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Impact of Strong Column Weak Beam for a Six-Story Residential Building According to Indian Code

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***Abstract:** Ductile design and detailing provisions were revised in 2016 by the Bureau of Indian Standards. It introduced Strong Column Weak Beam Provision (SCWB) for beam-column joint. In this paper, an attempt is done to investigate the influence of SCWB provision on the Longitudinal Rebar Quantity (LRQ) of typical columns i.e. Corner Column, Edge Column, and Middle Column on seismic Zones III, IV, and V for six-story buildings. Story-wise variation reached a maximum from 100% to 200% in the 4th and 5th story whereas overall variation was observed from around 50% to 80% in LRQ of the column while considering SCWB over the conventional technique of column design. Finally, the study concludes that the requirement for design strength ratio i.e. Beam column capacity ratio ($\sum M_c \geq 1.4 \sum M_b$) has resulted in excessive quantity of rebar and thereby increasing its cost specifically for the residential buildings and apartments of smaller heights.*

***Keywords:** Strong Column-Weak Beam, Longitudinal Rebar Quantity, Ductile Design and Detailing, Typical Column*

I. INTRODUCTION

There appears to be no justification for using the ratio 1.4 instead of 1.2 for the beam-column capacity ratio, and it is unnecessary prescriptive over strength without any rationale [1]. Current Ductile detailing provisions of the Indian code is obsolete and important issues like strong column and weak beam and joint shear design are ignored [2]**.** The SMRF design under the current design provisions of Indian standards has a higher probability of damage, as compared with the Ordinary Moment-Resisting Frame design, because of the higher allowable ultimate drift limit was found that the SMRF design under the current design provisions of Indian standards has a higher probability of damage, as compared with the Ordinary Moment-Resisting Frame design, because of the higher allowable ultimate drift limit [3]. Adequate anchorage and confinement of bars in joint of special moment resisting frame is necessary to prevent brittle failure of joint under seismic loading.

The design and detailing of the beam-column joint is inadequate in IS 13920: 1993as it does not address anchorage and shear failure in this region. So the ratio of 1.1 i.e $\sum M_c \geq 1.1 \sum M_b$ is proposed [4]. Building with SCWB design has more Strength and ductility than Weak Column strong beam (WCSB) design also the failure mechanism exhibits inelasticity in WCSB design [9]. Reinforced beam-column joint should be designed such that column should be elastic while inelasticity should be confined to beams. To satisfy the condition beam-column joint should be designed as $\sum M_c \geq 1.2 \sum M_b$ [10].

Strong Column Weak Beam provision was introduced only on the 2016 revision of Ductile Design and Detailing Code of practice which explicitly recommends for a moment of resistance of column to be greater or equal to 1.4 times that of beam i.e. $\sum M_c \geq 1.4 \sum M_b$ [5]. Whereas 1993 revision was silent and no recommendation was given for the same [6]. The sum of the moment of resistance of the columns should be at least 20% more than the sum of moment of resistance of beams [7]. On the contrary, the sum of the design flexural strength of the column is at least 40% above the strength of adjacent beams at the joint [8].

II. BUILDING CONFIGURATION

A six-story residential RC framed apartment building with discontinuity of slab diaphragm and several re-entrant corners having the plinth area of 29m × 21m and building height of 20m is the subject under consideration. The dimensions of structural members are fixed so that the rebar percentage stays within the upper limit while considering the SCWB (Strong Column Weak Beam) action and above the minimum percentage while the effect is not considered.

Three critical columns namely Corner Column (CC), Edge Column (EC), and Middle Column (MC) are considered as shown in Figure 1, for the analysis and comparison of the effect on three seismic Zones III, IV, and V where Special Moment Resisting Frame (SMRF) must be used as per ductile detailing provisions in **IS 13920: 2016**.

