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Flexural Ductility of High-Strength Concrete Members

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Abstract: ***Advances in concrete technology in many countries have now made the practical use of concrete with strengths 1 0 0 Mpa a possibility. HSC, due to its very high compressive strength, is less ductile and as such creates a less ductile response in the structural members. The current practice of structural member design recommends low tension steel ratio in order to ensure adequate ductility of the construction structure so that the necessary warning can be given prior to the failure of the member. Especially, the ductile failure mode is essential for the appropriate redistribution of the moment of earthquake-proof and statistically indeterminate structures. Ductility is an important parameter in the RC beams for proper redistribution of moments. In seismic areas, ductility is an important factor in the design of HSC members under flexure. HSC due to its very high compressive strength is less ductile and as such creates a less ductility response in the structural members. The investigation is carried out to understand the ductility behaviour of balanced and doubly reinforced beams. To understand the effect of tensile , compression reinforcement ratio and compressive strength of concrete and also the effect of (L/d) ratio on the ductility of balanced and doubly reinforced HSC beams. To understand the response of HSC beams in flexure with compression reinforcement, nine beams were tested. Three beams of M100 balanced section and six beams of M100 doubly reinforced with varying amount of longitudinal compression reinforcement were tested. The beams are of rectangular cross section with dimensions 100mm X 170mm and overall length of 2000mm, 2600mm, and 3200mm with an effective length of 1800mm, 2400mm, and 3000mm so that l/d ration is 15, 20 and 25. The ductility index is calculated using Bilinear method for all the analysed beams***

Keywords: High Strength Concrete, Ductile, Doubly reinforced beam, Ductility Index

1. Introduction

The definition of High Strength Concrete(HSC) has changed over the period of time. The development of concrete technology resulted in several concretes with different engineering properties which attracted engineers and researchers to explore more. HSC are known to have more durable properties and better corrosion resisting properties than the conventional concrete. Higher compressive strength of concrete results in a higher modulus of elasticity and thus improves serviceability. Ductility is an important parameter in the RC beams for proper redistribution of moments. In seismic areas, ductility is an important factor in the design of HSC members under flexure. HSC due to its very high compressive strength is less ductile and as such creates a less ductility response in the structural members. In general, ductility indices have been defined in the literature. They are 'Deflection Ductility' and 'Curvature Ductility'. Deflection ductility is defined as the ratio of 'deflection at ultimate load to the 'deflection at first yield load and denoted by 'μ_d'.

To understand the response of HSC beams in flexure with compression reinforcement, nine beams were tested in this investigation. Three beams of **M100** balanced section and six beams of **M100** doubly reinforced with varying amount of longitudinal compression reinforcement were tested.

Table 1 Specimen Details of Doubly Reinforced HSC Beam

BEAM	b (mm)	d (mm)	L/d	ρ %	ρ' %	Shear Reinf.
HSC/15/BS	100	125	15	3.97	0.00	8Ø @ 90mm
HSC/15/30	100	125	15	5.43	1.66	8Ø @90mm
HSC/15/70	100	125	15	6.43	3.22	8Ø @90mm
HSC/20/BS	100	125	20	3.97	0.00	8Ø @90mm
HSC/20/30	100	125	20	5.43	1.66	8Ø @90mm
HSC/20/70	100	125	20	6.43	3.22	8Ø @90mm
HSC/25/BS	100	125	25	3.97	0.00	8Ø @90mm
HSC/25/30	100	125	25	5.43	1.66	8Ø @90mm
HSC/25/70	100	125	25	6.43	3.22	8Ø @90mm

All the beams were tested in the loading frame of capacity 500 kN. The beams were simply supported and subjected to pure bending with two point loading. The load was applied from a 500 kN. jack, symmetrically with respect to mid span section. The abbreviation used in this thesis HSC/15/BS, HSC/15/30, HSC/15/70 indicate: HSC- high strength concrete, 15-effective span to effective depth ratio (l/d), BS-balanced section, 30% increase in the moment carrying capacity of balanced section, 70% increase in the moment carrying capacity of the balanced section respectively.

Objective

To understand the effect of tensile reinforcement ratio, compression reinforcement ratio and compressive strength of concrete and also the effect of effective length to effective depth ratio on the ductility of balanced and doubly reinforced HSC beams.

2. Materials and Mix Proportions

To obtain mix design M100 concrete, the materials are selected carefully and testing of their qualities are done as per IS code provision.

2.1 Materials used

53 grade OPC cement along with coarse aggregate passing through 12.5mm and retained on 4.75mm sieve. The fineness modulus was 6.04 and specific gravity was 2.67.The fine aggregate was river sand with zone-II with fineness modulus was 2.62 are used. To improve workability of concrete, chemical admixture super plasticizer- naphthalene based polymer (Conplast SP 430) was used.

