Three-dimensional finite element analysis on the flexural behavior of composite beams under linear displacement

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Abstract. This paper presents a three-dimensional finite element model for reinforced concrete beams to study their flexural behavior under linear displacement with different mesh sizes. The model was assessed in terms of failure modes and ultimate strength of composite beams with three different mesh sizes. This was found to be accurate in taking the linear displacement of the specimens. The analysis was further carried out to study various parameters like the percentage of horizontal and vertical web reinforcement, bending moment, shear strength, compression damage, and tension damage. Based on the results of this study optimum mesh size was proposed for further analysis.

Keywords: Mesh size, shear-moment interaction, horizontal web reinforcement, composite sections and linear displacement.

1. Introduction

In finite element analysis, mesh size plays a major role to get the maximum output. In this paper, design models and the design procedure was done as well as how to overcome the errors obtained while doing the analysis. And also explaining the horizontal and vertical web reinforcement, bending moment, shear strength, compression damage, and tension damage.

Several investigations have been done to show the effect of mesh size on the accuracy of the results obtained using finite element analysis. Osman, M.Y. and Suleiman, O.M.E., has worked on this and said neglecting large deflection effects can lead to overestimation of the deflection. He presented the nonlinear beam theory and compiled the computer program for the finite element. Membrane stresses and consequently causes the increase of beam stiffness when large deflection occurred. In the evaluation of deflection, the end condition plays a major factor. Lamination lay-up may cause a change in stiffness. The greater stiffness change can cause lesser beam restraints [1]. The conventional deep beam gets a lower load-carrying capacity when compared to the fiber-reinforced deep beam. The conventional deep beam gets a lower load-carrying capacity than that of the STM reinforced beam. But the better results are shown for the reinforced concrete deep beam. When comparing to Conventional deep beams reinforced concrete deep beam is not much stiffer than STM reinforced deep beam [2]. Liu, Y. and Glass. G. concluded that
the results between static, impact, and modal analysis and said the model has to be made 10 divisions on each side for steady loading and response condition and 80 divisions have to be made along the axis for a thin-walled beam to simulate crash response correctly with less than 10% error. The author has not performed the mathematical models to show the relationship between the accuracy of results, element size, and computing time [3]. Sun, H., Rajendran, S., and Song, D.Q., performed both experiment and finite element analysis to find the strain energy release rate values. Woven-fabric carbon fiber-composite epoxy material has been presented to find the strain energy release rate in midplane delamination in DCB and SLB. The difference for the DCB and SLB specimens in experimental and FEM is 4.1% and 2.04% [4]. Liu, Y. and Glass, G.A., said that the analysis will complete in less than 20 seconds if the modal is made with the finest mesh coat and also said that the proper mesh generation is required for the structural analysis. The modeling for the regular shapes only and said it can be done to the irregular shapes and finally concluded that it can be applied to fluid flow problems and heat transfer problems [5]. Raut, P., said that the number of active degrees of freedom is the same. The element aspect ratio in both meshes is equivalent. Four types of meshes have been used and said in mesh numbers 2 & 4 the nodal spacing ratio between them in x, y, z direction is the same [6]. Sazzad, M.M., Azad, M.S., Islam, M.T. And Rahman, F.I., the author concluded that the average divisions of mesh are 50 or 60 can secure optimum output and said that it is difficult to make an exact mesh size and also can’t understand about the accuracy of the mesh size. So he finally stated that accuracy is obtained by keeping an average mesh size of 50 to 60 [7]. Mohammed, M.S., said the detailed response of composite beams over the whole loading range up to failure can be developed by a finite element program. And also saida very accurate prediction of the behavior of steel and concrete composite beam by using the two-dimensional model and also said that the failure that occurred in the analysis is not caused by the buckling or large deformation [8]. Alias, R., Matalan, S.J., And Kasa, A. has obtained the increment of mesh size was increased the maximum foundation settlement value and maximum deflection value and said that in concrete cantilever retaining wall mesh size influences the finite element analysis performance. The investigation has been done on three types of mesh sizes in the analysis fine, medium, coarse, and said there is no difference in the FEA result by changing the mesh size [9]. Debnath, V. and Debnath, B., said in beam analysis element 188 or any other solid element can’t give a good result when compared to 189 elements. And also said in solving the beam analysis we should use element 189 than any other element [10]. The conventional deep beam is comparatively lesser than the deep beam with an i- section and deep beam with truss reinforcement when carrying load capacity. When compared to conventional deep beams, the deep beam with the I section and the deep beam with truss reinforcement are stiffer, Deep beam with shear reinforcement and without shear reinforcement gets a difference of 40% to 50% on yield loading [11, 12]. Kosan, M.F.S., Zaaid, A.M.A., Othman, M.Z., Abdullah, S., and Thanakodi, S., said to determine the accuracy of results mesh size should be one of the factors. The Refinement finite element grid causes a common error when it is insufficient. In simulation analysis model simplification is very important. Sometimes we won’t get accurate results because if the number of elements or grid is more it takes more time to run the analysis [13]. Liu, W., Geni, M., and Yu, L., said that the tetrahedral element has more accuracy than the hexahedral element. The structure boundary can approach accurately when it has a surface boundary of a higher order.in modal analysis, calculation error can be increased by changing element size. The calculation accuracy becomes stable when the mesh size is changed to one point or place [14]. Sazzad, M.M., Rahman, F.I., and Mamun, M.A.A., studied the factor of the slope with water and without water by taking different sizes of mesh 0.4m to 1.0m. With the help of 6 node triangle elements and mixed elements are used to compute the factor of safety [15]. Aman Dutt has obtained different results by changing the element size and type. It was observed the author compared the model with 2mm, 3mm, 4mm, 5mm, 6mm sizes of mesh deflection using Ansys. It was concluded that there is no major change in the deflection and also said that the error in deflection is less when compared to vonmises stress and said displacement is predicted accurately than
stresses. In the ends, due to stress concentration, there is a large variation in vonmises stress. Displacement and vonmises stress of the cantilever beam decreases by changing the mesh size [16]. Perumal, K., Kumar, A., Lingeshwaran, N. and Susmitha, S. said that by replacing the fine aggregate with coconut husk it can be minimized and also the water for mix proportion has to be minimized by using admixture. It helps in reducing the men power and time consumption is minimized [17]. The present study analysis on the simply supported beam is done using Abaqus software to predict the change in results with the change in mesh size.