Grade of concrete: M25

Size of beam: 300mm x 600mm

Size of Column: 450 mm x 600mm

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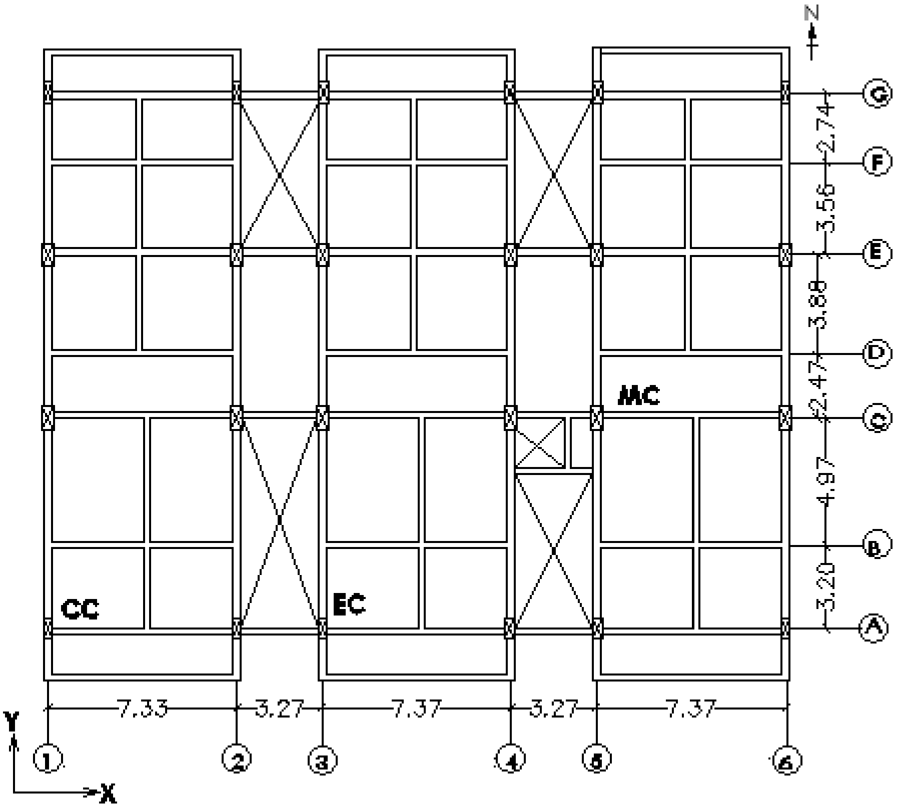

Figure 1 Typical Beam layout of Building (All Dimensions are in Meter)

III. PROBLEM STATEMENT

Beam-column joint of special moment-resisting frame in the seismic region should be designed properly such that, upon elastic failure, the failure is confined to the beam alone. Hence, to address this, new provision of Strong Colum Weak Beam was introduced. The provision demands for design strength of column to be at least 1.4 times to that of the beam in a principal plane. So the impact on quantities of rebar brought by factor 1.4 in terms of longitudinal rebar of the column needs to be re-evaluated. This results in column strength to be increased based on beam strength or moment capacity of the beam. For a beam column joint with beam of 300 x 600mm and column with axial load of 800 kN of dimension 300 x 600mm an example is demonstrated as

If Assuming p = 1.6% and d′ / d = 0.1 from Table 51 of **SP-16**

$Mu/bd^3 = 4.70$ for doubly-reinforced section

hogging moment capacity Mu = 4.77 (300) (545) (545) = **425.04** kNm.

For the sagging moment capacity

from Table 3 of SP-16

$Mu / bd^2 = 2.503$ for p = 0.8%.

Mu = 2.503 (300) (545) (545) = 223.04 kNm. Therefore,

Σ Mbeam = 425.04 + 223.04 = **648.08** kNm

Now for a column of 300 x 600mm

Pu = 1.5 x 800 = 1200 kN

Pu/f_{ck} bD = 1200/ (25x 300x 600) = 0.26 and p = 2% from Chart 48 of SP-16

$Mu/fck\ bD^2 = 0.22$

Column moment $M_u = 0.14 \times 25 \times 300 \times 600^2 = 378$ kNm

Σ Mcolumn = 2 x 378 = **756** kNm as column is continuous upward from the joint

Now for comparision

1.15ΣMbeam = ΣMcolumn which already ensures the moment capacity of the column is greater in the joint than that of the column. But as per the requirement moment capacity of the column should be 1.4 x ΣMbeam = 1.4 x 648.08 = 907 kN-m for which the rebar percentage of the column needs to be increased. So in this paper, an attempt is done to investigate the additional requirement of the rebar in the column. Initially, the analysis and design are carried out normally, and afterward, the design following SCWB criteria is carried out and the rebar quantity and percentage are compared. ETABS is used for the analysis of the building in all the zones. Response spectrum analysis is carried out for the linear dynamic analysis as the building contains discontinuities in the slab- diaphragm and there is the presence of a re-entrant corner.

