Journal of Civil Engineering and Environmental Technology
Print ISSN: 2349-8404; Online ISSN: 2349-879X; Volume 2, Number 4; April-June, 2015 pp. 304-308

http://www.krishisanskriti.org/jceet.html

A STUDY ON CODAL PROVISIONS APPLIED TO RCC STRUCTURES: NEED FOR DEVELOPMENT OF COMMON CODAL PROVISIONS

Ankita Suman Mohanty[1] and Aloke Kumar Datta[2]

[1]PG Student, Department of Civil Engineering NIT Durgapur, India-713209
[2]Department of Civil Engineering NIT Durgapur, India-713209
E-mail: [1]ankitasumanmohanty@gmail.com, [2]dattarec@yahoo.comAbstract

Abstract—*The need to modify codes arises from factors like unprecedented growth of knowledge, developments in design philosophy, and rapid advances in construction technology. The intent of this paper is to highlight the urgency and necessity of developing the 'Uniform Code' for structural concrete and to inform readers about the efforts being made by various technocrats worldwide in this respect. Different countries have different codes for Reinforced Cement Concrete (RCC) structures but it should be obvious that the practices in any country should remain more or less in line with the international developments, without any country lagging too much behind, or following a totally different path. In this research, a comparative study on the amount of required flexural reinforcements was conducted using Indian Standard (IS), British Standards Institution (BS), European Standard (EC2), and American Concrete Institute (ACI). The comparison included design case of rectangular beam subjected to bending for different spans and loads on the beam. It was found that EC2 require less reinforcement as compared to the other codes. The study showed that the difference is due to the variation of load safety factors for different codes. . In addition the comparison included, combined action of shear and flexure for the reinforced concrete beams. With the increasing M_u/V_u ratio the difference increases up to 60% for shear reinforcement and 20% for flexure reinforcement proposing EC2 requires lesser area as compared to other codes.*

1. INTRODUCTION

There are about 200 countries in this world with variety of geography, topography and climatic conditions. Some of the countries are developed and some are still developing, some have their own and some are depended on other countries for the code of practice. There is a rapid progress nowadays in the development of codes which is a challenge for the technocrats to combine the advancement of knowledge and unify it with the codes to form a better technology that can be utilised with its simplicity and sophistication. Diversity of codal provisions for countries worldwide is a tough challenge to be faced when one moves from one part to another and adapting to it is rather another difficulty to be faced by the engineers. The codes differ on the basis of design equations, load safety factors for material and loads etc. For simplification it is necessary to form uniform guidelines for the concrete codes which can be appropriate in terms of safety, economy and suitability to the environment for countries worldwide. Knowledge of main features of and differences of various code of practice is deemed a necessity for the formation of uniform guidelines throughout the world.

2. LITERATURE REVIEW

Present scenario reveals that technology and its application has no boundary or cannot be country specific. Because of this researchers and technocrat are trying to make the thing easy implementable and accessible irrespective of boundary and locations. In this regard few developments on codal provisions and their implications in research are addressed here.

Tiejiong et al. (2014)[1] investigated on the redistribution of moments in normal strength concrete and high strength concrete using Canadian code, EC2 and ACI and found that codes worldwide do not have specific rules for High strength concrete beams except for the European code. The study proved Canadian code to be better than EC2 to predict the redistribution of moments. The study revealed that ACI and Canadian codes fail to reflect the actual effect of concrete strength at a low steel ratio level however EC2 is non-conservative at a low steel ratio but is over conservative at a high steel ratio level.

Rao and Injaganeri (2013)[2] carried out an experimental study for the evaluation of minimum shear reinforcement in reinforced concrete beams using ACI 318, IS, BS, Canadian code and American Association of State Highway and Transportation Officials (AASHTO). The study revealed that minimum shear reinforcement varies with the compressive strength of concrete as per ACI 318, Canadian code and American Association of State Highway and Transportation Officials(AASHTO)but as per IS and BS code it varies with the yield strength of shear reinforcement.

Ali et al. (2012)[3] made a comparative study on the amount of reinforcements required in a rectangular beam subjected to combined loads using ACI code and BS code. The research reveals that amount of reinforcement required using BS code was less than ACI code when factor of safety was not included. Keeping safety criteria into consideration excess reinforcement may be uneconomical. The research was also extended to flat slab-columns and found out that the punching shear strength and flexural reinforcement is more using ACI code while shear reinforcement is more using BS. The paper concludes that BS code is preferred over ACI for lower reinforcement requirements.

