Finite Element Analysis of Self Compacting Concrete Beam with Polystyrene Embedded on Neutral Axis

M.FRANCHIS DAVID
PG Student of Structural Engineering
MepcoSchlenk Engineering College
Sivakasi, Tamilnadu, India

R.THEENATHAYALAN
Assistant Professor, Civil Department
MepcoSchlenk Engineering College
Sivakasi, Tamilnadu, India

Abstract—In recent Days, the construction industry faces many problems due to the shortage of raw materials. If it continues, within five or ten years all the naturally existing raw materials will be depleted by concrete construction. For that, we need to reduce the usage of existing raw materials by material replacement in concrete member. In flexural member both the compressive force and tensile force acting in the neutral axis of concrete is zero. The materials filled near to the neutral axis contribute neither strength nor resistance. So the materials in the neutral axis of any concrete member can be replaced by cheaper filler materials like low grade concrete, PVC balls and expanded polystyrene sheets or can be left hollow. In this project, the behaviour of flexural member with replacement of expanded polystyrene sheets having various thicknesses of 12 mm, 25 mm, 50 mm is analyzed for M20 grade self-compacting concrete (SCC) members and thereby to find the optimum thickness of expanded polystyrene sheets for replacement in the neutral axis, without affecting the flexural behaviour of member by Nonlinear finite element analysis with FEM software ANSYS.

Key words: Neutral axis, Self-compacting concrete, expanded polystyrene sheet, partial replacement.

I. INTRODUCTION

In this paper an attempt is being made to reduce weight and cost of the self compacting concrete structures by replacing the concrete with expanded polystyrene sheet in the neutral axis. Based on the literature, it is understood that in RC beams, less stressed concrete near neutral axis can be replaced by some lightweight material. Several types of infilled materials like Brick, Expanded polystyrene sheet(EPS), LSRC (Lightweight Sandwich Reinforced Concrete) sections, Terracottahollow blocks, etc were already experimented which shows good result. But it was observed that EPS does not provide thenecessary cross section to resist shear and compaction process is tedious.

To overcome these drawbacks an attempt has been made to investigate the effects of RC beam with partial replacement of concrete in the core of the neutral axis by EPS and using self-compacting concrete.

A. Expanded polystyrene sheet:

EPS can be a good partial replacement material in the core of the neutral axis in beams and yield excellent results in both bending and shear. EPS has been a material of choice for over half a century because of its application to various fields, excellence in performance in reduced cost. It is widely used in many everyday applications where itslightweight, strength, durability, thermal insulation and shock absorption characteristics provide economic, high performance products.

B. Self-compacting concrete:

SCC is a concrete that can flow and consolidate under its own weight, passing through the spaces between the reinforcement bars to fill the formwork. They have high cohesiveness and high workability. SCC can be transported without any segregation and placed without the use of vibrators to construct concrete free from honeycombs. The materials used for SCC are in par with that of the RCC. This paper deals with the reduction of materials in SCC by replacing materials in the neutral axis zone.

SCC mix design were developed using class F fly ash as a filler material along with Portland cement of 53 grade, VMA(Viscosity Modifying Agent) Master Glenium SKY 8630, super plasticizers Conplast SP-430. To qualify Self-Compacting Concrete mixes Slump flow, V-funnel, L-Box, U-Box tests were conducted and the fresh properties obtained are checkedagainst the specifications given by EFNARC (European Federation of National Associations Representing for Concrete) guidelines. Compressive strength tests were conducted to know the strength properties of the mixes at the age of 7 and 28 days of curing. Young’s modulus tests were conducted for the mixes after 28 days and the value of 21960 N/mm2 for the young’s modulus is obtained. After the many trails, the mix ratio 1:2.13:1.76 isachieved by satisfying all the requirements given by EFNARC guidelines.

C. Neutral Axis Calculation:

According to IS 456 Annexure G), the neutral axis depth is calculated as 80mm from the top of the 150x200mm beam by the formula X_u=(0.87fyAst)/(0.36fckb).The ultimate load for the proposed SCC beam is calculated as 100 KN and check the proposed beam is under reinforced section theoretical method.

