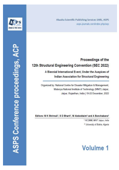
ASPS Conference Proceedings 1: 307-314 (2022)

Proceedings of

12th Structural Engineering Convention - An International Event (SEC 2022)

Available at https://asps-journals.com/index.php/acp



Parametric Study to Decide the Optimal Rebar Grade for Flexural Members

Krishna Murari[1,*], Harvinder Singh[2], Inderpreet Kaur[3], SavleenTakkar[4]

[1]Department of Civil Engineering, M. tech Student, Guru Nanak Dev Engineering College, Ludhiana, 141006, India
[2]Department of Civil Engineering, Professor, Guru Nanak Dev Engineering College, Ludhiana, 141006, India,
[3]Department of Civil Engineering, Assistant Professor, Guru Nanak Dev Engineering College, Ludhiana, 141006, India,
[4]Department of Civil Engineering, Assistant Professor, Guru Nanak Dev Engineering College, Ludhiana, 141006, India,

Paper ID - 040052

Abstract

The growing interest of using higher strength reinforcing steel for certain applications within the reinforced concrete industry is driven primarily by relief of congestion; particularly in buildings assigned a high seismic design category. Construction efficiency can be improved by high strength bar or combined with high strength concrete which allows reinforced concrete to be used in more demanding applications. High grade steel generally increases the cost as well allows smaller concrete member which creates a problem of placement of reinforcement. Therefore there is a need to study the better option between lower quantity of high grade and high quantity of lower grade. This paper presents the parametric study to see the effect of beam span and member sizes on the results obtained in design of simply supported flexural members using different rebar grades, such as Fe415, Fe500, Fe550 and Fe600 in terms of crack width and member deflections for mild and moderate exposure conditions. It was observed that detailing plays vital role in cost saving and crack width limit governs final steel requirement in moderate exposure condition. Cost analysis was also performed for different grades and Fe500 is found optimum grade.

Keywords:High Strength Steel, Design, Cost Analysis, Rebar Grade

1. Introduction

Concrete is strong in compression howeverbears very low tensile force whilst steel is good in carrying tensile force and it elasticity to concrete. Steel is commonly used as reinforcement in concrete structure, in view of the fact that both steel and concrete have approximately same thermal expansion properties; in addition to that it provides excellent flexural property. Another reason for effectiveness of steel as reinforcement is that it bonds well with concrete. Conventionally, methods of design and analysis for concrete members reinforced with normal strength steel have been developed [4], [8], [9]. Newly, high strength reinforcing steel is commercially available which are having strength more than conventional steel. Using high strength steel as reinforcement results inreduced quantity of reinforcement required, which further improves constructability as there is comparatively less reinforcement congestion. One of the basic principles of Reinforced Concrete structure design is that it is assumed, steel and concrete will act together to withstand induced forces.

Through 1980- 1985, Thermo-mechanically treated (TMT) bars were introduced in Indian construction practices [6].

Hot bars which are coming out of last rolling mill stand are promptly quenched between a series of water jets in Thermo-mechanical treatment: an advanced heat treatment process. Rapid quenching resulting in vigorous cooling of surface and provides the bars having hardened surface with hot core. The bars are then allowed to cool in ambient conditions. In the course of such slow cooling, the heat released from core tempers the hardened surface while core is turned in to ferrite-pearlite aggregate composition. Consequently, an optimum combination of high strength, ductility, flexural and other desirable properties is achieved throughTMT process which changes the structure of material to a composite structure of ductile ferrite pearlite composition along with tough surface rim of tempered marten site [5]. Now in India high strength TMT bars of grade Fe415, Fe500 and Fe550 are available in market.

In some of structures such as, building bridges, marine facilities and many others to create leaner structures Fe600 grade steel is being used [5].

2. Relevance

The speedy development of economic construction, people are rapidly looking for more and more new materials for building construction. This is a vital part of human life. Reinforced concrete is broadly used in conventional engineering structures as a kind of magnificent building material. One of the reason is, the steel bar is protected by concrete and has the property of durability and fire

*Corresponding author. Tel: +919876227224; E-mail address: krishnamurarigne@gmail.com

Proceedings of the 12th Structural Engineering Convention (SEC 2022), NCDMM, MNIT Jaipur, India | 19-22 December, 2022

doi:10.38208/acp.v1.514

resistance. On the other hand, its nobility is excellent.Fe 550 and Fe 600 are not introduced in design engineering codes up to now, along with the above described factors, fewer private client/contractor projects and none of public government projects are in a position to propose for using these higher grades of reinforcement in their technical specification. It is expected that in near future Fe550 or Fe600 or even higher grades might come up and being used in construction industry, with the huge infrastructure development/construction happening in India. It is very useful to decreased consumptionof steel leading to overall economy.

