Experimental Investigation on Evaluation of Minimum Flexural Reinforcement in RC Beams

Syed jakeer hussain, P.Poluraju

Abstract: ***Generally Reinforced concrete (RC)beams are designed with different percentages of flexural reinforcement depending on capacity demand. The amount of reinforcement provided effects the behavior i.e. crack propagation and failure process in RC beam. Minimum reinforcement ratios for RC beams should provide enough ductility after loss of tensile stress in concrete due to cracking. In this present study experimental work has carried out to understand behavior of RC beam. This study has carried out by varying different percentages of tension reinforcement i.e. 0.25%, 0.37%, 0.39%, 0.50%, 0.59%, 0.79%. with size 2200mm × 150mm × 300mm. The beams were tested under four-point loading with loading frame (force controlled). The behavior of RC beams was assessed through load-deflection curve, flexural strength, ductility resulted from four point bending test. From experimental study it has been observed that flexural cracking strength is size dependent.***

Index Terms: fracture mechanics, four-point bending, flexural cracking strength, minimum reinforcement, size effect.

I. INTRODUCTION

Concrete beams are provided with steel reinforcement to bear tensile stresses. The percentage of steel reinforcement provided control the behavior and failure process in reinforced concrete (RC) beam. The failure can be of steel yielding followed by crushing of concrete in case of under reinforced beams and crushing of concrete in case of over reinforced beams. While designing reinforced concrete (RC)beam, minimum ductility needs to be assured to perform satisfactorily. This can be attain by providing sufficient quantity of tensile reinforcement. If beam is provided with less amount of steel than required, the failure turn to brittle. Minimum reinforcement in reinforced concrete (RC)beam should prevent brittle failure and must give proper warning before failure. For a reinforced concrete (RC)beams Assume if the beam is provided with less area of steel reinforcement than required then failure tends to brittle. This stimulates instability in overall response of beam. Prior to concrete cracking the load deflection response of PCC beam and RC beam is same. If ultimate strength generated with the reinforcement provided is less than the flexural cracking strength ($\rho<\rho min$). This will create immediate crack growth and leads to brittle failure. Therefore, certain amount of minimum tension reinforcement is necessary for ductile behavior ($\rho>\rho min$). provisions for minimum flexural reinforcement specified by most codes of practice is based on empirical approach without any theoretical background. Most of the codal provisions incorporate two parameters mainly compressive strength of concrete and yield strength of steel. They neglect other parameters such as fracture energy of concrete and size of member. However, behavior of RC beams does not depend only on material properties but also on the size as well. The criteria for evaluating minimum reinforcement is beam should not fail instantly up on concrete crushing. To obtain this condition, ultimate capacity (Mu) of RC beam should be greater than or equal to its cracking moment (Mcr).most of the codes use flexural strength to evaluate cracking stress in beam. But large-scale specimens have less cracking bending strength than that of flexural strength. The benchmark for evaluating minimum flexural reinforcement in RC beams specified by some national standards are mentioned in Table 1.Flexural cracking strength of concrete is always higher than uniaxial tensile strength of concrete. Assume if concrete is a brittle material, thereupon after the extreme tension fibres reaches uniaxial tensile strength, right away it should fail. However, concrete is a quasi brittle material due to its tension softening nature. It can transmit stress across crack faces. This nature can be created using nonlinear fracture mechanics model (NLFM). cohesive crack model and fictious crack model are able to carry quasi brittle nature of concrete. In traditional design method, tests on cylinder split tensile test, compression test and modulus of rupture are used to define concrete properties. These properties only cannot characterize the behavior of concrete. The utilization of fracture mechanics principles is essential to examine fracture and crack growth behavior of concrete. as percentage of flexural reinforcement increases, ultimate strength and ductility of RC beam increases. Using fracture mechanics principles minimum percentage of flexural reinforcement is inversely proportional to beam depth. Ductility number of RC beam increases with increasing beam depth [1]. Codal provision equations are independent of beam depth. But from experimental studies it has proved reinforced concrete beam responses are size dependent. It has been observed that flexural cracking strength is size dependent. Flexural cracking strength is inversely proportional to beam depth [2]. Experimental studies were conducted on beams by varying depth and length of specimens. Reinforcement percentage is taken as 0.15%. from studies it has been observed that load bearing capacity increases with decrease in member size. Another observation identified in this study is when a member size

