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Analysis of Flexural Behavior of Doubly Reinforced High-Strength Concrete Beams using ANSYS

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Abstract: ***The nature of fracture in high strength concrete(HSC) is brittle. High strength concrete due to its very high compressive strength, is less ductile and as such creates a less ductile response in the structural members. The paper describes the nonlinear finite element modeling and analysis of doubly reinforced HSC beams for flexural behavior. The finite element method is an analytical tool which is able to model RCC and calculate the non linear behavior of the structural members. The concrete was modeled with 8-noded SOLID-65 element that can translate either in the x, y or z-axis directions and longitudinal and transverse steels were modeled as discrete elements using 3D-LINK8 bar element available in the ANSYS elementary library. Concrete and reinforcing steel are represented by separate material models which are combined together to describe the behavior of the reinforced concrete material. A total of nine beams were modeled of size 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 beams are analyzed by varying the l/d ratio and percentage of reinforcement of HSC beams. The beams were simply supported and tested under two point loading. Analyses were carried out by calculating the cracking load, deflection and ductility using IS and ACI codes. The comparisons between analytical, experimental and calculated results using IS and ACI are observed with the objective to establish the validity of the proposed models.***

Keywords: High Strength Concrete, Doubly reinforced beam, ANSYS

1. Introduction

The high-strength concrete (HSC) is often considered as a relatively new material, its development has been gradual over many years. As the development has continued, the definition of HSC has changed. However in recent years, development of concrete technology resulted in several concretes with different engineering properties which attracted engineers and researchers to explore more. HSC is specified where reduced weight is important or where architectural considerations require smaller load-carrying elements. In high-rise buildings, HSC helps to achieve more efficient floor plans through smaller vertical members and has also often proven to be the most economical alternative by reducing both the total volume of concrete and the amount of steel required for a load-bearing member. Doubly reinforced sections are generally adopted when the dimensions of the beam have been predetermined from other considerations and the design moment exceeds the moment of resistance of a singly reinforced section. The additional moment carrying capacity needed is obtained by providing compression reinforcement and additional tensile reinforcement. Despite a large number of investigations carried out in the past on flexural behaviour of HSC beams, controversy still remains with regard to some vital design issues. One such issue is the serviceability requirement of deflection. Beams tested by several investigators consistently demonstrated significantly larger deflections at service load than what would be predicted by codes. Another important design issue is the ductility or the ability of a RC member to deform at or near the ultimate load without significant strength loss. Because concrete becomes increasingly more brittle as its compressive strength is increased, guaranteeing adequate ductility represents one of the primary design concerns when HSC is involved. Various types of FEM packages such as ANSYS, STRAND7, MSC and NASTRAN have been integrated in many of general purpose finite element analysis. ANSYS is a finite element based powerful tool for structural analysis widely used in the computer-aided engineering field. ANSYS software allows engineers to construct computer models for structures, apply operating loads, other design criteria and study of responses such as stress levels, deflections, temperature distributions etc.

2. Scope of Present Study

- To develop analytical models and to investigate the relative importance of the nonlinear behavior of doubly reinforced HSC beams under static loads.
- To obtain the cracking load of doubly reinforced HSC beams using ANSYS
- To compare the cracking load predicted by IS, ACI and ANSYS
- To obtain the load deflection behavior of doubly reinforced HSC beams
- To compare working load deflection by IS, ACI and ANSYS

3. Modeling of Beams

3.1 Geometry and beam Details

Table 1: Specimen Details Of Doubly Reinf. 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

3.2 Finite Element Model

The ANSYS finite element program, operating on a WINDOW operating system was used to simulate the behavior of the experimental beams. An eight node Solid-65 element was used to model the concrete which has eight nodes with three degree of of freedom at each node translation in the nadal x, y and z directions. The element is capable of plastic deformation, cracking and crushing. A lin8 element was used to model the steel reinforcement which has two nodes and each node has three degree of freedom, translation.