2. Problem Statement
Finite element analysis plays a major role in the analysis part. Every structural engineer considers this analysis to check their designs. Several types of research have been done on the different elements such as retaining wall, plates, shear wall, etc. but there is no clarification in any of the research that at what size of mesh we can use for the beams or columns. So in this research, the mesh deflection of various beams such as conventional beam, I section beam, C section beam, T section beam, double C section beam are analyzed.

3. Material Geometry
3.1. Concrete Property
The properties of concrete used in the FE modeling are M30 Grade. The properties of elasticity and damaged properties are shown in Table 1. The density of concrete is 2.5E-006.

| S.no | Description                      | Values  |
|------|----------------------------------|---------|
| 1    | Young Modulus (MPa)              | 210000  |
| 2    | Poisson's ratio                  | 0.2     |
| 3    | Dilation angle                   | 31      |
| 4    | Eccentricity                     | 0.1     |
| 5    | fb0/fc0                          | 1.16    |
| 6    | K                                | 0.67    |
| 7    | Viscosity parameters             | 0       |

3.2. Steel Property
The properties for the steel bars used in the FE modeling are shown in the Table 2. The density of concrete is 7.85E-006.

| Young Modulus (MPa) | Poisson's ratio |
|---------------------|-----------------|
| 200000              | 0.3             |

3.3. Cross Section Details
The beam length and width are fixed for every component with the same standard length as shown in Figure.1 the composite members are taken from the Indian standard codebook 456.
4. Finite Element Analysis

4.1. Introduction

Finite Element Analysis helps to identify the behavior of many physical properties such as mechanical stress, fatigue, motion, mechanical vibration, fluid flow, and electrostatics. This plays a major role in the analysis part for the structural engineers to reduce the time of implementation and also to get the accurate values for the design to check the analysis and the beam has been assigned a beam id as shown in Table 3.

Table 3. Beam ID’s

| S.NO | Mesh Group | Beam ID | DESCRIPTION |
|------|------------|---------|-------------|
| 1    |            | 25BCB   | Conventional Beam |
| 2    |            | 25BCI   | Composite Beam with I s/c (ISMB400) |
| 3    | 25 mm      | 25BCC   | Composite Beam with C s/c (ISMC400) |
| 4    |            | 25BCT   | Composite Beam with T s/c (ISST250) |
| 5    |            | 25BDC   | Double C Composite Beam |
| 6    |            | 50BCB   | Conventional Beam |
| 7    |            | 50BCI   | Composite Beam with I s/c |
| 8    | 50 mm      | 50BCC   | Composite Beam with C s/c |
| 9    |            | 50BCT   | Composite Beam with T s/c |
| 10   |            | 50BDC   | Double C Composite Beam |
| 11   |            | 75BCB   | Conventional Beam |
| 12   |            | 75BCI   | Composite Beam with I s/c |
| 13   | 75 mm      | 75BCC   | Composite Beam with C s/c |
4.2. Effect of horizontal reinforcement
Horizontal reinforcement improves the performance of the beams by increasing their shear resistance capacity. Only a few types of research revealed that there is a slight or negligible effect. In this analysis, it has been used 1% of the horizontal reinforcement shown in Table 4.