2.2 Mix Proportion

Mix design procedure given in Perumal and Sundararajan **[4]** has been used in this experimental investigation. This procedure is formulated by combining the IS method and ACI method.The final mix proportion for M100 concrete was 1:0.63:1.40 with 0.20 w/c ration and 3% super plasticizer.

2.3 Casting of Concrete Specimen

To understand the response of HSC beams in flexure with compression reinforcement, nine beams were tested in this investigation. The beams are of rectangular cross section with dimensions 100mm X 170mm and overall length of 2000mm, 2600mm, and 3200mm with an effective length of 1800mm, 2400mm, and 3000mm so that l/d ratio is 15, 20 and 25. Three beams of **M100** balanced section and six beams of **M100** doubly reinforced with varying amount of longitudinal compression reinforcement were tested. A 30% and 70% increase in moment carrying capacity of the balanced section was considered to design the doubly reinforced section and it was designed according to IS 456-2000.

3. Experimental Procedure

All the beams were tested in the loading frame of capacity 500 kN. The beams were simply supported and subjected to pure bending with two point loading

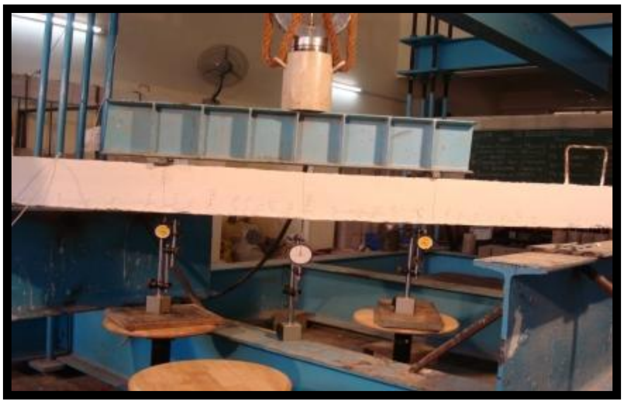

Plate: Loading Frame Test Setup

The load was applied from a 500 kN. jack, symmetrically with respect to mid span section. For measuring deflection, two dial gauges of least count 0.01 mm were placed within the region of pure bending under the two-load points. In addition, one dial gauge was also placed at the center of the beam

4. Analysis of Deflection Ductility

The investigation is carried out to understand the ductility behaviour of balanced and doubly reinforced beams. To understand the effect of tensile , compression reinforcement ratio and compressive strength of concrete and also the effect of (l/d) ratio on the ductility of balanced and doubly reinforced HSC beams, the ductility index is calculated using Bilinear method for all the analysed beams.

By knowing ultimate deflection and deflection at yield point, ductility index was calculated for M100 beams. The values are shown in the TABLE 2 below.

Table 2: Ductility Index for Analyzed HSC Beams

BEAMS	ρ %	ρ' %	$(\rho + \rho')$ %	(ρ' / ρ) %	μd
HSC 100/15/BS	3.97	0	3.97	0.00	1.90
HSC 100/20/BS	3.97	0	3.97	0.00	2.14
HSC 100/25/BS	3.97	0	3.97	0.00	2.36
HSC 100/15/30	5.43	1.66	7.09	0.30	1.41
HSC 100/15/70	6.43	3.22	9.65	0.50	1.37
HSC 100/20/30	5.43	1.66	7.09	0.30	1.53
HSC 100/20/70	6.43	3.22	9.65	0.50	1.45
HSC 100/25/30	5.43	1.22	7.09	0.30	1.59
HSC 100/25/70	6.43	3.22	9.65	0.50	1.50

It was observed from the TABLE 2 that the ductility values ranged between 1.37 to 2.37. This indicates that the doubly reinforced HSC beams will have lesser rotation capacity and they fail to provide minimum ductility of 3. This point has to be carefully addressed where the ductility demand was required between 3 to 5. Rotation enhancement technique may be adopted such as use of fiber, wrapping or confinement of concrete on the compression zone to achieve required ductility.

It was also observed from the TABLE 2 deflection ductility increases as l/d ratio increases in balanced and doubly reinforced section. However deflection ductility decreases with increase in moment carrying capacity. For clear understanding of ductility behaviour of beams the graphs were plotted between deflection ductility and tension and compression reinforcement ratio.

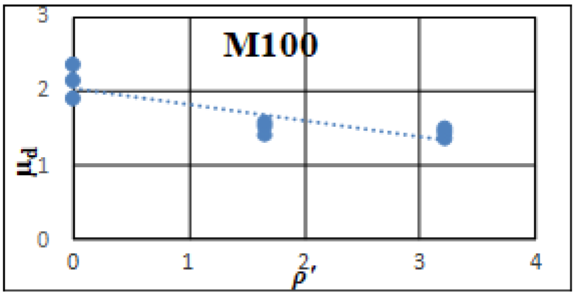

Figure 1: Ductility Index Vs Compression Reinf.

