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Numerical Study of Steel Fiber Reinforced Concrete Continuous Deep Beams With Openings

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Abstract: Deep beams have been used in many structures for structural and architectural purposes. However, the empirical methods did not design deep beams with openings. Strut and tie model (STM) are extensively used for these structures with D-region but if there is any openings, this opening will disrupt the flow of force transfer from loading point to supports and thus reduce the load carrying capacity. Building code (ACI 318-08) [1] and (ECP 203-2007) [2] did not give any explicit guidance for designing deep beam with openings. This study investigates the behaviour of reinforced concrete continuous deep beam with openings strengthened with steel fibres, considering many factors such as opening size, opening position, position of load and types of steel fibres. By using the 3D finite element model study these parameters. this study include twelve specimens with dimension (3600*1100*100) mm each span 1800mm, height of deep beam 1100mm, it's wide is 100mm. The results of this study shows that when the openings are located near the beam longitudinal centre line, the failure load is increased by 20.6% and cracks are reduced. Also, the study shows that the smaller openings give more carrying load capacity by 19.5% than the bigger ones. End hooked is the best type of steel fiber increased load failure by 24.1% than other types, ultimate load increase by 33.5% when decrease (a/d) ratio from 0.68 to 0.41 when (a) = distance from face of support to applied load and (d) = depth of beam. deep beams with opening produce earlier cracks compared to similar deep beams without opening. Steel fiber improved capacity for deep beams, load failure and ductility. Continuous deep beams increase results for load failure about 15% compare with simple deep beams.
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Keywords: Continuous deep beam; Steel fiber; Deflection; ANSYS; Opening; Ductility

1. Introduction

Deep beam used in many structures and many buildings. Deep beam or transfer girder used for architecture purpose when lower column on the exterior façade is removed. Types of deep beams such as simply supported, continuous and cantilever. Deep beam is used to transfer the axial load of columns above to the supporting columns below. Deep beams used in highways, piles capes and foundation walls. Define deep beam as spans over all depth ratio (L/d) is greater than four or the concentrated loads applied within distance equal to or less than two times depth from the face of support. Limit empirical method L/d smaller than 1.25 for simple deep beam and for continuous deep beam 1.25< L/d <2.5. limit for strut and tie method 1.25< L/d <4 that according to (ECP -203-2007)[2]. In modern buildings there are services like water supply, sewage, air –conditioning, electricity, telephone and computer net- work. This services need to make openings in deep beams. Empirical method does not solve or design deep beams with openings D-region. Strut and tie model method (STM) is used for these structures with D-region but if there is any opening, this opening will disrupt the flow of force transfer from loading point to supports and usually reduce the load carrying capacity. (ACI 318-08) [1] and (ECP -203-2007) [2] do not give any explicit guidance for designing these element with openings and strut and tie method is complicated method. These model continuous deep beam, concrete compressive strut and steel tensile tie connected at joints that called nodes. The force transfer from loading point to supports through strut and tie model. Steel fiber reinforced concrete (SFRC) is used in construction industries in recent years. Steel fiber reduce amount of reinforcement in structural member such as slabs. The using of steel fiber enhance behavior of reinforced concrete such as load capacity, ductility, flexibility and workability in concrete matrix. Codes equations are deals only with normal reinforced concrete without steel fibers.

2. Numerical Modeling

In this research studied behavior of twelve continuous deep beams using ANSYS 19 program. Dimension of continuous deep beam (3600*1100*100) mm as shown in Figure1. Each span 1800 mm, height of deep beam 1100 and it's wide is 100 mm. all continuous deep beams were reinforced with 2Ø12 as a main steel, upper steel was 2 Ø 16 and continuous deep beams with openings have additionally steel bars around openings 2Ø10. "SOLID 65" was used to model the concrete material. It is used for the 3D modeling of solids with or without reinforcing bars. This element is capable of cracking in tension and crushing in compression. It is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y and z directions as shown in Figure 2. "LINK 180" was used to reinforcement in the deep beam. The 3D element is uniaxial tension compression element with three degree of freedom each node: translation in the nodal x, y and z directions. As in a pin jointed structures, no bending of the element is considered. Plasticity, creep, swelling, stress stiffening, and large deflection capabilities are included. The nodes of this element are aligned with the nodes of the solid65 elements to allow for merging the nodes together. Hence, a perfect bond between concrete and steel is automatically introduced as shown in Figure 2. In this study, the steel fiber was modeled using the smeared model. An eight - node solid element, "SOLID185", was used for the steel plates at support and load locations. The element is defined with eight nodes having three degrees of freedom at each node and translations in the nodal x, y, and z directions. Steel plate modeled using Solid185 elements, was added at the support locations in order to avoid stress concentration problems and to prevent localized crushing of concrete elements near the supporting points and load application locations. This provided a more even stress distribution over the support area.