3. Objective of the Study

The present study was conducted with the following objectives:

- To design flexural members using different rebar grades, such as Fe415, Fe500, Fe550 and Fe600.
- To conduct parametric study to see the effect of beam span and member sizes on the results obtained in Objective 1 in terms of crack width and member deflections.
- To interpret the results to get an optimized value of the rebar grade based on the cost considerations and member performance.

4. Analytical Study

There are several types and grades of steel bars available in the market to reinforce concrete but according to strength and cost characteristics and availability of same in the market, Steel Grades Fe415, Fe500, Fe550 and Fe600 have been taken for analysis and design. Comparative study of the same has been done using Microsoft Excel sheets. Dead loads and live loads are calculated as per Indian standards IS 875 part 1 and IS 875 part 2 [2], [3]. Guidelines of IS 456 are also followed while applying checks in slab and beam design [1].

Mainly slab is designed for gravity loads which include dead load and live load. The details of both are tabulated here:

4.1 Load distribution on beam

If Floor loading is “w” kN/m^2, l_x is shorter span and l_y is longer span, then

Equivalent UDL on longer span W$_1$ (kN/m)

$$=\frac{w\,l_x}{2}\left[1-\frac{1}{3}\left(\frac{l_x}{l_y}\right)^2\right]$$

Equivalent UDL on Shorter span W$_2$ (kN/m)

$$=\frac{w\,l_x}{3}$$

Table: 1 Slab load Details

Component		(DL + LL) kN/m^2
Self (140mm thick)		3.5+0.0
Water proofing + Floor finish		3.5+0.0
Live load		0.0+3.0
Total		10.0

4.2 Relevant Codal Provisions

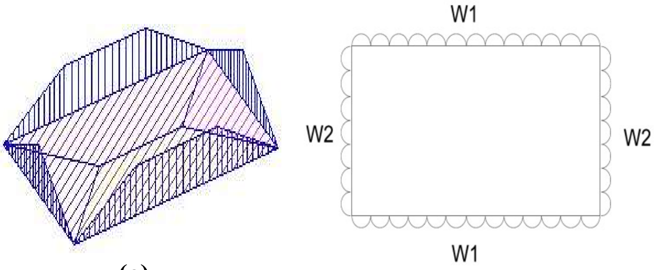
- Minimum area of tension reinforcement shall not be less than that of given by the following clause(26.5.1.1(a) IS 456:2000):

$$\frac{A_s}{bd}=\frac{0.85}{f_y}$$

- The maximum area of tension reinforcement shall not exceed 0.00bD.(26.5.1.1(b) IS 456:2000)
- Maximum spacing of shear reinforcement as per clause 26.5.1.5 IS 456:2000.
- Minimum reinforcement in either direction in slabs shall not be less than 0.15 percent of the total cross sectional area (clause 26.5.2.1 IS 456:2000).
- Maximum diameter of reinforcing bars shall not exceed one-eighth of the total thickness of the slab (clause 26.5.2.2 IS 456:2000).
- The vertical deflection limits may generally be assumed to be satisfied provided that the span to depth ratios are not greater than the values obtained as per provision of IS456:2000 Clause 23.2.1.
- Crack width requirements as per Table No. 5,16 and clauses 35.2 and 43.1 IS 456:2000.

5. Results and Discussions

The results of the Quantity of Concrete and different grade of steel for different span are shown in Tables (1 and 2). Also cost comparisons of different grades for mild and moderate conditions are shown in Figures (1 and 2).



(a) **(b)**

Fig.1(a) Load distribution in 2-way slab(b) Equivalent UDL on Beam

Table: 2 Quantity of Concrete and different grades of steel for Different span for mild exposure condition

Span (m)	**Concrete (m^3)**	**Steel (kg)**			
		Fe 415	**Fe500**	**Fe550**	**Fe600**
3.5	3.584	129.04	105.72	96.047	86.376
5.25	4.910	250.44	233.56	219.41	214.57
7.0	6.234	506.64	486.66	469.40	452.15

Table: 3 Quantity of Concrete and different grade of steel for Different span for moderate exposure condition

