FINITE ELEMENT ANALYSIS OF BEAM WITH SELF COMPACTING CONCRETE

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Abstract - *Self-Compacting Concrete (SCC) is a relatively new concrete material used in civil engineering. This type of concrete has high workability and can achieve a high grade of concrete. Hence, the behaviour of Self Compacting Concrete (SCC) members is significantly different from that of traditional RC members. In this study, the ABAQUS Simulia V6.12.3 program is used to model the behaviour of reinforced self-compacting concrete beam. The finite element modelling done by using concrete damaged plasticity approach. For validation, a reinforced concrete beam was modelled by using the data from a previous research paper. The main goal of this project is to investigate flexure behaviour and deflection of SCC beam for concrete mix M1 to M9 by varying the composition of bottom ash, fly ash as replacement of cement, and eco sand as replacement of M Sand. This project presents the results of numerical studies of the flexural behaviour of simply supported self-compacting concrete beams under two-point loading. The numerical analysis was carried out using the finite element method (FEM). Through this research work, it was found that the proposed modelling method manages to capture with acceptable accuracy the behaviour of self-compacting concrete members. The results of the numerical analysis were examined and compared. M5 (Bottom Ash – 10%, Fly Ash – 30 %, Eco Sand – 30%) mix shows higher ultimate load for beam compared to other mixes.*

Key Words: SCC Beam, concrete damaged plasticity, Finite Element Modelling, ABAQUS

1. INTRODUCTION

Reinforced concrete is a heterogeneous material to be modelled within finite element packages. A perfect material model in the finite element model should be capable of representing both the elastic and plastic behaviour of concrete in compression and tension. The compressive behaviour of concrete should include both elastic and inelastic behaviour of concrete including strain-softening portions. The simulation of concrete behaviour under tension should include tension softening, stiffening and local bond effects in RC elements. Therefore, the development of a finite element model (FEM) may need intensive material testing is needed to model complex material mixes. More number of numerical material models available in the literature with the information to develop complete stress-strain curves of concrete. In this paper, D. Mehmet Ozcan et al. (2009) used the ABAQUS program to model the behaviour of RC beams. The FEM uses the concrete damaged plasticity approach. This model helps to support that the FEM model is an effective replacement for the traditional experimental work for the analysis of hardened properties of concrete. For validation, a reinforced concrete beam was modelled which had been experimentally tested and reported by M. Singh et al. (2017). This paper presents and modifies nine numerical models that can be easily adopted with minimum changes to the ABAQUS FE package. Modifications for nine stress-strain curves under compression and tension are suggested to be used with the damaged plasticity model in ABAQUS. This material model presented in the paper is capable of representing the formation of cracks and post-cracking behaviour of reinforced concrete elements. Nine numerical stress-strain relations and the damaged plasticity model in ABAQUS are briefly discussed.

2. DEVELOPING THE MATERIAL MODEL

The concrete damaged plasticity model is used in this study to model the mechanical behaviour of SCC Beam. The parameters required for the CDP model to accurately represent the material behaviour of SCC are calibrated with the relation derived in the paper M. Singh et.al [2]. The uniaxial stress-strain curves of SCC under compression and tension are obtained from the below relations.

2.1 Stress strain in compression

The stress strain behaviour under uniaxial compression can be obtained from the experimental tests. The inelastic (ε_c^{in}) strain can be obtained by subtracting the elastic (ε_{0c}^{el}) component from the total strain (ε_c) as follows.

$$\varepsilon_c^{in} = \varepsilon_c - \varepsilon_{0c}^{el} \quad (1)$$

$$\varepsilon_{0c}^{el} = \sigma_c / E_0 \quad (2)$$

Where E_0 is the initial (undamaged) elastic modulus.

