastly different column capacity assessments due to higher partial safety factors. It is concluded that all four codes have evolved based on different design philosophies and, hence, have varying partial safety factors. Thus, a direct code comparison is not appropriate.

1 Introduction

A column is a principal structural member designed to carry the superstructure loads to the substructure safely and efficiently through axial compression [1]. Although there are different types of columns in the construction industry, RCC columns have wide applications for load transfers, particularly in their seismic response [2,3]. Literature has attributed many structural failures to poor column performance [4]. A typical column failure in a structure, though maybe a local failure, progressively leads to a more catastrophic global failure of the structure. This reality has led to the development of newer design techniques to focus on the performance of columns under varying structural conditions [5 - 8]. Therefore, the subject of column capacity determination continues to be of interest to researchers. In a comparison of four international codes, the authors have concluded that the Indian code estimation of strengths is conservative compared to the American, European and Canadian codes [9]. It has

* Corresponding author: colonel.sudhir@christuniversity.in

 https://doi.org/10.1051/e3sconf/202564801008

been an accepted research conclusion that column failures result from inadequate strength or the inability to deform sufficiently [10]. Therefore, the subject of column capacity determination continues to hold research interest for researchers.

2 Research Significance

This research attempted to contribute to a reliable estimation of the strength prediction of various types of M40 grade (fck = 40 MPa) composite concrete columns subjected to uniaxial concentric compression loads. Limited literature was available on comparing the various international codes' column load-carrying capacities and strength parameters of concrete [11]. This study compared four international codes for the concrete column load-carrying capacity assessment.

2.1 Experimental outline

As a part of the experimentation, 36 square columns of 200 x 200 x 700 mm were tested for uniaxial concentric compression load capacity using a 1000 KN Hydraulic Universal Testing Machine (UTM) and a 2000 KN hydraulic loading frame. All columns were of the same slenderness ratio of 3.5. All columns were of M40 grade concrete. The Plain Cement Concrete (PCC) column is taken as a reference column. The Reinforced Cement Concrete (RCC) column had four longitudinal bars of 12 mm diameter. The lateral reinforcement/stirrups used were 8 mm bars at 100 mm centre-to-centre spacing. The concrete design mix of the grade was M40 with a water-cement ratio of 0.36. The maximum coarse aggregate (CA) size was 20 mm, the fineness modulus of fine aggregate (FA) was 2.6, and Auramix 400 was the admixture. The FA and the CA grading curves are in Figs. 1 and 2.

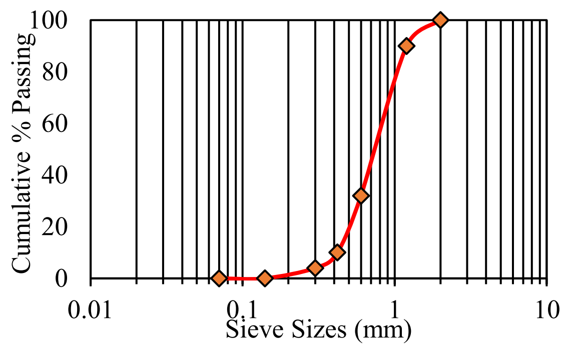

Fig. 1. Grading curve of fine aggregates

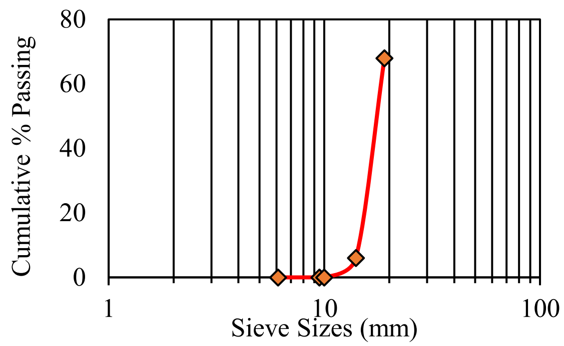

Fig. 2. Grading curve of coarse aggregates

The details of the columns tested are shown below in Table 1 and Fig. 3.