Span (m)	**Concrete (m^3)**	**Steel (kg)**			
		Fe 415	**Fe500**	**Fe550**	**Fe600**
3.5	3.584	129.04	105.72	105.72	105.72
5.25	4.910	252.50	242.87	242.87	244.934
7.0	6.234	506.641	499.08	499.08	476.99

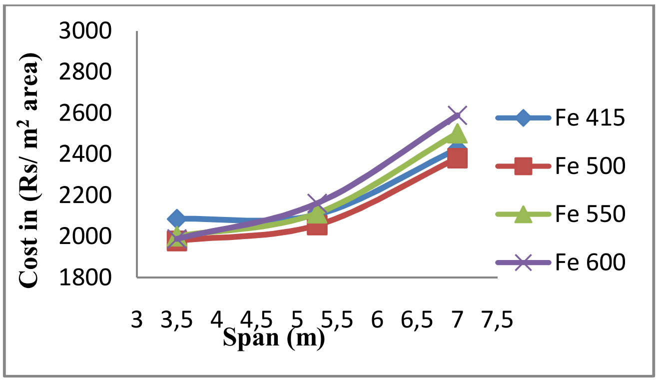


Fig: 4.1 Cost v/s span for different grades of steel in Mild Condition

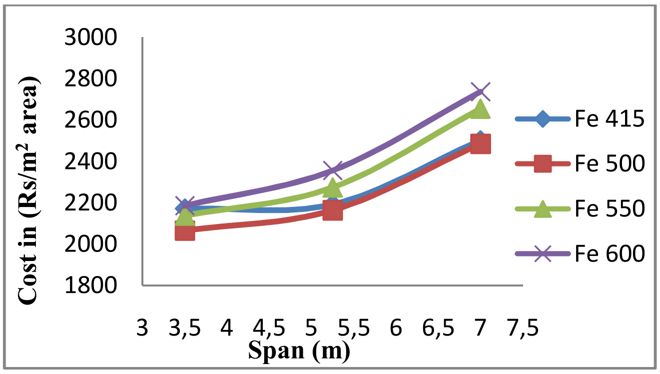


Fig: 4.2 Cost v/s span for different grades of steel in Moderate Condition.

Using higher grade of steel leads to lesser area of reinforcement but at the same time we have to follow the minimum steel requirement criteria as per guidelines of Indian standards also other serviceability criteria. Hence for deciding optimum rebar grade all these point should be taken care.

Typical detailed calculation in presented in appendix at the end [1], [7].

6. Conclusions

As per the calculations and results for various aspect ratio of slab and two different exposure conditions, the following points have been observed.

- Detailing plays vital role in cost saving.
- Crack width limit governs final steel requirement in moderate exposure condition.
- Provided clear cover & amount of steel has significant role instead of grade of steel in crack width control.
- Fe 500 is found as Optimum grade of steel based on the cost considerations and member performance.
- Fe 600 is found as Optimum grade of steel based on the total quantity of steel required.
- Overall cost saving is more for shorter span and mild exposure condition.

Disclosures

Free Access to this article is sponsored by SARL ALPHA CRISTO INDUSTRIAL.

References

1. IS 456:2000 Plain and Reinforced Concrete - Code of Practice (Fourth revision)
2. IS 875 Part 1 (1987) Code of Practice for design loads (Other than Earthquakes) for Building and structures
3. IS 875 Part 2 (1987) Imposed Load Code of Practice for design loads (Other than Earthquakes) for Building and structures
4. Mast, Robert F., Mina Dawood, Sami H. Rizkalla, and Paul Zia. (2008). “Flexural Strength Design of Concrete Beams Reinforced with High-Strength Steel Bars.” ACI Structural Journal 105 (5): 570–77. https://doi.org/10.14359/19940.
5. Prachi H.Kondubhairi, M.V.Nagendra (2018). “Review on Experimental Analysis of Flexural Behavior of RC Beams by Using High Strength Steel”International Research Journal of Engineering and Technology (IRJET) 5 (6) .
6. Roy, N K, and R R Sandhwar. (2007). “Study on Behaviour of MS, CTD & TMT Steel Bars.” International Journal of Innovative Research in Science, Engineering and Technology (An ISO 3297: 9813–17.
7. Pillai Menon “Reinforced Concrete Design” (Third edition).
8. Saifullah, I, M Nasir-uz-zaman, S.M.K Uddin, M A Hossain, and M H Rashid. (2011). “Experimental and Analytical Investigation of Flexural Behavior of Reinforced Concrete.” International Journal of Engineering & Technology: 146–53.
9. Tejaswi, S., and J Eeshwar Ram. (2015). “Flexural Behaviour of RCC Beams.” International Journal of Innovations in Engineering and Technology (IJET) 5 (1).

