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Elastic and flexural resistance assessment on low grade reinforced Self Compacting Concrete beam element

Manjula V.
umashriman@gmail.com
Dr. M.G.R. Educational and Research Institute, Chennai, Tamil Nadu

Dr. T. Felixkala
kalastrut@yahoo.co.in
Dr. M.G.R. Educational and Research Institute, Chennai, Tamil Nadu

ABSTRACT

Self Compacting Concrete (SCC) is one of the innovative techniques to overcome the placement of concrete in narrow and congested reinforced concrete elements with high deformability and excellent stability characteristics. In this experimental research, SCC mixture was developed with GGBS and Crusher Rejected Fines (CRF) replaced cement and river sand respectively to achieve the lower strength of M20 to M30 SCC grade. This paper is focused on the experimental study on the actual behaviour of the structural component member under transverse loading. As well as to provide a valuable supplement to the laboratory test results, using sophisticated numerical tool ANSYS finite element software, Reinforced self-compacting concrete beams were modeled and analyzed. The comparison between ANSYS results and experimental test results were made in terms of strength, flexural resistance, and deflection of the structural elements. The first crack in the control SCC significantly delayed than the SCC with GGBS and CRF. The finite element model can make a reasonable estimate on the prediction values of ultimate loads and ultimate deflections.

Keywords— *Modulus of elasticity, Modulus of rupture, Crusher rejected fines, Non-linear finite element method*

1. INTRODUCTION

One of the most significant mechanical parameters of concrete is the elastic modulus, which indicates the concrete ability to deform elastically. Flexural strength also known as modulus of rupture, bend strength or fracture strength is a material property defined as the stress in a material just before it yields in a flexure test. Dharmaraja and Malathy (2016) experimentally investigated two self compacting concrete beams designed to flexure failure and the beams are strengthened by 0% and 2% of corrosion inhibitor (Hexamine). The report reveals that the SCC beams cracks in the moment region and with significant ultimate deflection fails due to shearing of the compression concrete. The delay in first crack load has been observed for SCC beams with corrosion inhibitor of 2%. The average ultimate loads for conventional concrete (CC) beams and 2% of Hexamine (H2) concrete beams are 97 KN and 85 KN respectively at 28th day. Badiger and Malipatil (2014) experimentally programmed to study the structural element beam subjected to various load conditions. The uniform size of the beam is 250X450mm with effective span 3840mm. One-third of the full beam was used for modeling due to the symmetrical loading and shape of the beam. The load-deflection curve for different depths of the beam is done and the load at first crack is obtained. The depths adopted are 250mm, 350mm, 450mm, and 500mm. Deflections and stresses at the center line along with initial and progressive cracking of the finite element model compare well with the manual calculations obtained for a reinforced concrete beam. In point of modeling, it was proved that beam without steel plate shows more cracks than the beam with steel plate. Hence for more accurate analysis, steel cushion has to be included in the modeling. Saifullah et al. (2011) started with literature reviews and calibrated a beam model using a finite element analysis package (ANSYS, SAS 2005). A mild-steel reinforced concrete beam with flexural reinforcement was analyzed to failure and compared to experimental results to calibrate the parameters in ANSYS. The conclusions based on the calibration model is that the deflections and stresses at the center line along with initial and progressive cracking of the finite element model compare well to experimental data obtained from a reinforced concrete beam. The failure mechanism of a reinforced concrete beam is modeled quite well using FEA and the failure load predicted is very close to the failure load measured.

The optimized four GGBS & CRF based SCC mix proportions SCC40, SCC50, SCC60, & SCC70, whose strength relates to the desired low-grade SCC (M20 to M30) are selected for this structural study along with control SCC. In the current work, Cylinders were cast and tested in compresso meter to determine Young's modulus for 28 and 90 days. Reinforced SCC beams were designed as per IS 456-2000 and two-point loading method is implemented to study on the behaviour of beam element on first cracking, behaviour beyond first cracking and load-deformation response at different mix ratios. The study was beneficial by comparing the experimental results with a finite element of the beams modeled in ANSYS software.

2. EXPERIMENTAL PROGRAM

2.1 Stress-Strain behaviour in compression

The cylinder specimen with the compressometer is placed in the universal testing machine and the deformation is noted in the dial gauge for every load increment. The stress-strain behaviour of SCC for 28 days and 90 days are shown in figure 1 and figure 2.