Table 1. Details of 36 columns tested

Ser No.	Type of Column	Curing Period in days	Number of Specimens	Remarks
1	Plain Cement Concrete (PCC)	7	4	M40 grade concrete design mixed, W/C of 0.36, and an all-round cover of 50 mm in all 48 columns
2	PCC	14	4	
3	PCC	28	4	
4	Reinforced Cement Concrete (RCC)	7	4	Longitudinal reinforcement of four rods of 12 mm with 10 mm lateral reinforcement @ 100 mm c/c and FE 550D steel
5	RCC	14	4	
6	RCC	28	4	
7	Indian Standard Medium Weight Beam (ISMB) based	7	4	ISMB 100 along the column length
8	ISMB based	14	4	
9	ISMB based	28	4	

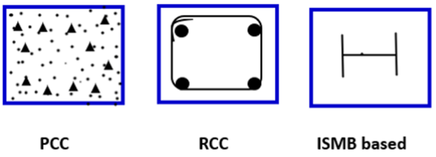

Fig. 3: Different types of columns tested

 https://doi.org/10.1051/e3sconf/202564801008

2.2 Mix Design

The summary of the mix design for concrete and fresh concrete properties is shown in Table 2 below:

Table 2. Summary of M40 mix design and fresh concrete properties

Ser No.	Constituents	Constituent densities (Kg/cubic meter) and fresh concrete properties	Remarks
1	Cement	431	OPC 53
2	Water	155	W/C ratio = 0.36
3	Fine Aggregate	626	M-sand
4	Coarse Aggregate	1173	Maximum size of 20 mm
5	Admixture	4.31	1% of cement
6	Initial setting time (Minutes)	132	
7	Final setting time (Minutes)	289	
8	Slump (mm)	92	
9	Compaction factor	0.87	

Two grades of steel were employed in the tested columns. The longitudinal reinforcement grade was 550D (yield strength of 550 MPa), and the Indian standard medium weight beam (ISMB) 100 I section-based columns (similar properties to W6 × 8.5 sections in the AISC steel manual) were of steel yield strength 250 MPa. The RCC columns had a clear cover of 20 mm, whereas the ISMB columns had a 50 mm to 62.5 mm cover. The average 28-day concrete compressive strength of 1:3 cement mortar cubes of standard size 150 x 150 x 150 mm was 37 MPa.

3 Results and Discussions

IS 456:2000 is the Indian standard for PCC and RCC design, and there is a need to compare the Indian design provisions with the global design standards. The comparison was made with three important international codes. It was intended to examine the influence of material and load factors on the concrete column capacity per global design philosophies represented by these codes. In this direction, BS 8110, ACI 318, and EN 1994 were chosen for comparison with IS 456 as they represent international standards being followed in structural design projects worldwide. The code comparison also explored the compatibility of the Indian design code with the global design standards, as major design projects involve national and international designers and consultants. Such a comparison will also assist Indian designers in evaluating the need for Indian code revisions, if any.

A comparison of the strength reduction factors of various codes is a prerequisite for the comparison of the column load-carrying capacities as per the respective code provisions. Also, the code comparisons provide a deeper understanding of concrete design methodologies [9]. Four codes, namely, IS 456:2000 [12], BS 8110-1:1997 [13], ACI 318-14 [14], and European Standard code EN 1994-1-1-2004 [15], were considered in this study. A compilation of the four codes considered for the study is as in Table 3 below:

Table 3. Summary of M40 mix design and fresh concrete properties

Ser No.	Code	Concrete strength reduction factor	Steel strength reduction factor
1	IS 456: 2000	1.5 (Sec 36.4.2.1)	1.15 (Sec 36.4.2.1)
2	BS 8110-97	1.5 (Sec 2.4.4.1, Table 2.2)	1.15 (Sec 2.4.4.1, Table 2.2)
3	ACI 318 -2018	None	None
4	EN 1994-1-1-2004	1.5 (Table 2.1N)	1.15 (Table 2.1N)