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Syed jakeer hussain, Department of Civil Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, A.P, India-522502

P. Polu Raju, Department of Civil Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, A.P, India-522502.

increases the structural ductility decreases; hence brittleness of member increases [3]. The minimum reinforcement amount is an increasing function of concrete tensile strength and toughness, whereas minimum reinforcement decreases as beam depth increases. Mechanical and geometrical parameters affecting beam behavior is studied by nonlinear fracture mechanics model (NLFM) [4]. The amount of minimum reinforcement for beam size from small to large depends on steel-concrete bond relationship, brittleness of concrete and amount of distributed reinforcement. Another observation identified in this study is increase of minimum reinforcement is controlled by energy equilibrium after first flexural crack appears [5]. A method of combining fracture mechanics yield realistic results regarding crack formation, propagation, and failure. Refined study has to be done in this area to understand the failure mechanism of lightly reinforced concrete beams [6]. Fracture parameters like fracture energy of concrete (Gf) and stress intensity factor (K) were calculated as per the recommendations prescribed by RILEM [7].

$$\mathbf{G_f} = \frac{\mathbf{U-0.5mg\delta_0}}{\mathbf{1.15bh\left[1-\left(\frac{a_0}{h}\right)\right]/cos\alpha}} \qquad (1)$$

Where U is the area under load-deflection curve up to the point of instability, δ_0 is the vertical deflection at that point(mm), α is the angle between crack plane formed and vertical plane of section(in degree), mg is the unit weight of the section(N/mm), a_0 is the initial notch depth(mm), b and h are the width and height of the section respectively**.**

$$K=\sqrt{(\mathbf{G_f} * \mathbf{E})} \qquad (2)$$

Where G_f is Energy Release Rate or Fracture Energy,N/mm

E is Modulus of Elasticity, N/mm^2

E=[1+3.15(d/l)+8(d/l)g(a/d)]*(1/4b)(l/d)3(df/dδ)] **(2(i))**

Where

l= span length, mm

d=depth of beam, mm

b=width of beam, mm

(df/dδ)=initial slope of F-δ curve

$$g(a/d)=\frac{\mathbf{0.15}}{\mathbf{[1-\left(\frac{a}{d}\right)]^3}} \qquad (2(ii))$$

Minimum reinforcement in concrete structures can be modeled by linear elastic fracture mechanics (LEFM) model[8]. Fracture mechanics problem can be solved by dimensional analysis. By varying fracture parameters like fracture energy of concrete and modulus of elasticity of concrete, yield strength of steel gives a ductility number (N_D) [1].

$$(N_D) = \frac{f_y}{\sqrt{G_f E}}\left(\frac{A_s}{A_g}\right)h^{0.5} \qquad \mathbf{(3)}$$

Where

G_f = fracture energy of concrete.

E= modulus of elasticity.

A_s= area of steel.

A_c= gross area of cross section.

f_y = yield strength of steel, h = size of the member.

Table I: code provisions for minimum and maximum Reinforcement

Codes	Minimum Reinforcement	Maximum Reinforcement	Equation Number
ACI 318-14 [9]	$A_{smin} = \frac{0.25(f1c)0.5}{f_y} b_w d$	Strain in extreme tensile steel ≥ 0.005	**(4)**
IS 456-2000[10]	$\frac{A_s}{bd} = \frac{0.85}{f_y}$	0.04bD	**(5)**
EURO CODE 2 [11]	$A_s = \frac{0.26 \text{ x fctm b x d}}{f_y}$	0.04A_c	**(6)**
BS 8110 (1997) [12]	$0.13 = 100 \frac{A_s}{b_w} h$ $f_y = 460 \; N/mm^2$	0.04bD	**(7)**

II. RESEARCH SIGNIFICANCE

The main objective of this present study is to determine the behavior of lightly reinforced concrete beam provided with minimum amount of steel reinforcement. By varying percentage of tensile reinforcement and results are validated through experimental work. However the percentage of reinforcement increases the ductility nature of beam increases. In this present experimental study work has done on six numbers of reinforced concrete beams. By varying percentage of steel reinforcement and one plain cement concrete beam were cast. Parameters like flexural strength, fracture energy, stress intensity factor has studied. The effect of size of member and ductility in design of reinforced concrete beam can forecast by applying fracture mechanics. There exists a dispute in evaluation of minimum Flexural reinforcement in RC members. Beams were tested under four point bending test using loading frame which is force controlled. Therefore, an effort has been made to find out effect on ductility and minimum flexural reinforcement in reinforced concrete beams.