After this, the nonlinear analysis of finite element software ANSYS v15 is used to evaluate the maximum stresses in steel and EPS, Load- displacement curve and crack pattern at ultimate load of control and partially replaced SCC. Past material research indicates not only the material type but also the properties used for the nonlinear analysis, so as to prevent validation.

II. SCOPE & SIGNIFICANCE

As SCC is costlier than normal concrete, economical SCC members can be designed by reducing the concrete area. Self-weight of the beam is reduced by replacing the core with EPS.EPS can be a good partial replacement material in the core of the neutral axis in beams and yield excellent results in both bending and shear. SCC is a solution for problems like in adequate compaction causing honeycombs and reduction in durability.

III. SPECIMEN DETAILS

Table 1 Specimen details

S. No	specimen	EPS thickness (mm)	Position of EPS about neutral axis	
			Above (mm)	Below (mm)
1.	B1	-	-	-
2.	B2	12	6	6
3.	B3	25	12.5	12.5
4.	B4	50	25	25

B1 - control beam
B2 – beam partially replaced with 12mm EPS at neutral axis
B3 – beam partially replaced with 25mm EPS at neutral axis
B4 – beam partially replaced with 50mm EPS at neutral axis

IV. ANALYTICAL WORK

A. Element used:

i. Concrete:

The Solid65 element having eight nodes with three degree of freedom at each node (translations in the nodal X, Y,Z directions) is used for modeling the concrete. This element is having capability of plastic deformation, cracking in three orthogonal directions, and crushing. This element is shown in Fig.1

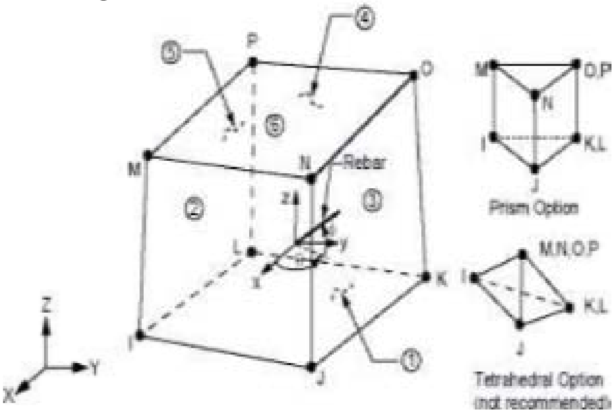

Fig.1 Element Solid 65

ii. Steel Reinforcement:

A Link180 element is used to model steel reinforcement. This element is a 3D spar element and it has two nodes with three degrees of freedom – translations in the nodal x, y, and z directions. This element is also capable of plastic deformation and is shown in Fig. 2

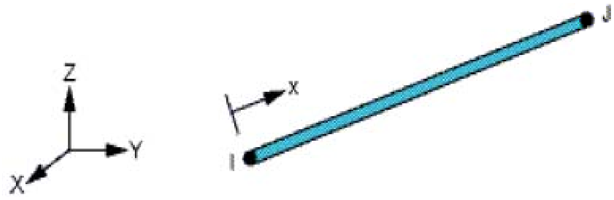

Fig.2 Element Link 180

iii. Expanded polystyrene sheet:

A Shell 63 is used to model the EPS. It has both bending and membrane capabilities. Both in-plane and normal loads are permitted. This element has six degrees of freedom at each node: translation in the nodal x,y and z directions about the nodal x,y and z axis is shown in Fig.3

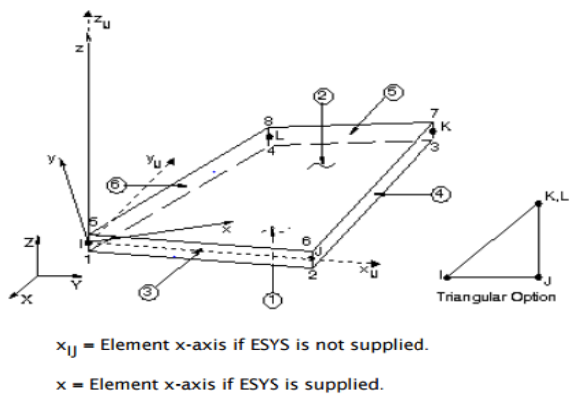

Fig.3 Element shell 63

V. MODELLING PROCEDURE

A. Element properties:

The elemental properties of the material are given in the preprocessor stage of the Ansyssoftware.

i. Element Types:

The ANSYS contains more than 100 different element types for a material to be considered. Each element type has a unique characteristic features and a prefix that identifies the element category.

