

# International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: [www.ijirset.com](http://www.ijirset.com)

Vol. 7, Issue 12, December 2018

## Non-Linear Analysis of Reinforced Concrete Beam with Transverse Circular Opening Using Finite Element Method ABAQUS

Henok Manaye Kebede<sup>1</sup>, Lohith Kumar B C<sup>2</sup>

Lecturer, Department of Civil Engineering, Madda Walabu University, Bale Robe, Oromia, Ethiopia<sup>1</sup>

Assistant Professor, Department of Civil Engineering, Madda Walabu University, Bale Robe, Oromia, Ethiopia<sup>2</sup>

**ABSTRACT:** Passage of essential services through transverse opening in reinforced concrete beams has many advantages in terms of economy as well as aesthetic. However, provision of opening in reinforced concrete beam result in a substantial decline of load resistance capacity of beam. The aim of this study is to analyse the effect of transvers openings on the strength of reinforced concrete beam using finite element method ABAQUS. Recently finite element method widely used to investigate reinforced concrete structural elements. The material behaviour of concrete is modelled using concrete damaged plasticity approach. The parameters studied in this study are ultimate load carrying capacity, mid-deflection, crack pattern and mode of failures when the size of opening, concrete strength, depth of beam and vertical position of opening is changed over the span of the beam. Finally, the results are discussed by comparing with solid beam. It is found that as the opening size increases more than 40% of the solid beam depth the load resistance of the beam decrease significantly. In addition to this the crack type and location of the failure changed from mid span to opening location. When the concrete strength and depth of the beam increase for constant size of opening the carrying capacity of the beam increased.

**KEYWORDS:** Transverse opening, Shear, Crack pattern, Ultimate load, Mid-deflection, Concrete strength, vertical position of opening

### I. INTRODUCTION

Now day the system of service installation on building shows new innovation on transvers of the basic service like sanitary, electrical and communication through the intruded structural element. Previously pipes and ducts for passage of services lay under the beam, this construction trend create obstruction on the clear height of the story. Therefore, the designers increase the height of story to get the intended clear height. When the height of the building increase at same time it increases the weight of the building which transverse to the foundation. As per the weight of structure increased it increase the cost of the construction. So, provision of service through the beam has advantage over passing service under the beam in terms of reducing the all over height of the building and weight, this lead the construction economical.

Reinforced concrete beam hold the load applied on it by developing combined resistance of concrete, shear and flexure reinforcement together so, providing hole on reinforced concrete beam remove concrete and shear reinforcement from beam this action create stress concentration around opening this cause the possibility of crack appearance at low load at the corner of opening. Furthermore, the presence of an opening in the beam has additional problem like it reduce beam strength, excessive cracking and deflection under the service load considerable and there also a disturbance of internal resistance forces and moments in a continuous beam. Because of many variables such as opening shape, size, and location along the span, specific design rules are not stated [1]. As a result, most designers do not consider the effect of opening their analysis it is based on intuition which lead to disastrous consequences.

# International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: [www.ijirset.com](http://www.ijirset.com)

Vol. 7, Issue 12, December 2018

## II. LITRATURE REVIEW

The structural behaviour of reinforced concrete beam with web openings interrelating with traditional design approach, classification of opening and guideline for opening location in the beam. If the opening size is small it is possible to design using solid beam analysis and design approach as long as the depth of the compression cord is less than the opening depth however, if the opening size is large it needs special analysis and design techniques why because it reduced the strength and stiffness highly[2]. Strut-tie and finite element modes method used to investigate the effect rectangular opening on the reinforced concrete deep and shallow beam, the result indicated that the diagonal shear failure occurred before the yielding of longitudinal bars [3]. Experimentally investigated reinforced concrete T-beam with strengthen web opening in shear zone using mild steel strips or uni-directional CFRP fabrics result, shows the strengthening techniques increased the shear capacity of the beam but, the ductility of the beam decreased distinctly [4] and Glass fiber reinforced polymer (GFRP) also used to strengthen and rehabilitate the small opening but, it is not increases the ultimate load carrying capacity of beam with large opening [5]. Introducing pre stress force around opening region in the form of pre stress tendons placed near web openings leads to increase the shear crack strength and the crack width becomes smaller according to growth of pre stressed tensile force [6].

## III.METHODS AND MATERIAL

### Material Constitutive Behaviours for FEM

#### Concrete Model

##### Elastic Behaviour of Concrete

Cracking model define concrete properties after yielding has occurred. Before yielding has occurred concrete elasticity is defined simply isotropic. This isotropic elasticity defines the slope of the stress versus strain curve in both tension and compression until the plastic limit is reached. The elastic behaviour was modelled as linear isotropic with standard values of modulus of elasticity of each concrete according to its grade. According to Ethiopian code of practice the modules of elasticity can be calculated using the following formula.

$$E_{cm} = 22 \left[ \frac{f_{cm}}{10} \right]^{0.3}$$

$f_{cm}$  is in MPa. Using this formula the elastic modulus of concrete is 29961.95105MPa.

Normal density of concrete 2400Kg/m<sup>2</sup> and poisons ratio taken 0.2 for cracked and 0 for cracked concrete.