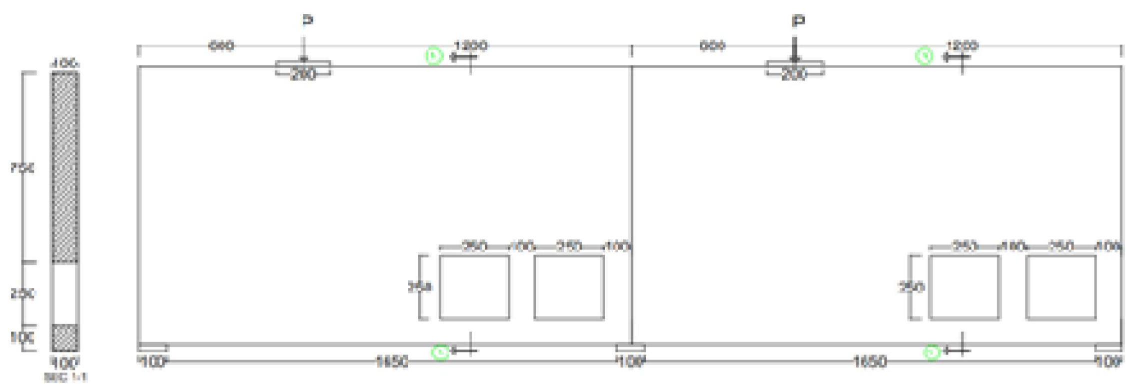

Figure 1: continuous deep beam dimensions

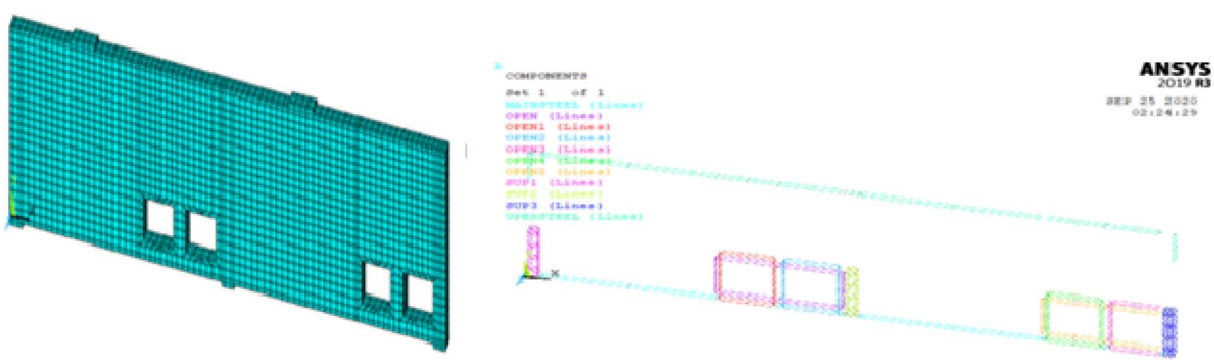

Figure 2: mesh of concrete, reinforcement, steel plate and support.

The modeling was similar for all beams where the exact concrete dimensions and reinforcement were represented using a suitable FEM mesh. The three support plates (100 x100 x 25mm) and the two loading plate (200 x 100 x 25 mm) were precisely modeled. The bond between steel reinforcement and concrete was assumed as perfect. The actual material properties obtained from laboratory testing were used where the concrete compressive strength (fcu) and the steel yield stress (fy) were taken as 39.6 MPa and 500 MPa respectively. Table 1 shows names of twelve continuous deep beams and their description.