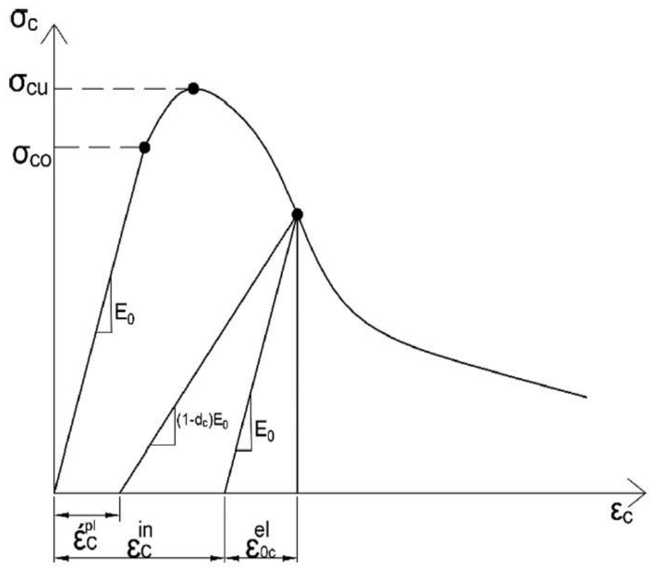


Fig 1. Uniaxial stress-strain showing various components of strain (plastic, elastic) and damage.

Fig.1 shows the plastic strain (ε_c^{pl}) component which can be obtained from the damage parameter in compression(d_c). This parameter varies from 0 to 1 which helps to characterize the degradation of the material stiffness where it is zero for an undamaged state and one for a complete damage state. With the parameter, the plastic strain as well as compressive stress and effective compressive stress can be obtained as follows

$$\sigma_c = (1 - d_c)\, E_0\, (\varepsilon_C - \varepsilon_c^{pl}) \quad (3)$$

$$\bar{\sigma}_c = \sigma_c / (1 - d_c) = E_0\, (\varepsilon_C - \varepsilon_c^{pl}) \quad (4)$$

$$\varepsilon_c^{pl} = \varepsilon_c^{in} - \frac{d_c}{(1-d_c)} \frac{\sigma_c}{E_0} \quad (5)$$

2.2 Stress strain in tension

In order to characterising the hardening and softening phase of the material, it is important to get the cracking strain ε_t^{ck} that can be obtained as

$$\varepsilon_t^{ck} = \varepsilon_t - \varepsilon_t^{el} \quad (6)$$

$$\varepsilon_t^{el} = \sigma_t / E_0 \quad (7)$$

This is practically the inelastic strain (ε_c^{in}) defined earlier when the material is under uniaxial compression. Eqs. (3) – (7) derived for uniaxial compression are similarly applied to uniaxial tension to evaluate the plastic strain, tensile stress and effective tensile stress.

3. MATERIAL PROPERTIES USING IN ABAQUS

The damage parameter in tension is assumed to activate when the peak tensile strength is achieved. For the present study, the damage parameter recommended by Mahmud et al. [3] is used which is as follows.

$$d_c = 1 - \frac{\frac{\sigma_c}{E_0}}{0.2\, \varepsilon_c^{in} + \frac{\sigma_c}{E_0}} \quad (8)$$

$$d_t = 1 - \frac{\sigma}{ft} \quad (9)$$

In addition to the stress strain behaviour, there are five other parameters required to completely define the CDP model which are discussed as follow:

Table 1. CDP Parameters

CONCRETE DAMAGE PLASTICITY				
Dilation Angle	Eccentricity	fb0/fc0	K	Viscosity Parameter
30	0.1	1.05	0.6667	0.005

Table 2 shows the material property of plain concrete, parameters correspond to the figure 4 and 5 are used in analysis.

Table 2 Material property of concrete

Mass Density kN / m³	Youngs Modulus N/mm²		Poisson Ratio
25	30013.2		0.2
Compression Behaviour		Tension Behaviour	
Yield Stress MPa	Inelastic strain	Yield Stress MPa	Inelastic Strain
11.264	0	2.55	0
18.553	0.000156	1.669	0.000289
24.047	0.000371	1.044	0.000583
27.168	0.000666	0.669	0.000878
26.530	0.001032	0.484	0.00117
24.572	0.001312	0.418	0.00143
21.915	0.001618	0.401	0.00171
18.650	0.001949	0.382	0.00198
9.874	0.002304	0.322	0.00225
6.865	0.00268	0.198	0.0025
4.923	0.005641	0	0.003
3.578	0.008411		
2.638	0.011146		
1.998	0.01386		