##### Plastic Behaviour of Concrete

Concrete Damage Plasticity (CDP) is one of the possible constitutive model and used for this study. This technique has the potential to represent complete inelastic behaviour of concrete both in tension and compression including the damage behaviour. In Abaqus the parameters required to define the yield surface consists of four constitutive parameters [8].

Table-1: constitutive parameters used to define yield surface

Dilation angle ( $\psi$ )	Eccentricity ( $\epsilon$ )	$F_{bo}/f_{co}$	$K_c$	Viscosity parameter ( $\mu$ )
50°	0.1	1.16	2/3	0

##### Compressive and Tensile Behaviour of the Concrete

In concrete damage model (CDM) two main failure mechanisms are assumed: tensile cracking and compressive crushing of the concrete. The evolution of the yield surface is controlled by tensile and compressive equivalent plastic strain. Load and unloaded response of concrete specimen seems to be weakened because the elastic stiffness of the material appears to be damaged or degraded. The degradation of the elastic stiffness on the strain softening branch of

# International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: [www.ijirset.com](http://www.ijirset.com)

Vol. 7, Issue 12, December 2018

the stress-strain curve is characterized by two damage variables, tension damage ( $d_t$ ) and compression damage ( $d_c$ ) parameters, which can take values from zero to one. Zero represents the undamaged material where as one represents total loss of strength [7].

The stress-strain relations under uniaxial tension

$$f_t = (1 - d_t) \cdot E_0 \cdot (\epsilon_t - \epsilon_t^{pl}) \text{ Where } \epsilon_t^{pl} \text{ -tensile plastic strain, } \epsilon_t \text{ - Tensile inelastic strain}$$

The stress-strain relations under uniaxial compression are taken into account in the following equation:

$$\sigma_c = (1 - d_c) \cdot E_0 \cdot (\epsilon_c - \epsilon_c^{pl}) \text{ Where } \epsilon_c^{pl} \text{ -compressive plastic strain, } \epsilon_c \text{ -compressive inelastic strain}$$

In case of the experimental test result is not available the compression and tension stress behaviour of concrete can be calculated by using mathematical models from literature.

Interface behaviour between rebar and concrete is modelled by implementing tension stiffening in the concrete modelling to simulate load transfer across the cracks through the rebar. Tension stiffening also allows to model strain-softening behaviour for cracked concrete. Thus it is necessary to define tension stiffening in CDP model. So, in order to define the tension stiffening fracture energy approach is used. In this approach; the amount of energy (GF) which is required to open a unit area of crack is assumed as a material property. The tensile behaviour of concrete as bilinear model defined using Crack opening ( $w_c$ ) which is calculated as a ratio of the total external energy supply (GF) per unit area required to create, propagate and fully break crack in concrete. However tensile fracture energy of concrete is defined as a function of the concrete compressive strength using the following formula [8].

$$G_F = G_{f0} \left( \frac{f_c}{10} \right)^{0.7} \text{ in this equation } G_{f0} \text{ is a coefficient related to the maximum aggregate size (dmax).}$$

The stress-strain relations under uniaxial compression computed using  $\frac{\sigma_c}{f_{cm}} = \frac{k\eta - \eta^2}{1 + (k - 2)\eta}$  [8].

### Steel Reinforcement Model

Steel of the reinforcing bars has approximately linear elastic behaviour when the steel stiffness introduced by the young's or elastic modulus keeps constant at low strain magnitudes. At higher strain magnitudes, it begins to have nonlinear, inelastic behaviour, which is referred to as plasticity. The plastic behaviour of steel is described by its yield point and its post-yield hardening. The steel shift from elastic to plastic behaviour occurs at a yield point on a material stress-strain curve. Other general properties of reinforcement steel are the mean value of density may be assumed to be 7850 kg/m<sup>3</sup> and the design value of the modulus of elasticity,  $E_s$  may be assumed to be 200 GPa [9].

### General Materials Properties and Model Assembling

Different materials with different properties are used in the simulation to act as one structural element to resist the applied load. So, in order simulate as one structural element in the Abaqus the inter face properties of the parts must be defined. In this study, truss elements are used to represent the reinforcement are embedded in "host" continuum solid elements or in the concrete.

**Table2.** Interaction type between independent parts

No.	constrain surface	Type of constrain
1	Between plate (both supporting and loading) and concrete	Tie
2	Between reinforcement cage and concrete	Embedded region

The plastic behaviour of steel is described by its yield point and its post-yield hardening. The steel shift from elastic to plastic behaviour occurs at a yield point on a material stress-strain curve.

# International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

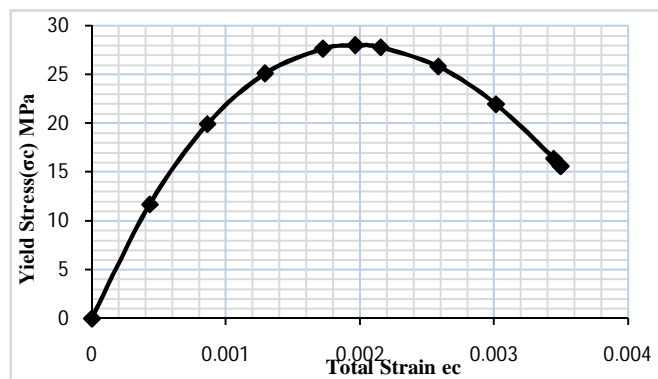
Visit: [www.ijirset.com](http://www.ijirset.com)