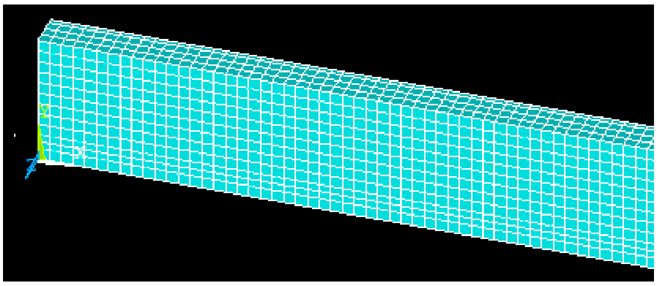

Plate 1: Generating Volumes For Concrete Element

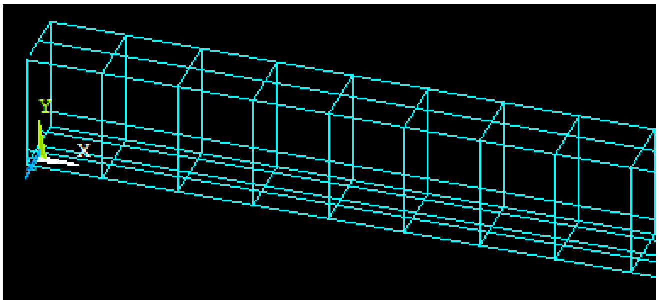

Plate 2: Meshing of Steel Elements

3.3 FE Model Input data

For concrete, ANSYS requires input data for material properties as follows: elastic modulus Ec, ultimate uniaxial compressive strength *fck*, ultimate uniaxial tensile strength(modulus of rupture) *fr*, Poisson's ratio μ, shear transfer coefficient β and compressive uniaxial stress-strain relationship for concrete. The shear transfer coefficient β, represents conditions of the crack face. The value of β ranges from 0 to 1.0 with0 representing a smooth crack (complete loss of shear transfer) and 1.0 representing a rough crack (no loss of shear transfer). The value of β used in this study was 0.3.

4. ANSYS Analysis

The finite element models were loaded at the same locations as the full size beams. During the experiment, the supports were provided with rollers to allow rotations, but in the finite element model the nodes at the supports was restrained in y direction and loads were applied directly on the nodes.

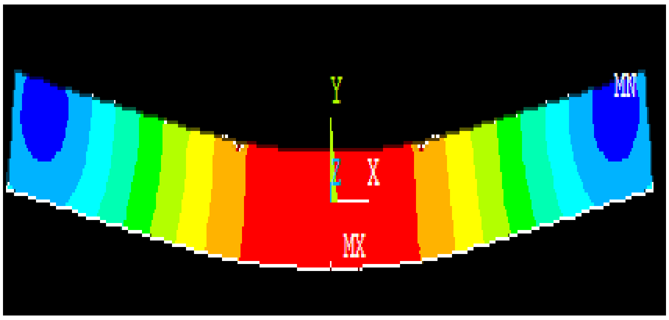

Plate 3: Ultimate deflection

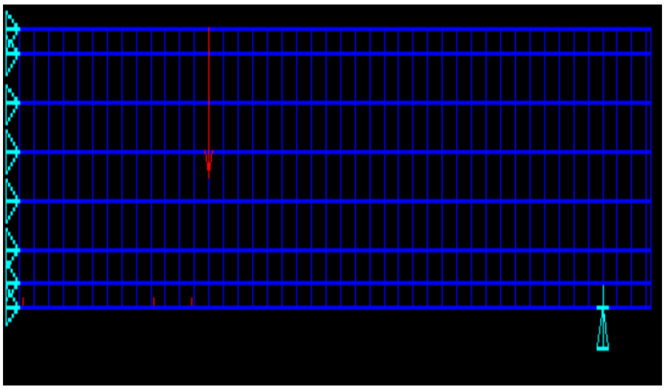

Plate-4: First Cracking Pattern

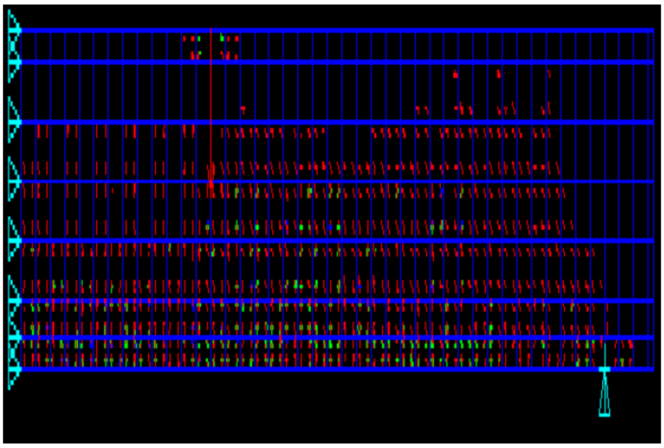

Plate 5: Cracks at Ultimate stage

5. Results and Observations

The ANSYS's results were compared with experimental values and calculated values as per IS and ACI codes.