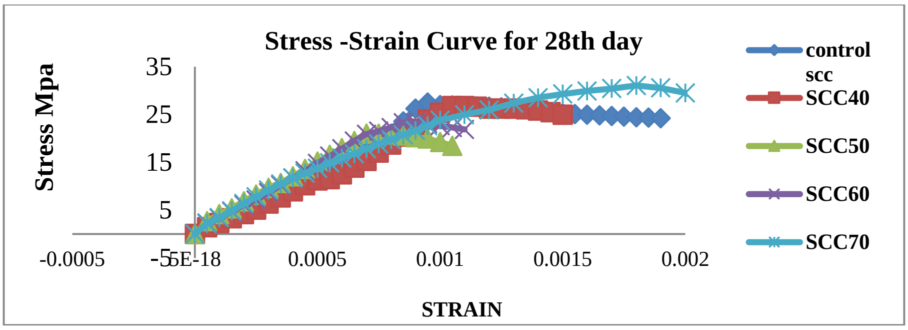

Fig. 1: Comparison of Stress –Strain relationship for SCC Mix at 28 days

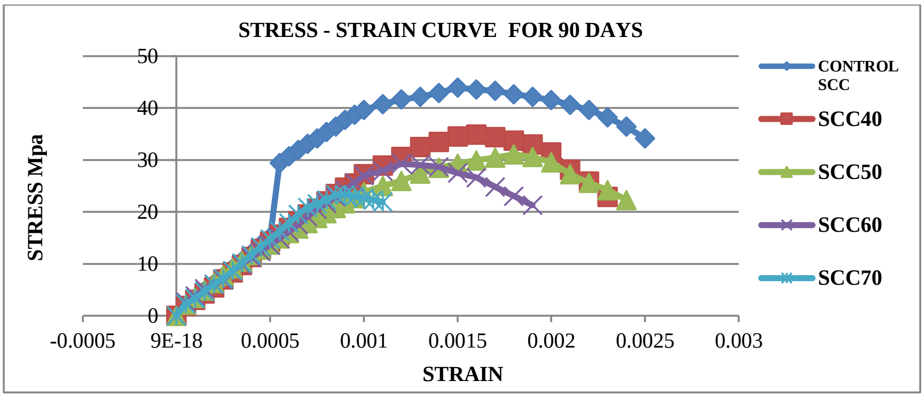

Fig. 2: Comparison of Stress –Strain relationship for SCC Mix at 90 days

Table 1: Compressive strength & Modulus of Elasticity N/mm^2 [E] Values of SCC

Mix Designation		Control SCC	SCC40	SCC50	SCC60	SCC70
28 days	Compressive strength	40.10	30.65	27.45	25.60	22.32
	Modulus of Elasticity	28964.13	25477.71	24845.31	23025.48	22985.38
90 days	Compressive strength	45.25	33.00	30.04	28.45	24.48
	Modulus of Elasticity	35058.48	28025.48	28308.56	27459.31	27025.65

3. FLEXURAL RESISTANCE BEHAVIOUR OF GGBS & CRF BLENDED SCC BEAM ELEMENT

3.1 Preparation of SCC beams specimens

For testing, Reinforced self compacting beams of size 150mm x 300mm and span 1000mm were designed as per provisions of IS code 456. Below sketch gives complete details of beams with reinforcement details. The beams were cast using a wooden mould. The specimens were prepared using plain concrete which was designed as Okamura method. After 24 hours, cubes were removed from the mould and covered with wet sacking to ensure proper curing. Prior to testing, every beam was whitewashed to facilitate observations of cracks.