Table 3 Material property of steel rebar

Mass Density kN / m^3	Youngs Modulus N/mm^2	Yield Strength kN / mm^2	Poisson Ratio
7850	210000	Fe 415	0.3
Yield Stress MPa		Plastic Strain	
250		0	
415		0.002	
415		0.01	
622.5		0.15	

4. GEOMETRICAL SPECIFICATION

4.1 Size of Beam

- Cross section of Beam = 100 x 200 mm
- Length = 1500 mm
- Effective Span = 1350 mm

4.2 Reinforcement Detailing

- Main reinforcement = 4 # 12 mm dia.
- Transverse Reinforcement
  2 legged 8 mm dia at 90 mm c/c.

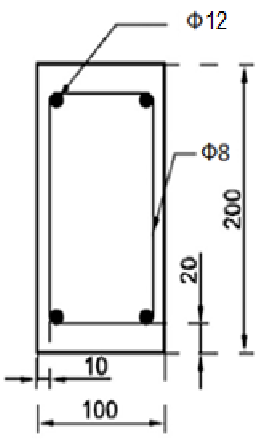


Fig 2 Cross Section

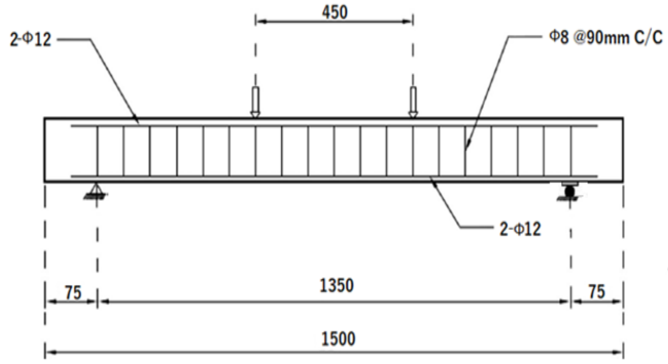


Fig 3 Longitudinal Section

Table 4 Materials used

Cement	Ordinary Portland Cement, Grade 53
Fine Aggregate	Manufactured Sand and Eco Sand
Coarse Aggregate	Aggregate Size 12.5 mm
Water	Potable tap water
Filler Material	Fly Ash and Bottom Ash
Chemical Admixture	Super Plasticizer – Master Glenium Sky 8233

Table 5 Combination of beam

MIX ID	BOTTOM ASH (%)	FLY ASH (%)	Eco Sand (%)
M1	5	25	10
M2	5	30	20
M3	5	35	30
M4	10	25	20
M5	10	30	30
M6	10	35	20
M7	15	25	30
M8	15	30	10
M9	15	35	20

5. MESHING

Concrete block has meshed with an element type of 20 node quadratic hexahedron of size 15 mm. Reinforcement bars are meshed with an element type of 10 node tetrahedron of size 10 mm.

