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# Flexural Behaviour of Reinforced Concrete Beams using ANSYS

Gopinath Reddy[1] and Dr. T. Muralidhara Rao[2]
[1]Student, CVR College of Engineering/Structural Engineering, Civil Engineering Department, Hyderabad, India.
Email: sgnr1234@gmail.com
[2] Professor, CVR College of Engineering / Civil Engineering Department, Hyderabad, India.
Email: tmuralidhararao@gmail.com

***Abstract*—In the present paper,the flexural behavior of reinforced concrete beams with minimum flexural tension reinforcement and the beams with the design reinforcement was studied by varying the concrete grades(M20,M25 and M30), grades of steel (Fe250,Fe415 and Fe500) and different beam width-to-depth ratios(0.5,0.6 and 0.7) under three point bending using ANSYS 12.1 version through load-deflection diagrams. The variation of deflection, strain energy and stress intensity factor was studied for different beam width-to-depth ratios and different grades of concrete and steel. Twenty seven reinforced concrete beams with minimum flexural reinforcement and twenty seven reinforced concrete beams with design reinforcement have been modelled and analysed in ANSYS. Total beams modelled and analysed were fifty four.**

***Index Terms*—Strain energy, Stress Intensity factor, Peak load, Finite element analysis, ANSYS.**

## I. Introduction

Concrete structural components exist in buildings and bridges in different forms. Reinforced concrete (RC) has become one of the most important building materials and is widely used in many types of engineering structures. The economy, the efficiency, the strength and the stiffness of reinforced concrete make it an attractive material for a wide range of structural applications. Understanding the response of structural components during loading is crucial to the development of an overall efficient and safe structure. Different methods have been utilized to study the response of structural components. Experimental based testing has been widely used as a means to analyze individual elements and the effects of concrete strength under loading. This method of testing produces real life response but it is time consuming and the use of materials can be quite costly. Hence, in recent years, the use of finite element analysis has increased due to the progressing knowledge and capabilities of computer software and hardware. It has now become the choice method to analyze concrete structural components [2][4][5][6]. The use of computer software to model these elements is much faster and extremely cost-effective. The use of finite element analysis has been the preferred method to study the behavior of concrete for economic reasons [7][9][10][11].The evaluation of adequate margin of safety of concrete structures against failure is assured by the accurate prediction of ultimate load and the complete load-deformation behaviour or moment-curvature response[1][3][8]. A typical three point bend setup is presented in Figure 1.

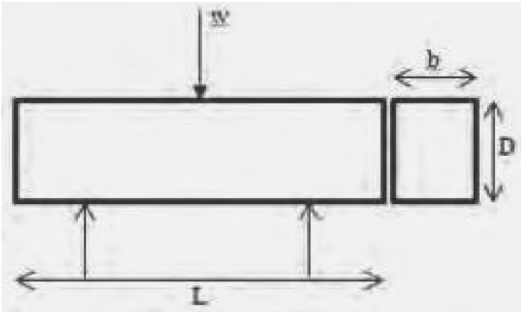


Figure 1. Typical three point bending test set up

## II. Sample Load Calculation

**Design of reinforced concrete beam [13]**
CASE – 1(Fe 250)
b/D=0.5 & M20

| | |
|---|---|
| Grade of steel: | Fe250 |
| Grade of concrete: | M20 |
| Length of beam: | 2500mm |
| Width/Total depth of beam: | 0.5 |
| Load: | 190KN/m |

For simply supported beams, if the uniformly distributed load is acting than maximum bending moment at mid span is M = $\frac{wl^2}{8} = \frac{190 \times 2.5 \times 2.5}{8}$ = 148.437 KN/m

Factored bending moment = 1.5 × M = 1.5 × 148.437 = 222.65 KN/m

For Fe250, $\frac{x_{umax}}{d} = 0.53$

$M_{ulim} = 0.36 \left(\frac{x_{umax}}{d}\right)\left(1\text{-}0.42\frac{x_{umax}}{d}\right) bd^2 f_{ck}$

$222.65 = 0.36 \times 0.53\,(1\text{-}(0.42{\times}0.53))\ b \times (2b)^2 \times 20$

b = 266mm

D = 532mm

d = 492mm

clear cover = 25mm

**Calculation of tension reinforcement:**

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

$222.65 = 0.87 \times 250 \times A_{st} \times 492\,\left(1\text{-}\frac{A_{st} \times 250}{20 \times 266 \times 492}\right)$

$A_{st} = 2865 mm^2$

Provide 25mm diameter bars

Number of bars = $\frac{2865}{\frac{\pi}{4} \times 25^2} = 6$

Minimum $A_{st} = \frac{0.85}{fy} bd = \frac{0.85}{250} \times 266 \times 492 = 445\ mm^2$

$A_{st\ min} = 445\ mm^2$

**Calculation of shear reinforcement :**

Dead load = 0.266 × 0.532 × 1 × 25 = 3.537 KN/m

Live load = 190 KN/m

Factored load = 190 + 3.537 = 193.537 KN/m

$$V_u = \frac{wl}{2} = \frac{193.537 \times 2.5}{2} = 242\ KN$$

$\tau_c$ *for* $M_{20}$ from IS456-2000

$100 \times \frac{A_{st}}{b \times d} = 100 \times \frac{2865}{266 \times 532} = 2.189$

$\tau_c = 0.8\ N/mm^2$

$\tau_{cmax} = 2.8\ N/mm^2$ for M20

$\tau_v = \frac{V_u}{bd} = \frac{242}{266 \times 532} = 1.848\ N/mm^2$

$\tau_v > \tau_c$

Design shear

$V_u = V_{us} + V_{uc}$

$V_{uc} = \tau_c \times bd = 0.8 \times 266 \times 492 = 104697.6$ N

$V_{us} = V_u - V_{uc} = 242000 - 104697.6 = 137224$ KN

Use 8mm diameter, 2-legged stirrups

$A_{sv} = 2 \times \frac{\pi}{4} \times 8^2 = 100.5\ mm^2$

$S_v = \frac{0.87 \times f_y \times A_{sv} \times d}{V_{us}} = \frac{0.87 \times 250 \times 100.5 \times 492}{137224} = 75$ mm

**Calculation of development length :**

$L_d = \frac{\phi \sigma_s}{4 \times \tau_{bd}} = \frac{25 \times 0.87 \times 250}{4 \times 1.2 \times 1.6} = 708$ mm

$L_d \le (\frac{M_1}{V} + L_0)$

$= (\frac{222.65 \times 10^6}{242000} + (x_0 + 8\phi))$

$= \frac{222.65 \times 10^6}{242000} + (125 + (8 \times 25))$

$= 1245.04$ mm

Therefore development length $L_d$ = 708mm

Similarly for different grades of steel (Fe250, Fe415 and Fe500), different grades of concrete (M20, M25 and M30) and beam width to total depth ratios (0.5,0.6 and 0.7) are designed and presented in Table I, Table II and Table III respectively.

TABLE I
DESIGN DETAILS OF REINFORCED CONCRETE BEAM WITH DESIGN REINFORCEMENT (Fe250)

| Grade of steel | b/D | Grade of concrete | Width b (mm) | Total depth D (mm) | Design steel $A_{st}$ $(mm^2)$ | Minimum steel $A_{st\ min}$ $(mm^2)$ |
|---|---|---|---|---|---|---|
| Fe250 | 0.5 | M20 | 266 | 532 | 2865 | 445 |
| | | M25 | 247 | 494 | 3127 | 381 |
| | | M30 | 233 | 466 | 3340 | 337 |
| | 0.6 | M20 | 301 | 502 | 3060 | 473 |
| | | M25 | 279 | 465 | 3362 | 403 |
| | | M30 | 263 | 439 | 3603 | 357 |
| | 0.7 | M20 | 333 | 476 | 3272 | 494 |
| | | M25 | 309 | 442 | 3589 | 422 |
| | | M30 | 291 | 416 | 3861 | 372 |