Vol. 7, Issue 12, December 2018

**Table3.** Plastic properties of reinforced steel

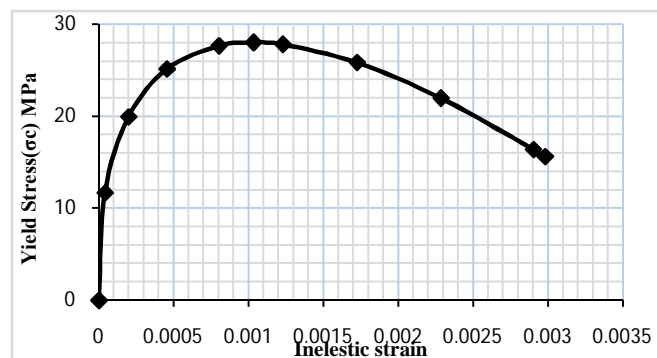
Yield stress (MPa)	Plastic Strain
400	0
<b>500</b>	<b>0.75</b>

The relation between  $\sigma_c$  and  $\varepsilon_c$  (compressive stress and shortening strain shown as absolute values) for beam can be defined for short term uniaxial loading using the stress-strain relations under uniaxial compression equation as shown in Figure 1.



**Fig.1** The idealized stress-strain relation of concrete

**Abaqus** will convert the inelastic strain into plastic strain that is compatible with the present model. Thus, the uniaxial relationships will provide the hardening variables which are needed in these models. Therefore, the concrete compression Hardening for beams expressed in figure 2.



**Fig2.** Concrete compression hardening

The degradation of the elastic stiffness on the strain softening branch of the stress-strain curve is characterized by two damage variables, which tension damage and compression damage parameters which can take values from zero to one. The compression and tension damages parameter which is expressed in Figure 3 and 4.

# International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: [www.ijirset.com](http://www.ijirset.com)

Vol. 7, Issue 12, December 2018

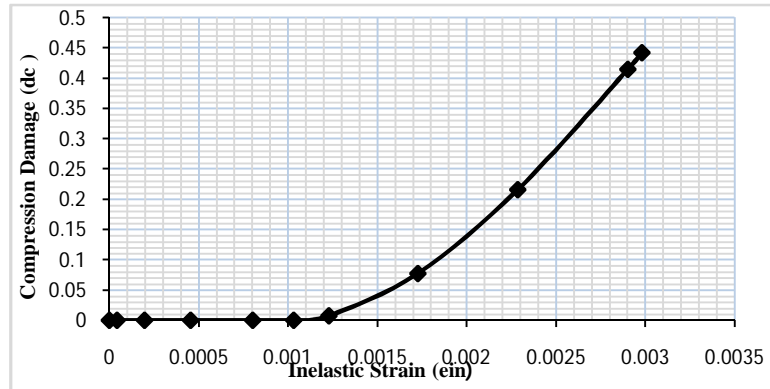


Fig3. Concrete compression damage

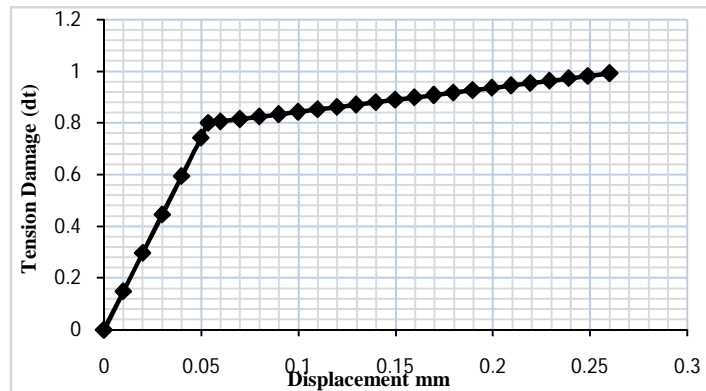


Fig4. Concrete tension damage

The concrete's brittle behaviour is defined by stress-displacement response rather than a stress-strain response. Specifying the post failure stress versus corresponding cracking displacement is enough to describe this approach.

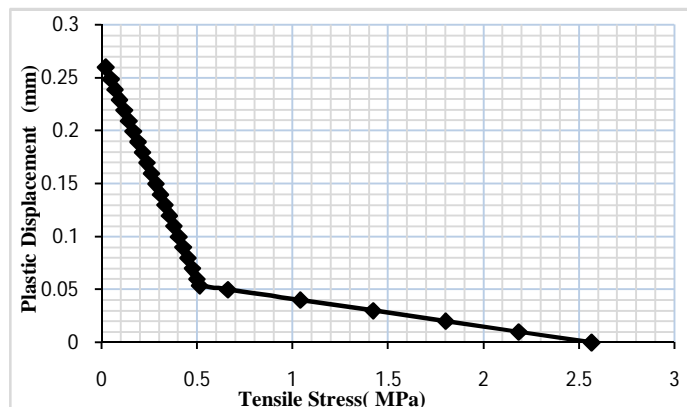


Fig5. Concrete tension stiffening

# International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: [www.ijirset.com](http://www.ijirset.com)

Vol. 7, Issue 12, December 2018

The support types used for models expressed in table 4 as well as there are a lot of analysis system in Abaqus from those option we used static general.

