Flexural And Shear Capacity of RCC Rectangular Beams Under Fire and Comparision with Theoritical Values Under Various Conditions

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I. INTRODUCTION

Reinforced concrete structures designed for safety towards flexure and also shear failure. The RC beams are designed first for flexural strength and later resistance towards the shear load. For safety purpose limiting proportion of longitudinal reinforcement is provided to find flexible performance to the beam. Later beams are intended for shear load as sudden failure of shear happen without warning. The flexure failure in the concrete beams which are reinforced depends upon the dimensions, steel percentage, types of loading. Effective design of the RC beam structures provides the sudden failures due to flexure and shear.

1. Aim and objective of this research

The experimental study is to find the flexure capacity of RC beams which are classified as under, balanced and over reinforced beams with changeable steel percentage.

The study includes:

- Reinforced concrete beams behaviour.
- Comparing the investigational values with theoretical values as per IS456.
- Studying the RC beams behavior under flexure.
- The effect of tensile steel reinforcement amount taken to study the flexural behaviour at failure.

2. Flexure and shear in concrete

Reinforced concrete beam behavior

Plain concrete beams are not enough as flexural members as concrete is feeble in tension. when the tensile stresses are emerged in the plain concrete beams the concrete cannot take the bending stresses as it is feeble in tension but it can take the compressive stresses as it is good in compression.

If huge amount of steel is provided, the strain which present in concrete reaches earlier to its restrictive value before the steel reaching to its restrictive value which causes the crushing of the concrete on the top compression zone and the failure is sudden as steel not got yielded this occurrence is exactly not known but it was observed in the rectangular beams as they fail in compression. If the strain in concrete reaches limiting value so, this type of processes of adopting more steel in the tension zone should be avoided otherwise because of steel not got yielded without warning it suddenly fails .These beams are termed as over reinforced beams. Designs of this type of beams are avoided and IS456-200 will not recommend this type of beams. It is recommended to design under or balanced RC beams.

3. Flexure in Concrete

The cracks which develop by the maximum moment in the rc beams are called as flexure cracks. When the strain in steel reaches the restrictive value other than the concrete this cracks emerge. The type of cracks is vertical and tends to the collapse of beams either of these two cases.

a) Under-Reinforced Beams: compression reinforcement yielding excessively takes place in the tension zone causing flexure cracks and finally failing of the reinforced concrete beam in flexure.
b) Over-Reinforced Beams: concrete crushing in the top fibre zone above the flexural cracks as yielding of longitudinal reinforcement will not happen.

4. Failure modes in flexure:

By observing the path of crack and failure position it is necessary to record different type of cracks formed. The functional load and L/D ratio influence the formation and type of cracks in the rc beams. Three types of cracks are identified in simply supported beam under uniform distributed load on the mid span (amlan et al, 2011)

- Flexural cracks: in the mid span these cracks are located. They emerge from the underneath of the tensile reinforcement and travel vertically upwards.
- Web shear cracks: at neutral axis these webs hear cracks are located. And from the support they were close, travelled inclined towards the axis of beam.

The shear failure in the RC beams emerges because the insufficient shear reinforcement and low shear L/D ratio. In comparison with moment failure shear failure is failure without sudden warning which form mostly inclined cracks starting from the support towards the axis of the beam and the applied load.

a) Diagonal tension failure: Insufficient amount of shear reinforcement imparts formation of inclined cracks rapidly.
b) Shear compression failure: inclined crack formation from the lean of inclined crack due to the concrete crushing.
c) Shear tension failure: if the tensile bars are does not anchorage properly the cracks diagonally propagate through the bars.

Failure Modes in Flexure

Compression failure:

The strain in concrete yields before the strain in steel reaches its limiting value.

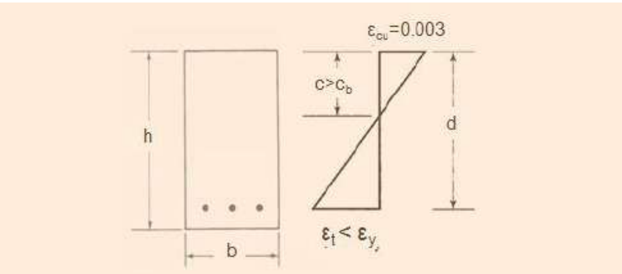

Figure 1. Compression failure

This beam has over reinforcement and brittle failure takes place, therefore sudden, and is not permissible by the ACI and IS456.

Tension failure:

The strain which present in steel reaches before the strain in concrete goes its restrictive value.