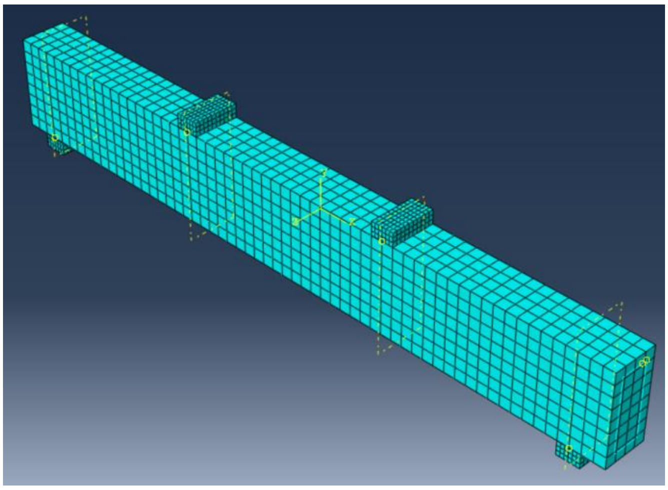


Fig 4 Meshed concrete beam

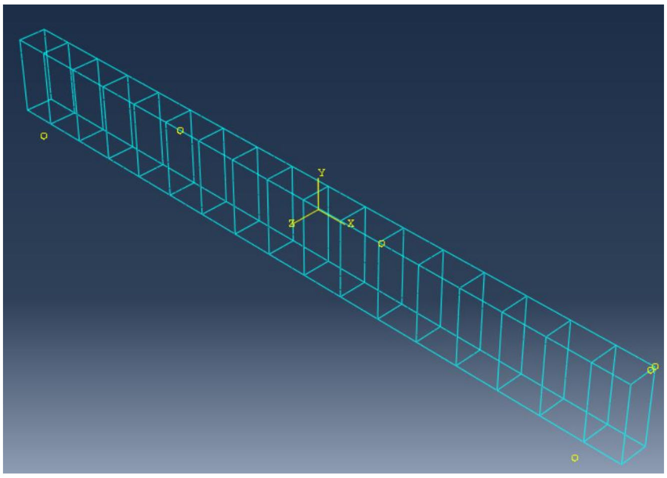


Fig 5 Meshed Reinforcement

6. LOADING AND BOUNDARY CONDITION

Totally 9 specimens of 1.5 m with varying percentages of fly ash (25%, 30%, 35%), bottom ash (5%, 10%, 15%) as partial replacement of cement and eco sand (10%, 20%, 30%) as partial replacement of fine aggregate were modelled and analysed for the load carrying capacity and flexural behaviour. The ends of the specimens were simply supported. One end is provided with pinned support and the other end is with roller support. Both ends were restrained against distortion. Beam specimens were loaded with two-point loading condition till failure and results were obtained by non-linear analysis. The beam is modelled as displacement control method of about 10 mm.

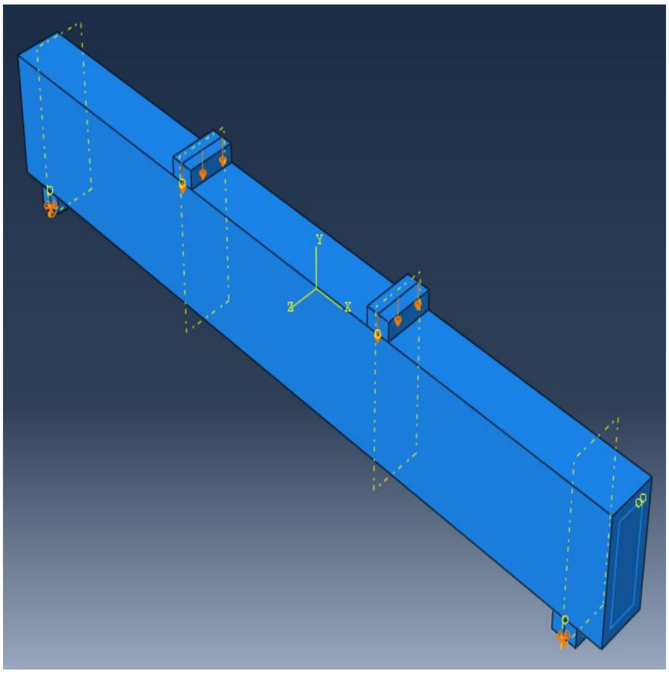


Fig 6 Loading Condition

7. RESULT AND DISCUSSION

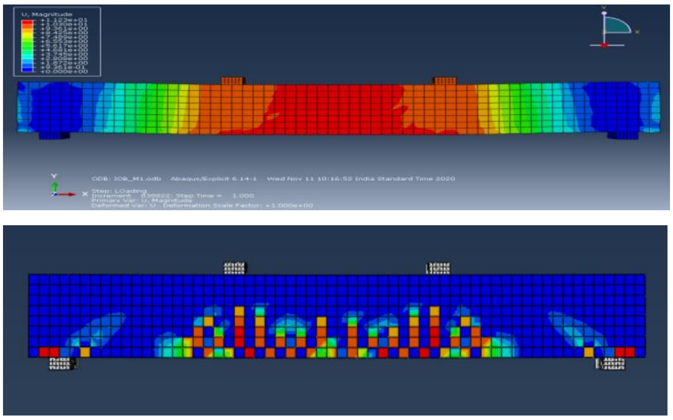
From the non-linear analysis, vertical deformation, yield load and ultimate load, crack pattern was determined for all the nine specimens with incremental load.