IV. RESULTS AND DISCUSSION

The building was analyzed twice for each zone both considering SCWB (denoted by ‘SCWB’) and without considering (denoted by ‘NSCWB’) and the result is presented in terms of the requirement of Longitudinal Rebar Quantity on typical columns. Response spectrum analysis was conducted as the linear dynamic seismic analysis. Relative Strength of Beams and Columns at a joint is specified such that the moment of resistance of column in a joint must be 1.4 times that of the beams meeting at that principle plane. Graphs are plotted as Story height v/s Longitudinal Rebar Quantity (LBR) in mm^2 to show the height-wise variation as shown in Figures 2,3 and 4.

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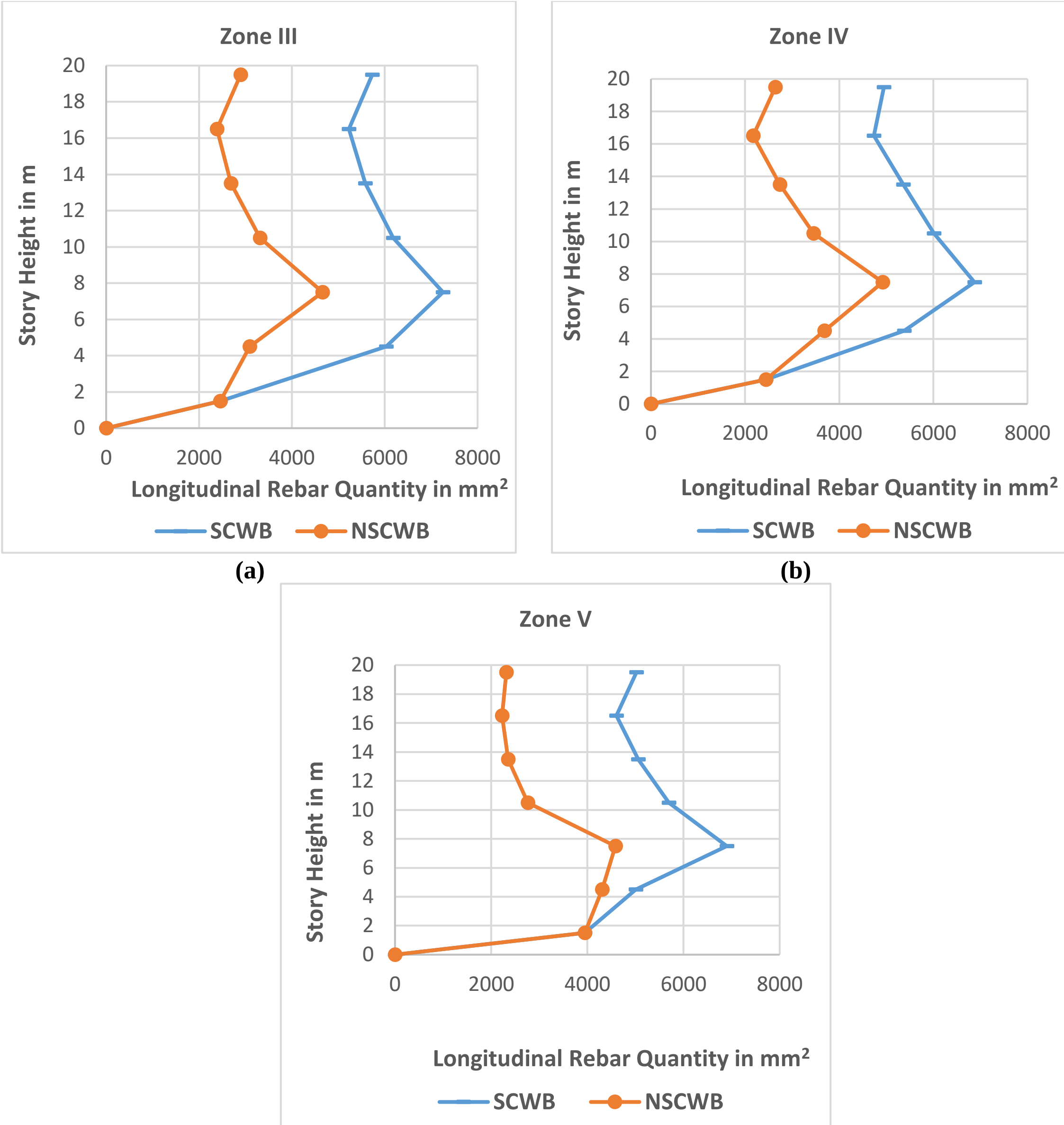
A. Corner Column (CC)