Table 1

Beam	Description
Group (1) Control Beams	
BN-1/3L	Control continuous deep beam without opening
BA1-1/3L	Continuous deep beam with opening (250*250) mm at position A
BA2-1/3L	Continuous deep beam with opening (350*350) mm at position A
BB1-1/3L	Continuous deep beam with opening (250*250) mm at position B
Group (2) Deep Beams with Fiber and Openings (250*250) mm	
BA1-EH-1/3L	Continuous deep beam with opening (250*250) mm at position A and reinforced with end hooked fiber
BA1-CR-1/3L	Continuous deep beam with opening (250*250) mm at position A and reinforced with end corrugated rounded fiber
BA1-CS-1/3L	Continuous deep beam with opening (250*250) mm at position A and reinforced with corrugated segmented fiber
Group (3) Deep Beams with Fiber and Openings (350*350) mm	
BA2-EH-1/3L	Continuous deep beam with opening (350*350) mm at position A and reinforced with end hooked fiber
BA2-CR-1/3L	Continuous deep beam with opening (350*350) mm at position A and reinforced with corrugated rounded fiber
BA2-CS-1/3L	Continuous deep beam with opening (350*350) mm at position A and reinforced with corrugated segment fiber
Group (4) Deep Beams with Opening (250*250) mm and in Position A or B	
BA1-CR-1/3L	Continuous deep beam with opening (250*250) mm at position A and reinforced with end corrugated rounded fiber
BB1-CR-1/3L	Continuous deep beam with opening (250*250) mm at position B and reinforced with end corrugated rounded fiber

3. Parametric study

Test specimens were divided to four groups with different parameters under study. The numerical program aimed to investigate effect of parameters on stiffness, strength, ductility, cracking behavior and deflection. Table 2 show these parameters .

Table 2

Parametric study	
1-	Effect of openings
2-	Effect of openings size
3-	Effect steel fiber shape
4-	Effect of opening position

Where position A at height 100mm from bottom of deep beam and position B at center line of deep beam.

4. Results

Results show cracks pattern, ultimate load, cracking load and maximum deflection for continuous deep beams.

4.1. Cracks Pattern

The ANSYS program displays circles at locations of cracking or crushing in concrete elements. Cracking is shown with a circle outline in the plane of the crack, and crushing is shown with an Octahedron outline. The first crack at integration point is shown with a red circle outline, the second crack with a green outline, and the third crack with a blue outline. The cracks obtained from the analysis using ANSYS 19 as shown in Figure 3 to Figure 7.

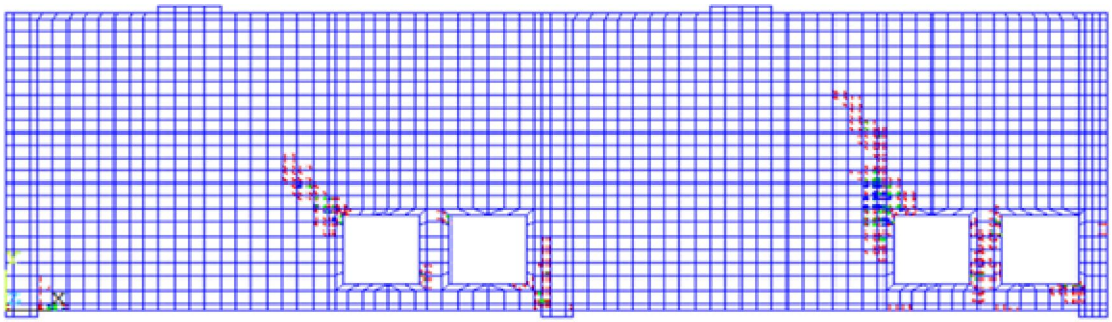

Figure 4. Analytical cracks for specimen (BA1 – 1/3L)