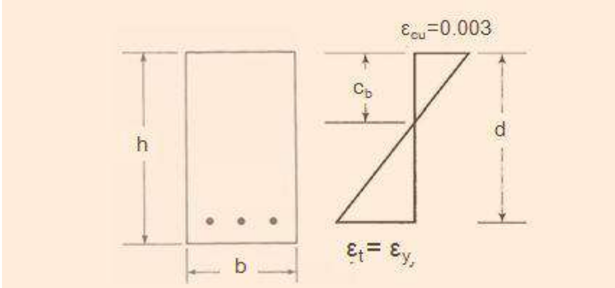

Figure 2. Tension failure

This beam is called under-reinforced beam and failure is ductile, thus providing an enough amount of caution time, and is adopted by the ACI and IS456.

Balanced failure:

The strain which present in steel and the strain which present in concrete reaches simultaneously towards their limit value.

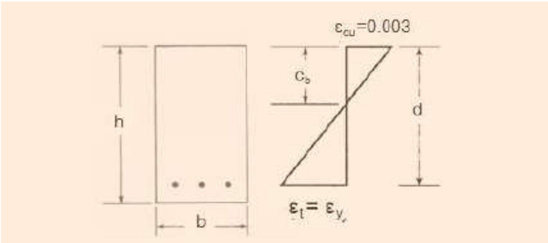

Figure 3.Balanced failure

This beam is called as balanced reinforcement beam and the failure is ductile and is permitted by the ACI and IS456.

II. LITERATURE REVIEW

Atteshamuddin S.Sayyad and Subhash v. Patnakar[1] (2013) studied on "effect of stirrup orientation on flexural response of rc deep beams" .The effect of orientation of stirrups provided in the rc beams having the different (a/d) ratio is studied. For the same flexural and shear reinforcement in rc beams the deep beams failed in the shear .For that beams of three different stirrup orientation is taken as lateral stirrup, vertical stirrup ,inclined stirrup which are provided with two unlike (a/d) ratio. In this study it was found that a/d showed a great control on the ability of shear in the rc beams as the a/d ratio increases the capability of shear found more in beams which are short. The a/d ratio influenced the outcome of three different stirrups on the rc beams. The shear cracks are stopped near the neutral axis incase of vertical stirrup orientation with a/d ratio of 0.50 which showed the behavior of the beam as ductile. The moment strength is increased in the RC beam by orientation of the stirrups as horizontal and inclined but the ductility got decreased. The shear cracks are resisted effectively by the lateral stirrups and inclined stirrups than the vertical stirrups. From the support towards the load the shear cracks are prevented by the inclined stirrups.

Arivalagan.S [2] (2012) conducted study on "moment capacity, cracking behavior and ductile properties of reinforced concrete beams using steel slag as a coarse aggregate". This study shows the test process, method of preparation and the beams are casted with eco- friendly concrete which is prepared by taking the steel slag which is the waste product from steel industry. The beams with and without reinforcement by using steel slag and usual concrete are compared towards eight flexural RC beams. The size of the beam taken as 150 x 150 x 900 mm and concrete grade as M20 were considered to study the flexural behavior. From the investigational outcome it was found that the moment carrying strength of ssrc beams was increased more than the nwc beams. The size of the fracture width is small in ssrc beams as bunch of cracks formed. The deflection is other advantage in ssrc beams. The deflection is obtained higher for ssrc beams in steady load up to failure where as nwc beams showed failure in brittle mode without caution.

III. METHODOLOGY

1. Indian code flexure and shear design procedure:

Singly reinforced rectangular beam:

A rectangular beam having size b x h reinforced with longitudinal reinforcement placed on tension fiber.Then effective depth=h-ce, calculated from tremendous compression fiber to c.g of strain and stress distribution of steel across the section which can be seen in fig.4.1. The distribution of stress is called stress block.

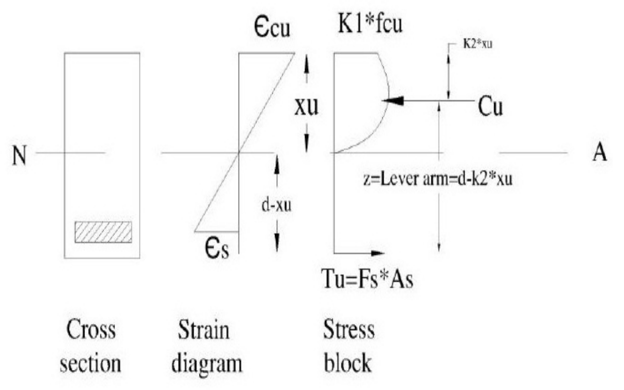

Figure 4. Strain diagram

In the strain diagram similar triangle is applied

$$\frac{\varepsilon cu}{xu} = \frac{\varepsilon s}{d - x_u} \quad -(1)$$

$$\varepsilon s = \varepsilon cu \times \frac{d - x_u}{x_u} \quad -(2)$$

. The neutral axis depth is obtained by the equation 4.4-1 as

$$xu = \frac{\varepsilon cu}{\varepsilon s} \times (d - xu) = \frac{\varepsilon cu}{\varepsilon s} \times d - \frac{\varepsilon cu}{\varepsilon s} \times xu$$