Bernado and Lopes(2012)[4] found that ACI code is the most appropriate to ensure some ductile behaviour by limiting the amount of torsional reinforcement after studying American, Canadian and European codes.ACI imposes a maximum and minimum value for the reinforcement ratio.

Ameli and Ronagh (2007) [5]reviewed the provisions of the current standards in relation to torsion of reinforced concrete beams and found that except for ACI all other standards such as EC2, Canadian code and Australian code had predicted the torsional capacities conservatively. The paper revealed that EC2 and Canadian code were more successful in predicting the ultimate torques compared to other standards. The paper concluded that Australian standard was the least deviated and its conservativeness can be trusted more confidently as compared to others.

Chee Khoon Ng et al. (2006)[6] compared BS 8110 and EC2 taking into account both concrete cube strength and cylinder strength for beams reinforced with mild steel or high yield steel and found similar values. The slight differences are due to steel reinforcement provisions and concluded that either of the codes can be used.

N.Subramanian (2005)[7] analysed punching shear strength of high strength concrete according to IS 456,ACI 318,Australian code, BS 8110,EC2 and CEB-FIP M90 code and suggests revision of IS provisions according to CEB-FIP M90 provisions to get consistent results for normal and high strength concrete as CEB-FIP code considers size effect and contribution of reinforcement ratio.

Based on the literature review it is clear that numerous researcher have worked on various provision of codes. However the comparisons were limited to few provisions and codes. No study was found in the literature review which has the purpose of forming uniform guidelines for concrete codes worldwide. In this research, an intensive comparison work was carried out to find out the effects of design results on the amount of flexural reinforcement as well as comparative study for the flexure and shear reinforcements are carried out for a single span rectangular reinforced concrete beams using IS, BS, EC2 and ACI codes Effect of load safety factor was taken into consideration and recommendation for the formation of uniform code is presented.

3. DESIGN EQUATIONS

3.1 Flexure

The design procedures in IS 456:2000,BS 8110:97,EC2,ACI 318:08 are based on the simplified rectangular stress block as given in IS 456:2000-38.1,BS 8110:97-3.4.4,EC2-3.1.7,ACI 318:08-10.3.4 respectively.

The area of required flexural reinforcement can be calculated from the equation of moment of resistance as given by IS 456:2000(Annex G-1.1(b))[12]-

$$M_u = 0.87 f_y A_{st} d \left(1 - \frac{A_{St} f_y}{b d f_{ck}}\right)$$

As per BS 8110:97 (clause 3.4.4.4)[11] the area of required reinforcement is given by:

$$A_s = \frac{M_u}{0 \cdot 95 f_y z}$$

Where

$$z = d\left(0 \cdot 5 + \sqrt{0.25 - \frac{K}{0 \cdot 9}}\right) \leq 0.95d$$

And

$$K = M_u \; f \quad f_{cu} b d^2$$

As per EC 2 (clause 3.1.7)[13] the area of required reinforcement is given by:

$$A_S = \frac{M}{f_{yd} z}$$

Where

$$z = \frac{d}{2}\left[1 + \sqrt{1 - 3 \cdot 53K}\right]$$

And

$$K = \frac{M}{b d^2 f_{ck}}$$

As per ACI 318:08(clause 10.3.4)[8] the area of required reinforcement is given by:

$$A_s = \frac{M_u}{\phi f_y \left(d - \frac{a}{2}\right)}$$

Where

$$a = d - \sqrt{d^2 - \frac{2M_u}{0\cdot 85 f_c^{'} \phi b}}$$

3.2 Shear

The nominal shear stress in a beam can be calculated from IS456:2000(clause 40.1)[12] from the following equation:

$$\tau_v = \frac{V_u}{bd}$$

The design of shear reinforcement a beam using vertical stirrups can be calculated from IS456:2000(clause 40.4)[12] from the following equation:

$$V_{us} = \frac{0.87 f_y A_{sv} d}{s_v}$$

As per BS 8110-1-1997(clause 3.4.5.2)[11] the design shear stress υ at any cross section from the following equation:

$$\upsilon = \frac{V}{b_v d}$$

As per table 3.8 BS 8110:97[11] the design concrete shear stress υ_c is given by:

$$\upsilon_c = 0.79\left\{100A_s / \left(b_v d\right)\right\}^{1/3} \left(400/d\right)^{1/4} / \gamma_m$$

with the following limitation: γ_m =1.25, 0.15 $\leq$ 100 A_s/bd $\leq$3, 400/ d $\geq$1 and $f_{cu} \leq 40$ N/mm^2.