(a) (b)

(c)

Figure 2: Longitudinal Rebar Quantity in CC

It can be predicted from Figure 2 that the variation obtained on Longitudinal Rebar Quantity in Corner Column in all zones shows a similar pattern in all zones. Similar LRQ was obtained in the base story as the governing load is gravity load and not lateral loads. The percentage variation on LBR in columns in each story is obtained and shown in Table I. It can be depicted from Table I that increment in LBR is maximum with 118.9% and 118% in 5th story for Zones III and IV whereas the maximum variation of 115% is obtained in Zone V for 4th story.

Table I: LRQ Variation In All Zones For Cc

Story	Zone III LRQ (mm^2)		Increment	Zone IV LRQ (mm^2)		Increment	Zone V LRQ (mm^2)		Increment
	SCWB	NSCWB		SCWB	NSCWB		SCWB	NSCWB	
Story6	5733	2899	97.8%	4952	2642	87.4%	5018	2316	116.7%
Story5	5232	2390	118.9%	4738	2173	118.0%	4603	2230	106.4%
Story4	5581	2688	107.6%	5361	2737	95.9%	5061	2354	115.0%
Story3	6181	3317	86.3%	6013	3454	74.1%	5699	2766	106.0%
Story2	7255	4663	55.6%	6874	4925	39.6%	6900	4583	50.6%
Story1	6035	3091	95.2%	5383	3686	46.0%	5011	4310	16.3%
Base	2462	2462	0.0%	2443	2443	0.0%	3946	3946	0.0%

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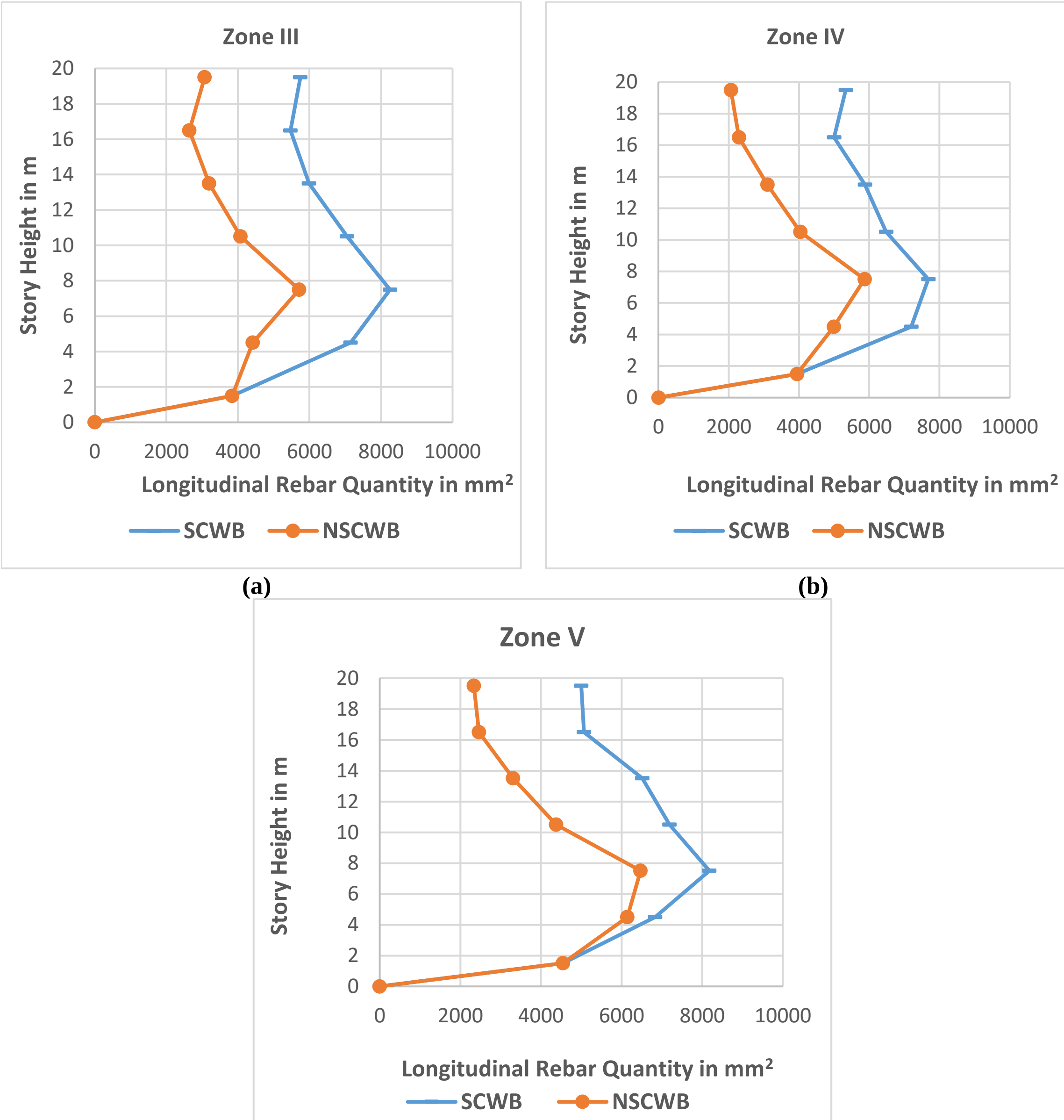
B. Edge Column (EC)