TABLE II
DESIGN DETAILS OF REINFORCED CONCRETE BEAM WITH DESIGN REINFORCEMENT (Fe415)

| Grade of steel | b/D | Grade of concrete | Width b(mm) | Total depth D(mm) | Design steel $A_{st}$ $(mm^2)$ | Minimum steel $A_{st\ min}$ $(mm^2)$ |
|---|---|---|---|---|---|---|
| Fe415 | 0.5 | M20 | 273 | 546 | 1607 | 283 |
| | | M25 | 253 | 506 | 1760 | 241 |
| | | M30 | 238 | 476 | 1892 | 213 |
| | 0.6 | M20 | 308 | 514 | 1728 | 299 |
| | | M25 | 286 | 477 | 1885 | 256 |
| | | M30 | 269 | 449 | 2029 | 225 |
| | 0.7 | M20 | 341 | 488 | 1840 | 313 |
| | | M25 | 317 | 453 | 2003 | 268 |
| | | M30 | 298 | 426 | 2161 | 236 |

TABLIII
DESIGN DETAILS OF REINFORCED CONCRETE BEAM WITH DESIGN REINFORCEMENT (Fe500)

| Grade of steel | b/D | Grade of concrete | Width b (mm) | Total depth D (mm) | Design steel $A_{st}$ $(mm^2)$ | Minimum steel $A_{st\ min}$ $(mm^2)$ |
|---|---|---|---|---|---|---|
| Fe500 | 0.5 | M20 | 276 | 552 | 1298 | 240 |
| | | M25 | 256 | 512 | 1417 | 205 |
| | | M30 | 241 | 482 | 1520 | 181 |
| | 0.6 | M20 | 311 | 519 | 1399 | 253 |
| | | M25 | 289 | 482 | 1522 | 217 |
| | | M30 | 272 | 454 | 1635 | 191 |
| | 0.7 | M20 | 345 | 493 | 1482 | 266 |
| | | M25 | 320 | 458 | 1621 | 227 |
| | | M30 | 301 | 430 | 1745 | 200 |

## III. Finite Element Modelling

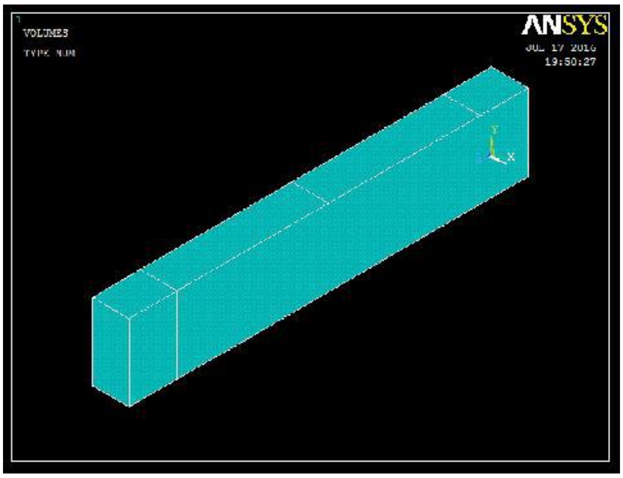


Figure 2. 3D Modeling of concrete beam

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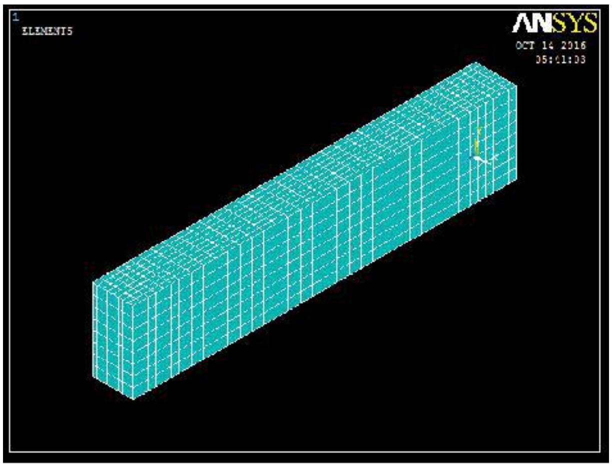