TABLE 6 Ultimate load and Deflection of Beam

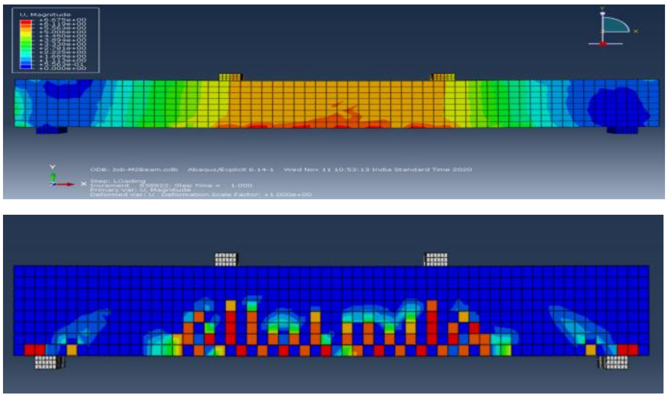
BEAM	Ultimate Load (kN)	Displacement (mm)
M0	76.83	1.637
M1	82.74	1.805
M2	86.57	2.045
M3	79.38	1.922
M4	82.35	2.259
M5	91.01	2.359
M6	84.84	1.872
M7	81.89	1.866
M8	81.03	1.989
M9	82.59	2.101

7.1 Deflection contour and Crack pattern

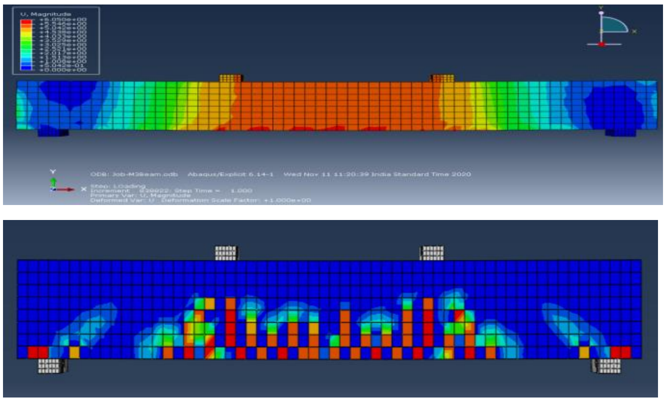
The deflection contour and crack pattern of all beams shown in "Fig 7" are taken from ABAQUS output file at the ultimate load.