A cursory assessment of Table 3 above highlighted that the ACI has no strength reduction factors, while the other codes have factors of 1.5 and 1.15 for concrete and steel, respectively. Further, only the ACI code advocated the application of the reduction factors for design moment and axial force strengths. In the case of the other three codes, the reduction factors were applied to the material strengths of concrete and reinforcement steel. Furthermore, ACI 318-18 prescribed a variable strength reduction factor (φ). The net tensile strain in extreme tension reinforcement responds to the variations in this factor [11], and ACI is the only code to do so.

The predicted load-carrying capacities using different design codes were compared with the experimental values of 36 columns in Table 4.

Table 4. Predicted load-carrying capacities of columns based on codes.

Ser No	Code	M40 Column Type	Grade of Steel (fy) Mpa	Load Carrying Capacity Expressions	Load Carrying Capacity as per Code in KN	Average Experimental Ultimate load in KN	The ratio of (Experimental load/Code load)
1	IS 456: 2000 Page 71	PCC	550	$0.4 * (f_{ck} * A_g)$	640	581	0.91
		RCC		$0.4 * (f_{ck} * A_c) + 0.67 * (f_y * A_{sc})$	800	743	0.93
		ISMB Based	250	$0.4 * (f_{ck} * A_c) + 0.67 * (f_y * A_{is})$	861	809	0.94
2	BS 8110-97 Para 3.8.4.1	PCC	550	$0.45 * (f_{ck} * A_g)$	720	581	0.81
		RCC		$0.45 * (f_{ck} * A_c) + 0.75 * (f_y * A_{sc})$	907	743	0.82
		ISMB Based	250	$0.45 * (f_{ck} * A_c) + 0.75 * (f_y * A_{is})$	968	809	0.84
3	ACI 318 - 2018 Para 22.4.2.2	PCC	550	$0.85 * f_c(A_g - A_{st}) + f_y * A_{st}$	1360	581	0.43
		RCC			1593	743	0.47
		ISMB Based	250		1710	809	0.47
4	EN 1994-1-1-2004	PCC	550	$0.85 * (A_c * f_c) + (A_s * f_{ys}) + (A_l * f_{yl})$	1360	581	0.43
		RCC			1593	743	0.47
		ISMB Based	250		1710	809	0.47

Load carrying capacity comparisons. A comparison of the load-carrying capacities of this study's experimental data and various codes for columns is shown in Fig. 4.

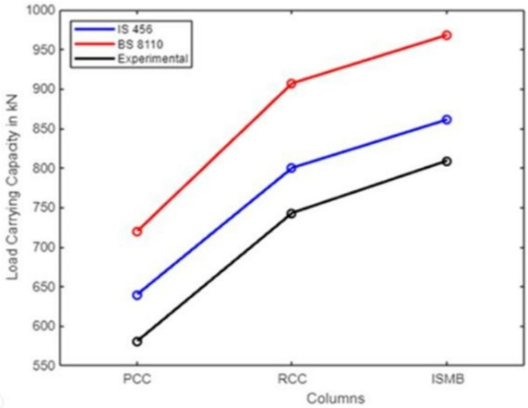

Fig. 4. Load carrying capacities of columns

4 Conclusions

The experimental results of 36 columns of different configurations showed the following trends:

1. The direct comparison of the various codes/standards, such as IS, BS, ACI and EN, for determining the load-carrying capacity of compression-loaded columns is deemed inappropriate, as each of these codes has evolved on different design philosophies and tested using cube and cylinder specimens. Therefore, the partial safety factors stipulated in these code expressions for the load carrying capacities of the columns are different.
2. The experimental results suggest that the load-carrying capacities experimentally determined of the tested columns compare well with the capacities recommended by the IS code and the BS code (Fig. 3). In contrast, the other two codes have vastly different assessments due to higher partial safety factors.
3. Among the codes, the load-carrying capacities of IS 456:2000 were considered conservative compared to those assessed as per the other three codes. This inference aligned with the already reported assessment in [9].
4. IS 456 is generally more conservative for short columns than ACI 318 and BS 8110. ACI 318 uses cylinder specimen-based strength and φ-factors, and this leads to numerically higher load carrying capacities.
5. Eurocode EN 1994 seems more suitable for composite structural design. BS 8110 has similar code provisions to IS 456 and is conservative and more aligned with British construction practices.