**Table4.** Boundary condition used on the models

No.	Name	Displacement / Rotation	Distribution	Type
1	Pin Support	$U_1=0, U_2=0$	Uniform	Static, General
2	Roller support	$U_2=0$	Uniform	Static, General
3	Displacement for B----	$U_2=-6$	Uniform	Static, General

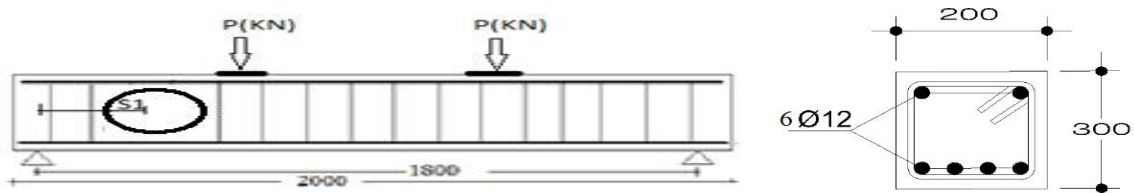
The meshing size and element type are main factors to get acceptable result and plays a vital role in the FEA since the properties and governing relationships are assumed over the discretised elements and expressed mathematically on the specified points called nodes so, expressed in Table 5.

**Table5.** Element for working models

No.	Material Type	Element Type
1.	Concrete, Loading plate and Supporting plate	C3D20R
2.	Steel Reinforcement	Beam

### Description of Models

- Concrete with characteristic cube compressive strength of 25MPa
- characteristic yield strength of reinforcement 400MPa
- Two point loading applied on beam at 1/3 distance from effective span length on both side.
- Stirrups provided at 150mm C/C.



**Fig -6:** Cross sectional dimension and Reinforcement detailed of beam with circular opening in shear zone

All dimensions expressed using mm. In order to make it easy to recognize the size and location of openings on the beam, abbreviation of words are used. So, B, BR, S1 and H stand to express solid beam, beam with rectangular opening, distance in shear zone and depth of opening respectively.

**Table6.** Cross section of the circular opening

No.	Identification code for beams	Circular opening	D/H(%)
	At S1	Diameter (mm)	
1	BC1-S1	40.00	13.33
2	BC2-S1	60.00	20.00
3	BC3-S1	80.00	26.67
4	BC4-S1	100.00	33.33
5	BC5-S1	120.00	40.00
6	BC6-S1	140.00	46.67
7	BC7-S1	160.00	53.33
8	BC8-S1	180.00	60.00
9	BC9-S1	190.00	63.33

# International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: [www.ijirset.com](http://www.ijirset.com)

Vol. 7, Issue 12, December 2018

## IV. RESULTS AND DISCUSSION

### 1) Stiffness and Deflection

When the depth of opening on this location was less than 47% of the solid beam the reduction of the load carrying capacity falls below 3.8% but when the depth of opening was between 47% and 64% of the solid beam the reduction of the capacity could be ranged from 3.8% to 72% of the solid beam.

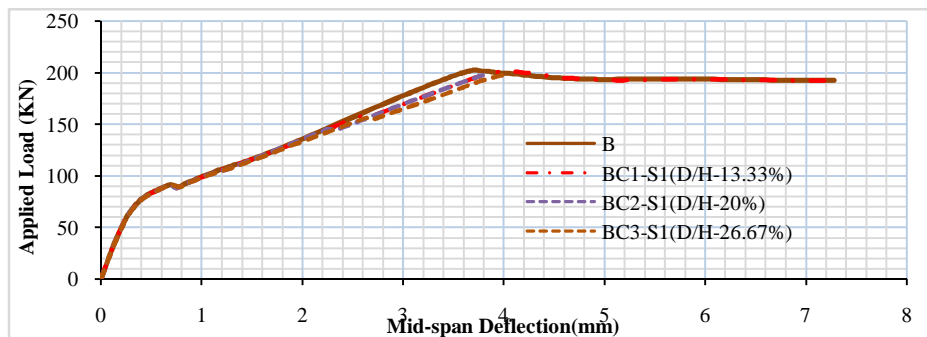


Fig7. Applied load versus mid span deflection of B, BC1-S1, BC2-S1, BC3-S1

When the depths of Circular openings to depth of solid beam for models BC4-S1, BC5-S1 and BC6-S1 are 33.33% , 40% and 46.67% respectively according to Figure 8 the performance beam falls slightly when the openings size increase as expressed on this figure in different way. Their load carrying reduction is 3.52%, 3.52% and 3.83% of the solid beam respectively.