$$xu(1+\frac{\varepsilon cu}{\varepsilon s}) = \frac{\varepsilon cu}{\varepsilon s} \times d$$

$$xu(\frac{\varepsilon s+\varepsilon cu}{\varepsilon s}) = \frac{\varepsilon cu}{\varepsilon s} \times d$$

$$xu = \frac{\varepsilon cu}{\varepsilon cu+\varepsilon s} \times d \text{ --(3)}$$

Here

$\frac{\varepsilon cu}{\varepsilon cu+\varepsilon s}$ Is called neutral axis factor

For equilibrium cu = tu

$$k_1 k_3 f_{cu}\ bx_u = f_s\ A_S$$

$$f_s = \frac{k_1 k_3 f_{cu}\ bx_u}{A_S} = \frac{k_1 k_3 f_{cu}\ b}{A_S} \times \frac{\varepsilon cu}{\varepsilon cu+\varepsilon s} \times d$$

$$f_s = k_1 k_3 f_{cu} \times \frac{\varepsilon cu}{\varepsilon cu+\varepsilon s} \times \frac{bd}{As} \text{ let p =steel ratio } = \frac{As}{bd}$$

$$f_s = \frac{k_1 k_3 f_{cu}\ bx_u}{p} \times \frac{\varepsilon cu}{\varepsilon cu+\varepsilon s} = \frac{fsp}{k1k3\ fcu} \text{ -------------------- (4)}$$

After receiving fs graphically, the final flexure of confrontation is calculated as

$$Mu = T_u \times Z = f_s A_s (d - k_2 xu)$$

$$Mu = C_u \times Z = k_1 k_2 f_{cu}\ bx_u (d - k_2 xu)$$

Consider

$$mu = f_s A_s (d - k_2 \times \frac{\varepsilon cu}{\varepsilon cu+\varepsilon s} \times d) = f_s A_s d(1 - k_2 \frac{\varepsilon cu}{\varepsilon cu+\varepsilon s})$$

From (4)

$$\frac{\varepsilon cu}{\varepsilon cu+\varepsilon s} = \frac{k2 f_s p}{k1k3fcm}$$

Mu = $f_s A_s d(1 - \frac{k2 f_s p}{k1k3fcm})$ --------------------------- (5)

term $1 - \frac{k2 f_s p}{k1k3fcm}$ is lever arm factor

Using $A_s = pbd \; in \; (5)$, the final flexure of confrontation is computed as

Mu = $f_s(pbd)d(1 - \frac{k2 f_s p}{k1k3fcm})$ let r = (1- $\frac{fsp}{fcu} \times \frac{k2}{k1k3}$)

$\frac{M_U}{bd^2}$ = p f s x r dividing both sides by fcu we get or

$\frac{M_U}{bd^2}$= p × $\frac{fs}{fcu} \times R$ --- (6)

A graph plotted between $\frac{M_U}{fcubd^2}$ as shown in fig and can be used for design

Blocks:

Stress blocks suggested by different investigators are from different codes. in many codes the rectangular block suggested by hog nested and Whitney equivalent are used.

Stress block of IS456 – 2000:

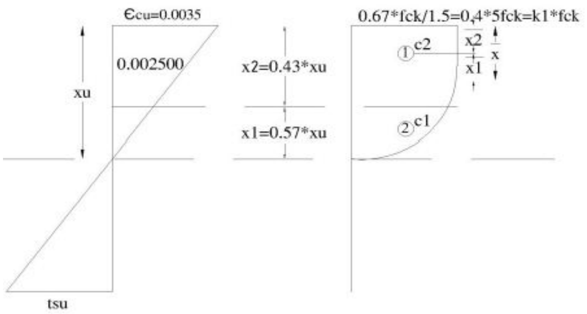

Figure 5. Stress block

Ultimate strain ecu=0.0035 is suggested in is456-2000 & strain where the stress goes design strength e0=0.002. Using similar triangle properties
On strain diagram

$$\frac{0.0035}{xu} = \frac{0.002}{x1}$$

$x_1 = 0.57xu$--------- -------------------------------------(7)