References

1. Isleem, H.F.; Abid, M.; Alaloul, W.S.; Shah, M.K.; Zeb, S.; Musarat, M.A.; Javed, M.F.; Aslam, F.; Alabduljabbar, H. Axial Compressive Strength Models of Eccentrically Loaded Rectangular Reinforced Concrete Columns Confined with FRP. Materials 14, 3498 (2021)
2. Buka-Vaivade, K.; Sliseris, J.; Serdjuks, D.; Pakrastins, L.; Vatin, N.I. Rational use of HPSFRC in multi-storey buildings. Mag. Civ. Eng. 84, 3–14 (2018)

3. Ahmad, S.; Hasnain, G. FEA of reinforced concrete beam-column joint with steel fibres for cyclic loading. Int. J. Struct. Integr. 12, 670–687.
4. Li, H.; Xiao, S.; Huo, L. Damage investigation and analysis of engineering structures in the Wenchuan earthquake. J. Build. Struct. 2018, 4, 10–19 (2021)
5. Deierlein, G.; Moehle, J. A Framework Methodology for Performance-Based Earthquake Engineering. In Proceedings of the 13th World Conference on Earthquake Engineering, Vancouver, BC, Canada, 1–6 p. 14 (2004)
6. Lao, X.-C.; Han, X.-L. Performance index limits of high reinforced concrete shear wall components. J. Cent. South Univ. Technol. 18, 1248–1255 (2011)
7. Asghar, R.; Shahzad, A.; Amjad, S.U.; Akhtar, A. Comparative Study on the Seismic Performance of Bare Frame and Infilled Frame RC Structures with Brick Masonry and Low-Strength Concrete Block Masonry Infills. In Proceedings of the 2nd Conference on Sustainability in Civil Engineering CSCE20, Islamabad, Pakistan, 12 August (2020); p. 8.
8. Asghar, R.; Shahzad, A.; Amjad, S.U.; Akhtar, A. Experimental Determination of the Mechanical Properties of Brick Masonry and Low-Strength Concrete Block Masonry. In Proceedings of the 2nd Conference on Sustainability in Civil Engineering CSCE20, Islamabad, Pakistan, 12 August (2020); p.6.
9. Qi, Y.-L.; Han, X.-L.; Ji, J. Failure mode classification of reinforced concrete column using Fisher method. J. Cent. South Univ. 2013, 20, 2863–2869.
10. Acun, B.; Sucuoğlu, H. The effect of displacement history on the performance of concrete columns in flexure. In Advances in Performance-Based Earthquake Engineering; Springer: Dordrecht, The Netherlands, 2010; pp. 373–382.
11. Mahamid, Mustafa, et al. "Comparison of Provisions for Non-slender Reinforced Concrete Columns: American Concrete Institution, Eurocode, Indian Standard, and Canadian Standards Association." Practice Periodical on Structural Design and Construction 27.4, 04022041 (2022).
12. Indian Standard Plain and Reinforced Concrete - Code of Practice, IS 456: 2000.
13. Structural use of concrete — Part 1: Code of practice for design and construction, BS 8110- 1: 1997.
14. ACI-318(American Concrete Institute), Building code requirements for reinforced concrete. Detroit (MI): American Concrete Institute; (2019)
15. Eurocode 4. Design of composite steel and concrete structures, Part 1-1: general rules and rules for building, Brussels: EN 1994-1-1:2004. European Committee for Standardization (2004)