It is evident from Figure 3 that the pattern of variation in the LRQ in Edge Column shows a consistent increment from base to the top in all Zones with maximum variation in the 5th story ignoring the difference in 6th or top story (as top story is liable to obtain maximum because the moment of resistance is contributed only by a column in joint as there is no succeeding column upward). Also, from Table II it can be illustrated that the SCWB effect causes the rise of rebar quantity by 107%, 118.3%, and 105.6% respectively for Zones III, IV, and V in the 5th story.

Table II: LRQ variation in all Zones for EC

Story	Zone III LRQ (mm^2)		Increment	Zone IV LRQ (mm^2)		Increment	Zone V LRQ (mm^2)		Increment
	SCWB	NSCWB		SCWB	NSCWB		SCWB	NSCWB	
Story6	5742	3070	87.00%	5332	2065	158.20%	4998	2336	114.00%
Story5	5473	2644	107.00%	5002	2291	118.30%	5069	2466	105.60%
Story4	5988	3198	87.20%	5876	3098	89.70%	6514	3308	96.90%
Story3	7052	4077	73.00%	6485	4039	60.60%	7194	4374	64.50%
Story2	8252	5711	44.50%	7681	5867	30.90%	8180	6472	26.40%
Story1	7154	4412	62.10%	7195	4992	44.10%	6836	6143	11.30%
Base	3836	3836	0.00%	3941	3941	0.00%	4545	4545	0.00%



(c)