5.1 Cracking Load

At initial stages of loading , first crack was observed which is called cracking point load. The cracking load from ANSYS result was compared with experimental values and codal values. The results are tabulated in Table-1.

Table 2: Comparison of Cracking Loads

BEAM	f_{ck} (MPa)	P_{cr} ANSYS (kN)	P_{cr} (EXP) (kN)	P_{cr} (IS) (kN)	P_{cr} (ACI) (kN)
HSC/15/BS	105	13	12	11.5	9.26
HSC/15/30	105	16	15	11.5	9.26
HSC/15/70	105	17.6	16	11.5	9.26
HSC/20/BS	99.3	9.8	10	8.4	8.3
HSC/20/30	99.3	11.4	12	8.4	8.3
HSC/20/70	99.3	13.2	13	8.4	8.3
HSC/25/BS	97.4	8.8	8	6.66	5.26
HSC/25/30	97.4	10.4	10	6.66	5.26
HSC/25/70	97.4	11.8	12	6.66	5.26

In the above table it was observed that ANSYS predicts very much similar to experimental values. The cracking load has increased with the increase in compression reinforcement. The cracking load has decreased with the increase in l/d ratio for all the types of beams.

5.2 Load deflection behavior

Gradual load of 0.2kN was applied at each step and corresponding deflection were noted down in ANSYS analysis. Load vs deflection curves for all the beams were plotted and are shown in the Fig 1-3.