Table 2 Element type

Material	ANSYS Element
Concrete	SOLID 65
Steel reinforcement	LINK 180
EPS	SHELL 63

ii. Real Constants:

Real constants are the constant values which are required for the element matrix calculation, as it is independent from nodal locations and properties. Typical real constants include area, thickness, inner and outer diameter, etc. Every element type have their basic real constants.

Table 3 Real constant for control beam

ANSYS Element	Real constant
LINK 180	Set 1, set 2
SOLID 65	Set 3

Set 1: Area 10 mm bar 78.5 mm^2.
Set 2: Area 8 mm stirrup 50 mm^2.
Set 3: solid 65 all values given zero

Table 4 Real constant for beam with 12 mm EPS

ANSYS Element	**Real constant**
LINK 180	Set 1, set 2
SOLID 65	Set 3
SHELL 63	Set 4

S e t 1: Area 10 mm bar 78.5 mm^2.
S e t 2: Area 8 mm stirrup 50 mm^2.
S e t 3: solid 65 all values given zero
S e t 4: thickness 12 mm

Table 5 Real constant for beam with 25 mm EPS

ANSYS Element	**Real constant**
LINK 180	Set 1, set 2
SOLID 65	Set 3
SHELL 63	Set 4

Set 1: Area 10 mm bar 78.5 mm^2.
Set 2: Area 8 mm stirrup 50 mm^2.
Set 3: solid 65 all values given zero
Set 4: thickness 25 mm

Table 6 Real constant for beam with 50 mm EPS

ANSYS Element	**Real constant**
LINK 180	Set 1, set 2
SOLID 65	Set 3
SHELL 63	Set 4

Set 1: Area 10 mm bar 78.5 mm2.
Set 2: Area 8 mm stirrup 50 mm2.
Set 3: solid 65 all values given zero
Set 4: thickness 50 mm

iii. Material Properties:

Various material properties are used for each element type. Typical material properties include Young's modulus (modulus of elasticity), Poisson ratio, etc.

Table 7 Material Properties

Material	**Young's modulus (N/mm^2)**	**Poisson ratio**
Concrete (M20 SCC)	21960	0.2
Reinforcement (Fe 415)	$2x10^5$	0.3
EPS	3.45	0.34

B. Element Modeling:

i. Concrete modeling:

Reinforced concrete beams are taken for analysis are simply supported beams with span of 1.2 m and cross section of 150mm x 200mm. It consists three longitudinal reinforcementbars of 10mm at bottom and two hanger reinforcement bars of 10mm at top. Stirrups are provided with 150mm spacing, and as nominal cover 25mm provided for all four beams.

The SOLID65-3D concrete element simulates tension and compression properties in concrete. The required properties include elastic modulus, and Poisson's ratio, which are indicated in Table 7.

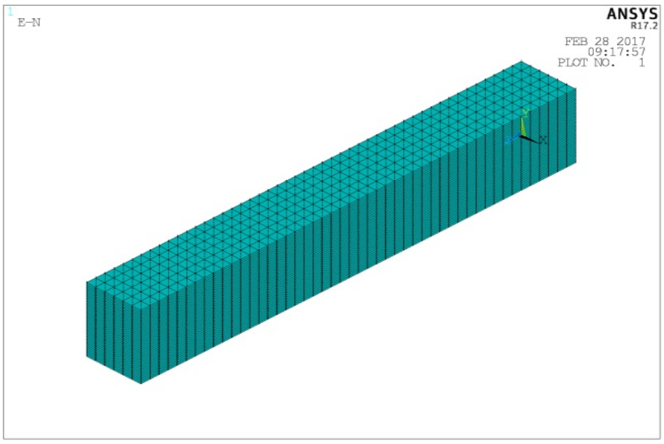

Fig.4 Modeling of concrete beam element

ii. Reinforcement Modeling:

There are three techniques to model steel reinforcement in finite element models for reinforced cement concrete: smeared model, discrete model, and embedded model. The smeared model assumes that reinforcement is uniformly extended throughout the concrete elements in a defined area of the FE mesh. This approach is used in large scale projects, where the reinforcement doesn't contribute enough, regarding the response of the structure. Here, in this project, the smeared model was used for reinforcement model.

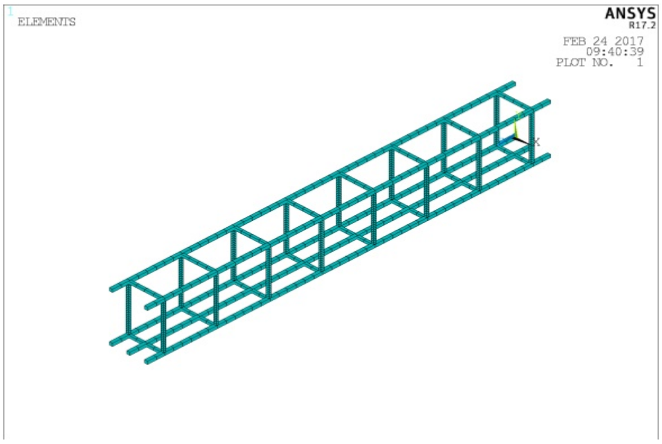

Fig.5Modeling of Reinforcement for control beam

iii. EPS Modeling:

EPS is modeled by shell 63 element. Key points are created at required co- ordinates (x,y and z axes) and these points are connected by lines. Area inside these lines is converted into single area. Mesh this area by 25x25mm by giving shell 63 properties. The image of EPS of 12mm thickness is given in the following fig. 6 and other EPS have same configuration except thickness.

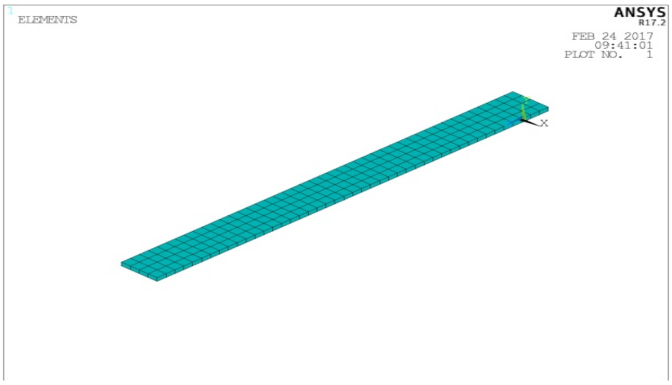

Fig.6Modeling of 12 mm EPS

The EPS is fixed inside the reinforcement in the neutral axis depth. The modeling of EPS with reinforcement is shown in fig.8