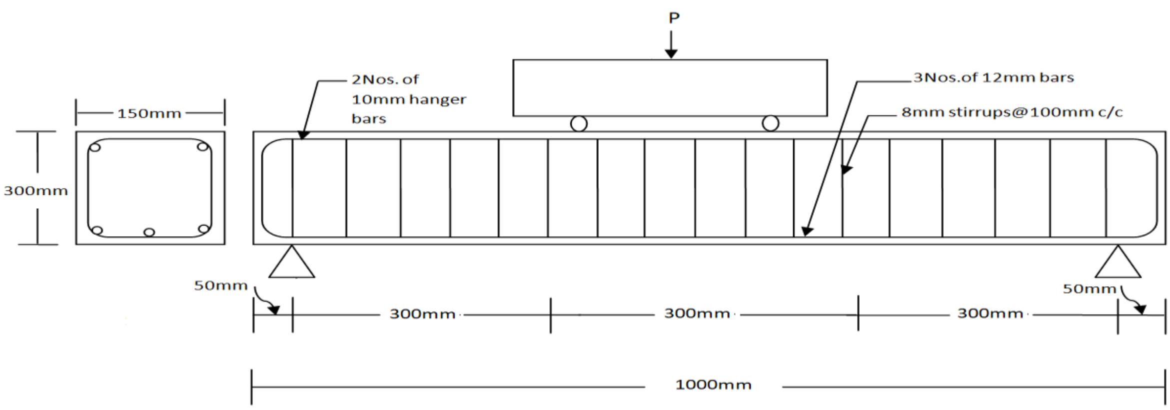

Fig. 3: Reinforcement details of R.C.C. Beam as per IS 456:2000

4. RESULTS AND DISCUSSION

4.1 Load–Deflection relationship between SCC Beams

The mid-span loading-displacement curve was the important factor to evaluate the mechanical behaviours of the simply supported RC beam. Figure 4 illustrated the five mid-span loading-displacement curves of the RCC beam of different percentages of GGBS

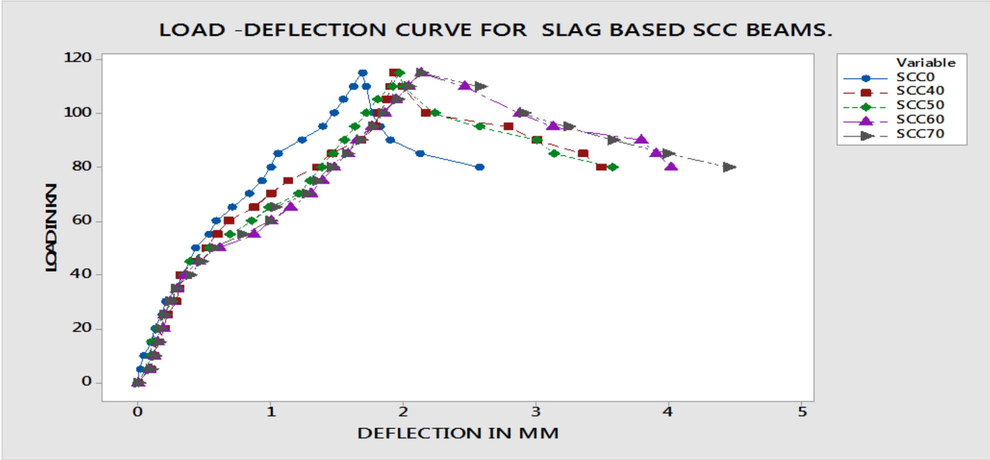

Fig. 4: Load-Deflection Curve for GGBS Based SCC Beams

Table 2: Analytical and Experimental Test Results for SCC Beams using GGBS and CRF under Flexure

Beam no.	Theoretical design moment (N mm)	Design load (KN)	Load at First Crack	Ultimate Load	Ultimate Deflection	Stiffness (N/m)
SCC0	32534207.680	94	29.0	105.95	2.691	$39.4x10^6$
SCC4	30435106.905	92	26.15	99.70	1.675	$59.54x10^6$
SCC5	30158109.345	88	24.35	94.0	1.633	$57.64x10^6$
SCC6	29985706.245	87	21.55	90.40	1.671	$52.14x10^6$
SCC7	29430990.75	86	19.65	90.35	1.674	$54.4x10^6$
SCC0	32534207.680	94	29.0	105.95	2.691	$39.4x10^6$
SCC4	30435106.905	92	26.15	99.70	1.675	$59.54x10^6$

4.2 Energy absorption capacity

The energy absorption capacity of reinforced concrete (RC) elements is one of the crucial structural properties that define their seismic resistance. The test results revealed that the energy absorption capacity with the NSM ductile materials increases by up to 80% compared with the control beam.