And $x_2 = x_u - o.57x_u = 0.43x_u$

Area of stress block is a =$A_1 + A_2$

a =
$\frac{2}{3} \times O.45 \, f_{ck} \times o.57x_u + O.45 \, f_{ck} \times 0.43x_u$
= $O.171 \, f_{ck} \, x_u + 0.193 \, f_{ck} x_u$
a = $O.3645 \, f_{ck} \, x_u$---------- ------------------------------(8)

By considering moment of areas regarding severe compression region we can have neutral axis depth of stress block

$$x = \frac{\sum aixi}{\sum ai}$$

$$x = \frac{0.171fckxu\left(\frac{3}{8} \times 0.57xu + 0.43xu\right) + 0.1935fckxu \times \frac{0.43xu}{2}}{0.36fckxu}$$

Stress block parameters obtained is

$k_1 = 0.45$

$k_2 = 0.42$

--(10)

$$k_3 = \frac{0.3645}{0.45} = 0.81$$

Rectangular Beam by IS456-2000 stress block:

Case 1: Balanced section:

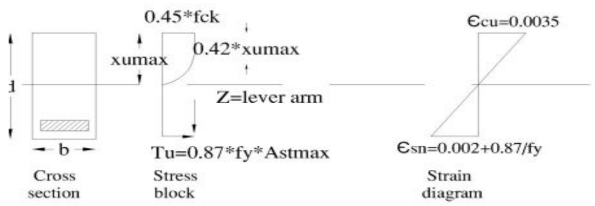

Figure 6. Balanced section

We consider the balanced section when strain in steel and concrete reaches simultaneously previous to collapse.
Equilibrium cu =tu

0.36$f_{ck} X_{umax} b = 0.87 f_y Ast_{max}$

$X_{umax} = \frac{0.87 f_y}{0.36 f_{ck}} \frac{Ast_{max}}{bd}$

$\frac{X_{umax}}{d} = \frac{0.87 f_y}{0.36 f_{ck}} \frac{Ast_{max}}{bd}$

but $\frac{Ast_{max}}{bd} = p_{tmax}$

$p_{tmax} = (\frac{X_{umax}}{d}) \times \frac{0.36 f_{ck}}{0.87 f_y}$

(11)

$p_{tmax} = (\frac{X_{umax}}{d}) \times \; 0.414 \frac{f_{ck}}{f_{y}}$

Stress strain diagram gives

$$\frac{0.0035}{\mathrm{xumax}} = \frac{0.002 + \frac{0.87 f_y}{es}}{\mathrm{xumax} - d}$$

$$\frac{xumax}{d} = \frac{0.0035}{0.0055 + \frac{0.87 f_y}{Es}} - (12)$$

Values of $\frac{xumax}{d}$ got from equation (12). The steel grade decides the value. From clause 38.1 gives the value.

F_Y	$\frac{Xumax}{d}$
250	0.53
415	0.48
500	0.46

p_{tmax} Given in equation (11) is called restrictive proportion steel and denoted as p_{tlim}.

Moment of resistance can be found by, the internal moment of cu & tu as

$M_{ulim} = Cu \times Z = 0.36 f_{ck} X_{ulim} b(d - 0.42 X_{ulim})$

From equation (11)

$$\frac{X_{umax}}{d} = 2.42 \frac{f_y}{f_{ck}} \; p_{tmax}$$

$M_{ulim} = Tu \times Z = 0.87 f_y Ast \quad (d - 0.42 X_{ulim})$

$M_{ulim} = Tu \times Z = 0.87 f_y Ast \quad (d -$

$0.42 \times 2.42 \frac{f_y}{f_{ck}} \; p_{tmax} d)$

$M_{ulim} = 0.87 f_y Ast \quad (1 - \frac{f_y}{f_{ck}} \; p_{tmax})$

$$\frac{M_{Ulim}}{f_{ck} bd^2} = 0.87 \frac{f_y}{f_{ck}} \frac{A_{st}}{bd} \left(1 - \frac{f_y}{f_{ck}} ptlim\right)$$

$$\frac{M_{Ulim}}{f_{ck} bd^2} = 0.87 \frac{f_y}{f_{ck}} \; ptlim \left(1 - \frac{f_y}{f_{ck}} ptlim\right) \; (13)$$

From equation 4.5-5-2 $ptlim$ can be expressed as

$$\frac{ptlimfy}{fck} = 0.414 \; \frac{xumax}{d} \quad (14)$$

Values of $\frac{\mathrm{m_{ulim}}}{\mathrm{f_{ck} bd^2}}$ & $\frac{ptlimfy}{fck}$