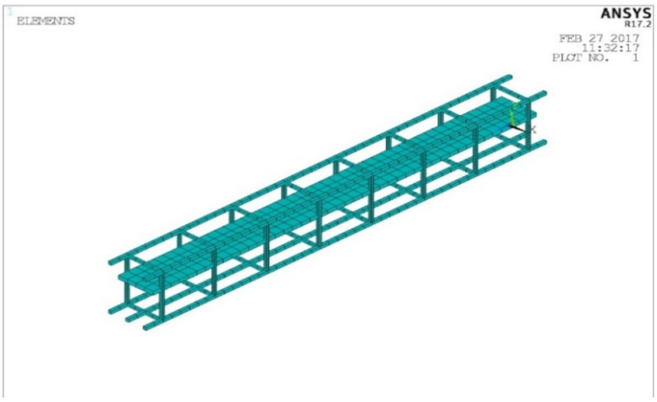

Fig.7Modeling of EPS with reinforcement

C. Load Stepping and nonlinear analysis:

In nonlinear analysis, the load is applied to the specimen by means of load steps. The ANSYS program uses the Newton–Raphson equilibrium iterations for updating the model stiffness. In this study, for the RC solid elements, convergence criteria were based on force and displacement, and the convergence tolerance limits were initially chosen by the ANSYS program. For the nonlinear analysis, automatic time stepping predicts and controls load step sizes. For smooth convergence behavior, automatic time stepping up to a selected maximum load step size can be used. In case of sudden convergence behavior, automatic time stepping will divide the load increment until the minimum load size. The maximum and minimum load step sizes are required for the automatic time stepping. The displacement is given in the direction of UY and UZ at both the end of beam and ultimate load is given as a pressure of 80 N/mm^2 on single element at one third distance of the beam from both ends.

VI. RESULT AND DISCUSSION

After analyzing, the results of the partially replaced SCC beams are derived and compared with the control SCC beam.

A. Max deflection at mid span:

Max deflection of four beams is shown in following figures. The max deflection of control beam is 8.78 mm and partially replaced beams are having max deflection of 8.51mm, 8.53mm and 8.55mm for thickness of 12mm, 25mm and 50mm EPS respectively at the ultimate load 100 kN.