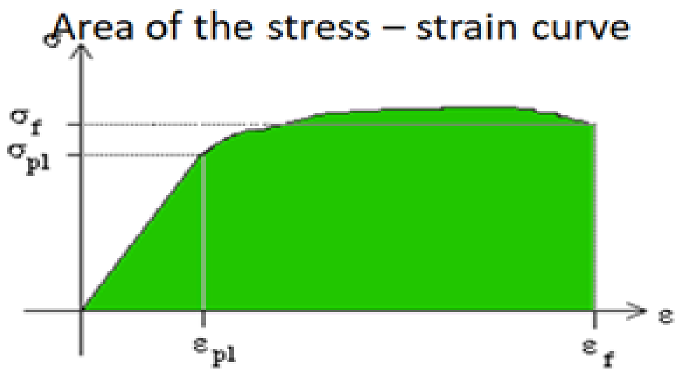

Fig. 5: Area of the Stress-Stain Curve

Table 3: Energy absorption capacity SCC beams

SCC Beam Designations	Energy Absorption Capacity (KN mm)	% Increase
Control SCC	191.8925	Reference
SCC40	286.56	63.4%
SCC50	274.8825	57.8%
SCC60	270.42	54.16%
SCC70	278.2025	59.5%

4.3 Ductility Characteristics

Ductility of a structure, element or section can be expressed in terms of the maximum imposed deformation, in terms of ductility factors, where the ductility factor is defined as the maximum deformation divided by the corresponding deformation present when yielding occurs. The yield displacement (Δy) is the lateral displacement at 80% of the ultimate load at the ascending part of the curve while the failure displacement (Δf) is lateral displacement at 80% of the ultimate load at the descending part of the curve. The ductility factor is computed by

$$\text{Ductility factor (R)} = \frac{\Delta f}{\Delta y}$$

The displacement ductility factor R is shown defined for ideal elastoplastic behaviour in Figure 6.

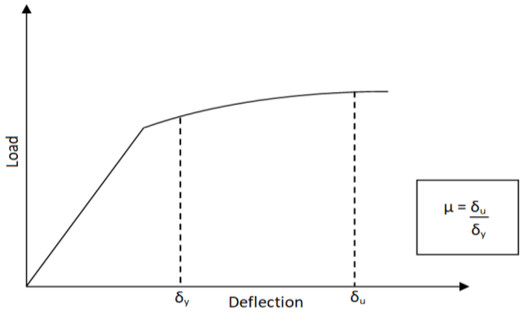

Fig. 6: Typical Load - Deflection Curve

Table 4: Ductility factor of SCC Beams of grade M30 to M20 with GGBS and CRF

SCC Beam Designations	Yield Deflection	Ultimate Deflection	Ductility Ratio	% Increase/Decrease
Control SCC	1.719	2.691	1.565	Reference
SCC40	1.193	1.675	1.405	11.3%
SCC50	1.306	1.633	1.25	25.2%
SCC60	1.768	1.671	0.945	65.3%
SCC70	1.762	1.674	0.95	63.4%

4.4 Analytical Analysis of SCC Beams – A Study of Finite Element Model

The response of reinforced SCC beams under static loading has been studied using Non-linear finite element analysis, along with initial and progressive cracks to failure. The experimental and analytical results were compared and presented in this research work to make more scientific conclusions. The flexural crack pattern of SCC beams have been determined and shown in the figure 7 and figure 8 below.