III. EXPERIMENTAL PROGRAM

A. Materials

Ordinary Portland cement (OPC) 53 grade confining to IS: 12269[13] was used in this experimental study. Initial and final setting time was 180 and 325 min, respectively tested according to IS: 4031[14].Specific gravity of cement was tested and was found to be 3.12. Fine aggregate collected from natural river bed is used. Fine Aggregates which passes through 4.75mm sieve is used. Specific gravity of fine aggregate of Zone-2 was tested as per IS: 2386[15] and resulted as 2.62.The coarse aggregate was taken as a combination of 20mm (60%) and 10mm (40%) as per IS

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code. Specific gravity of coarse aggregate was tested and resulted as 2.73.Portable water was used for casting and curing of specimens. High strength deformed bars of yield strength 500 N/mm^2. Is used as flexural reinforcement. Steel bars of diameter 8mm, 10mm were used as flexural reinforcement. 6mm diameter bars are used as shear reinforcement. Steel reinforcement confining to IS: 1786[16] is used.

B. Concrete mix proportion

Concrete of grade M30 was designed confining to IS: 10262 [17]. Mix proportion for 1 m^3 ofM30 grade concrete is 1: 2.03: 3.59. Water cement ratio is taken as 0.45. The material quantities were listed in the Table II.

Table II : Mix Proportion details

Cement kg/m^3	F.A kg/m^3	C.A kg/m^3		`Water kg/m^3
		20mm	10mm	
355.55	724.07	767.12	511.41	160

C. Compressive strength of concrete

Cube of standard dimensions (150mm × 150mm × 150mm) were cast and tested after 7 days and 28 days under compressive testing machine (CTM). Results were obtained and tabulated below in Table III.

Table III : Compressive Strength of Cubes

Specimen	No of cubes	Compressive strength (7 days) N/mm^2	Compressive strength (28 days) N/mm^2
Cubes	3	28	36

D. Split tensile strength of concrete

Cylinders of standard dimensions (150mm × 300mm) were cast and tested after 7days and 28days under compressive testing machine (CTM). Following results were obtained and tabulated below in Table IV.

Table IV: Split Tensile Strength of Cylinders

Specimen	No of Cylinders	Split Tensile strength (7 days) N/mm^2	Split Tensile Strength (28 days) N/mm^2
Cylinders	3	2.7	3.2

E. Flexural strength of concrete

Concrete beams of dimension (500mm × 100mm × 100mm) were cast and tested after 28days under flexure testing machine (FTM).following results were obtained and tabulated below in Table V

Table V: Flexural Strength of Concrete

Specimen	No of beams	Flexural strength N/mm^2
Beams	3	6.2

F. Specimen details

Rectangular beam specimens of size 2200mm × 150mm × 300mm were cast. Concrete cover of 25mm is adopted.M30 grade concrete was used. Beam details were mentioned in Fig. 1. Reinforcement details were mentioned in Fig. 2.