Figure 3. Elements of concrete beam

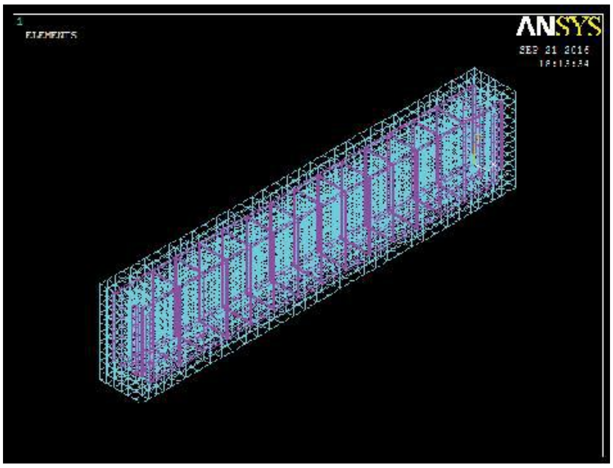


Figure 4. 3D Modeling of reinforced concrete beam

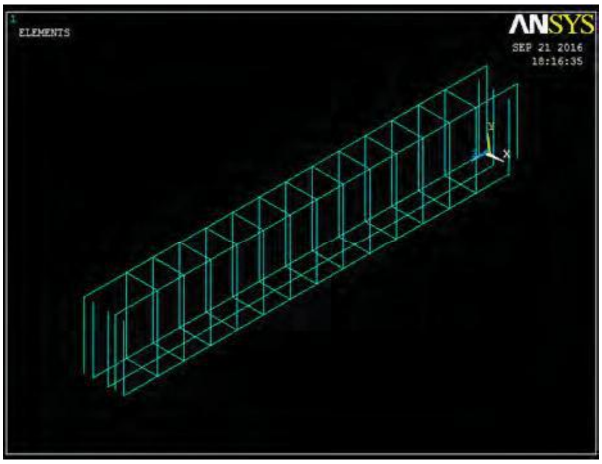


Figure 5. Reinforcement of beam

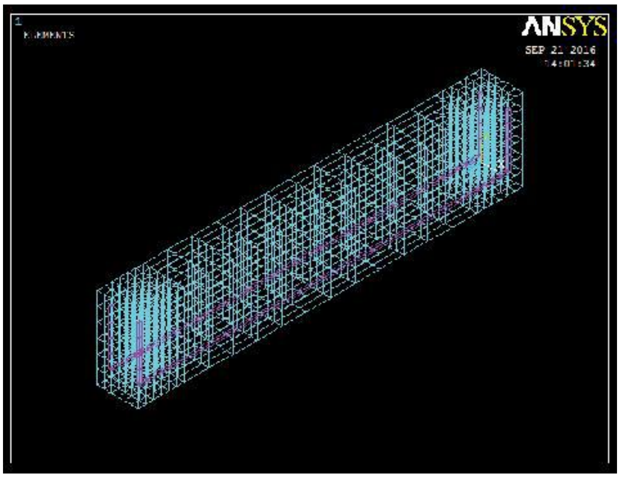


Figure 6. 3D Modeling of nominal tension reinforced concrete beam

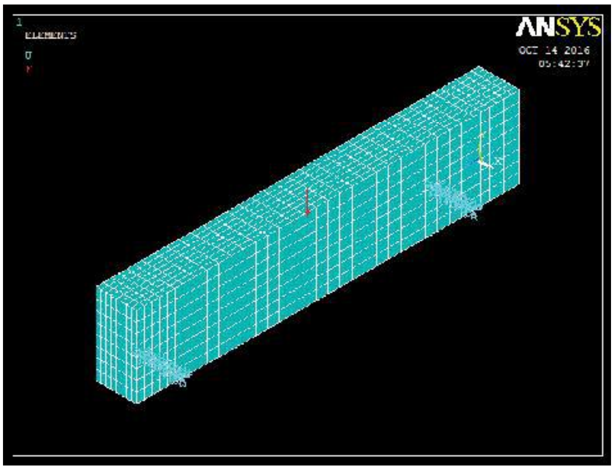


Figure 7. Application of load on reinforced concrete beam

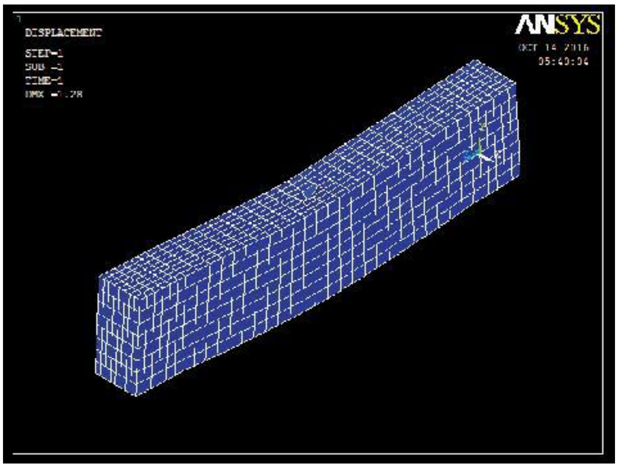


Figure 8. Deformed shape of reinforced concrete beam

DOI:10.32377/cvrjst1201

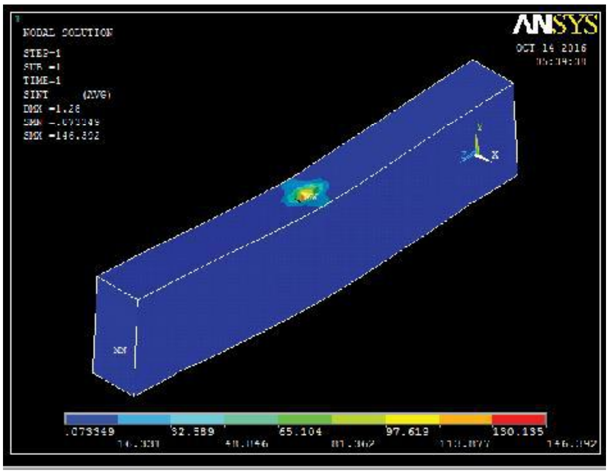


Figure 9. Stress intensity of reinforced concrete beam

## IV. Analysis Of Reinforced Concrete Beams

In the present paper, the flexural behavior of reinforced concrete beams with minimum flexural tension reinforcement and the beams with the design reinforcement was studied by varying the concrete grades (M20,M25 and M30), grades of steel (Fe250,Fe415 and Fe500) and different beam width-to-depth ratios (0.5,0.6 and 0.7) under three point bending using ANSYS 12.1 version[12] through load-deflection diagrams. The variation of deflection, strain energy and stress intensity factor was studied for different beam width-to-depth ratios and different grades of concrete and steel and presented in Table IV to Table IX. Twenty seven reinforced concrete beams with minimum flexural reinforcement and twenty seven reinforced concrete beams with design reinforcement have been modeled and analysed in ANSYS and presented in Figure 2 to Figure 9. Total beams modeled and analysed were fifty four. The variation in the flexural behaviour of RC beams is studied with minimum Tension reinforcement and Design Tension reinforcement for different grades of steel and presented in Table X to Table XV and Figure 10 to Figure 21 respectively. Similarly the variation in the flexural behavior of RC beams is also studied using minimum Tension reinforcement and Design Tension reinforcement for different $\left(\frac{b}{D}\right)$ ratios and presented in Table XVI to Table XXI and Figure 22 to Figure 33 respectively.

TABLE IV
REINFORCED CONCRETE BEAM WITH MINIMUM TENSION REINFORCEMENT (Fe250)

| Grade of steel | b/D | Grade of concrete | Peak load $P_{max}$ | Max deflection $\Delta_{max}$ | Strain Energy N-mm | Stress intensity factor N/$mm^2$ |
|---|---|---|---|---|---|---|
| Fe250 | 0.5 | M20 | 483840 | 1.01 | 244339 | 54.564 |
| | | M25 | 482620 | 1.069 | 257960 | 58.645 |
| | | M30 | 481780 | 1.126 | 271242 | 62.064 |
| | 0.6 | M20 | 484430 | 1.003 | 242942 | 54.021 |
| | | M25 | 483100 | 1.073 | 259183 | 58.152 |
| | | M30 | 482200 | 1.133 | 273166 | 61.497 |
| | 0.7 | M20 | 485000 | 1.009 | 244682 | 53.484 |
| | | M25 | 483500 | 1.079 | 260848 | 57.436 |
| | | M30 | 482500 | 1.151 | 277679 | 60.849 |

TABLE V
REINFORCED CONCRETE BEAM WITH MINIMUM TENSION REINFORCEMENT (Fe415)

| Grade of steel | b/D | Grade of concrete | Peak load $P_{max}$ | Max deflection $\Delta_{max}$ | Strain Energy N-mm | Stress intensity factor N/$mm^2$ |
|---|---|---|---|---|---|---|
| Fe415 | 0.5 | M20 | 484300 | 0.957 | 231738 | 53.196 |
| | | M25 | 483000 | 1.013 | 244639.5 | 57.292 |
| | | M30 | 482000 | 1.07 | 257870 | 60.788 |
| | 0.6 | M20 | 485000 | 0.956 | 231830 | 52.823 |
| | | M25 | 483500 | 1.012 | 244651 | 56.753 |
| | | M30 | 482500 | 1.073 | 258861 | 60.174 |
| | 0.7 | M20 | 485380 | 0.957 | 232254 | 52.226 |
| | | M25 | 484000 | 1.017 | 246114 | 56.08 |
| | | M30 | 483000 | 1.085 | 262027.5 | 59.497 |

TABLE VI
REINFORCED CONCRETE BEAM WITH MINIMUM TENSION REINFORCEMENT (Fe500)

| Grade of steel | b/D | Grade of concrete | Peak load $P_{max}$ | Max deflection $\Delta_{max}$ | Strain Energy N-mm | Stress intensity factor N/$mm^2$ |
|---|---|---|---|---|---|---|
| Fe500 | 0.5 | M20 | 484500 | 0.937 | 226988 | 52.631 |
| | | M25 | 483000 | 0.986 | 238119 | 56.616 |
| | | M30 | 482000 | 1.037 | 249917 | 60.031 |
| | 0.6 | M20 | 485000 | 0.936 | 226980 | 52.309 |
| | | M25 | 483700 | 0.988 | 238948 | 56.186 |
| | | M30 | 483000 | 1.044 | 252126 | 59.577 |
| | 0.7 | M20 | 485600 | 0.935 | 227018 | 51.681 |
| | | M25 | 484140 | 0.993 | 240375 | 55.522 |
| | | M30 | 483000 | 1.058 | 255507 | 58.932 |

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TABLE VII
REINFORCED CONCRETE BEAM WITH DESIGN TENSION REINFORCEMENT (Fe250)

| Grade of steel | b/D | Grade of concrete | Peak load $P_{max}$ | Max deflection $\Delta_{max}$ | Strain Energy N-mm | Stress intensity factor N/$mm^2$ |
|---|---|---|---|---|---|---|
| Fe250 | 0.5 | M20 | 483840 | 1.28 | 309657 | 146.392 |
| | | M25 | 482620 | 1.314 | 317081 | 156.926 |
| | | M30 | 481780 | 1.347 | 324478 | 167.464 |
| | 0.6 | M20 | 484430 | 1.289 | 312215 | 149.408 |
| | | M25 | 483100 | 1.323 | 319570 | 159.068 |
| | | M30 | 482200 | 1.356 | 326931 | 168.69 |
| | 0.7 | M20 | 485000 | 1.298 | 314765 | 149.392 |
| | | M25 | 483500 | 1.332 | 322011 | 159.378 |
| | | M30 | 482500 | 1.365 | 329306 | 169.916 |

TABLE VIII
REINFORCED CONCRETE BEAM WITH DESIGN TENSION REINFORCEMENT (Fe415)

| Grade of steel | b/D | Grade of concrete | Peak load $P_{max}$ | Maximum deflection $\Delta_{max}$ | Strain Energy N-mm | Stress intensity factor N/$mm^2$ |
|---|---|---|---|---|---|---|
| Fe415 | 0.5 | M20 | 484300 | 1.043 | 252562 | 87.65 |
| | | M25 | 483000 | 1.123 | 271204 | 106.892 |
| | | M30 | 482000 | 1.203 | 289923 | 126.134 |
| | 0.6 | M20 | 485000 | 1.143 | 277177 | 92.675 |
| | | M25 | 483500 | 1.157 | 279704 | 111.917 |
| | | M30 | 482500 | 1.237 | 298426 | 130.152 |
| | 0.7 | M20 | 485380 | 1.242 | 301421 | 97.421 |
| | | M25 | 484000 | 1.256 | 303952 | 115.654 |
| | | M30 | 483000 | 1.27 | 306705 | 133.887 |