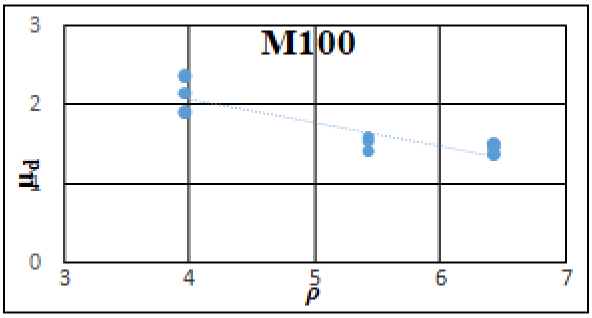

Figure 2: Ductility Index Vs Tension Reinf.

From the above FIG 1 and FIG 2 it was observed that ductility index decreases as tension reinforcement or compression reinforcement ratio increases. Same trend was observed even with literature data.

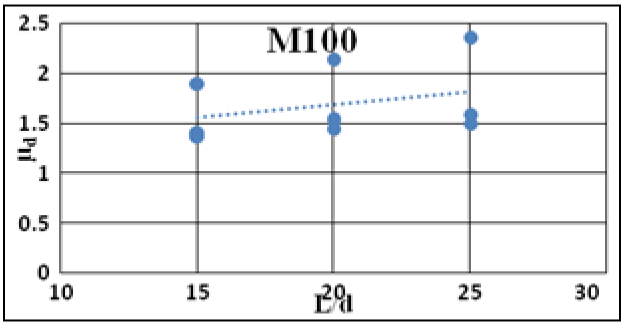

Figure 3: Ductility Index Vs (l/d) Ratio

From FIG 3 it was observed that ductility index increases with increase in L/d ratio.

The deflection ductility was compared with HO et al equation **[16] (EQ -1)** and PRABHAKARA equation**[17] (EQ -2)** which was proposed for singly reinforced beams.

$$\mu_d = 9.5\ (f_{ck})^{-0.30} * (\rho/\rho_b)^{-0.75} \ldots\ldots\ldots\ldots\ldots (1)$$

$$\mu_d = 9.5\ (f_{ck})^{-0.15} * (\rho/\rho_b)^{-0.30} \ldots\ldots\ldots\ldots\ldots (2)$$

The graphs were plotted between deflection index vs tension, compression and total reinforcement ratio for experimental and letarature values using HO et al **[16]** and PRABHAKARA **[17]** equations and are shown in **FIG 4-6**

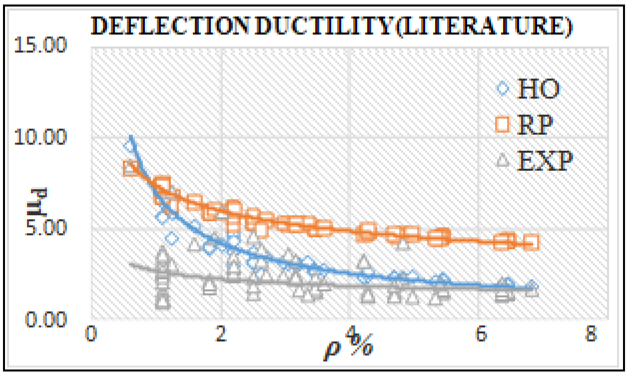

Figure 4: Deflection Ductility Vs Tension reinforcement

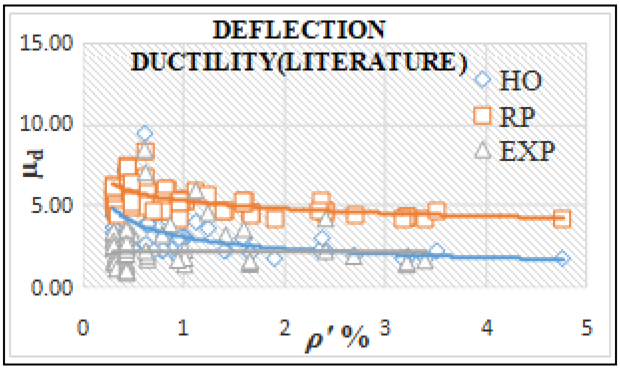

Figure 5: Deflection Ductility Vs Compression reinforcement

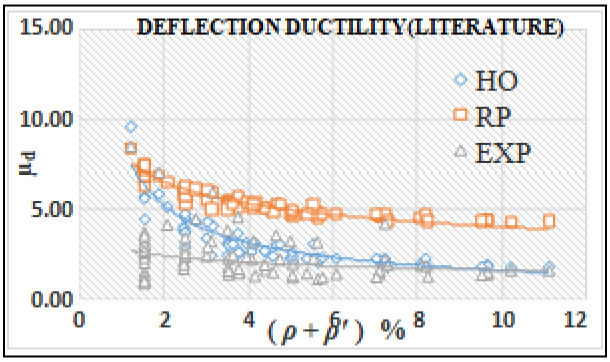

Figure 6: Deflection Ductility Vs Total Reinf. Ratio

It was observed from FIG 4-6 that deflection ductility decreases with increase in tension, compression and total reinforcement ratio. The EQ 1 and 2 gives higher values when compared to experimental values which seems to be unrealistic.