For different grade of steel is given in table (page 10 of sp-16) this table is produced in table 4.1

Case 2: Under Reinforced Section:

In Under Reinforced Section, the strain in steel reaches its restrictive value first and at this phase the strain in compressive fiber of concern is less than restrictive strain can be seen in fig 4.4

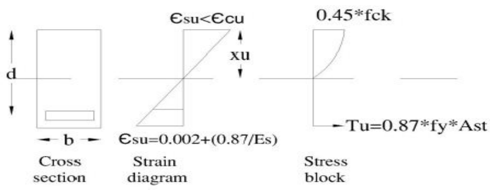

Figure 7. under reinforced section

The equilibrium condition gives the neutral axis depth.

Cu= tu

$0.36 f_{ck} X_{umax} b \; = 0.87 f_y Ast_{max}$

$X_u = \frac{0.87 f_y}{0.36 f_{ck}} \frac{Ast}{b} \; = 2.41 \frac{fy}{fck} \frac{Ast}{b}$

$$\frac{xu}{d} = \; 2.41 \frac{fy}{fck} \frac{Ast}{bd} \quad - (16)$$

By taking ultimate tensile strength of steel moment of confrontation is calculated

$$M_{ur} = T_u \times Z$$

Or $M_{ur} = 0.87 f_y Ast$ (d-0.42X_u)

$= 0.87 f_y Ast \quad d(1\text{-}0.42 \times 2.42 \frac{f_y}{f_{ck}} \frac{Ast}{bd})$

Considering $p_t = \frac{100 Ast}{bd}$ expressed as % we get

$M_{ur} = 0.87 f_y Ast \quad d(1\text{-}1.0122 \frac{f_y}{f_{ck}} \frac{pt}{100})$

or $\frac{fy}{fck}\left(\frac{pt}{100}\right)^2 - \frac{pt}{100} + \frac{MuR}{0.87\ fybd^2} = 0 \quad -(17)$

Equation (17) is a quadratic equation in terms of $\left(\frac{pt}{100}\right)$

Solving for pt, the value can be obtained as

$$p_t = 50 \times \frac{1 - \sqrt{1 - \frac{4.6Mu\,R}{fckbd^2}}}{\frac{fy}{fck}}$$

$$p_t = 50 \frac{fy}{fck}\left[1 - \sqrt{1 - \frac{4.6Mu\,R}{fckbd^2}}\right. \quad -(18)$$

Case 3: Over Reinforced Section:

The sections in which the restrictive strain in concrete is reached earlier than the yield strain of steel are called Over Reinforced Section.

Neutral axis depth is calculated by using equation 4.5-6. Moment of confrontation is computed by using strength of concrete.

$$M_{ur} = Cu \times Z$$

$$= 0.36 f_{ck} X_u b \left(d - 0.42 X_u\right) \quad -(19)$$

$$\frac{xu}{d} > \frac{xulim}{d}$$

IV. EXPERIMENTAL PROGRAMME

The beams were all loaded in the same compressive machine in the structural laboratory. The Universal Testing Machine (UTM) had a compressive strength of 40 tons. The beams were all carefully positioned on the machine. The machine was manually controlled and an effort was made to maintain an even constant slow speed while applying the load. A dial gauge was setup under the beam specimen to check the deflection with respect to the load.

Figure 8. universal testing machine

1. Test on Under Reinforced Beam

Figure 9. Reinforcement of URB

Figure 10. Appearance of URB before test

Crack pattern in Under Reinforced Beam:

First crack is observed at 100kN is flexural in under reinforced beam. It is 43% of ultimate load. On increasing the load further more cracks increase and travelled upwards from the bottom centre of the beam .all the cracks are maximum flexural and the beam failed at an ultimate load of 230kN.It shows that the steel got yielded as more cracks developed .finally the beam obtained an deflection of 2.2mm at an ultimate failure load of 230kN.The beam exbhited ductile nature.

Figure 11. Appearance of URB after test

2. Test on Balanced Reinforced Beam:

Figure 12. Reinforcement of BRB

Figure 13. Appearance of BRB before test

Crack pattern in Balanced Reinforced Beam:

First crack is observed at 140kN is flexural in under reinforced beam. It is 44.82% of ultimate load. on increasing the load further more cracks increase and travelled upwards from the bottom centre of the beam .all the cracks are maximum flexural and the beam failed at an ultimate load of 290kN.it shows that the steel got yielded as more cracks developed .Finally the beam obtained an deflection of 1.9mm at an ultimate failure load of 290kN.the beam exbhited ductile nature.