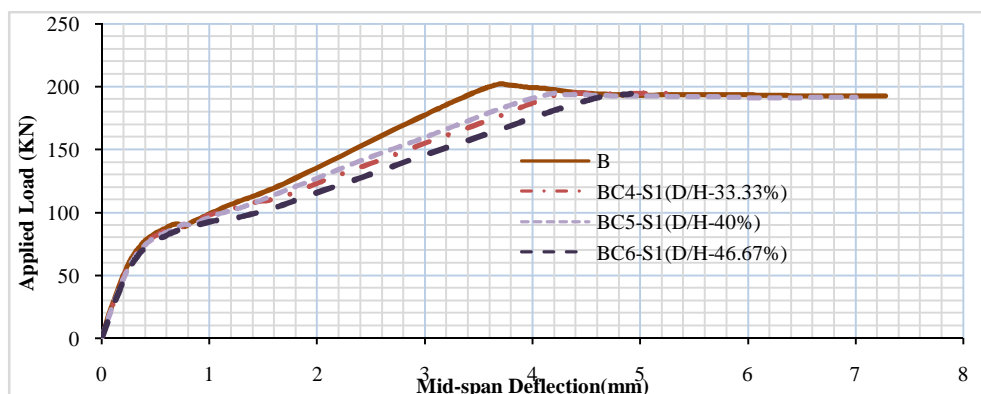


Fig8. Applied load versus mid span deflection of B, BC4-S1, BC5-S1, BC6-S1

Models BC7-S1, BC8-S1 and BC9-S1 as results reported in Figure 9 indicate that the increasing of opening size highly reduces the strength of the beam and the openings depths are 53.33%, 60% and 63.33% respectively reduce their strength by 65.22%, 66.8% and 72.04% of the solid beam.

The removal of concrete from the beam and disturbance of shear reinforcement due to opening from normal provision highly reduce the stiffness.

# International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: [www.ijirset.com](http://www.ijirset.com)

Vol. 7, Issue 12, December 2018

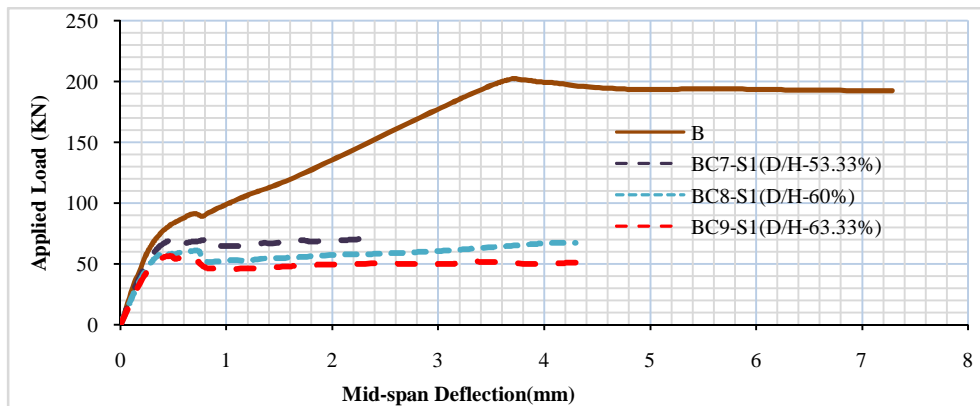


Fig9. Applied load versus mid span deflection of B, BC7-S1, BC8-S1, BC9-S1

Generally the load carrying capacity of the beam with circular opening in present and KN with relation to the ratio of depth of opening and all over depth of the beam expressed shortly in figure 10.

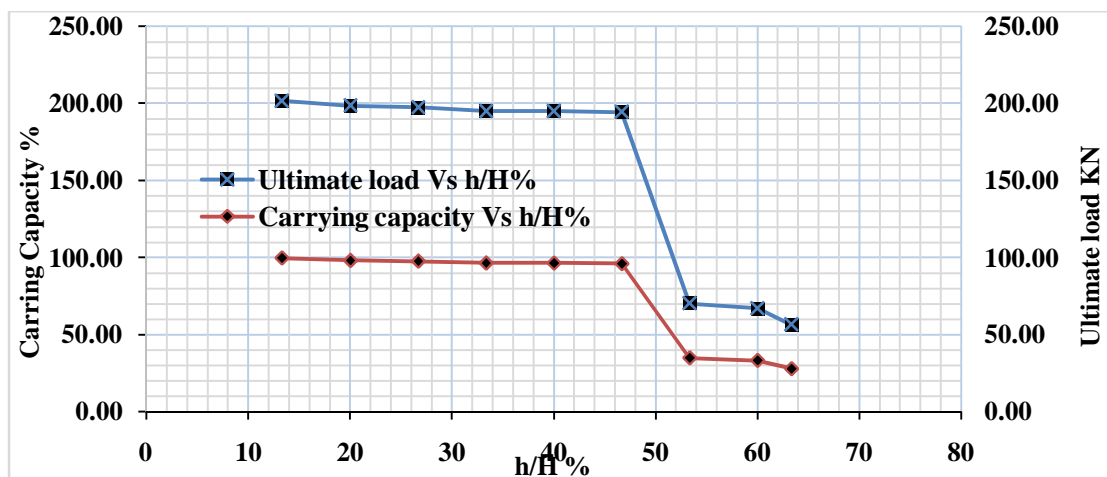


Fig10. Ultimate Load, Carrying Capacity Vs h/H for circular opening at S1

The beam with opening which is subjected to load is not similar to that of solid beam because the first crack appeared at the corner of the opening and passes through it at low load level and as far the loading increased the cracks appeared at the bottom of the beam.