TABLE IX
REINFORCED CONCRETE BEAM WITH DESIGN TENSION REINFORCEMENT (Fe500)

| Grade of steel | b/D | Grade of concrete | Peak load $P_{max}$ | Maximum deflection $\Delta_{max}$ | Strain Energy N-mm | Stress intensity factor N/$mm^2$ |
|---|---|---|---|---|---|---|
| Fe500 | 0.5 | M20 | 484500 | 0.948 | 229653 | 64.532 |
| | | M25 | 483000 | 1.031 | 248986 | 79.958 |
| | | M30 | 482000 | 1.113 | 268233 | 95.384 |
| | 0.6 | M20 | 485000 | 0.964 | 233770 | 67.417 |
| | | M25 | 483700 | 1.047 | 253217 | 82.843 |
| | | M30 | 483000 | 1.133 | 273619 | 101.863 |
| | 0.7 | M20 | 485600 | 0.982 | 238429 | 70.303 |
| | | M25 | 484140 | 1.067 | 258288 | 89.322 |
| | | M30 | 483000 | 1.153 | 278449 | 108.342 |

TABLE X
REINFORCED CONCRETE BEAM WITH MINIMUM TENSION REINFORCEMENT (Fe250)

| Grade of steel | Grade of concrete | b/D | Peak load $P_{max}$ | Maximum deflection $\Delta_{max}$ | Strain Energy N-mm | Stress intensity factor N/$mm^2$ |
|---|---|---|---|---|---|---|
| Fe250 | M20 | 0.5 | 483840 | 1.01 | 244339 | 54.564 |
| | | 0.6 | 484430 | 1.003 | 242942 | 54.021 |
| | | 0.7 | 485000 | 1.009 | 244682 | 53.484 |
| | M25 | 0.5 | 482620 | 1.069 | 257960 | 58.645 |
| | | 0.6 | 483100 | 1.073 | 259183 | 58.152 |
| | | 0.7 | 483500 | 1.079 | 260848 | 57.436 |
| | M30 | 0.5 | 481780 | 1.126 | 271242 | 62.064 |
| | | 0.6 | 482200 | 1.133 | 273166 | 61.497 |
| | | 0.7 | 482500 | 1.151 | 277679 | 60.849 |

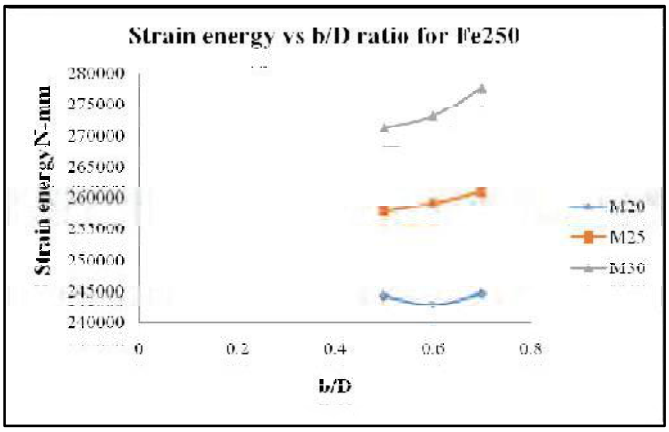


Figure10. Strain energy vs b/D ratio for Fe250

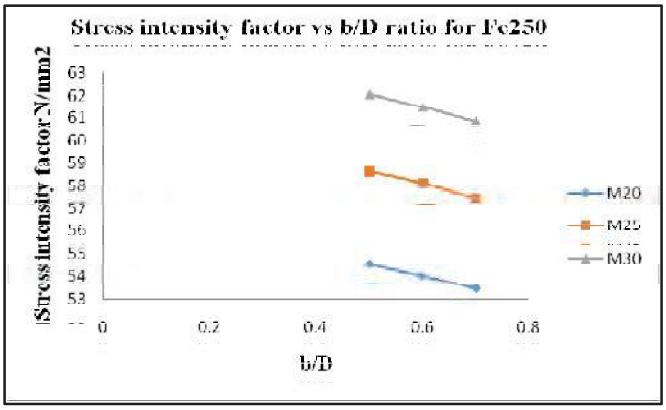


Figure11. Stress intensity factor vs b/D ratio for Fe250

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TABLE XI
REINFORCED CONCRETE BEAM WITH MINIMUM TENSION REINFORCEMENT (Fe415)

| Grade of steel | Grade of concrete | b/D | Peak load $P_{max}$ | Maximum deflection $\Delta_{max}$ | Strain Energy N-mm | Stress intensity factor N/$mm^2$ |
|---|---|---|---|---|---|---|
| Fe415 | M20 | 0.5 | 484300 | 0.957 | 231738 | 53.196 |
| | | 0.6 | 485000 | 0.956 | 231830 | 52.823 |
| | | 0.7 | 485380 | 0.957 | 232254 | 52.226 |
| | M25 | 0.5 | 483000 | 1.013 | 244639 | 57.292 |
| | | 0.6 | 483500 | 1.012 | 244651 | 56.753 |
| | | 0.7 | 484000 | 1.017 | 246114 | 56.08 |
| | M30 | 0.5 | 482000 | 1.07 | 257870 | 60.788 |
| | | 0.6 | 482500 | 1.073 | 258861 | 60.174 |
| | | 0.7 | 483000 | 1.085 | 262027 | 59.497 |

TABLE XII
REINFORCED CONCRETE BEAM WITH MINIMUM TENSION REINFORCEMENT (Fe500)

| Grade of steel | Grade of concrete | b/D | Peak load $P_{max}$ | Maximum deflection $\Delta_{max}$ | Strain Energy N-mm | Stress intensity factor N/$mm^2$ |
|---|---|---|---|---|---|---|
| Fe500 | M20 | 0.5 | 484500 | 0.937 | 226988 | 52.631 |
| | | 0.6 | 485000 | 0.936 | 226980 | 52.309 |
| | | 0.7 | 485600 | 0.935 | 227018 | 51.681 |
| | M25 | 0.5 | 483000 | 0.986 | 238119 | 56.616 |
| | | 0.6 | 483700 | 0.988 | 238948 | 56.186 |
| | | 0.7 | 484140 | 0.993 | 240375 | 55.522 |
| | M30 | 0.5 | 482000 | 1.037 | 249917 | 60.031 |
| | | 0.6 | 483000 | 1.044 | 252126 | 59.577 |
| | | 0.7 | 483000 | 1.058 | 255507 | 58.932 |