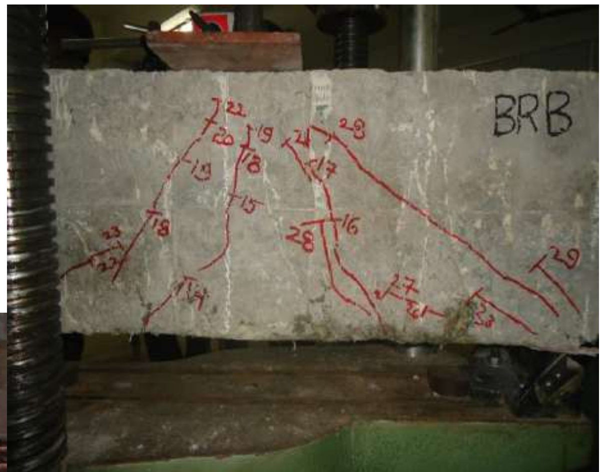

Figure 14. Appearance of BRB after test

3. Test on Over Reinforced Beam:

Figure 15. Reinforcement of ORB

Figure 16. Appearance of ORB before test

Crack pattern in Over Reinforced Beam:

First crack is observed at 140kN is flexural in under reinforced beam. it is 44.82% of ultimate load. On increasing the load further less cracks developed and the cracks are mostly shear. All the cracks are maximum shear and the beam failed suddenly as shear failure at an ultimate load of 260kN.it shows that the steel not yielded as less cracks developed .finally the beam obtained a deflection of 3.5mm at an ultimate failure load of 260kN.the beam exhibited brittle nature.

Figure 17. Appearance of ORB after test

Table 1. Principal of Test results

specimen label	moment at first crack knm	at service load				at ultimate load					type of failure
		moment (knm)	shear force kn	shear stress	deflection mm	moment (knm)	shear force kn	shear stress	deflection mm	crack width mm	
urb	21.25	32.65	76.98	1.92	1.88	48.97	115.47	2.88	2.21	1	flexure
brb	27.6	41.2	96.98	2.42	1.45	61.76	145.47	3.63	1.9	1	flexure
orb	29.75	36.9	86.98	2.16	2.38	55.35	130.47	3.25	3.5	2	shear

4. Graphs:

Under Reinforced Beam

The graph has been plotted for the load versus deflection obtained for the under reinforced beam. this graph shows that the curve is linear for first crack of 140kN.As the load increased corresponding deflections also got increased and finally the maximum deflection of 2.21mm is obtained for an ultimate load of 230kN. We can observe the curve plotted with the point relating with load with respect to deflection.

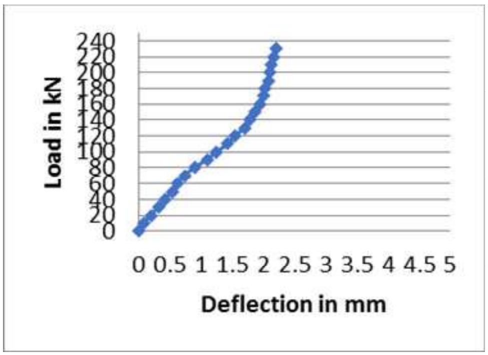

Figure 18. Load vs deflection curve for Under Reinforced Beam

Balanced Reinforced Beam:

The graph has been plotted for the load versus deflection obtained for the under reinforced beam. this graph shows that the curve is linear for first crack of 140kN.As the load increased corresponding deflections also got increased and finally the maximum deflection of 1.9mm is obtained for an ultimate load of 290kN. we can observe the curve plotted with the point relating with load with respect to deflection.

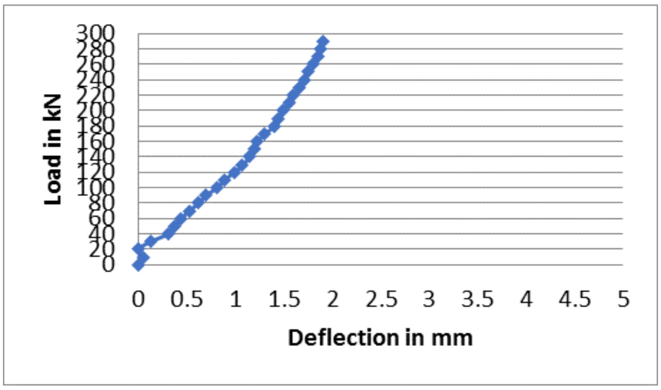

Figure 19. Load vs deflection curve for Balanced Reinforced Beam

Over Reinforced Beam:

The graph has been plotted for the load versus deflection obtained for the under reinforced beam. this graph shows that the curve is linear for first crack of 140kN.As the load increased corresponding deflections also got increased and finally the maximum deflection of 3.5mm is obtained for an ultimate load of 260kN. We can observe the curve plotted with the point relating with load with respect to deflection.