According to table 3.7 BS 8110:97[11] the area of shear reinforcement is given as follows:

If υ<0.5 υ_c then area required is zero.

If 0.5 $\upsilon_c < \upsilon < \upsilon_c$ +0.4 then area required is

then area required is $A_{sv} \geq 0.4 b_v s_v / 0.87 f_{yv}$

If υ_c +0.4< υ <0.8 $\sqrt{f_{cu}}$ or 5 N/mm^2 then area required is

$$A_{sv} \geq b_v s_v \left(\upsilon - \upsilon_c\right) / 0.87 f_{yv}$$

According to EN 1992-1-1(clause 6.2.3)[13] the design shear stress is given by:

$$v_{Ed} = V_{Ed} / \left(b_w 0.9d\right)$$

And the area of shear reinforcement is given by:

$$A_{sw}/s = v_{Ed} b_w / \left(f_{ywd} \cot\theta\right)$$

As per ACI 318:08(clause 11.2.2.1)[8] the concrete shear strength υ_c in a beam is calculated as-

$$\upsilon_c = \min of \left\{\left(0.16\sqrt{f_c^{'}} + 17\rho\frac{V_u d}{M_u}\right), \left(0.29\sqrt{f_c^{'}}\right)\right\}$$

Where $f_c^{'} \leq$70 N/mm^2 and $V_u d / M_u \leq 1$

$$\frac{A_{sv}}{s} = \begin{bmatrix} 0\, for V_u < \dfrac{\phi V_c}{2} \\ \dfrac{0.062\sqrt{f_c^{'}} b}{f_y} > \dfrac{0.35bs}{f_y}\; for\; \dfrac{\phi V_c}{2} \leq V_u \leq \phi V_c \\ \dfrac{V_u - \phi V_c}{\phi d f_y}\, for V_u \geq \phi V_c \end{bmatrix}$$

4. DESIGN RESULTS AND DISCUSSIONS

The design results of rectangular beams with different load combinations and span to depth ratios are presented. The IS 456:2000, BS 8110:97, EC2 and ACI318:08 codes were used in the design. The characteristic cube compressive concrete strength was 30N/mm^2 and cylinder compressive strength was 24N/mm^2 with concrete density of 24 KN/m^3. The characteristic yield strength was 500N/mm^2 for IS 456:2000 and EC2, 460 N/mm^2 for ACI 318:08 and BS 8110:9.Table 1 and 2 show the design results for bending moment of three groups of simply supported beams ..In beam numbering, the first letter denotes the type of member considered, e. g B means beam; the second letter denotes the variable, e.g., R means span/depth ratio; the third letter denotes the type of loading, e.g., W means uniformly distributed load. The first numeral represents R and second denotes W. The beam cross sectional dimension considered was selected as 350 $\times$ 700 mm with an effective depth of 625 mm. For table 1 the dead load considered was the self-weight of the beam=0.3 $\times$ 0.7 $\times$ 24=5.88 KN/m which remains constant for all the beams and the live load values were varied from 20 to 30 KN/m. For table 2 the live load considered was 5.88 KN/m which remains constant for all the beams and the dead load values were varied from 20 to 30 KN/m. The difference in the factor of safety for the live load among all the codes resulted in the larger bending moments in IS code as compared to the other codes. Table 3 and 4 show the design results for bending moment and shear force of three groups of simply supported reinforced concrete beams. Span/depth ratios are varied to get variation in M_u/V_u. As M_u/V_u ratio increases the differences for flexural and shear reinforcements become more pronounced reaching up to 20% in case of flexural reinforcement and up to 60% in case of shear reinforcement and differences are evaluated taking IS code as the reference. But as the loads are increased EC2 gives lesser value for both flexural and shear reinforcements as compared to other codes.