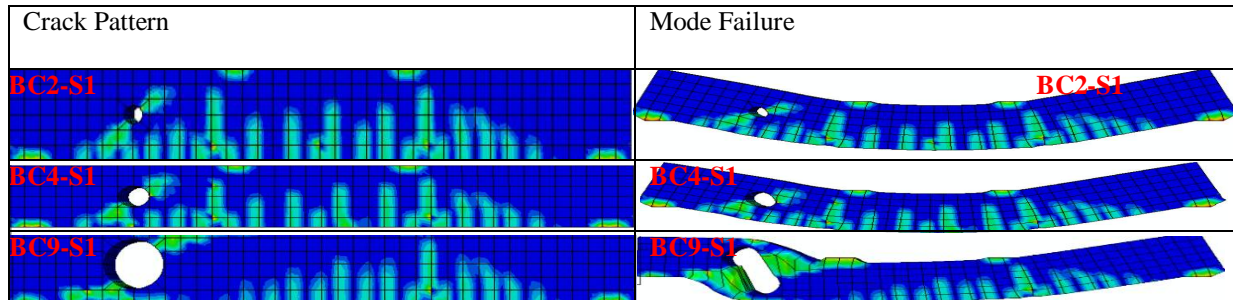
# International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: [www.ijirset.com](http://www.ijirset.com)

Vol. 7, Issue 12, December 2018

**Table7.** Crack pattern and mode of failure for circular opening at S1



The responses of the beams when the size of opening increased are expressed in Table 8.

**Table8.** Summary of circular opening at S1

Types of Opening	Diameter of opening (mm)	Ultimate Load (KN)	% load difference	Load(KN)at First Crack	Failure mode		Location of maximum Compressive stress of concrete
					Types of crack	Location	
<b>B</b>	-----	202.12	----	66	Flexure	Mid-span	at top of beam
<b>BC1-S1</b>	40	201.66	0.23	66	Flexure	Mid-span	at top of beam
<b>BC2-S1</b>	60	198.60	1.74	66	Flexure	Mid-span	at top of beam
<b>BC3-S1</b>	80	197.43	2.32	66	Flexure	Mid-span	at top of beam
<b>BC4-S1</b>	100	195.01	3.52	66	Flexure	Mid-span	at top of beam
<b>BC5-S1</b>	120	195.00	3.52	66	Shear	Opening region	at top of beam
<b>BC6-S1</b>	140	194.37	3.83	60	Shear	Opening region	at top of beam
<b>BC7-S1</b>	160	70.30	65.22	50	Shear	Opening region	Opening region
<b>BC8-S1</b>	180	67.11	66.80	45	Shear	Opening region	Opening region
<b>BC9-S1</b>	190	56.51	72.04	40	Shear	Opening region	Opening region

### 1. Effect of vertical position of circular opening on beam

The vertical position of the opening in shear zone also has similar effect with that of at mid span but the reduction of load carrying capacity of the reinforced concrete beam with opening in shear zone is more than in flexure zone this happen due to the shear in beam resisted by combined action of concrete in the cross section and shear reinforcement therefore the removal of concrete from shear zone of the beam affect the load carrying significantly as reported in Figure 11 and 12.