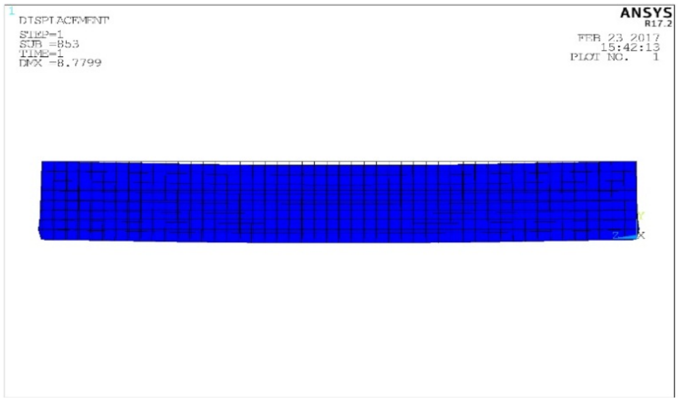

Fig.8 Maximum deflection of Control beam

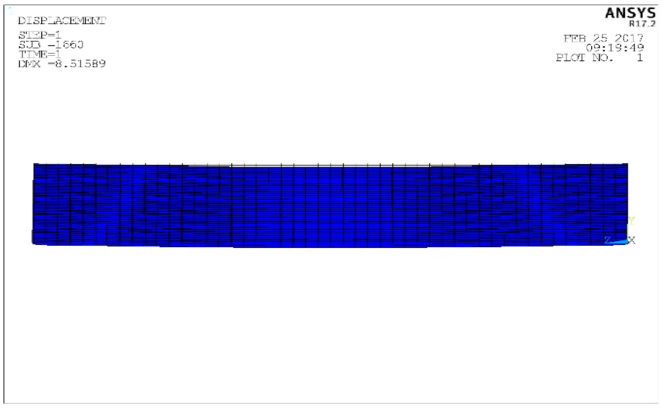

Fig.9Maximum deflection of beam with 12 mm EPS at ultimate load of 100 kN

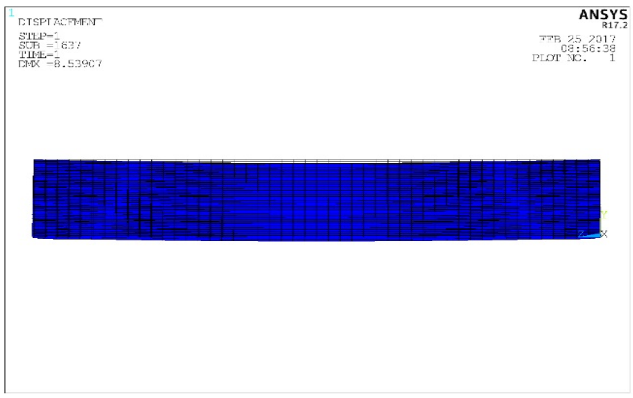

Fig.10 Maximum deflection of beam with 25 mm EPS at ultimate load of 100 kN

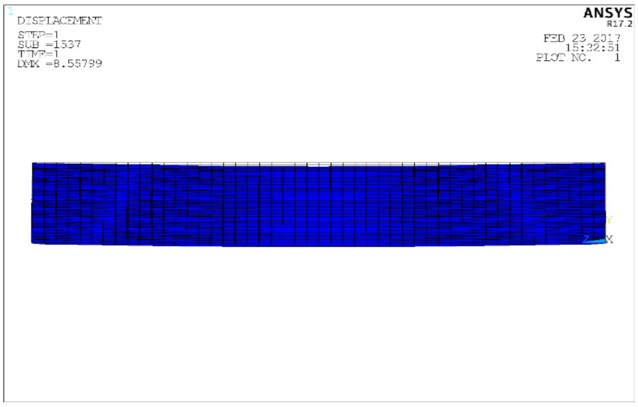

Fig.11Maximum deflection of beam with 50 mm EPS at ultimate load of 100 kN

It clearly shows that the maximum deflection of partially replaced beams have lesser value than the control beam.

B. Stress distribution in steel reinforcement:

Von misses stress diagram of steel reinforcement in four beams areshown in following figures. Themaximum stressin steelreinforcement ofcontrol beam is 1006 MPa and that of partially replaced beams are 817 MPa, 815MPa and 794 MPa for thickness of 12mm, 25mm and 50mm EPS respectively at ultimate load of 100 kN.