Appendix

Reference	Step	Calculations	Output
	1.	**Thickness of slab and durability consideration** Effective length l_x = 3.5 m =3500 mm l_y = 5.25m =5250 mm Provide , d = 115 mm Assuming clear span cover = 20 mm Providing 10 mm ϕ bar Total depth of slab, =115 + 20 + 10/2 =140mm Assuming total depth, D = 140 mm Since =$\frac{ly}{lx}$= $\frac{5250}{3500}$=1.5 **So, Design as Two Way Slab**	**d =115 mm** **D = 140 mm**
	2.	**Design Load** Self-load of slab = 0.140x 25 = 3.5 KN/m^2 Finishing load =3.5 KN/m^2 Partition wall load = 0.000 KN/m^2 Dead load = 3.5+3.5+0 = 7 KN/m^2 Live load = 3 KN/m^2 (according to occupancy) Total load = 10 KN/m^2 Design load , w=1.5(DL+LL)=15 KN/m^2 Considering unit width of slab , w = 15 KN/m	**l_x = 3500 mm** **l_y = 5250 mm**
		Moment Calculation +ve Bending moment coefficient at mid span αx =0.089 , αy=0.056 , **For Short Span** Mid span moment , $M_s = \alpha_x w l_x^2$ $= 0.089\times15\times3.5^2$ = 16.35 KN-m **For Long Span** Mid span moment , $Mm = \alpha_y w l_x^2$ $= 0.056\times15\times3.25^2$ = 8.87 KN-m	
IS 456-2000 **Table 26**		**Check for depth from Moment Consideration** Depth of Slab '= $\sqrt{\frac{Ms}{0.133\times fck\times b}}$ = $\sqrt{\frac{16.35\times10^6}{0.133\times20\times1000}}$ = 78.4 mm	**d = 78.4 mm** **< 115 mm, ok**

Reference	Step	Calculations	Output
	3.	**Calculation of area of steel** Min Ast = 0.12 % of bD = 0.0012 × 1000 × 115	**Min Ast = 138 mm^2**
IS456-2000 AnnexG-1.1.b		**Area of Steel along short span :** $Ast = \frac{20 \times 1000 \times 115}{2 \times 500}\left(1-\sqrt{1-\frac{4.6 \times 16.35 \times 10{}^\wedge 6}{20 \times 1000 \times 115^2}}\right)$ A_{st} = 354.29 mm^2>A_{st} min Providing 10 mm ϕ bars Spacing =$\frac{1000 \times 78.5}{354.29}$ =221.57 mm Provide 10 mm ϕ @ 200 mm c/c Actual Ast provided =$\frac{1000 \times 78.5}{200}$= 392.5 mm^2 Pt =$\frac{392.5 \times 100}{1000 \times 115}$= 0.341 %	**Provide 10 mm ϕ @ 200 mm c/c** **Ast$_{provided}$ =392.5 mm^2**
IS456-2000 AnnexG-1.1.b		**Area of Steel along Longer span :** $Ast = \frac{20 \times 1000 \times 115}{2 \times 500}\left(1-\sqrt{1-\frac{4.6 \times 8.78 \times 10{}^\wedge 6}{20 \times 1000 \times 115^2}}\right)$ Ast = 182.87 mm^2>Ast min Providing 8 mm ϕ bars Spacing =$\frac{1000 \times 50.4}{182.87}$=275.60 mm Provide 8 mm ϕ @ 200 mm c/c Ast provided =$\frac{1000 \times 50.4}{200}$= 252 mm^2 Pt =$\frac{252 \times 100}{1000 \times 115}$= 0.219 %	**Provide 8 mm ϕ @ 200 mm c/c** **Ast$_{provided}$ =252mm^2**
IS456-2000 (Cl.40.4, Table 19 Table 20)	4.	**Check for Shear** For x-direction i.e. short span Shear force at the face of the support, Vu = $\frac{wlx}{2}$=$\frac{15 \times 3.5}{2}$ = 26.25 kN	**Vu = 26.25 KN**