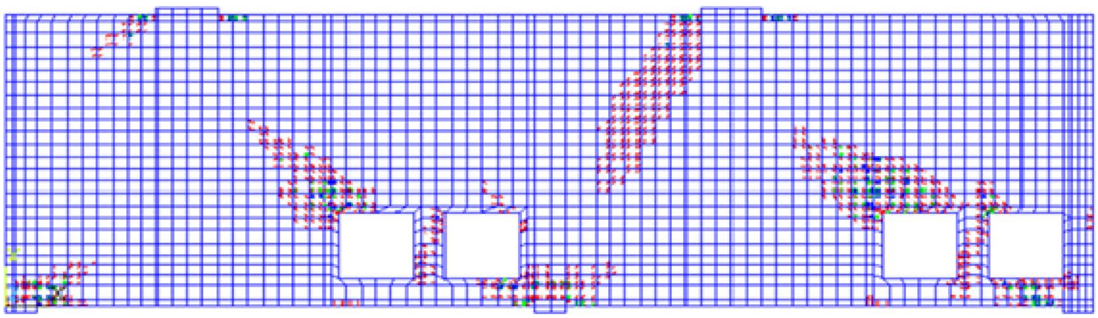

Figure 5. Analytical cracks for specimens (BA1 – EH – 1/3L)

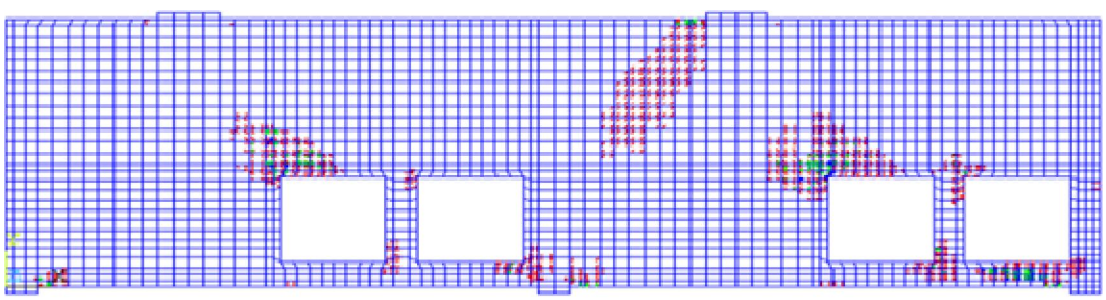

Figure 6. Analytical cracks for specimen (BA2 – EH – 1/3L)

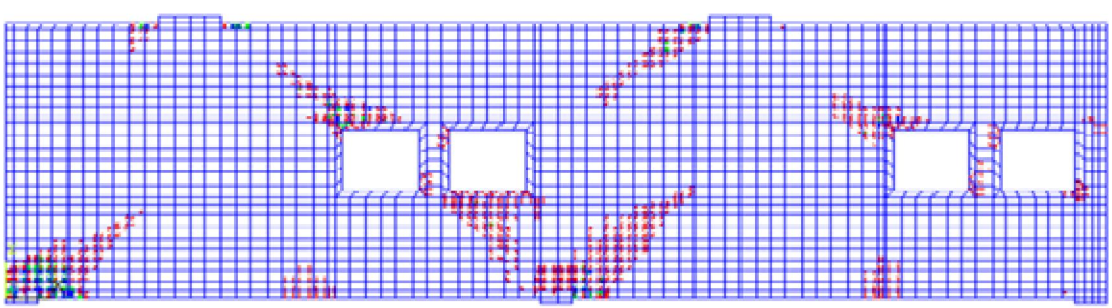

Figure 7. Analytical cracks for specimens (BB1 – CR – 1/3L)

4.2. Load deflection relation ship

Table 3 shows the failure load, cracking load and maximum deflection.

specimens	Failure load (KN)	Cracking load (KN)	Maximum deflection (mm)	Mode of failure
BN-1/3L	583.606	325.325	0.227	flexure
BA1-1/3L	170.089	120.74	0.263	Concrete crushing
BA2-1/3L	158.314	105.431	0.2489	splitting
BB1- 1/3L	276.735	156.561	0.365	Flexure diagonal splitting
BA1-EH-1/3L	408.318	301.840	0.606	Flexure diagonal splitting
BA1-CR-1/3L	338.571	199.712	0.447	Flexure diagonal splitting
BA1-CS-1/3L	313.644	175.899	0.359	Flexure diagonal splitting
BA2-EH-1/3L	256.95	160.989	1.1	Flexure diagonal splitting
BA2-CR-1/3L	252.6	153.954	1.0173	Flexure diagonal splitting
BA2-CS-1/3L	248.609	149.998	0.947	Flexure diagonal splitting
BB1-CR-1/3L	336.567	267.345	0.5197	Concrete crushing

4.3. Load Deflection Curves

Figure 8 to figure 11 show the load deflection curves for each of four groups under study.