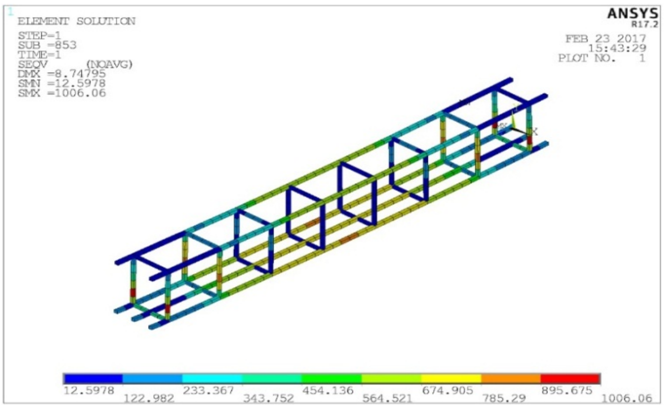

Fig.12Von misses stress diagram for control beam

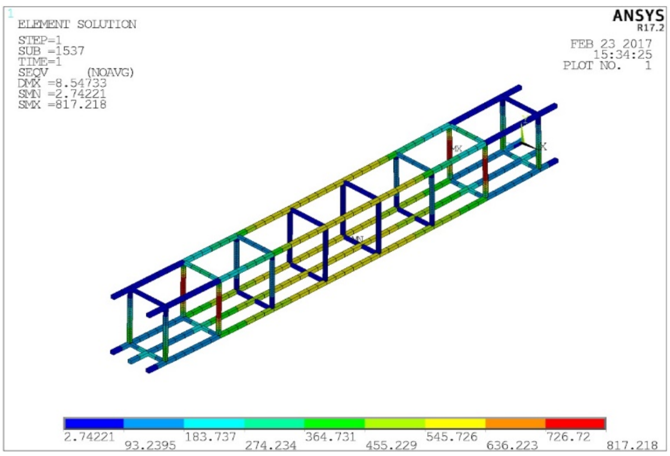

Fig.13 Von misses stress diagram for steel reinforcement of beam with 12 mm EPS

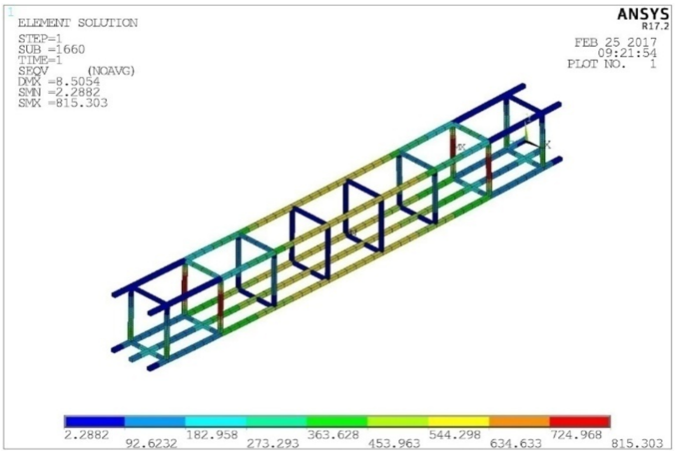

Fig.14Von misses stress diagram for steel reinforcement of beam with 25 mm EPS

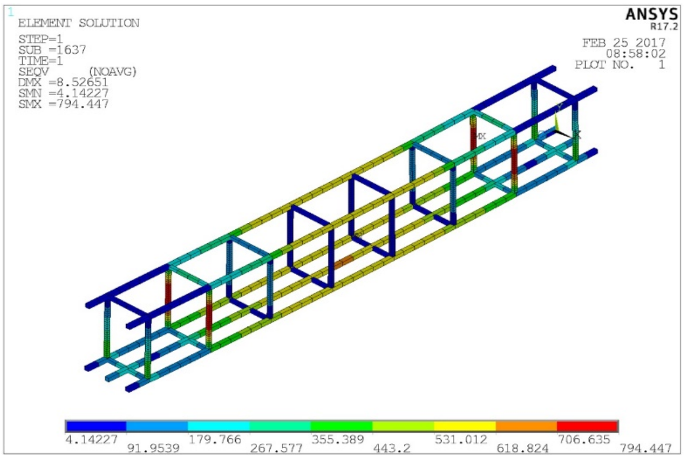

Fig.15Von misses stress diagram for steel reinforcement of beam with 50 mm EPS

It clearly shows that the stress in the reinforcement steel is reduced in partially replaced beams than the control beam, as the EPS shares the stress coming in the material.

C. Stress distribution diagram for EPS:

Von misses stress diagram of EPS in three beams are shown in following figures. The EPS has maximum stress of 0.027 MPa, 0.033 MPa and 0.055 MPawith thickness of 12mm, 25mm and 50mm respectively at ultimate load of 100 KN.