# International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: [www.ijirset.com](http://www.ijirset.com)

Vol. 7, Issue 12, December 2018

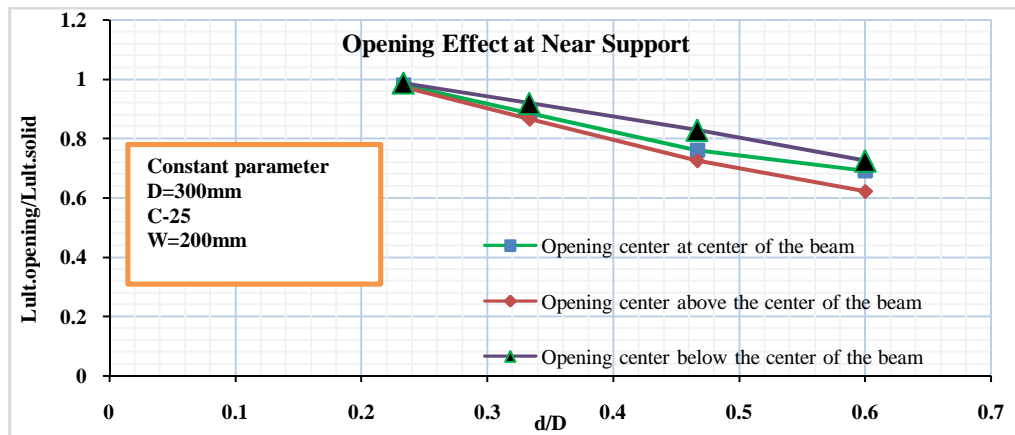


Fig11. Effect of opening near the support of the beam

Note: 'e' is the centres of opening on the y-axis/vertical position

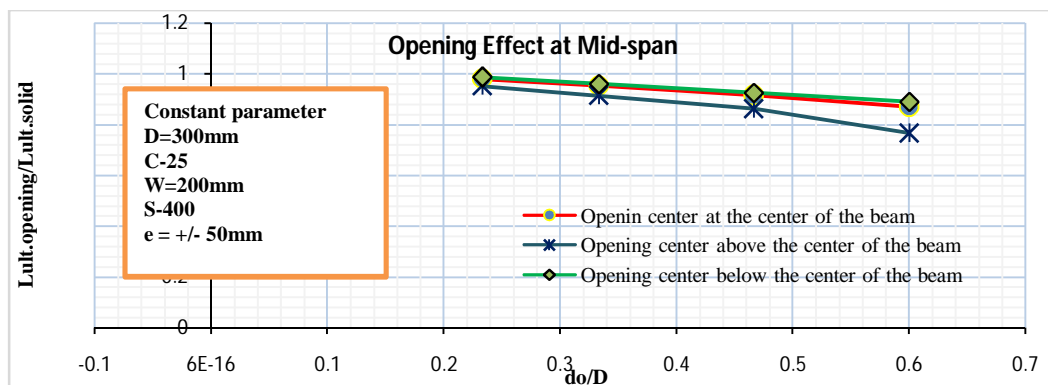


Fig12. Effect of opening at mid span of the beam

## 1. The effect of beam depth on beam with circular opening at support

When the depth of beam increase the load carrying capacity of the beam also increase for the same size of opening as reported in figure 13 and 14. The internal resistance of the beam developed due to the concrete amount in compression zone which is responsible to resist the compressive force and reinforcement in tension zone to resist the tensile force so, as per the depth increase the concrete size in compression also increase.

# International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: [www.ijirset.com](http://www.ijirset.com)

Vol. 7, Issue 12, December 2018

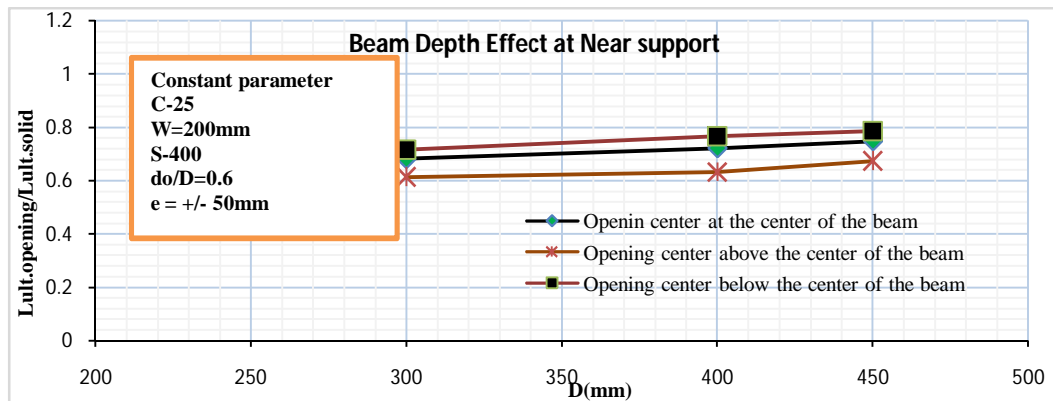


Fig13. The effect of Beam depth on carrying capacity of the beam with opening near the support

## 2. The effect of beam depth on beam with circular opening at mid-span of beam

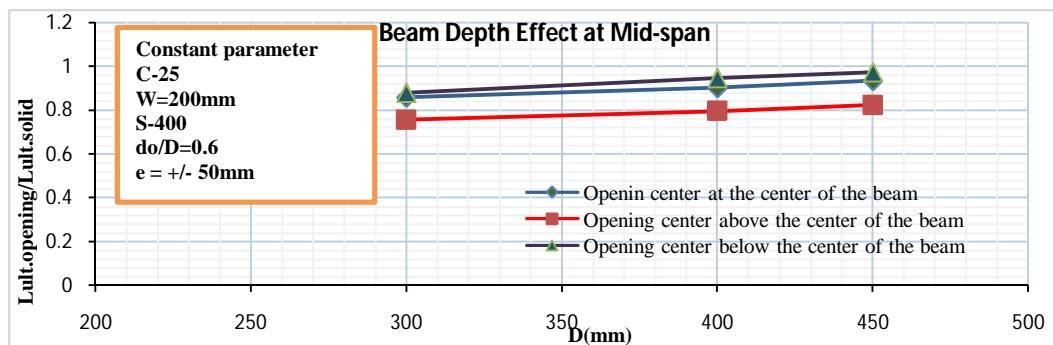


Fig14. The effect of beam depth on the carrying capacity of beam with opening at mid span

## 3. The effect of concrete strength on the beam with circular opening at support

The compressive strength of concrete is a vital properties of the material because concrete have high resistance for compressive force and week resistance for tensile so, the compressive force induce due to load on the beam mainly resisted by concrete. As the result of this studies shows in figure 15 and 16 for constant size of opening at both location the load carrying capacity of the beam increase when the compressive strength of the concrete increase.