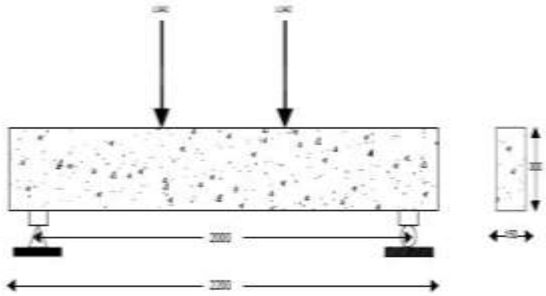

Fig. 1: Schematic diagram of four point bending test setup

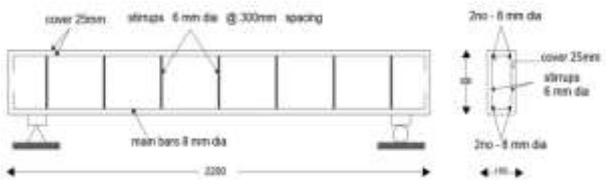

Fig. 2(a): reinforcement details for pt = 0.25%

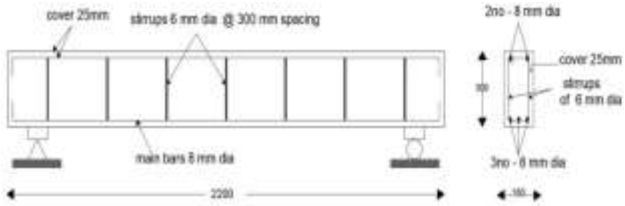

Fig. 2(b): reinforcement details for pt = 0.37%

Fig. 2(c): reinforcement details for pt = 0.50%

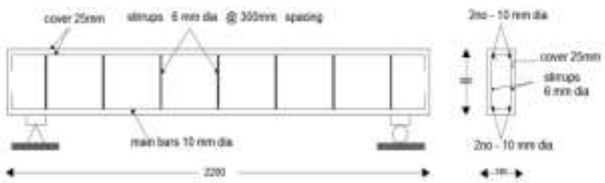

Fig. 2(d): reinforcement details for pt = 0.39%

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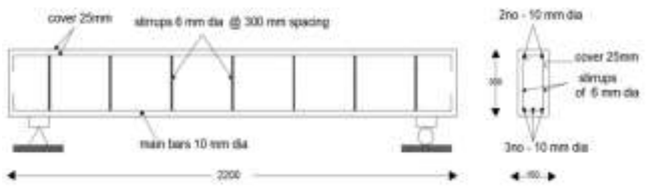

Fig. 2(e): reinforcement details for pt = 0.59%

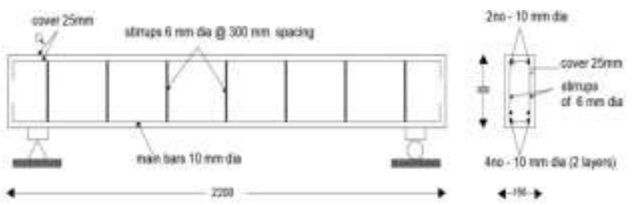

Fig. 2(f): reinforcement details for pt = 0.79%

Fig.2 : reinforcement details for $\rho_t = 0.25$, $\rho_t = 0.37\%$, $\rho_t = 0.50\%$, $\rho_t = 0.39\%$, $\rho_t = 0.59\%$, $\rho_t = 0.79\%$

Fracture energy of plain concrete beam was determined by three-point bending test. Concrete beam of dimensions 500mm × 100mm × 100mm were cast. Beam was provided with a notch of 5mm thickness. The notch to depth ratio maintained is 0.5. The average value of fracture energy was 147 N/m. Calculated critical stress intensity factor was evaluated as 63.08 N/mm. The modulus of elasticity of concrete was 26.5 Gpa.

G. Test setup and testing procedure

Fig. 3: Test setup

The beams were tested under four-point loading using loading frame which is force controlled. Beam is provided with statically determinate supports roller and hinge supports at two ends. Load was applied by hydraulic jack through load cell. The load was applied symmetrically at one third distance of one third of the span from supports. Load was transmitted through steel girder 1000mm × 100mm × 100mm placed below the concentrated load point in order to transfer the load at one third distance points. Load was applied gradually incremental manner. Mid span deflection is measured by linearly variable differential transducer (LVDT). The load was observed at first cracking in the constant bending moment region between two load points. Load corresponding to first flexural cracking, yielding of reinforcement at failure of beam was recorded. Ultimate and cracking moments were calculated from theoretical procedure.

IV. RESULTS AND DISCUSSIONS

After completing experimental study following results were obtained. Results were plotted in graphical method. Curves representing applied load *vs.* deflection are shown in Fig. 3.