4.3.1. Effect of openings

This chart chooses relationship between deflection (mm) and load (KN) for the first group which include four specimens (BA1-1/3L) - (BN-1/3L)-(BA2-1/3L) - (BB1-1/3L). Maximum deflection happened in specimen of the lower opening at the centerline of the beam which gives the highest ductility, also, this specimen gives the maximum load capacity for the beam with opening. At deflection 0.22 mm loads in beams were 583.61 KN in control specimen, 163.11 KN in specimen (BA1-1/3L), 145.8 KN in specimen (BA2-1/3L) and 240.65 KN in specimen (BB1-1/3L).

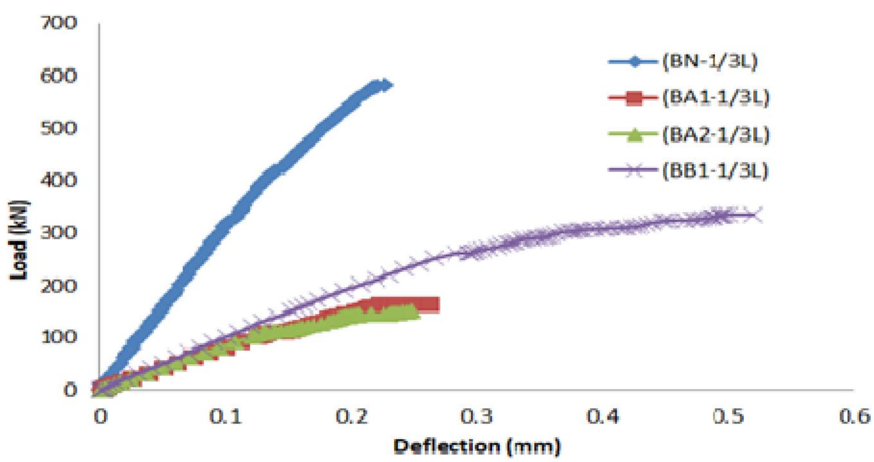

Figure 8. Analytical deflection at mid span for control specimens

4.3.2. Effect of openings size

This chart chooses relationship between load (KN) and deflection (mm) for second group which include four specimens (BA1-1/3L) – (BA1-EH-1/3L) – (BA1- CR-1/3L) – (BA1-CS-1/3L). Maximum deflection happened in specimen of the lower opening at position (A) strengthened with end hooked fiber which gives the highest ductility, also, this specimens gives maximum load capacity for the beam with opening. At deflection 0.26 mm loads in beams were 170.089 KN in specimen (BA1-1/3L), 236.65 KN in specimen (BA1-EH-1/3L),234.82 KN in specimen (BA1-CR-1/3L) and 252.57 KN in specimen (BA1-CS-1/3L). Getting effect of openings size when compare Figure 9 with Figure 10.

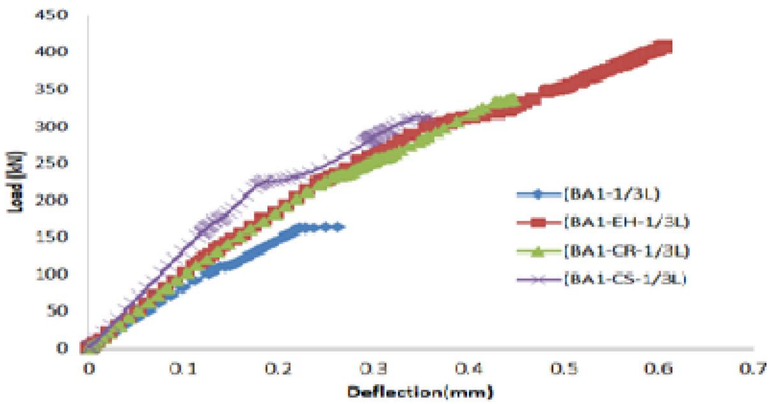

figure 9. Analytical deflection at mid span for second group

4.3.3. Effect steel fiber shape

This chart chooses relationship between load (KN) and deflection (mm) for third group which include four specimens (BA2-1/3L) – (BA2-EH-1/3L) – (BA2- CR-1/3L) – (BA2-CS-1/3L). Maximum deflection happened in specimen of the bigger opening at center line of the beam and strengthened with end hooked fiber which gives the highest ductility, also, this specimen gives maximum load capacity for beam with opening, At deflection 0.25 mm loads in beams were 158.314 KN in specimen (BA2-1/3L), 141.78 KN in specimen (BA2-CR-1/3L), 118.25 KN and 111.41 KN in specimen (BA2-CS-1/3L). Getting effect steel fiber shape when compare Figure 10 with Figure 8.