| Length (L) | Width (W) | Depth (D) | Effective Depth (d) | P_h | A_{st_h} | F_y | F_{ck} | Diameter of bar | NO OF BARS |
|------------|-----------|-----------|---------------------|-----|----------|-----|--------|----------------|------------|
| 1500       | 250       | 450       | 430                 | 0.01| 1075     | 415 | 30     | 18             | 4          |

4.3. Effect of vertical reinforcement
The effect of vertical reinforcement can be equivalent to increasing the rigidity of the boundary beam. The vertical reinforcement in the beam holds the horizontal beam tightly and gives strength to the beam. In this analysis, it has been used 1% of the horizontal reinforcement shown in Table 5.

| Length (L) | Width (W) | Depth (D) | Effective depth (d) | P_h | A_{st_h} | F_y | F_{ck} | Diameter of bar | No.of bars |
|------------|-----------|-----------|---------------------|-----|----------|-----|--------|----------------|------------|
| 1500       | 250       | 450       | 430                 | 0.01| 1075     | 415 | 30     | 10             | 10         |

4.4. Effect of I section
The reinforcement present in the beam is modified by replacing it with I section ISMB400 shown in Figure 2. The I section is placed in the middle of the beam and the load is applied. It can get more stress and more deflection when compared to the conventional beam. But these are used to prevent the vibrations. And the flanges are chosen to prevent buckling sideways or torsional.
4.5. Effect of T Section
It is a load-bearing structure of reinforced concrete, wood, or metal with a t shaped cross-section. The top member acts as a compression member in resisting compressive stress. Below the compression, the flange serves to resist shear stress. When compared to the I section, the disadvantage of not having a bottom flange affects a lot in the strength, but it can be used as inverted. The t section used in the designing part is ISST250 as shown in Figure 3.
4.6. Effect of C Section
The reinforcement in the beam is replaced by placing the C section in the middle of the beam to obtain the maximum strength of the conventional beam. The dimensions of the C section are chosen from the IS 456 codebook as shown in Figure.4

![Figure 4. Cross-section details of C Section](image)

4.7. Effect of double C section
The reinforcement is replaced by placing the two c sections facing the end of each one in the beam. The details of the c section are taken from the Is 456 codebook as shown in Figure.5
5. Discussion of Results

5.1. Damage Compression

The concrete is strong in compression and weak in tension. Normally concrete has zero strength in tension. The properties of concrete damage are shown in the material property. In the analytical analysis damage compression has no change in the models of different combinations. The damage compression values are mainly based on the properties of the grade of concrete. The results for the compression damage of conventional beam, I section composite beam, T section Composite Beam, C section Composite Beam and Double C Section Composite Beam with the mesh size of 25mm, 50mm, and 75mm is shown in Figure6 to Figure10. The compression damage occurs at the end of the support. Whereas the compression damage in T Section does not reach the top of the beam.
Figure 6. Damage Compression Behavior of Conventional Beam

Figure 7. Damage Compression Behavior of I Section Composite Beam
Figure 8. Damage Compression Behavior of T Section Composite Beam
Figure 9. Damage Compression Behavior of C Section Composite Beam
5.2. Damage in Tension
Concrete is weak in tension so extra reinforcement is provided in the tension zone to get more strength. When the mesh size is gradually increasing the cracks in the tension zone gets decrease. In the double c section, the tension zone cracks are very less when compared to the remaining composite beams. The results for the damage tension of Conventional beam, I section composite beam, T section composite beam, C section composite beam, and Double C section composite beam are shown in Figure11 to Figure15.