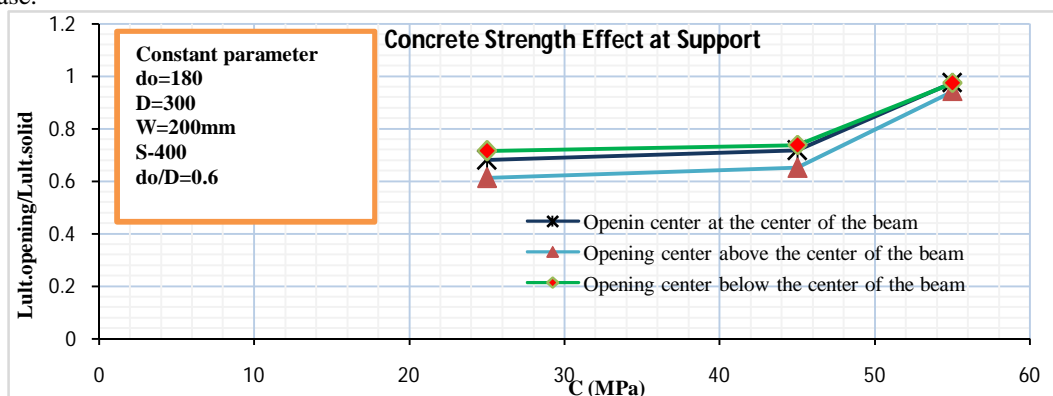


Fig15. The effect of concrete strength on the beam with opening at support

## International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: [www.ijirset.com](http://www.ijirset.com)

Vol. 7, Issue 12, December 2018

### 4. The effect of concrete strength on the beam with circular opening at mid-span

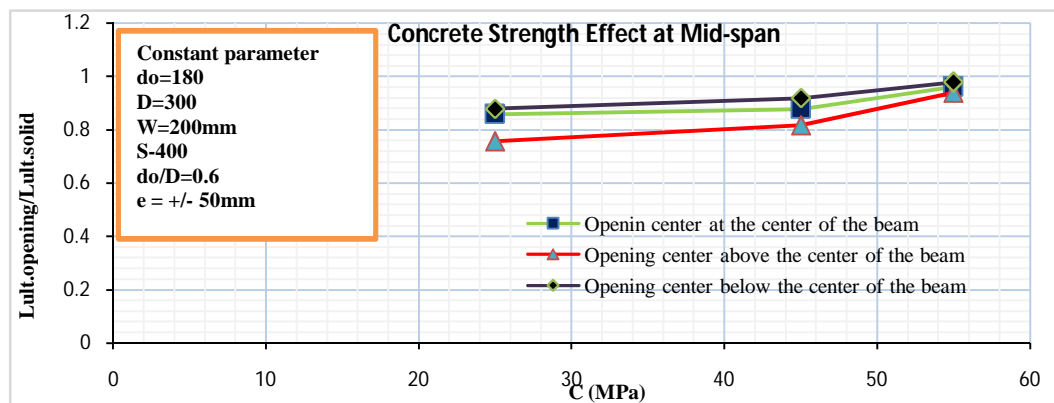


Fig16. The effect of concrete strength on the beam with opening at mid span

### V. CONCLUSION

The carrying capacities of beam decreases significantly when the opening depth exceed 40% of the solid beam and the crack type change from flexural to shear and also the location of failure shift from mid-span to opening location however The first crack appeared at low load around the corner of openings.

Generally, when the opening centres move above the centres of the beam the carrying capacity of the beam decrease more than moving down below the centres of the beam for both location of the openings. In addition to this the load carrying capacity of the beam with opening increase when the strength of the concrete and depth of the beam increase.

### REFERENCES

- [1]. ACI Committee 318, Building code requirements for reinforced concrete (ACI 318-02) and commentary (ACI 318R-02). American Concrete Institute, (2002).
- [2]. R. Vivek and T.ch. Madhavi, Behavior of Reinforced Concrete Beam with Openings. Journal of Engineering and Applied Science.11(9),2016.
- [3]. Waleed E. El-Demerdes, Salah E. El. Metwaly, Mohamed E. El-Zoughinby and Ahmed A. Ghaleb, Strut and Tie Model and 3D Nonlinear Finite Element Analysis for the Prediction of the Behavior of RC Shallow and Deep Beam with Opening. Engineering Research Journal, 4(1), 2014.
- [4]. Hamed Y.H., Abdel-Rahman G.T. and Said M., Behavior of RC Beams With Strengthened Openings in D-Region. Abu Dhabi, Proc. of the 9th Arab Structural Engineering Conference, 2003.
- [5]. Subhanjit M., J.N. Bandyapadhy and Chandral P., Strength and Rehabilitation of Reinforced Concrete Beam with Opning. International Journal of Civil and Structural Engineering. 2(1),2011.
- [6]. Shizou H., Keiichi K. and Daisuke A., Shear Behavior of RC Beams with Web Openings Reinforced by Prestress Forcess. Council on Tall Building and Urban Habitat, 2004.
- [7]. ABAQUS, User's Manual. Rhode Island, USA: Hibbit, Karls-Son and Sorensen, Inc. Version 6.8, 2008.
- [8]. Coronado C.A. and Lopez M.M., Sensitivity Analysis of Reinforced Concrete Beams Strengthened with FRP Laminates. Cement and Concrete Composite, 28(1), pp. 102-114, 2006.
- [9]. Ethiopian Building Code Standard EBCS-2, Design of Concrete Structures. Addis Ababa, Ethiopia: Ministry of Urban Development and Construction, 2013.
- [10] Jason L, Pijaudier-Cabot G, Huerta A, Ghavamian S, Damage and Plasticity for Concrete Behavior., European Congress on Computation Methods in Applied Sciences and Engineering, 2004.
- [11] Macgregor J.G., Reinforced Concrete Mechanics and Design. Third edition ed. New jersey: Prentice-Hall, Inc., 1997.
- [12] McCorman J.C. and James K., Design of Reinforced Concrete. Seven edition ed. Hoboken: John Wiley & Sons, Inc., 2006.
- [13] Naik N, Kumar R and Rajaiah K, Optimum Hole Shapes in Beams under Pure Bending. J. Eng. Mech., 112, pp 407-411, 1986]