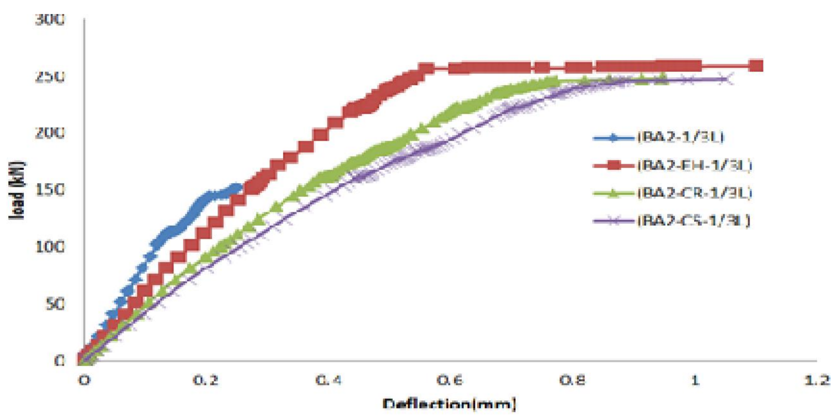

Figure 10. Analytical deflection at mid span for third group

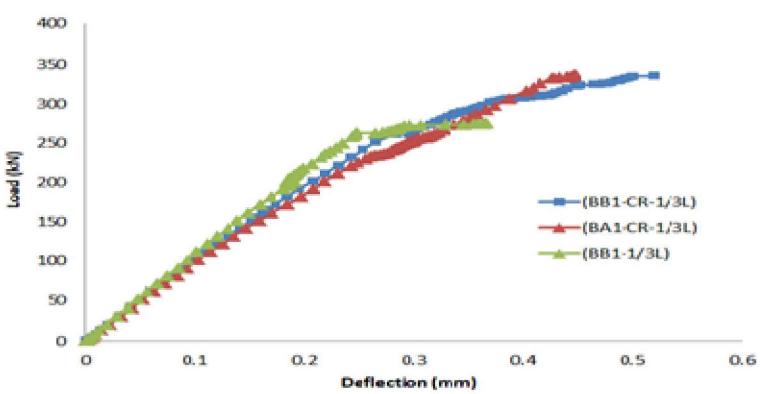

Figure 11. Analytical deflection at mid span for forth group

4.3.4. Effect of opening position

This chart choose relationship between load (KN) and deflection (mm) for forth group which include three specimens (BB1-1/3L) – (BA1-CR-1/3L) – (BB1- CR-1/3L). Maximum deflection happened in specimen of lower opening at center line of beam and strengthened with corrugated rounded fiber which gives the highest ductility, also, this specimen gives maximum load capacity for beam with opening. At deflection 0.36 mm loads in beams were 276.735 KN in specimen (BB1-1/3L), 292.79 KN in specimen (BA1-CR-1/3L) and 298.67 KN in specimen (BB1-CR-1/3L).

5. Conclusion

1) Reinforcement of continuous deep beam based on STMs is complicated and it is not easy to predict the failure mechanism.

2) Studying of the continuous deep beams show that the using of steel fiber can improve their ductility and increase their carrying load capacity.

3) Using of end hooked fibers increase failure load by 24.1% more than other types.

4) Rounded steel fiber is preferred more than segment steel fiber and increases load capacity by19.9% and ductility.

5) Continuous deep beams with 250*250 mm are more ductile and give higher load capacity by 19.5% than the case of opening size 350*350 mm.

6) Best location of openings at the beam center lines which increase capacity in failure by 20.6% and reduce cracks.

7) Decreasing (a/d) shear span to depth ratio from 0.68 to 0.41increases ultimate load by 33.55%.

8) Continuous deep beams increase the failure load by about 15% when compared with simple deep beams.

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