Table 1: Parametric study to compare steel required for bending using DL+LL (LL is varied)

Beam Number	Ultimate Design UDL(KN/m)				Ultimate Design Moment at mid span Mu(KN m)				Flexural Reinforcement(mm2)			
	IS	BS	EC2	ACI	IS	BS	EC2	ACI	IS	BS	EC2	ACI
BR6.4 W20	38.82	40.23	37.93	39.05	77.64	80.46	75.57	78.1	292.07	301.30 (-3.16 %)	282.65 (3.22%)	306.68 (-5%)
BR8 W25	46.32	48.23	45.43	47.05	149.75	150.72	141.99	147.03	576.09	576.43 (-0.05%)	539.27 (6.39%)	585.92 (-1.7%)
BR9.6 W30	53.82	56.23	52.93	55.05	242.19	253.03	238.18	247.72	961.28	1000.5 (-4.07%)	926.25 (3.64%)	1009.96 (-5.06%)

Table 2: Parametric study to compare steel required for bending using DL+LL (DL is varied)

Beam Number	Ultimate Design UDL(KN/m)				Ultimate Design Moment at mid span Mu(KN m)				Flexural Reinforcement(mm2)			
	IS	BS	EC2	ACI	IS	BS	EC2	ACI	IS	BS	EC2	ACI
BR6.4 W20	38.82	37.40	35.82	33.40	77.64	74.8	71.64	66.8	292.07	279.65 (4.25%)	267.69 (8.34%)	261.69 (10.4%)
BR8 W25	46.32	44.40	42.57	39.40	149.75	138.75	133.03	123.125	576.09	528.69 (8.22%)	504.17 (12.48%)	488.12 (15.27%)
BR9.6 W30	53.82	51.40	49.32	45.40	242.19	231.30	221.94	204.3	961.28	907.84 (5.55%)	859.55 (10.58%)	824.61 (14.21%)

Table 3: Simply supported beams with udl 100KN/m

Span	MU at midspan (KNm)	VU at d from support (KN)	MU/ VU	AS (mm2)				Difference (%)		
				IS	BS	EC2	ACI	BS	EC2	ACI
7	612.5	287.5	2.13	2888.59	2838.84	2669.84	2759.67	1.72	7.57	4.46
7.5	703.12	312.5	2.24	3542.09	3460.25	3176.39	3267.72	2.31	10.32	7.74
8	800	337.5	2.37	4453.94	4292.11	3777.05	3859.53	3.63	15.19	13.34

ASV/s at support (mm2/mm)				Difference (%)		
IS	BS	EC2	ACI	BS	EC2	ACI
0.675	0.827	0.569	0.969	-22.51	15.7	-43.55
0.735	0.887	0.612	1.078	-20.68	16.73	-46.67
0.763	0.941	0.653	1.187	-23.32	14.41	-55.57

Table 4: Simply supported beams with udl 140KN/m

Span	MU at midspan (KNm)	VU at d from support (KN)	MU/ VU	AS (mm2)				Difference (%)		
				IS	BS	EC2	ACI	BS	EC2	ACI
6	630	332.5	1.89	3005.43	2950.93	2764.20	2854.84	1.81	8.02	5.01
6.5	739.37	367.5	2.01	3847.19	3744.50	3392.94	3482.56	2.66	11.80	9.47
7	857.5	402.5	2.13	5270.12	4959.42	4172.39	4241.04	5.89	20.81	19.52

ASV/s at support (mm2/mm)				Difference (%)		
IS	BS	EC2	ACI	BS	EC2	ACI
0.93	1.099	0.685	1.28	-18.17	26.34	-37.63
1.029	1.191	0.743	1.435	-15.74	27.79	-39.45
1.071	1.269	0.798	1.587	-18.48	25.49	-48.17

5. Concluding Remarks

Based on the results of this work it was found that for flexural reinforcement EC2 has the least area as compared to the other codes when live load was varied and dead load was kept constant. On the other side when live load was kept constant and dead load was varied ACI was found to have the least area as compared to the other codes. The variation of results is due to the difference in load safety factors of various code of practice. For the combined action of bending moment and shear force the value for flexural and shear reinforcements shows a diverging difference among all the codes of practice. It was found that as the loads are increased EC2 gives more economical value for both flexural and shear reinforcements as compared to other codes. Hence, it is not easy to give preference among the codes but still if uniform guidelines for reinforced concrete codes are framed considering safety and economy of a structure it would be very helpful for people worldwide inculcating the modern technological advancements and eliminating the ethics of particular country dominancy. However, as the technology is advancing day by day technocrat are trying to make the thing easy implementable and accessible irrespective of boundary and locations. To make this possible the knowledge of design of various codes different provisions will be taken into account and among them the best provisions will be considered thereof. This will reduce the discrepancies between the design, standards, specifications, materials diversity across the world and hence unification of codes will lead to better technological improvements as it will be not any boundary specific.

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