Figure 10. Damage Compression Behavior of Double C Section Composite Beam

Figure 11. Damage Tension Behavior of Conventional Beam
Figure 12. Damage Tension Behavior of I Section Composite Beam
Figure 13. Damage Tension Behavior of T Section Composite Beam

Figure 14. Damage Tension Behavior of C Section Composite Beam
5.3. S MISES

S MISES is considered as a safe value by designing engineers and can be identified whether the design is failing or not, when the strength of the material is less than the von misses stress-induced in the material. The unidirectional test is the simple tension test. The material fails when the yield point value is less than the normal stress value induced in the material. Normal stress theory doesn’t work in many cases says most of the engineers by their experience. The stress is maximum towards the ends of the beam. When the mesh size is increasing gradually the S MISES value decreases in the conventional beam. Whereas in the remaining composite beam the S MISES values get an increase from 25mm mesh and decrease in the 75mm mesh. The S MISES value in the 75mm mesh is more than the 25mm Mesh. The results of S MISES for the Conventional beam, I section composite beam, T section composite beam, C section composite beam, and Double C section composite beam for the mesh size of 27mm, 50mm, and 75mm are shown in Figure16 to Figure20.

**Figure 15.** Damage Tension Behavior of Double C Section Composite Beam
Figure 16. S MISES Behavior of Conventional Beam
Figure 17. S MISES Behavior of I Section Composite Beam

(c) 75BCC

Figure 18. S MISES Behavior of T Section Composite Beam

(a) 25BCC

(b) 50BCC

(c) 75BCC
Figure 19. S MISES Behavior of C Section Composite Beam
5.4. Deflection
Deformation of the beam from its original unloaded position in the Y direction. The deflection occurs at the ends of the supports. When the beam is fixed at both ends and the load is applied in the anti-clockwise direction the beam tends to bend in the center of the beam. The deflection values in the conventional beam, C section composite beam, and Double C section composite beam gradually decreased with the increment of mesh size. Whereas in the I section and T section the deflection values increased with increment of mesh size. The results for the deflection of the composite beams for the mesh size of 25mm, 50mm, and 75mm are shown in Figure 21 to Figure 25.
Figure 21. Deflection Behavior of Conventional Beam

Figure 22. Deflection Behavior of I Section Composite Beam
Figure 23. Deflection Behavior of T Section Composite Beam

(a) 25BCT
(b) 50BCT
(c) 75BCT
5.5. Graphs of analytical Results

The analysis for the different beams has been done and the results of Load Vs Displacement and Stress Vs Strain Curve and Load Vs Strain are compared for the 25mm mesh size of different beams shown in

Figure 24. Deflection Behavior of C Section Composite Beam

Figure 25. Deflection Behavior of Double C Section Composite Beam
Figure 26 as well as the results are compared for the 50mm mesh size of different beams shown in Figure 27 and also the results are compared for the 75mm mesh size shown in Figure 28.
Figure 27. A Beam of Mesh size 50mm

Figure 28. A Beam of Mesh Size 75mm
5.6. Comparison of ultimate load of FE model results with experimental data

Table 6 shows the Load reduction factor of Ribeiro Neto, J.G. [18, 19] expression for maximum design shear strength of FEM analysis has been evaluated. Load ratios of Ribeiro Neto, J.G. [18, 19] $v_u^{\text{Ribeiro Neto, J.G.}} / v_u^{\text{FEM}}$ are given in table 4. For all the beams, the ratio $v_u^{\text{Ribeiro Neto, J.G.}} / v_u^{\text{FEM}}$ are less than 1. Thus, the load reduction factor is adequate to consider the load compression mode of failure. The mean value of Ribeiro Neto, J.G. [18, 19] The obtained mean value is 0.967 and the standard deviation is 0.021.

| S.NO | BEAM ID | $v_u^{\text{Ribeiro Neto, J.G.}} / v_u^{\text{FEM}}$ |
|------|---------|--------------------------------------------------|
| 1    | 25BCB   | 0.95                                             |
| 2    | 50BCB   | 0.97                                             |
| 3    | 75BCB   | 0.93                                             |
| 4    | 25BCC   | 0.97                                             |
| 5    | 50BCC   | 0.98                                             |
| 6    | 75BCC   | 0.98                                             |
| 7    | 25BCT   | 0.99                                             |
| 8    | 50BCT   | 0.95                                             |
| 9    | 75BCT   | 0.99                                             |

MEAN - 0.967
SD - 0.021
COV - 0.0004

5.7. Comparison between experimental and FE modal results

Table 7 gives the comparison of ultimate loads between analytical and experimental results. From Figure 29, it can be seen that the FE modal gave a high prediction of ultimate loads for the composite beams.
Table 7. Comparison of ultimate loads between analytical and experimental results

| S.NO | BEAM ID | AUTHOR LOAD | FEM LOAD | \( \frac{P_{\text{Ribeiro}}}{P_{\text{Abaqus}}} \) (%) |
|------|---------|-------------|----------|---------------------------------|
| 1    | 25BCB   | 121         | 127      | 95.28                           |
| 2    | 50BCB   | 205         | 212      | 96.70                           |
| 3    | 75BCB   | 240         | 258      | 93.02                           |
| 4    | 25BCC   | 320         | 330      | 96.97                           |
| 5    | 50BCC   | 348         | 355      | 98.03                           |
| 6    | 75BCC   | 375         | 383      | 97.91                           |
| 7    | 25BCT   | 289         | 292      | 98.97                           |
| 8    | 50BCT   | 306         | 321      | 95.33                           |
| 9    | 75BCT   | 314         | 318.7    | 98.53                           |