Figure 3: Longitudinal Rebar Quantity in EC

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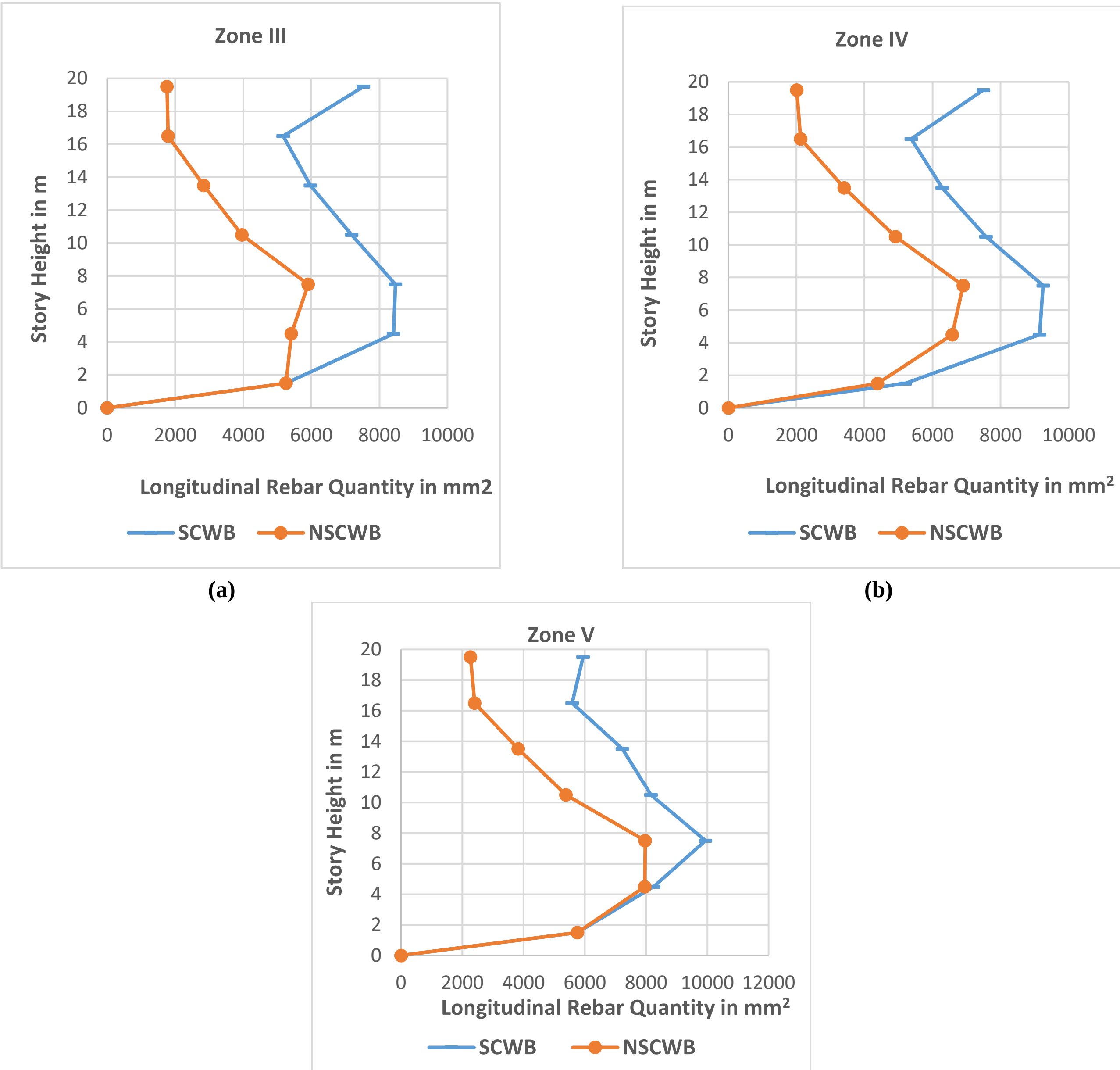
C. Middle Column (MC)

Comparision for the Longitudinal Rebar Quantity (LRQ) for the middle column is shown in Figure 4 and the percentage increment in LRQ with and without consideration of SCWB is compared in Table III. The distinctive difference can be noticed in Zones III and IV from the 2nd story onwards while in Zone V the difference is observed from the 3rd story and the constant variation can be witnessed in all Zones in Figure 4. Furthermore, if the top story is ignored for the above-mentioned reason, consideration of SCWB provision has a greater impact on Zone III with a maximum difference of 188.5% followed by 152.6% in Zone IV and 132.2% in Zone V as shown in Table III.

Table III: LRQ variation in all Zones for MC

Story	Zone III		Increment	Zone IV		Increment	Zone V		Increment
	LRQ (mm2)			LRQ (mm2)			LRQ (mm2)		
	SCWB	NSCWB		SCWB	NSCWB		SCWB	NSCWB	
Story6	7534	1758	328.6%	7498	2012	272.7%	5948	2265	162.6%
Story5	5173	1793	188.5%	5372	2127	152.6%	5584	2405	132.2%
Story4	5975	2838	110.5%	6286	3405	84.6%	7229	3824	89.0%
Story3	7183	3960	81.4%	7566	4913	54.0%	8161	5383	51.6%
Story2	8470	5908	43.4%	9251	6900	34.1%	9941	7973	24.7%
Story1	8419	5413	55.5%	9148	6576	39.1%	8244	7959	3.6%
Base	5255	5252	0.1%	5197	4383	18.6%	5758	5758	0.0%



(a) (b)

(c)

Figure 4: Longitudinal Rebar Quantity in MC

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D. Overall Quantity

After the individual comparison of LRQ in each story, total quantity for a column from top to base is evaluated and presented in Table IV. It is seen that Corner and Middle columns bear greater demand for LRQ than Edge columns in Zone III and Zone IV. Whereas, Corner Column's demand is much greater than both Edge and Middle Columns in Zone V while considering the SCWB effect.