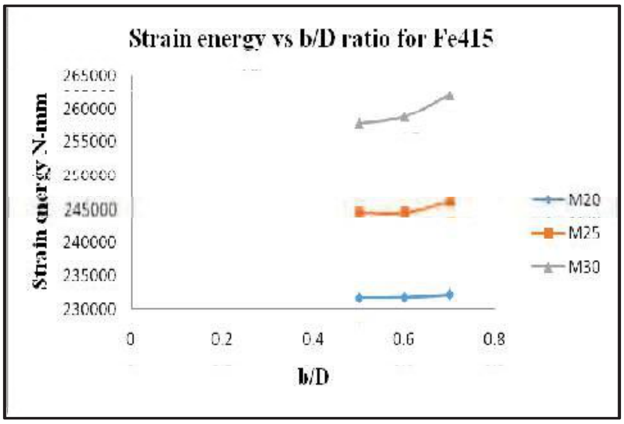


Figure12. Strain energy vs b/D ratio for Fe415

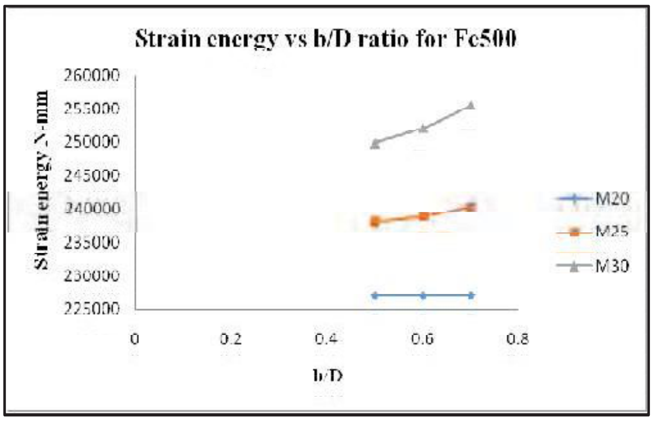


Figure14. Strain energy vs b/D ratio for Fe500

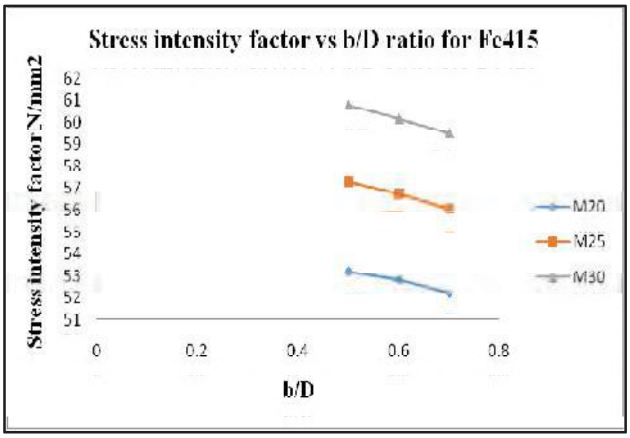


Figure13. Stress intensity factor vs b/D ratio for Fe415

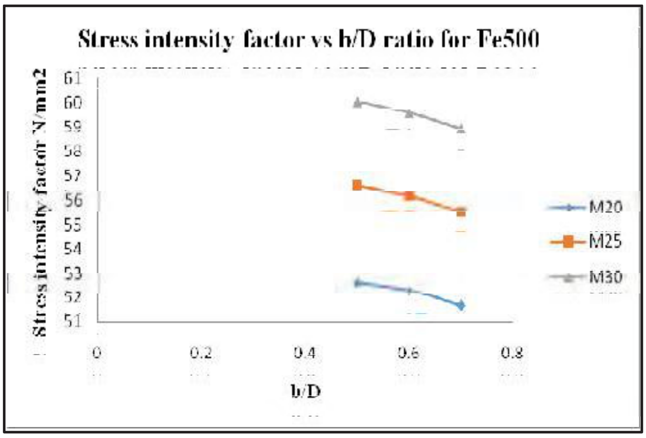


Figure15. Stress intensity factor vs b/D ratio for Fe500

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TABLE XIII
REINFORCED CONCRETE BEAM WITH DESIGN TENSION REINFORCEMENT (Fe250)

| Grade of steel | Grade of concrete | b/D | Peak load $P_{max}$ | Maximum deflection $\Delta_{max}$ | Strain Energy N-mm | Stress intensity factor N/$mm^2$ |
|---|---|---|---|---|---|---|
| Fe250 | M20 | 0.5 | 483840 | 1.28 | 309657 | 146.392 |
| | | 0.6 | 484430 | 1.289 | 312215 | 149.408 |
| | | 0.7 | 485000 | 1.298 | 314765 | 149.392 |
| | M25 | 0.5 | 482620 | 1.314 | 317081 | 156.926 |
| | | 0.6 | 483100 | 1.323 | 319570 | 159.068 |
| | | 0.7 | 483500 | 1.332 | 322011 | 159.378 |
| | M30 | 0.5 | 481780 | 1.347 | 324478 | 167.464 |
| | | 0.6 | 482200 | 1.356 | 326931 | 168.69 |
| | | 0.7 | 482500 | 1.365 | 329306 | 169.916 |

TABLE XIV
REINFORCED CONCRETE BEAM WITH DESIGN TENSION REINFORCEMENT (Fe415)

| Grade of steel | Grade of concrete | b/D | Peak load $P_{max}$ | Maximum deflection $\Delta_{max}$ | Strain Energy N-mm | Stress intensity factor N/$mm^2$ |
|---|---|---|---|---|---|---|
| Fe415 | M20 | 0.5 | 484300 | 1.043 | 252562 | 87.65 |
| | | 0.6 | 485000 | 1.143 | 277177 | 92.675 |
| | | 0.7 | 485380 | 1.242 | 301421 | 97.421 |
| | M25 | 0.5 | 483000 | 1.123 | 271204 | 106.892 |
| | | 0.6 | 483500 | 1.157 | 279704 | 111.917 |
| | | 0.7 | 484000 | 1.256 | 303952 | 115.654 |
| | M30 | 0.5 | 482000 | 1.203 | 289923 | 126.134 |
| | | 0.6 | 482500 | 1.237 | 298426 | 130.152 |
| | | 0.7 | 483000 | 1.27 | 306705 | 133.887 |

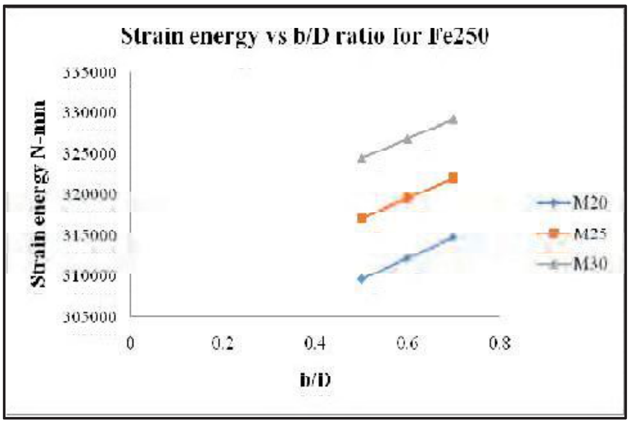


Figure16. Strain energy vs b/D ratio for Fe250

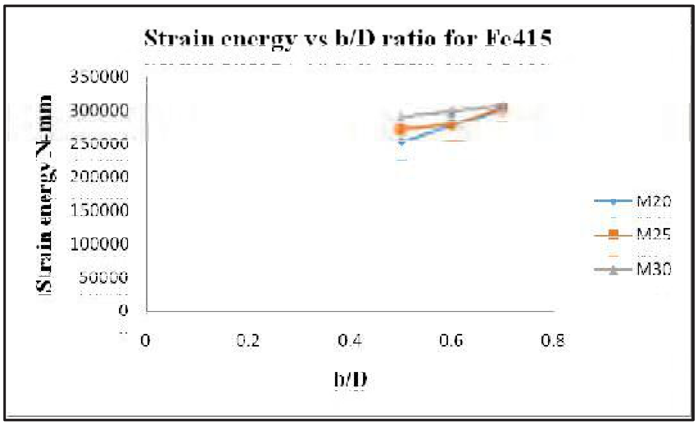


Figure18. Strain energy vs b/D ratio for Fe415

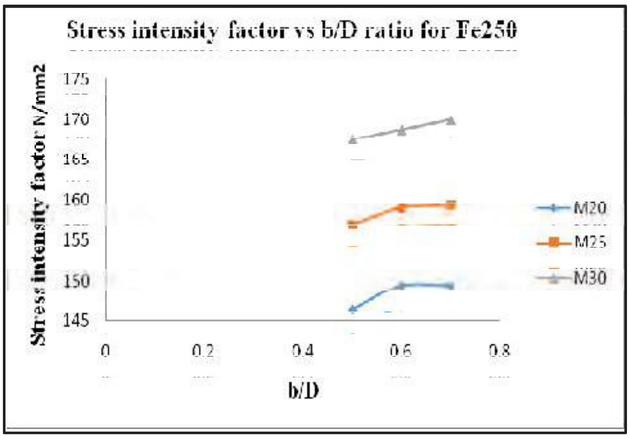


Figure17. Stress intensity factor vs b/D ratio for Fe250

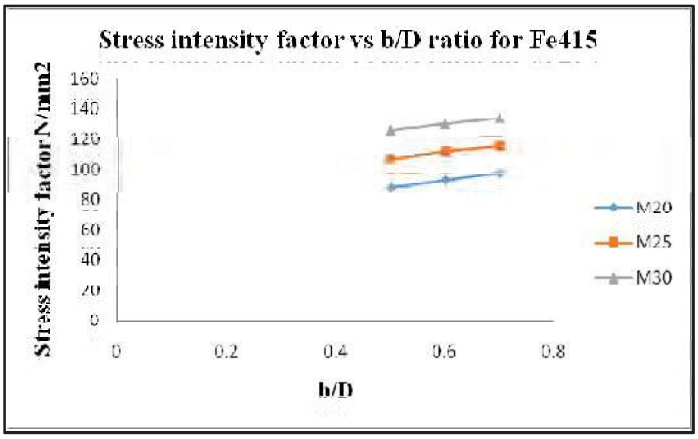


Figure19. Stress intensity factor vs b/D ratio for Fe415

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TABLE XV
REINFORCED CONCRETE BEAM WITH DESIGN TENSION REINFORCEMENT (Fe500)