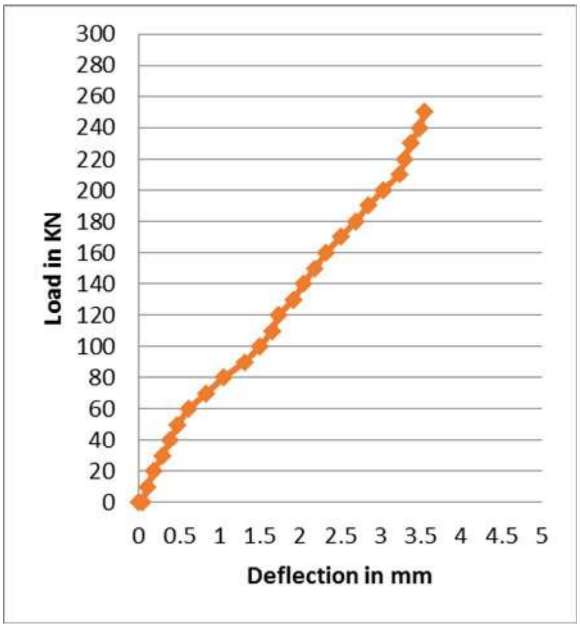

Figure 20. Load vs Deflection curve for Over Reinforced Beam

Comparison of URB, BRB and ORB Beams:

The comparison of load versus deflection of all the three beams of, BRB and orb has been plotted in the fig 6.16. On comparing of the three beams for a constant load of 230kN the maximum deflection of 3.3mm is obtained for over reinforced beam (ORB).

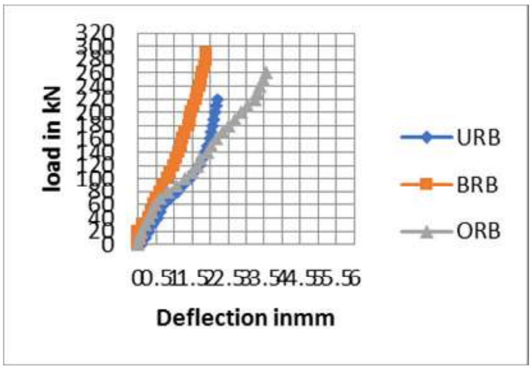

Figure 21. Load vs deflection curves of URB, BRB and ORB

5. Discussions

Discussion on Under Reinforced Beam:

The beam URB with 0.87% longitudinal reinforcement developed initial crack that was flexural at 43.4% of ultimate load. As the load increased further cracks extended upwards and a maximum deflection of 2.21mm is recorded at an ultimate load of 230kN.URB failed at flexure with an ultimate moment of 48.97kNm, the corresponding shear stress is 2.88N⁄〖mm〗^2 .The beam failed at an ultimate load of 230kN and recorded 58.6% higher ultimate strength.

The load and moment carrying capacity of URB beam increased as steel got yielded and a crack width of 1mm is observed. The failure of the beam is flexural and the beam exbhited ductile nature. As the load increased more no of cracks are observed it indicates that the steel got yielded. The deflection obtained for the beam is more as 2.21mm.Due to the depth of neutral is less than the limiting depth of neutral axis the tensile strain in steel reached it limits state first than the compressive strain in concrete so that the steel got yielded and failure of the beam obtained is ductile.

Discussion on Balanced Reinforced Beam:

The beam BRB with 1.19% longitudinal reinforcement developed initial crack that was flexural at 44.82% of ultimate load. As the load increased further cracks extended upwards and a maximum deflection of 1.9mm is recorded at an ultimate load of 290kN.BRB failed at flexure with an ultimate moment of 61.76kNm.The corresponding shear stress are 3.63N⁄〖mm〗^2 . The beam failed at an ultimate load of 290kN and recorded 62.2% higher ultimate strength.

The failure of the beam is ductile nature and a maximum crack width of 1mm is observed. As the load increased more no of cracks are observed it indicates that the steel got yielded. The deflection obtained for the beam is more as 1.9mm.Due to the depth of neutral is equal to the limiting depth of neutral axis the tensile strain in steel and the compressive strain in concrete reached their limiting strains at same time so that the steel got yielded and failure of the beam obtained is ductile.