Table IV: Overall LRQ for an Individual Column

	Corner Column (CC)		% incr	Edge Column (EC)		% incr	Middle Column (MC)		% increase
	SCWB	NSCWB		SCWB	NSCWB		SCWB	NSCWB	
Zone III	38479	21510	78.9	43497	26948	61.4	48009	26922	78.3
Zone IV	35764	22060	62.1	41512	26293	57.9	50318	30316	66.0
Zone V	36238	22505	61.0	43336	29644	46.2	50865	35567	43.0

V. RESULTS

1. Demand for LRQ in Corner Column is up to a maximum of 115% to 120% because of SCWB with the greatest demand being in Zone IV.
2. In Edge Column 105% to 120% maximum variation is observed because of SCWB for which the highest effect is seen again in Zone IV.
3. An extreme increment of about 130% to 190% is noticed in Middle Column that showed maximum demand in Zone III.
4. Overall Quantity of Longitudinal rebar in all typical Columns are maximum in Zone III and least in Zone V.
5. Strong Column Weak beam provision demands for more than about 50% to 80% rebar in total columns of the building whereas claims more than 100% LRQ from 4^{th} story onwards.

VI. CONCLUSION

The Strong Column Weak Beam (SCWB) provision specified in IS 13920: 2016 for the relative strength of beam and column at a joint that requires nominal design strength of column to be 1.4 times the sum of nominal design strength of beam on that principal plane, demands for excessive steel requirement. Thus to economize the design, the provision can be revised diminishing the multiplicative factor of 1.4 to lesser values while ensuring the beam hinge mechanism instead of story hinge in critical earthquake-shaking.

DECALARION

Funding/ Grants/ Financial Support	No, I did not receive.
Conflicts of Interest/ Competing Interests	No conflicts of interest to the best of our knowledge.
Ethical Approval and Consent to Participate	No, the article does not require ethical approval and consent to participate with evidence.
Availability of Data and Material/ Data Access Statement	Not relevant.
Authors Contributions	I am only the sole author of the article.

REFERENCES

1. Ashok K. Jain, A critical review of IS 13920: 2016, I.A.S.E. Conference on *Planning & Design of Tall Building including Earthquake and Wind Effects*, Dec 6-7, 2016, New Delhi
2. Vijay Namdev Khose, Yogendra Singh and Dominik H. Lang., *Limitations of Indian Seismic Design Codes for RC Buildings*, 14th Symposium on Earthquake Engineering, IIT Roorkee, December 2010, Proceedings pp. 1417-1423.
3. Putul Haldar and Yogendra Singh., *Seismic Performance and Vulnerability of Indian Code-designed RC Frame Buildings*, ISET Journal of Earthquake Technology, March 2009, Vol. 46, Paper No. 502, pp. 29-45.
4. Sudhir K. Jain, R.K. Ingle and Goutam Mondal, *Proposed codal provisions for design and detailing of beam-column joints in seismic regions*, The Indian Concrete Journal, August 2006.
5. *Indian Standard Ductile Design and Detailing of Reinforced Concrete Structures Subjected to Seismic Forces- Code of Practice*, IS 13920: 2016, Bureau of Indian Standards, New Delhi
6. *Indian Standard Ductile Design and Detailing of Reinforced Concrete Structures Subjected to Seismic Forces- Code of Practice*, IS 13920: 1993. Bureau of Indian Standards, New Delhi
7. *ACI 318, Building Code Requirements for Reinforced Concrete and Commentary*, American Concrete Institute, 2002.
8. *NZS 3102: Part 1, Concrete Structure Standard, Published by Standard Council*, New Zealand, 1995.
9. C. V. R. Murty, Rupen Goswami, A.R. Vijayanarayanan, Vipul V. Mehta, Some Concepts in Earthquake Behaviour of Buildings, Gujrat State Disaster Management Authority,2012.
10. Ductile Design and Detailing of Earthquake Resistant Structures, Lesson 42, Version 2 CE IIT, Kharagpur.

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