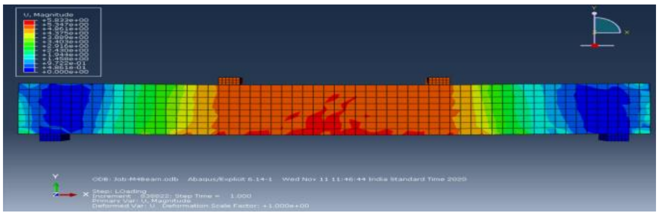
a. M1 Mix

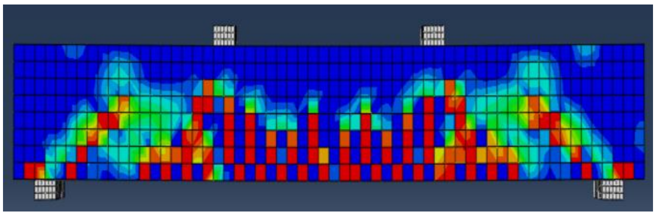


b. M2 Mix

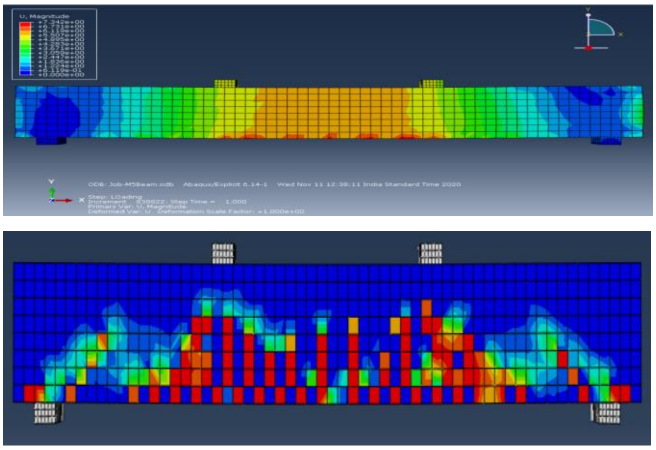


c. M3 Mix

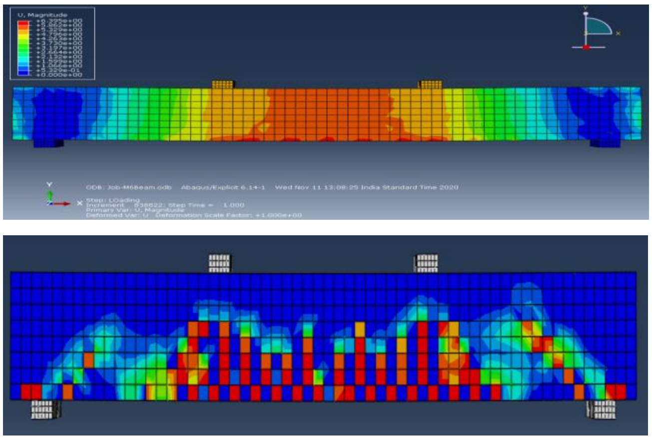




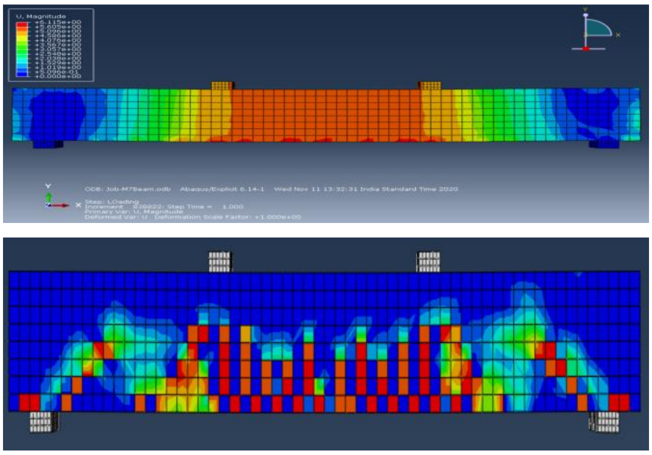
d. M4 Mix



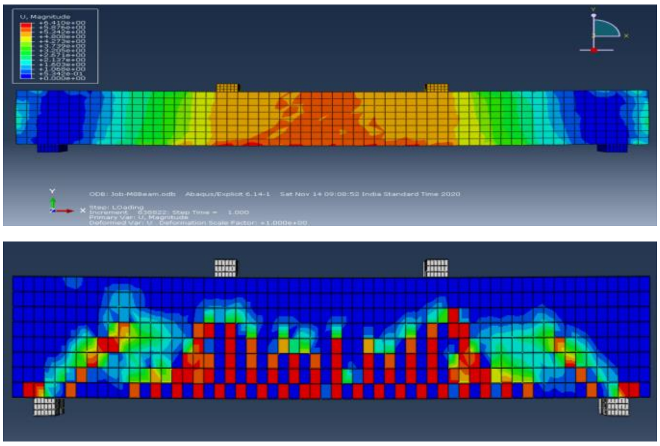
e. M5 Mix



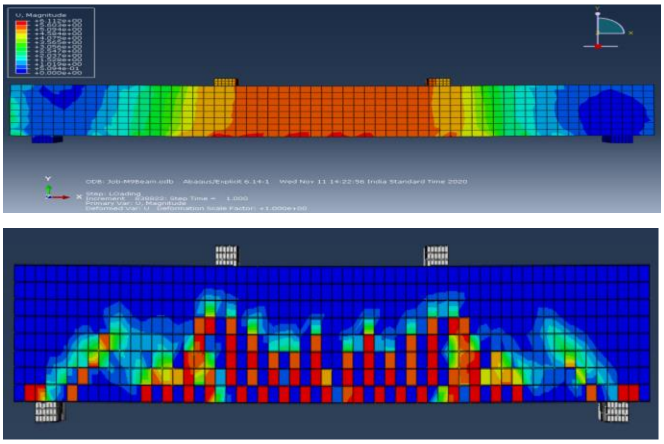
f. M6 Mix



g. M7 Mix



h. M8 Mix



i. M9 Mix

Fig 7 Deflection and crack Contour of MIX M1 to M9

7.2 Load Vs Displacement

Deflection response of all beams to the ultimate load were compared to one another and plotted as a graph shown in the "Fig 8". Comparing with normal SCC beam all other beams shows considerable increase in ultimate load given in "Fig 8".

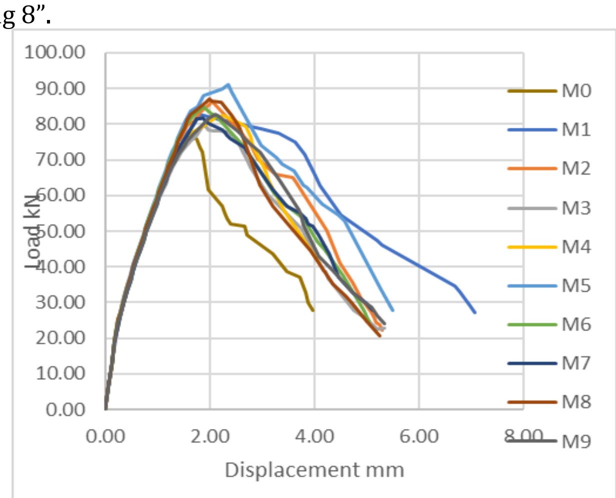


Fig 8 Load Vs Deflection curve

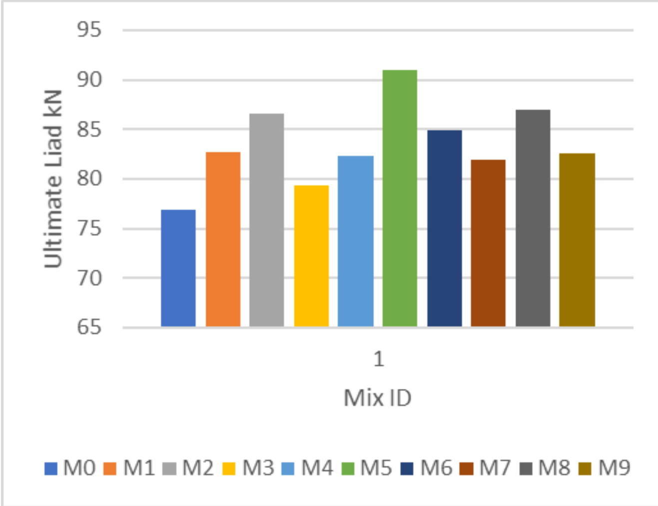


Fig 9 Comparison of ultimate load and deflection of all beams with conventional beam

8. CONCLUSIONS

In this study the flexural behavior and ultimate strength of the SCC beams are analysed under concrete damage plasticity model using commercially available finite element software ABAQUS Simulia V 6.12.3 From which the following conclusion are drawn.

- The proposed three-dimensional FE model is able to simulate the overall flexural behavior of all beams.
- The results obtained from numerical analysis, shows that the load carrying capacity of SCC beam with fly ash 30%, bottom ash 10% and eco sad 30% increased about 18.5% than the conventional beam.
- Increase in Load Carrying Capacity of SCC member is due to the presence of fly ash and eco sand.
- SCC with bottom ash content of 10%, fly ash content of 30% and Eco sand content of 30% is suggested as an efficient mix of concrete in SCC and it is economical when it is utilized in Large scale construction works.

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