6. Conclusion
1. The deflection and vonmises stress value decreased with an increase in mesh size.
2. The deflection between the considered section does not vary much and it is concluded that cross-section of the section will not have much effect.
3. In 25mm mesh size double c section was able to withstand a higher load compared to a conventional beam.
4. In 50mm and 75mm mesh size conventional beam was able to withstand higher load compared to other composite beams.
5. In von Mises, stress increased at the initial stage and strain increased at later stages with the further increase of load.

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References
[1]. Yassin Osman M, Mohammed Elmardi Suleiman O, State K and Assistant Professors 2017 Large Deflection of Composite Beams. International Journal of Engineering Research and Advanced Technology, 3(3), pp 26–39
[2]. Chiriki S.S and Harsha G.S, 2020. Finite element analysis of RC deep beams strengthened with I-section and truss reinforcement. Materials Today: Proc, 33, pp156-161
[3]. Liu Y, 2015 Choose the best element size to yield accurate FEA results while reduce FE model’s complexity. British Journal of Engineering and Technology, 1(7) pp 13–28.
[4]. Sun H, Rajendran S. and Song D.Q, 1998 Finite Element Analysis on delamination fracture toughness of composite specimens. In Proceedings of 2nd Asian ANSYS User Conference 2 pp. 1-8.
[5]. Liu Y and Glass G, 2013 Effects of mesh density on finite element analysis 1375 SAE Technical Paper.
[6]. Raut P2012 Impact of mesh quality parameters on elements such as beam, shell and 3D solid in structural analysis International Journal of Engineering Research and Applications, 2(6), 99–103.
[7]. Sazzad Md, Mahmud Azad M S, Islam M. T and Rahman F. I. 2017. Effect of mesh size of floor slab against lateral loads while using Etabs program International Journal of Advanced Structures and Geotechnical Engineering, 6(1), 40–44.
[8]. Mohammed MS, Nonlinear finite element analysis of typical compositebeams. The Iraqi Journal For Mechanical And Material Engineering pp 42-51
[9]. Alias R, Matlan S J, and Kasa A 2020 Finite element performance with different mesh size of retaining walls International Journal of Advanced Research in Engineering and Technology (IJARET), 11(3) pp 381–389.
[10]. Deb Nath Vand Deb Nath B, 2014 Deflection and stress analysis of a beam on different elements using ANSYS APDL International Journal of Mechanical Engineering and Technology, 5(6).
[11]. Visalakshia BSS 2020 Enhancement of shear strength of deep beams using hybrid fibres and suggesting an alternative for strut and tie model Materials Today: Proc 33 pp578-582.
[12]. Harsha GS, Poluraju P and Khed VC 2021 Computation of shear strength equation for shear deformation of reinforced concrete deep beams using finite element method. AIMS Materials Science, 8(1) pp42-61
[13]. Koslan MF S, Zaidi A M A, Othman M Z, Abdullah S and Thanakodi S2013. The effect of mesh sizing toward deformation result in computational dynamic simulation for blast loading application. Modern Applied Science 7(7) pp 23–28
[14]. Liu W B, GheniM, and Yu L 2011 Effect of mesh size of finite element analysis in modal analysis for periodic symmetric struts support Key Engineering Materials 462 pp 1008-1012
[15]. Dutt A 2015 Effect of Mesh Size on Finite Element Analysis of Beam International Journal of Mechanical Engineering 2(12) pp 8–10
[16]. Perumal K, Kumar A, Lingeshwaran N and SusmithaS 2020 Experimental studies on flexural behaviour of self compact concrete beam Materials Today: Proc 33 pp129-135
[17]. Ribeiro Neto JG, Vieira GS and Zoccoli RDO 2020 Experimental analysis of the structural behavior of different types of shear connectors in steel-concrete composite beams. *Revista IBRACON de Estruturas e Materiais* 13(6)

[18]. Al-Hadrayi Ziadoon MR, Abdulridha M M and Kadhim EH Fem Analysis of The Effect Mesh Size For I-Section Beam *Int. Journal of Mechanical Engineering and Technology* 9(9) pp 1348–1355