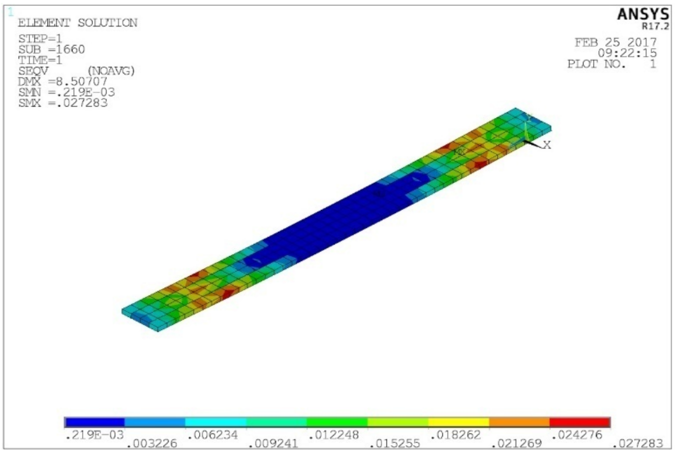

Fig.16Von misses stress diagram of 12 mm EPS

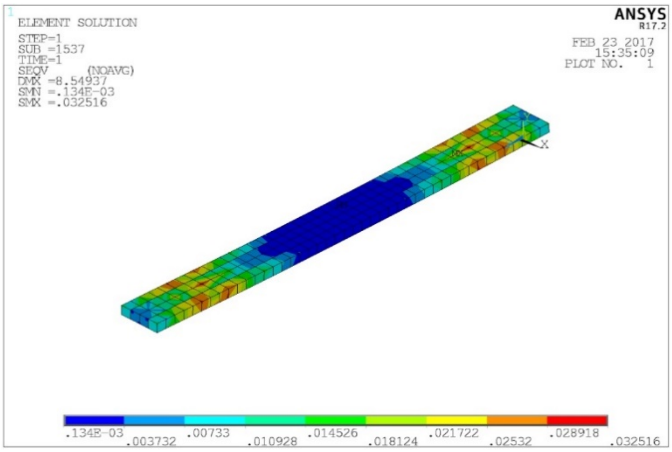

Fig.17Von misses stress diagram of 25 mm EPS

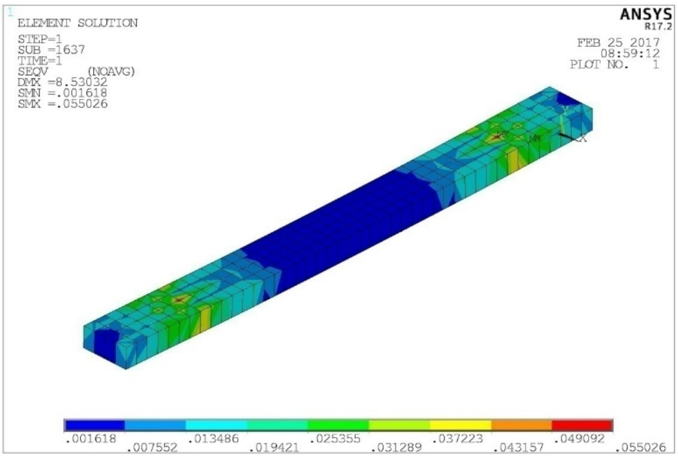

Fig.18Von misses stress diagram of 50 mm EPS

It clearly shows that, the maximum stress acting near the neutral axis zone is very less or negligible.

D. Load vs deflection curve:

Load vsmid span deflection curve for the four beams are shown in following figures.

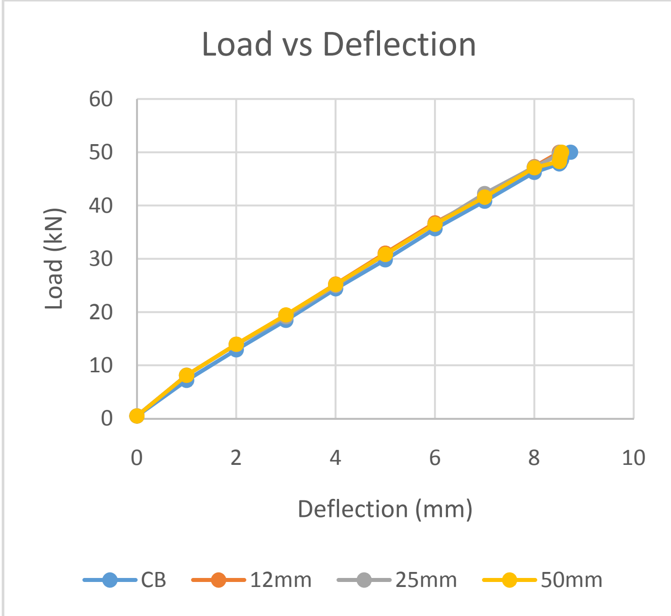

Chart 1 Load vs Deflection curve

From the load vs deflection curves, it is clear that, the partially replaced SCC beams can bear more load for the same deflection when compared with the control beam.

VII. CONCLUSIONS

The comparative study of control beam and partially EPS replaced beams is done bymeans of finite element analysis method using ANSYS v15.0 software. The results obtained are as follows:

The maximum deflection of partially EPS replaced beams at ultimate load is lesser than the max deflection of control beam. So it proves that, the bending behavior of partially replaced beam is better than the control beam.

The stress distribution in partially replaced beams is comparativelyhigher than the control beams. It shows that, the EPS contributing some amount of tensile behavior.

Up to 50mm replacement of EPS in the partially replaced SCC beams, the flexural behavior of the beams gives positive results. The experiment can be extended by increasing the thickness of the EPS near the neutral axis, so that maximum thickness of EPS at the center region can be found.

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