| Grade of steel | Grade of concrete | b/D | Peak load $P_{max}$ | Maximum deflection $\Delta_{max}$ | Strain Energy N-mm | Stress intensity factor N/$mm^2$ |
|---|---|---|---|---|---|---|
| Fe500 | M20 | 0.5 | 484500 | 0.948 | 229653 | 64.53 |
| | | 0.6 | 485000 | 0.964 | 233770 | 67.41 |
| | | 0.7 | 485600 | 0.982 | 238429 | 70.30 |
| | M25 | 0.5 | 483000 | 1.031 | 248986 | 79.95 |
| | | 0.6 | 483700 | 1.047 | 253217 | 82.84 |
| | | 0.7 | 484140 | 1.067 | 258288 | 89.32 |
| | M30 | 0.5 | 482000 | 1.113 | 268233 | 95.38 |
| | | 0.6 | 483000 | 1.133 | 273619 | 101.86 |
| | | 0.7 | 483000 | 1.153 | 278449 | 108.34 |

TABLE XVI
REINFORCED CONCRETE BEAM WITH MINIMUM TENSION REINFORCEMENT (b/D=0.5)

| b/D | Grade of concrete | Grade of steel | Peak load $P_{max}$ | Maximum deflection $\Delta_{max}$ | Strain Energy N-mm | Stress intensity factor N/$mm^2$ |
|---|---|---|---|---|---|---|
| 0.5 | M20 | Fe250 | 483840 | 1.01 | 244339 | 54.564 |
| | | Fe415 | 484300 | 0.957 | 231738 | 53.196 |
| | | Fe500 | 484500 | 0.937 | 226988 | 52.631 |
| | M25 | Fe250 | 482620 | 1.069 | 257960 | 58.645 |
| | | Fe415 | 483000 | 1.013 | 244639 | 57.292 |
| | | Fe500 | 483000 | 0.986 | 238119 | 56.616 |
| | M30 | Fe250 | 481780 | 1.126 | 271242 | 62.064 |
| | | Fe415 | 482000 | 1.07 | 257870 | 60.788 |
| | | Fe500 | 482000 | 1.037 | 249917 | 60.031 |

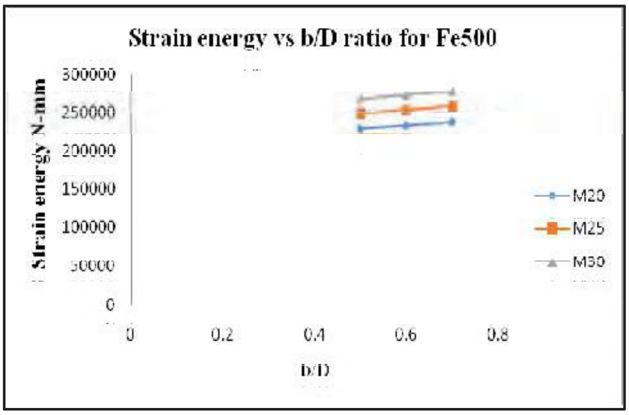


Figure20. Strain energy vs b/D ratio for Fe500

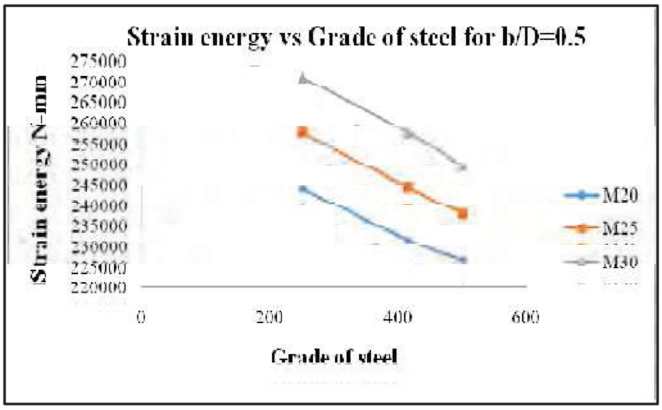


Figure22. Strain energy vs grade of steel for b/D=0.5

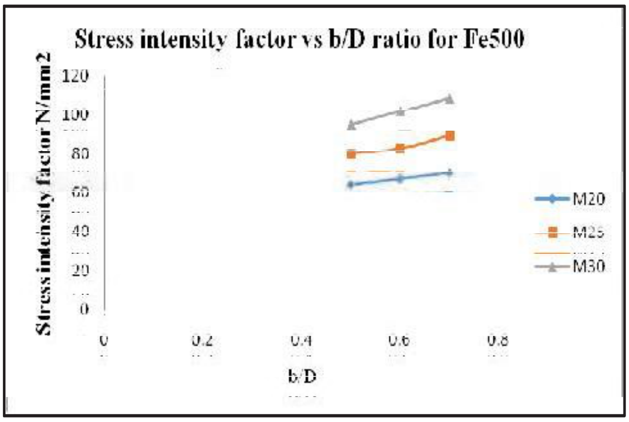


Figure21. Stress intensity factor vs b/D ratio for Fe500

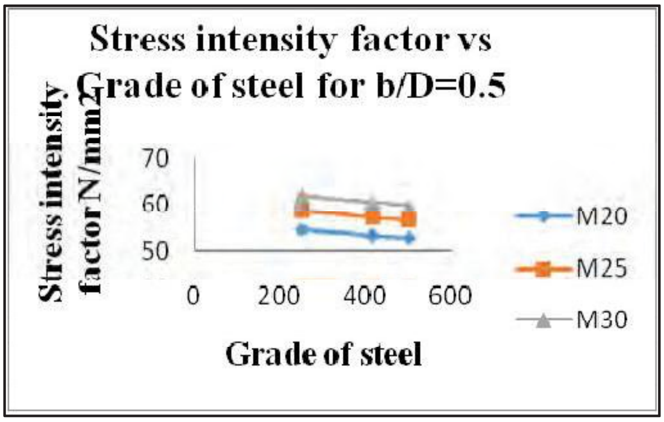


Figure23. Stress intensity factor vs grade of steel for b/D=0.5

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TABLE XVII
REINFORCED CONCRETE BEAM WITH MINIMUM TENSION REINFORCEMENT (b/D=0.6)

| b/D | Grade of concrete | Grade of steel | Peak load $P_{max}$ | Maximum deflection $\Delta_{max}$ | Strain Energy N-mm | Stress intensity factor N/$mm^2$ |
|---|---|---|---|---|---|---|
| 0.6 | M20 | Fe250 | 484430 | 1.003 | 242942 | 54.021 |
| | | Fe415 | 485000 | 0.956 | 231830 | 52.823 |
| | | Fe500 | 485000 | 0.936 | 226980 | 52.309 |
| | M25 | Fe250 | 483100 | 1.073 | 259183 | 58.152 |
| | | Fe415 | 483500 | 1.012 | 244651 | 56.753 |
| | | Fe500 | 483700 | 0.988 | 238948 | 56.186 |
| | M30 | Fe250 | 482200 | 1.133 | 273166 | 61.497 |
| | | Fe415 | 482500 | 1.073 | 258861 | 60.174 |
| | | Fe500 | 483000 | 1.044 | 252126 | 59.577 |