Proposed Equation

A thorough nonlinear regression analysis was carried out on present investigation and literature values of doubly reinforced beams by taking the influencing parameters of compressive strength of concrete, tension and compression reinforcement ratio in calculating deflection ductility. Based on the analysis an equation was proposed for deflection ductility (EQ 3).

$$\mu_d = 12 * (f'_c)^{-0.3} * (\rho)^{-0.35} * (\rho')^{0.15} \ldots\ldots\ldots (3)$$

Based on the proposed equation deflection ductility was calculated for tension, compression and total reinforcement ratio and illustrative in graph **FIG 7-9** were plotted

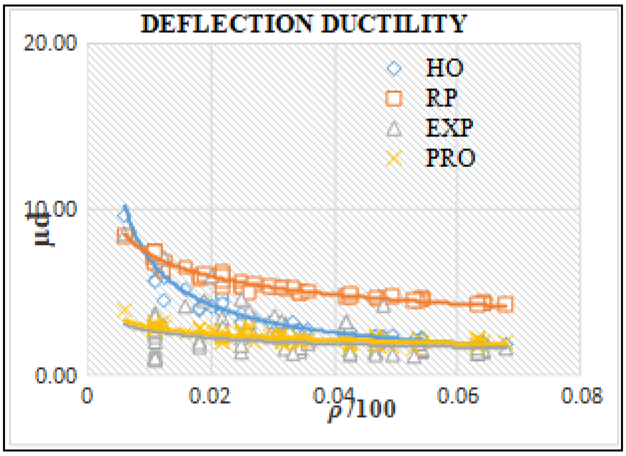

Figure 7: Ductility Vs Tension Reinf. With Proposed Eq.

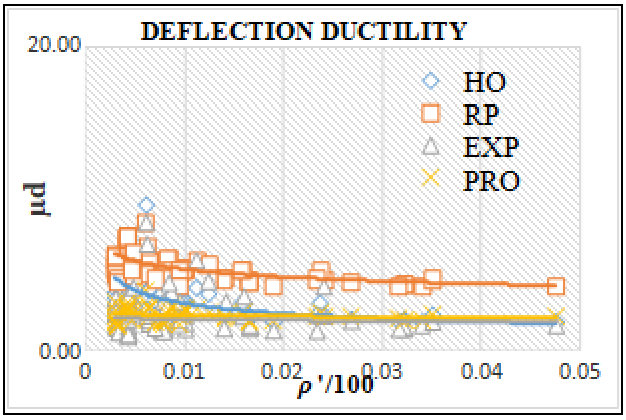

Figure 8: Ductility Vs Compression Reinf. With Proposed Eq.

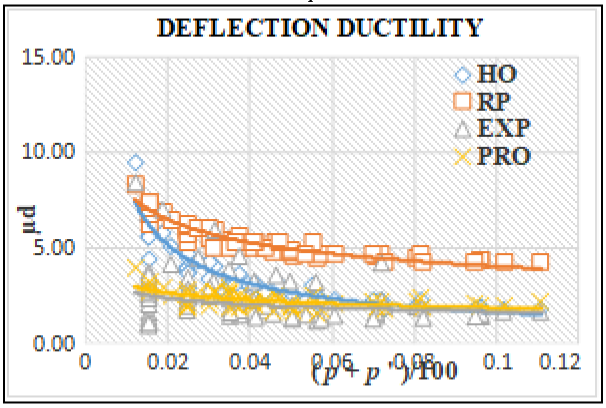

Figure 9: Ductility Vs Total Reinf. Ratio With Proposed Eq.

It is observed from the above graph that, experimental points and proposed points were very close even with total reinforcement ratio. The above proposed equation gives an average value of 0.98 and coefficient of variation around 40%.

5. Observations and Conclusion

Ductility is an important parameter for proper redistribution of moments in the flexural behaviour of HSC beams. It was calculated using the ratio of deflection at ultimate load to that of deflection at yield load

Based on the experimental results the following observations were made.

- It was observed from the graphs, ductility index decreased with increase in tension and compression reinforcement.
- Deflection ductility increases with increase in L/d ratio.
- The experimental deflection ductility was in the range between 1 to 2.5, which is less against the ductility demand of 3 to 5.
- The proposed equation resulted in values very close to the experimental values with an average of 0.98 and CV = 4.5%.

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