Reference	Step	Calculations	Output
		Nominal shear stress τv = Vu/bd = 26.25×10^3/1000×115 = 0.228 N/mm^2 ForPt = 0.341 % and M20, τc = 0.364 N/mm^2 For D=125mm, k=1.30 τc' =k×τc= 1.30×0.364 =0.473 N/mm^2 For M20, τcmax= 2.8 N/mm^2 τ v= 0.228 N/mm^2<τc= 0.364 N/mm^2 <τcmax= 2.8 N/mm^2 Hence, OK	**τv= 0.228 N/mm^2<τc=0.364 N/mm^2<τcmax= 2.8 N/mm^2** **Hence, Safe.**
	5.	**Check for deflection** $\text{fs} = 0.58 \times fy \times \frac{\text{area of cross section of steel required}}{\text{area of cross section of steel provided}}$ $\text{fs} = 0.58 \times 500 \times \frac{354.29}{392.5}$ $= 261.76\ \text{Mpa}$ $\text{Pt} = 0.341\%$ Modification factor (γ) = 1.32 $\left(\frac{l}{d}\right) max = 20\times 1.32 = 26.4$ $\left(\frac{l}{d}\right) provided = \frac{effective\ span}{effectiove\ depth} = \frac{3500}{115} = 30.43$ >26.4, **Hence we have to revise section or steel**. Now providing 10 mm ϕ steel @150mm c/c	

Reference	Step	Calculations	Output
		Actual Ast provided $=\frac{1000\times78.5}{150} = 523.33$ mm^2 Pt $=\frac{523.33\times100}{1000\times115} = 0.455$ % $\mathrm{fs} = 0.58 \times 500 \times \frac{354.29}{523.33} = 196.327$ Mpa	
		Modification factor (γ) = 1.56 $\left(\frac{l}{d}\right) max = 20\times 1.56 = 31.2 > 30.43$ **Hence safe.**	**Defection Criteria satisfied.**
IS456-2000 Cl.26.2.3.3	**6.**	**Check for development length** $\mathrm{Ld} = \frac{0.87 \times \mathrm{fy} \times \varphi}{4 \times \tau\mathrm{bd}} = \frac{0.87 \times 500 \times 10}{4 \times 1.92} = 566.41\ mm$ Ld=56.64 ϕ Ast = 523.33 mm^2 Xu = 0.87×fy×Ast/(0.362×fck×b) =31.44 mm M1=0.87fy×Ast(d - 0.42×Xu) =23.17 kNm Vu=26.25 kN Ld ≤ M1/Vu + lo **For short Span** Ld = M1/Vu + lo 56.64 $\phi \leq 23.17\times10^6/26.25\times10^3 + 8\times 10$	**Lo = 8ϕ** **Hence safe.**
IS 456-2000 ANNEX F (Clauses 35.3.2 and 43.1)	**7.**	**Crack width calculation using IS Code formula** Modular ratio, m$=\frac{280}{3\sigma_{cbc}}=\frac{280}{3\times7} = 13.33$ k $=\sqrt{2(pm)+(pm)^2} - (pm)$ where $p = \frac{pt}{100} = \frac{0.341}{100} = 0.00341$ Hence k = 0.259 and x = kd = 0.259× 115 = 29.84 mm NowIcr $= \frac{1000\times29.84^3}{3} + 13.33 \times 523.33 \times (115 - 29.84)^2 = 5.94 \times 10^7$ mm^4	

Reference	**Step**	**Calculations**	**Output**
Reinforced Concrete design By Devdas Menon		fst = $\frac{13.33\times10.9\times10^{6}}{5.94\times10^{7}}\times(115-29.84)=208.31\ Mpa$ Which is within 275 Mpa, the allowable stress for Fe500 steel. $\varepsilon_1=\frac{fst}{Es}\times\frac{D-x}{d-x}=\frac{208.31}{2\times10^{5}}\times\frac{140-\quad .84}{115-29.84}=0.00135$ $\varepsilon_2=\frac{b(D-x)(a'-x)}{3EsAst(d-x)}=\frac{1000(140-29.84)^{2}}{3\times2\times10^{5}\times523.33(115-\quad .84)}$ $=0.000454$ $\varepsilon_m=\varepsilon_1-\varepsilon_2=0.000896>0$ $a_{cr}=\sqrt{\left(\frac{S}{2}\right)^{2}+(d_c)^{2}}-\frac{d_b}{2}$ $=\sqrt{\left[\frac{150}{2}\right]^{2}+(20)^{2}}-\frac{10}{2}$ a_{cr}=43.74 mm $W_{cr}=\frac{(3a_{cr}\ \in_m)}{\frac{[1+2(a_{cr-}C_{\min})]}{(D-x)}}$ $=\frac{(3\times43.74\times0.000896)}{\frac{[1+2(43.74-2\quad)]}{(140-2\quad .84)}}$ =0.267 mm < 0.300 mm.	