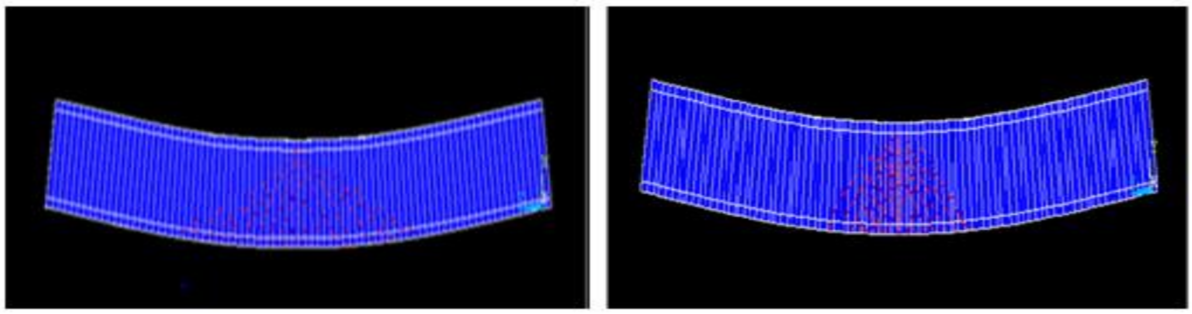

Fig. 7: Flexural Crack Pattern of Reinforced Beam SCC40 and SCC50

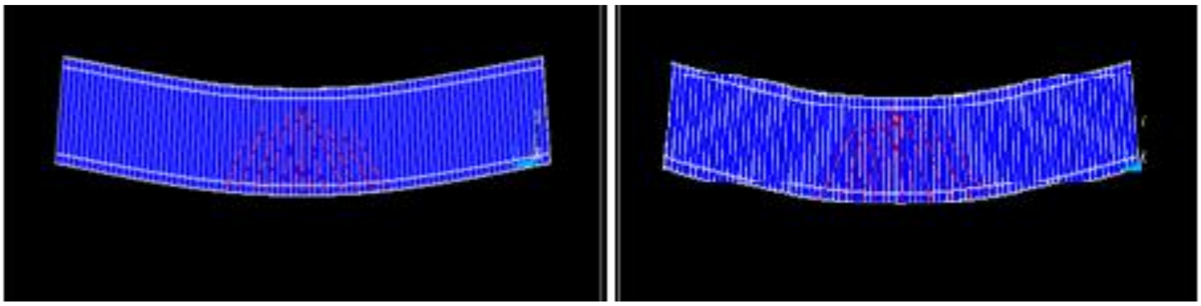

Fig. 8: Flexural Crack Pattern of Reinforced Beam SCC60 and SCC70

Table 7: Strength and Deformation Properties Pertaining to Ultimate Stage

S. No	Beam Designation	Experimental Ultimate Load (KN)	Analytical Ultimate Load (KN)	Experimental Deflection	Analytical Deflection (mm)
1	Control SCC	105.95	121	2.691	3.717
2	SCC40	99.70	124	1.675	3.788
3	SCC50	94.0	123	1.633	3.873
4	SCC60	90.40	119	1.671	3.915
5	SCC70	90.35	113	1.674	3.915

5. CONCLUSIONS

- The loading-displacement curve was linear at the load beginning and became nonlinear slowly with the increasing load. The first crack in the control SCC significantly delayed than the SCC with GGBS and CRF. While considering the ultimate load of the SCC beams with GGBS and CRF decreases with respect to the increase in the percentage of GGBS. All GGBS SCC beams show the typical structural behaviour under flexure. The ultimate load carrying capacity of beams with GGBS is very close to the control beam.

- The finite element model can make a reasonable estimate on the prediction values ultimate loads and ultimate deflections. A close agreement has been obtained between the predicted results. Deflections and stresses at the center line along with initial and progressive cracking of the finite element model compare well with the manual calculations obtained for a reinforced SCC beams. The load-deflection behaviour of Reinforced SCC beams obtained from the analytical is close to that to experimental values.
- The use of industrial by-products in SCC enhanced its performance in fresh state by avoiding the Viscosity Modifying Agent. The results from the structural and durable behaviour of all SCC are clearly pointing to the possibility of low strength SCC production with regard to its lower production costs. The incorporating GGBS in self compacting concrete step down the strength to low grade and the replacement of CRF to river sand compensate the higher end cost of SCC to cost-effective concrete

6. ACKNOWLEDGMENT

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BIOGRAPHY

Manjula. V
Assistant Professor & Research Scholar
Dr. M.G.R. Educational and Research Institute, Chennai, Tamil Nadu

Graduated in Structures (2010)
Sathyabama University, Chennai, India

Dr. T. Felix Kala
Dean
Dr. M.G.R. Educational and Research Institute, Chennai, Tamil Nadu

Graduated in Structural Engineering
SRM Engineering College, Tamil Nadu

Ph.D. in Civil Engineering (2011)
Sathyabama University, Chennai, Tamil Nadu