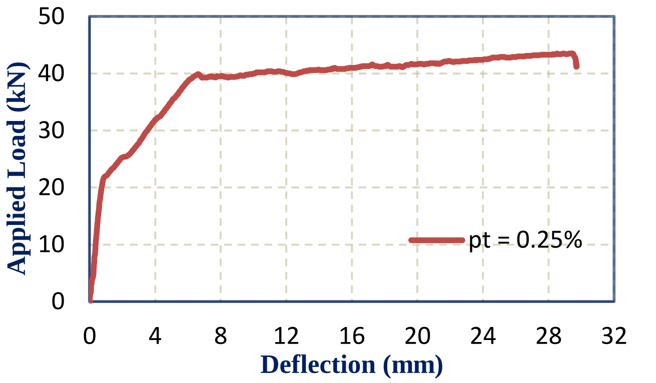

Fig. 4(a): Applied Load *vs* Deflection Curve for 0.25% Reinforcement

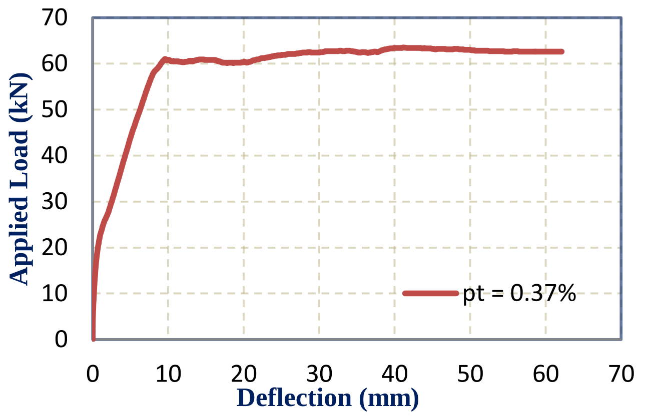

Fig. 4(b): Applied Load *vs* Deflection Curve for 0.37% Reinforcement

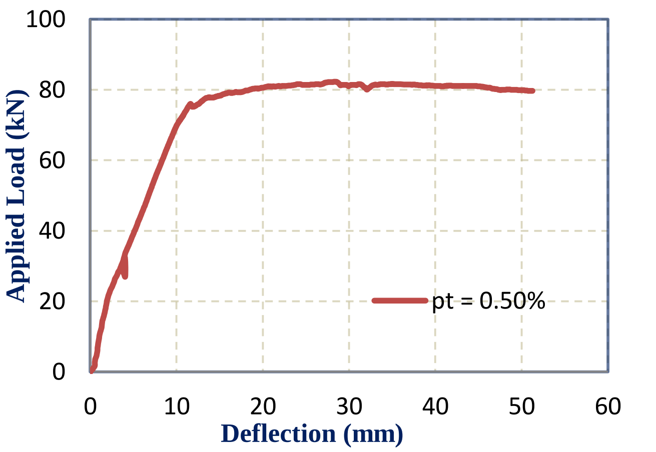

Fig. 4(c): Applied Load *vs* Deflection Curve for 0.50% Reinforcement

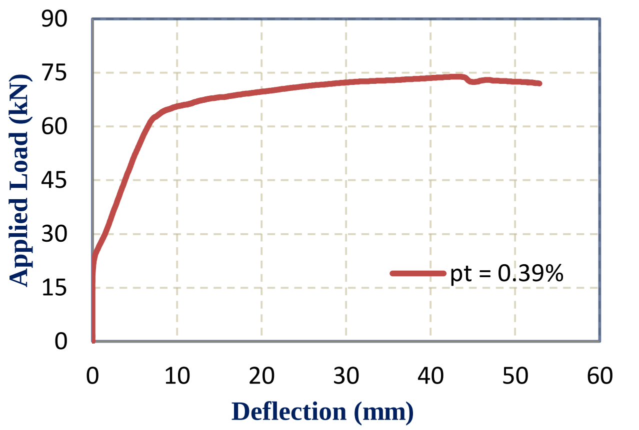

Fig. 4(d): Applied Load *vs* Deflection Curve for 0.39% Reinforcement

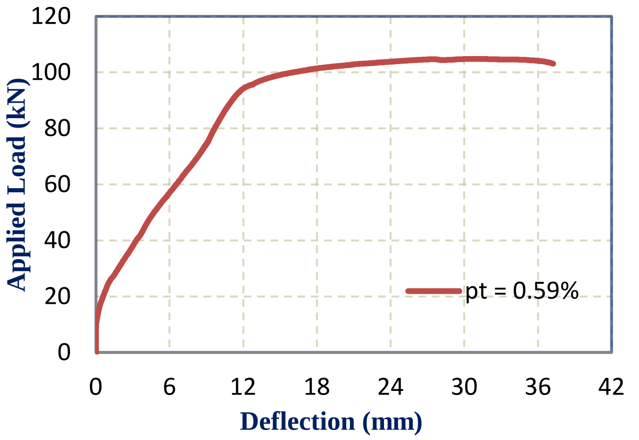

Fig. 4(e): Applied Load *vs* Deflection Curve for 0.59% Reinforcement

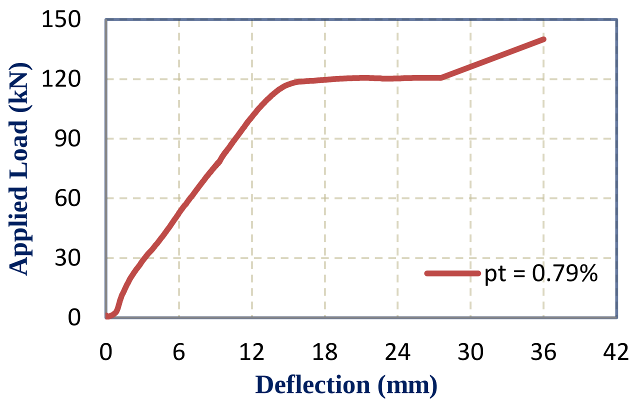

Fig. 4(f): Applied Load *vs* Deflection Curve for 0.79% Reinforcement

Fig. 4: Applied Load *vs* Deflection curve for ρ_t = 0.25%, ρ_t = 0.37%, ρ_t = 0.50%, ρ_t = 0.39%, ρ_t = 0.59% and ρ_t = 0.79%.

Beam provided with 0.25% flexural reinforcement shown in Fig. 4(a). The deflection of beam increases linearly up to just before peak load, then it shows relatively increased deformations before failure. Maximum deflection at peak load is 32mm. the nature of failure observed is ductile failure. Beam provided with 0.37% flexural reinforcement shown in Fig. 4(b). the deflection of beam increases linearly up to just before peak load, then it shows relatively large deformations before failure. Maximum deflection at peak load is 65mm. the nature of failure observed is ductile failure. Beam provided with 0.50% flexural reinforcement shown in Fig. 4(c). The deflection of beam increases linearly up to just before peak load, and then it shows relatively less deformation before failure. Maximum deflection at peak load is 50mm. the nature of failure observed is ductile failure. Beam provided with 0.39% of flexural reinforcement shown in Fig. 4(d). the deflection of beam increases linearly up to just before peak load, then it shows relatively increased deformations before failure. Maximum deflection at peak load is 55mm. the nature of failure observed is ductile failure. Beam provided with 0.59% flexural reinforcement shown in Fig. 4(e). the deflection of beam increases linearly up to just before peak load, then it shows relatively increased deformations before failure. Maximum deflection at peak load is 52mm. the nature of failure observed is ductile failure. Beam provided with 0.79% flexural reinforcement shown in Fig. 4(f). The deflection of beam increases linearly up to just before peak load, and then it shows relatively less deformations before failure. The maximum deflection at peak load is 36mm. the nature of failure observed is ductile failure.