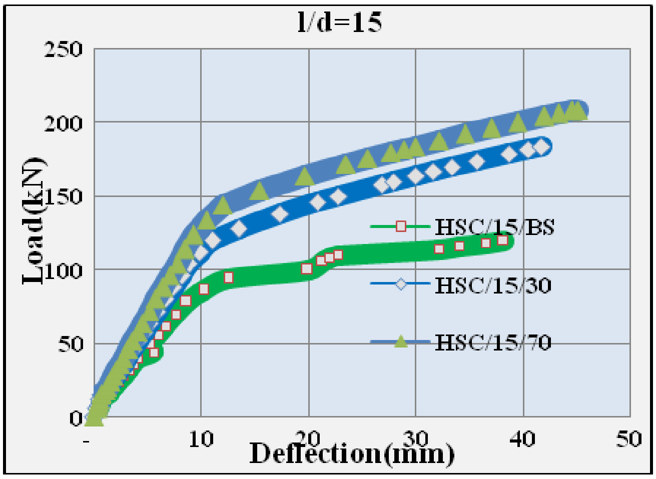

Figure 1: Load vs Deflection Curve for l/d=15 using ANSYS

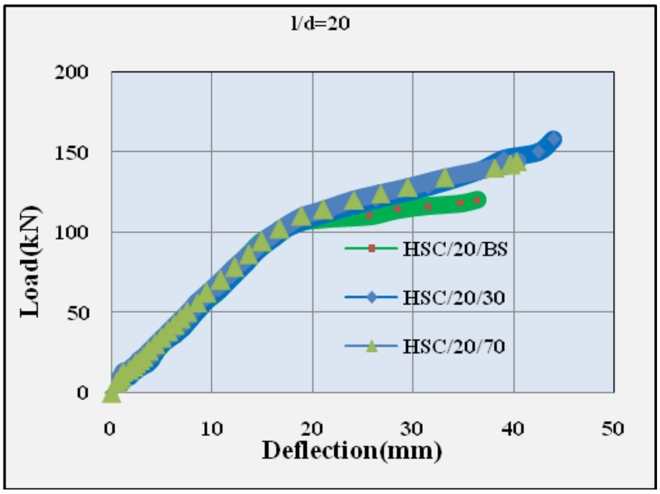

Figure 2: Load vs Deflection Curve for l/d=20 using ANSYS

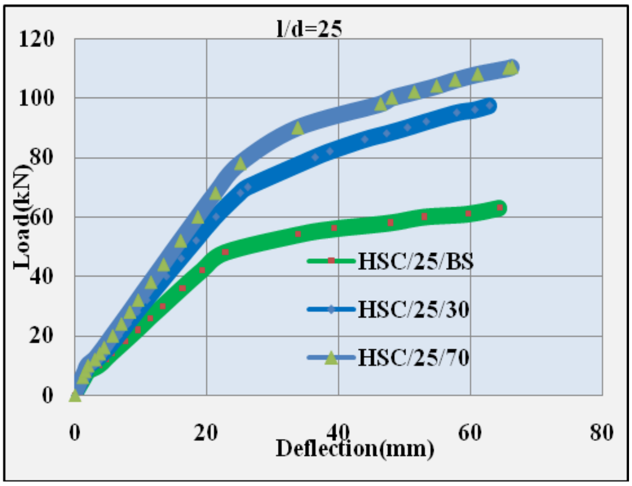

Figure 3: Load vs Deflection Curve for l/d=25 using ANSYS

The curves shows finite element analyses and experimental results are same. It was observed the finite element model is stiffer than the actual beam in the linear range. The micro crack produced due to drying shrinkage and handling are incorporated in the model. After the initiation of flexural cracks, the beam stiffness was reduced and the linear load-deflection behavior ended when the internal steel reinforcement began to yield.

5.3 Ductility

Ductility can be defined as the ability of the material to undergo large deformation without rupture before failure. Displacement ductility is the ratio of deflection at the ultimate load to the deflection at the first yielding of the tensile steel. The yield point is located by equating the area under the actual load deflection diagrams to the bilinear system keeping the initial angle same in both the conditions.

Table 3: Comparison of deflection Ductility

BEAM	EXP µd	ANSYS µd	µd EXP/ANSYS
HSC/15/B	1.90	2.93	0.65
HSC/15/30	1.41	3.30	0.43
HSC/15/70	1.37	3.70	0.37
HSC/20/B	2.14	2.90	0.74
HSC/20/30	1.53	2.30	0.67
HSC/20/70	1.45	2.53	0.69
HSC/25/B	2.36	2.30	1.03
HSC/25/30	1.59	1.80	0.88
HSC/25/70	1.50	2.12	0.71

It was observed from the above table that, the ductility ratio decreases with increase in l/d ratio. The experimental values were lower than that of ANSYS's values. This is due to the fact that the ANSYS model is stiffer than the experimental specimen. It was also observed, as the percentage of tension reinforcement increases, ductility factor is reduced, since the yielding of reinforcement occurs at later stages. Also the ductility factor is increased with increase in compression reinforcement.

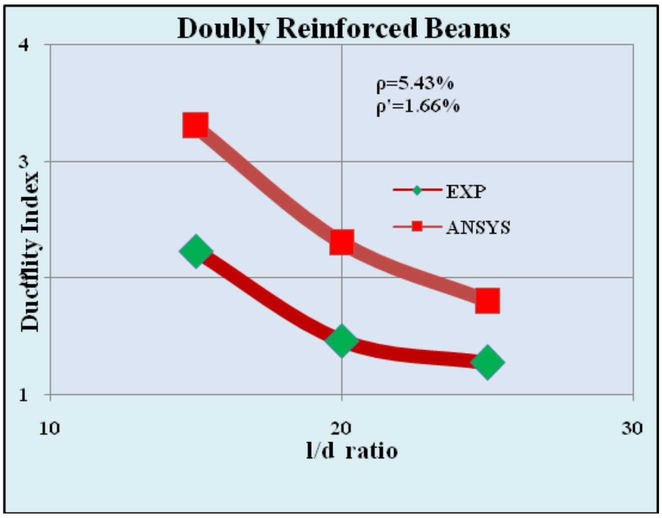

Figure 4: Ductility vs l/d ratio for doubly reinforced beams

Both experimental and ANSYS's results shows, there was decrease in ductility index with increase in l/d ratio. Stiffness increases with decrease in l/d ratio.

6. Conclusions

The flexural behaviour of HSC Balanced and Doubly reinforced beams was carried out using ANSYS software package. The concrete was modelled as eight node solid 65-3D element and steel was modelled as link 8.3D spar element.

The parameters like cracking load, deflection at working load and ductility behaviour were studied using ANSYS. The following conclusions were made based on the analysis.

- Cracking loads obtained from IS and ACI codes were less than the analytical and experimental values.
- The cracking load has been decreased with increase in l/d ratio.
- The load deflection behavior observed to be linear up to cracking load and non linear thereafter.
- Deflection ductility index decreases as the longitudinal reinforcement increases.
- Deflection ductility increases with increase in compression reinforcement.
- Ductility index decreases with increase in l/d ratio.

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