Discussion on Over Reinforced Beam:

The beam ORB with 1.7% longitudinal reinforcement developed initial crack that was flexural at 53.8% of ultimate load. As load increase further fewer cracks are observed and finally a maximum deflection of 3.5mm is recorded at an ultimate load of 260kN.ORB failed at shear with an ultimate moment of 55.35kNm, the corresponding shear stress is 3.25 N⁄〖mm〗^2 .The failure of the beam is brittle nature and a maximum crack width of 2mm is observed. Finally the beam failed at an ultimate load of 260kN and recorded 15% higher ultimate strength.

As the load increased less no of cracks are observed it indicates that the steel not got yielded. The load and moment carrying capacity of the over reinforced beam decreased compared with the URB and BRB. The deflection obtained for the beam is more as 3.5mm compared with the URB and BRB. Due to the depth of neutral is greater than the limiting depth of neutral axis the tensile strain in steel not reached it limits state compared with the compressive strain in concrete so that the steel got yielded and failure of the beam obtained is ductile.

Table 2. Comparison of test results with theoretical shear results

ORB	267	710	260	55.31

Beam identity	Effective depth mm	A_{st} mm^2	P_u kN	P_{uexp} kN	P_{uthe} kN	$\frac{P_{uexp}}{P_{uthe}}$
URB	267	392.4	230	115.47	92.64	1.24
BRB	267	482	290	145.7	113.82	1.28
ORB	267	710	260	130.7	145.47	0.89

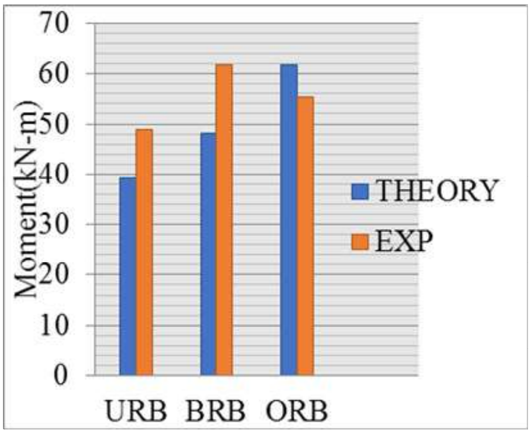

Figure 22. Moment carrying capacity

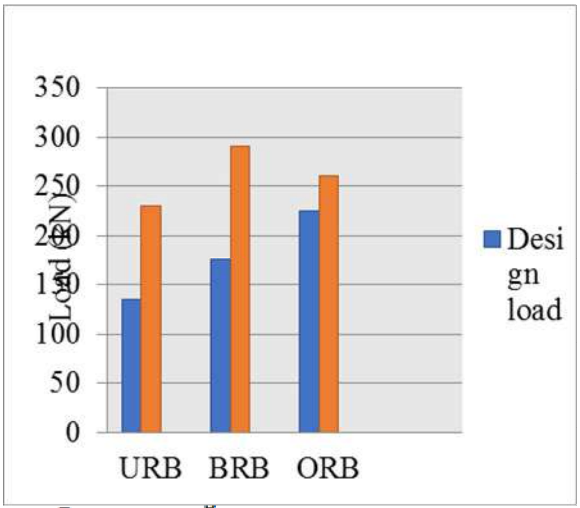

Figure 23. Load carrying capacity

V. CONCLUSIONS

Under Reinforced Beam (URB) and Balanced Reinforced Beam (BRB) both failed in flexure where more cracks are observed and exhibited ductile behavior.

Over Reinforced Beam (ORB) failed in shear where less cracks are observed and the behavior of the beam is brittle.

The increase in load capacity of 58.6 %, 62.2% observed in URB and BRB and an increase of 15% in ORB.

The increase in flexure capacity of 36.7%, 49.4% obtained in Under Reinforced Beam(URB) and Balanced Reinforced Beam(BRB) and an lesser of 5.4% in Over Reinforced Beam(ORB)

The flexure analysis showed that the ratio of m_uexp/m_uthe and p_uexp/p_uthe were decreased with an increase in the reinforcement ratio.

Under Reinforced Beam(URB) and Balanced Reinforced Beam(BRB) are recommended for design purpose as ductile behavior of the beam warning is provided before failure and Over Reinforced Beam(ORB) are avoided due to sudden failure without warning

VI. SCOPE FOR FURTHER STUDY

The above study is limited to M25 concrete and no replacement of cement. The study may be extended using higher grades of concrete like M40, M50 and also partial replacement of cement with fly ash and GGBS to know the performance of beams.

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