V. CONCLUSIONS

The following conclusions may be drawn from present experimental work

1. As the percentage of flexural reinforcement increases, ultimate strength and ductility of reinforced concrete beam increases.
2. Fracture parameters have been incorporated to study minimum flexural reinforcement in reinforced concrete beams.
3. The effect of beam size and percentage of flexural reinforcement. On ultimate strength of reinforced concrete beam is significant However, ultimate strength decreases as percentage of reinforcement decreases.
4. Using fracture mechanics concepts, percentage of minimum flexural reinforcement is found to be inversely proportional to beam depth, whereas most of codes of practice specify minimum reinforcement is independent of depth of beam

REFERENCES

1. Rao GA, Vijayanand I, Eligehausen R, "Studies on ductility and evaluation of minimum flexural reinforcement in RC beams", "*Materials and Structures*", Vol. 41, Issue 4, 2008, pp.759-71.
2. Nagesh, H. E., and G. Appa Rao. "Evaluation of Minimum Flexural Reinforcement in Design of Reinforced Concrete Beams". "*Recent Advances in Structural Engineering*", Springer, Vol.1, 2019, pp. 145-155.
3. Ozbolt, J., and M. Bruckner. "Minimum reinforcement requirement for RC beams", *European Structural Integrity Society*, Elsevier, Vol. 24, 1999, pp.181-201.

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4. Cadamuro, E., M. Corrado, and A. Carpinteri. "Size-scale effects on minimum flexural reinforcement in RC beams: application of the cohesive crack model", *Fracture Mechanics of Concrete Structures*, 2010, pp.207-215.
5. Bruckner, M., and R. Eligenhausen. "Minimum reinforcement in RC beams." In *2nd International PhD Symposium in Civil Engineering, Budapest*, 1998, pp. 1-7.
6. Hillerborg, Arne, Mats Modéer, and P-E. Petersson. "Analysis of crack formation and crack growth in concrete by means of fracture mechanics and finite elements", *Cement and concrete research*, Vol. 6, 1976, pp.773-781.
7. P.E. Petersson. Fracture Energy of Concrete: method of determination", *Cement and Concrete Research*, Vol.10, 1980, pp-78-89.
8. Ferro, Giuseppe, Alberto Carpinteri, and Giulio Ventura. "Minimum reinforcement in concrete structures and material/structural instability", *International Journal of Fracture* 146.4, 2007, pp.213-231.
9. ACI (American Concrete Institute). "Building code requirements for reinforced concrete." *ACI 318-14*, 2014.
10. Indian Standard, IS: 456-2000." Plain and Reinforced Concrete Code of Practice".
11. Euro code 2 (1992)," Design of Concrete Structures-Part 1- General Rules and Rules for Buildings." British standards Institution., London.
12. BS: 8110-97. *Structural use of concrete Part 1: Code of practice for design and construction*.
13. IS: 12269-1987, Indian standards ordinary Portland cement,53 grade, specification.
14. IS: 4031-1968, Test methods for ordinary portland cement. Bureau of Indian Standards.
15. IS: 2386-PART-3, method of test for aggregate for concrete, part-3: specific gravity, density, voids, absorption and bulking [CED 2: Cement and Concrete].
16. IS: 1786-1985, Specification for high strength deformed steel bars and wires for concrete reinforcement. Bureau of Indian standards.
17. IS: 10262-2009, "Guidelines for concrete mix design".

AUTHORS PROFILE

Syed jakeer hussain is doing his Master of Technology in Structural Engineering at Koneru Lakshmaiah Education Foundation (Deemed to be University), Vaddeswaram, Guntur district, Andhra Pradesh, India. He completed his B.Tech in Civil Engineering at K.L.University, Guntur district, Andhra Pradesh, India. He worked as a design engineer in steel structures industry, Domain (light gauge steel frame structures). He has published 1 research paper in international journal.

Dr. P. Polu Raju is working as Associate Professor and HoD in Department of Civil Engineering at Koneru Lakshmaiah Education Foundation (Deemed to be University), Vaddeswaram, Guntur district, Andhra Pradesh, India. He has completed Master of Technology in Structural Engineering from IIT Guwahati in 2009 and Ph.D. in Structural Engineering from IIT Madras in 2017. His research interests include Sandwich Panels, Rehabilitation and Retrofitting of RC structures. He has published 32 research papers in international journals and conferences and guiding 8 number of Ph.D. scholars, guided 20 number of masters and 10 number of bachelor's dissertation work. He is a lifetime permanent member of ICI (Indian Concrete Institute) & ISRD.