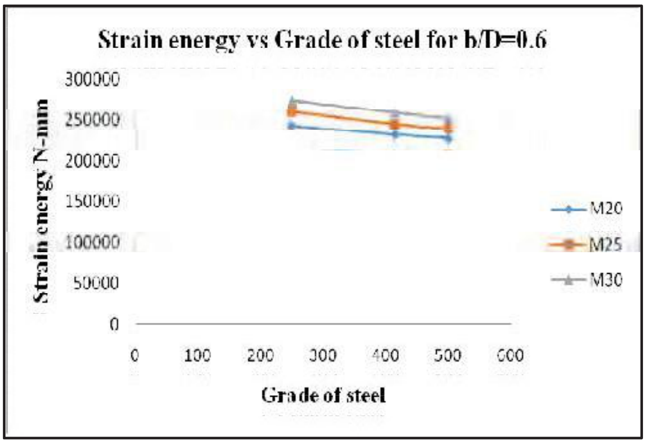


Figure24. Strain energy vs grade of steel for b/D=0.6

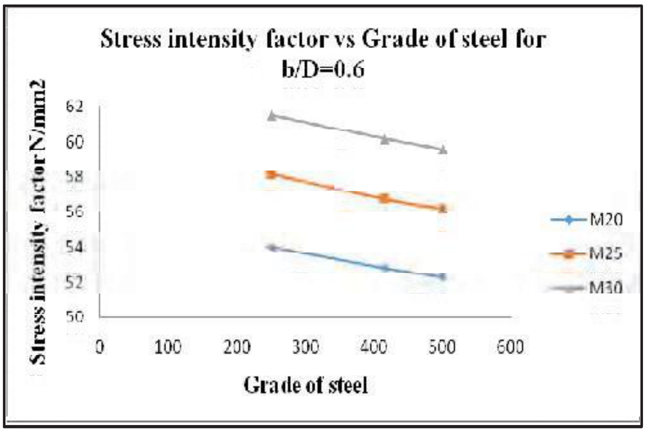


Figure25. Stress intensity factor vs grade of steel for b/D=0.6

TABLE XVIII
REINFORCED CONCRETE BEAM WITH MINIMUM TENSION REINFORCEMENT (b/D=0.7)

| b/D | Grade of concrete | Grade of steel | Peak load $P_{max}$ | Maximum deflection $\Delta_{max}$ | Strain Energy N-mm | Stress intensity factor N/$mm^2$ |
|---|---|---|---|---|---|---|
| 0.7 | M20 | Fe250 | 485000 | 1.009 | 244682 | 53.484 |
| | | Fe415 | 485380 | 0.957 | 232254 | 52.226 |
| | | Fe500 | 485600 | 0.935 | 227018 | 51.681 |
| | M25 | Fe250 | 483500 | 1.079 | 260848 | 57.436 |
| | | Fe415 | 484000 | 1.017 | 246114 | 56.08 |
| | | Fe500 | 484140 | 0.993 | 240375 | 55.522 |
| | M30 | Fe250 | 482500 | 1.151 | 277679 | 60.849 |
| | | Fe415 | 483000 | 1.085 | 262027 | 59.497 |
| | | Fe500 | 483000 | 1.058 | 255507 | 58.932 |

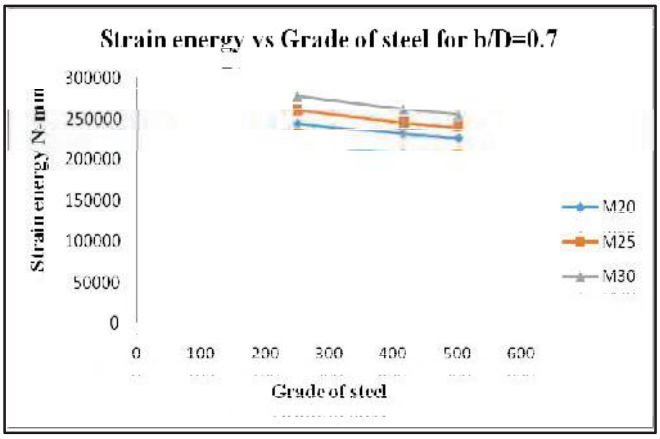


Figure26. Strain energy vs grade of steel for b/D=0.7

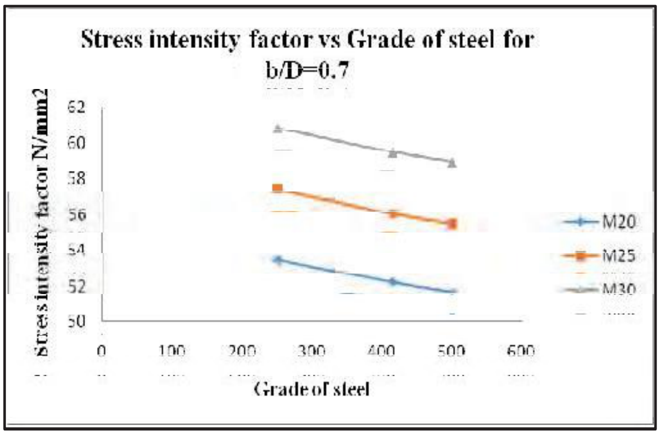


Figure27. Stress intensity factor vs grade of steel for b/D=0.7

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TABLE XIX
REINFORCED CONCRETE BEAM WITH DESIGN TENSION REINFORCEMENT (b/D=0.5)

| b/D | Grade of concrete | Grade of steel | Peak load $P_{max}$ | Maximum deflection $\Delta_{max}$ | Strain Energy N-mm | Stress intensity factor N/ $mm^2$ |
|---|---|---|---|---|---|---|
| 0.5 | M20 | Fe250 | 483840 | 1.28 | 309657 | 146.392 |
| | | Fe415 | 484300 | 1.043 | 252562 | 87.65 |
| | | Fe500 | 484500 | 0.948 | 229653 | 64.532 |
| | M25 | Fe250 | 482620 | 1.314 | 317081 | 156.926 |
| | | Fe415 | 483000 | 1.123 | 271204 | 106.892 |
| | | Fe500 | 483000 | 1.031 | 24898 | 79.958 |
| | M30 | Fe250 | 481780 | 1.347 | 324478 | 167.464 |
| | | Fe415 | 482000 | 1.203 | 289923 | 126.134 |
| | | Fe500 | 482000 | 1.113 | 268233 | 95.384 |

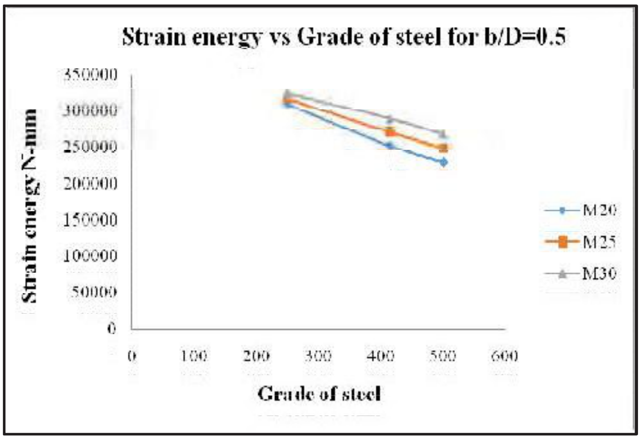


Figure28. Strain energy vs grade of steel for b/D=0.5

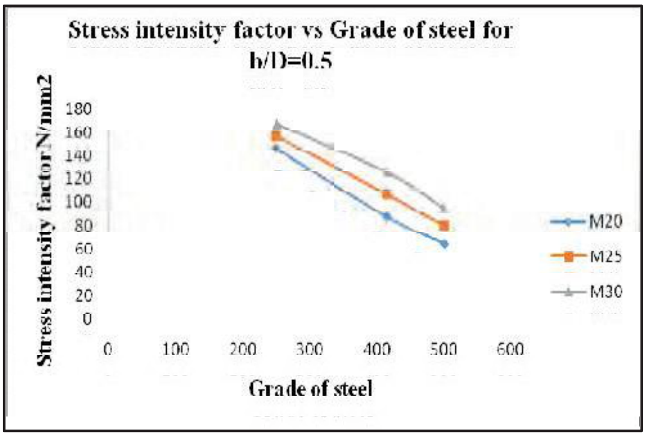


Figure29. Stress intensity factor vs grade of steel for b/D=0.5

TABLE XX
REINFORCED CONCRETE BEAM WITH DESIGN TENSION REINFORCEMENT (b/D=0.6)

| b/D | Grade of concrete | Grade of steel | Peak load $P_{max}$ | Maximum deflection $\Delta_{max}$ | Strain Energy N-mm | Stress intensity factor N/$mm^2$ |
|---|---|---|---|---|---|---|
| 0.6 | M20 | Fe250 | 484430 | 1.289 | 312215 | 149.408 |
| | | Fe415 | 485000 | 1.143 | 277177 | 92.675 |
| | | Fe500 | 485000 | 0.964 | 233770 | 67.417 |
| | M25 | Fe250 | 483100 | 1.323 | 319570 | 159.068 |
| | | Fe415 | 483500 | 1.157 | 279704 | 111.917 |
| | | Fe500 | 483700 | 1.047 | 253217 | 82.843 |
| | M30 | Fe250 | 482200 | 1.356 | 326931 | 168.69 |
| | | Fe415 | 482500 | 1.237 | 298426 | 130.152 |
| | | Fe500 | 483000 | 1.133 | 273619 | 101.863 |

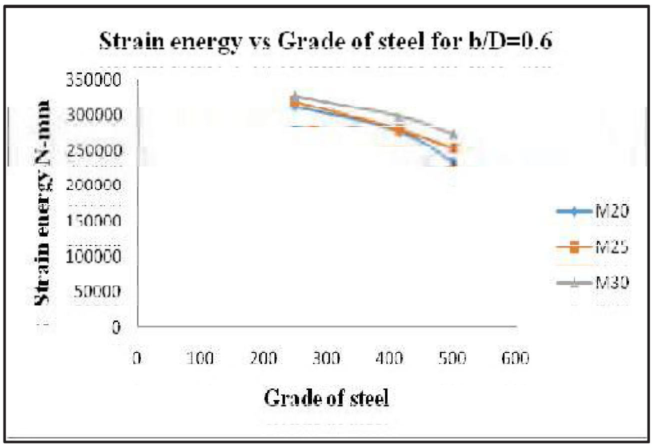


Figure30. Strain energy vs grade of steel for b/D=0.6

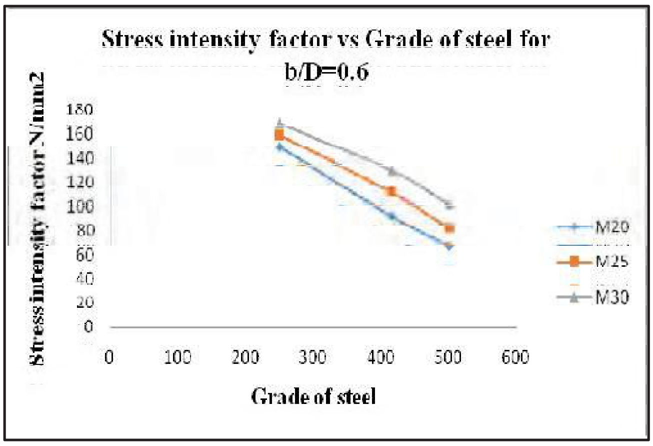


Figure31. Stress intensity factor vs grade of steel for b/D=0.6

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TABLE XXI
REINFORCED CONCRETE BEAM WITH DESIGN TENSION REINFORCEMENT (b/D=0.7)

| b/D | Grade of concrete | Grade of steel | Peak load $P_{max}$ | Max deflection $\Delta_{max}$ | Strain Energy N-mm | Stress intensity factor $N/mm^2$ |
|---|---|---|---|---|---|---|
| | M20 | Fe250 | 485000 | 1.298 | 314765 | 149.392 |
| | | Fe415 | 485380 | 1.242 | 301421 | 97.421 |
| | | Fe500 | 485600 | 0.982 | 238429 | 70.303 |
| | M25 | Fe250 | 483500 | 1.332 | 322011 | 159.378 |
| | | Fe415 | 484000 | 1.256 | 303952 | 115.654 |
| | | Fe500 | 484140 | 1.067 | 258288 | 89.322 |
| | M30 | Fe250 | 482500 | 1.365 | 329306 | 169.916 |
| | | Fe415 | 483000 | 1.27 | 306705 | 133.887 |
| | | Fe500 | 483000 | 1.153 | 278449 | 108.342 |

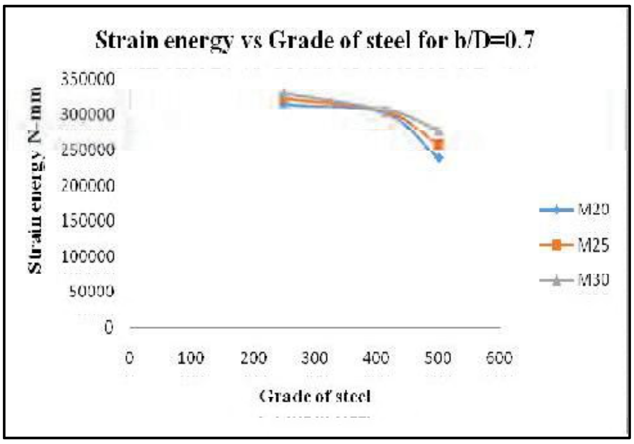


Figure32. Strain energy vs grade of steel for b/D=0.7

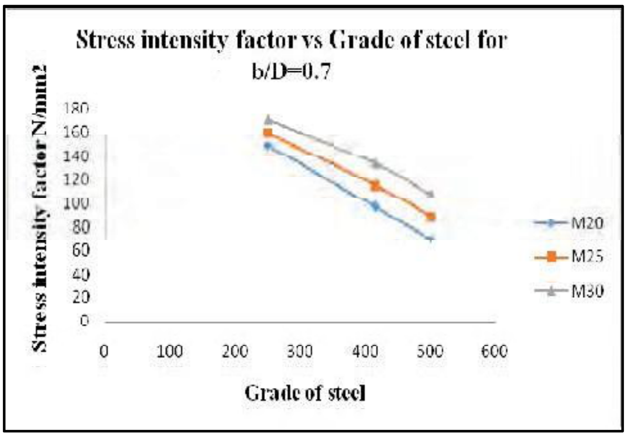


Figure33. Stress intensity factor vs grade of steel for b/D=0.7

## V. CONCLUSIONS

The flexural behavior of the reinforcedconcrete beams of different grades of steel (Fe250, Fe415 and Fe500), different grades of concrete (M20, M25 and M30) and width to total depth ratios (0.5, 0.6 and 0.7) has been analyzed based on the modelling of beams in ANSYS and the variation of strain energy and stress intensity factor has been studied and presented below.

**Reinforced concrete beams with minimum flexural reinforcement:**

1. In case of Reinforced concrete beams with minimum flexural reinforcement, for a particular grade of steel and b/D ratio, the strain energy and stress intensity factor was observed to be increasing with the increasing grade of concrete.
2. Similarly, for a particular grade of steel and grade of concrete, the Reinforced concrete beams with minimum flexural reinforcement have shown that the strain energy as increasing with the increasing b/D ratio.
3. For a particular grade of steel and grade of concrete, Reinforced concrete beams with minimum flexural reinforcement have shown that the stress intensity factor was decreasing with the increase in b/D ratio.
4. Similarly, for a particular b/D ratio and grade of concrete, Reinforced concrete beams with minimum flexural reinforcement have shown that the strain energy and stress intensity factor as decreasing with the increasing grade of steel.

**Reinforced concrete beams with designed reinforcement:**

1. In case of Reinforced concrete beams with designed reinforcement, for a particular grade of steel and b/D ratio, the strain energy and stress intensity factor was observed to be increasing with the increasing grade of concrete.
2. Similarly, for a particular grade of steel and grade of concrete, Reinforced concrete beams with designed reinforcement have shown that the strain energy and stress intensity factor as increasing with the increasing b/D ratio.
3. For a particular b/D ratio and grade of concrete, the Reinforced concrete beams with designed reinforcement have shown that the strain energy and stress intensity factor as decreasing with the increasing grade of steel.

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