



## **FINITE ELEMENT ANALYSIS OF DEEP BEAM UNDER DIRECT AND INDIRECT LOAD**

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### **ABSRTACT**

This research study the effect of exist of opening in web of deep beam loaded directly and indirectly and the behavior of reinforced concrete deep beams without with and without web reinforcement, the opening size and shear span ratio ( $a/d$ ) was constant. Nonlinear analysis using the finite element method with ANSYS software release 12.0 program was used to predict the ultimate load capacity and crack propagation for reinforced concrete deep beams with openings. The adopted beam models depend on experimental test program of reinforced concrete deep beam with and without openings and the finite element analysis result showed a good agreement with small amount of deference in ultimate beam capacity with (ANSYS) analysis and it was completely efficient to simulate the behavior of reinforced concrete deep beams. The mid-span deflection at ultimate applied load and inclined cracked were highly compatible with experimental results. The model with opening in the shear span shows a reduction in the load-carrying capacity of beam and adding the vertical stirrup has improve the capacity of ultimate beam load.

**KEYWORDS:** Reinforced Concrete Deep Beam, Direct and Indirect Load, Finite Element Analysis.

## 1. INTRODUCTION

The beams with depth greater than normal beam depending on span of beam and its thickness is much smaller than span and depth is called Deep Beam. The reinforced concrete deep beam is a very important structural element in structural engineering practice such as offshore structures, foundation, bridges and high rise building

The [CIRIA Guide \(1977\)](#) focusing on study the deep beam with have span to depth ratio less than 2 for single span beams and greater than 2.5 for continuous beam span. The span/depth ratio  $l/h$  is the most frequently parameter governing deep-beam behavior, this parameter was studied since many years ago and its effect on deep beam behavior ([Kong and Singh, 1972](#)) and, for buckling and instability, the depth/ thickness ratio  $l/h$  and the load-eccentricity/thickness ratio  $l/h$  are both relevant ([Garcia, 1982; Kong et al., 1986](#)).

[Ray \(1962\)](#) studied the shear strength capacity of reinforced and prestressed concrete deep beams have an opening with different reinforcement type, web reinforcement and without web reinforcement. Depends on The experimental results, [Ray \(1966\)](#) predict an equation to find the shear strength of deep beams with shear reinforcement. It was concluded that the predicted results using the normal beam theory underestimated the ultimate load of deep beams.

[Kong et al. \(1970\)](#) studied experimentally 35 simply supported with rectangular deep beams section with span to depth ratio varying from 1 to 3 and shear span/depth ratios from 0.23 to 0.7 . The tested beams were classified into seven group according to the type and amount of web reinforcement. The web reinforcement were arranged in seven different group and research showed the effect of reinforcement on deflections crack width, crack patterns, failure modes. The results shows that low  $(a/d)$  ratio with horizontal web reinforcement is effective, while with  $(a/d)$  ratio 0.7 its preferable to use vertical reinforcement. The horizontal bar reinforcement reduce the deflection of beam. The main causes of beam failure were the inclined cracks and crushing concrete at the load point is the secondary effect. Cracks width are increase with increase the span/depth ratio.

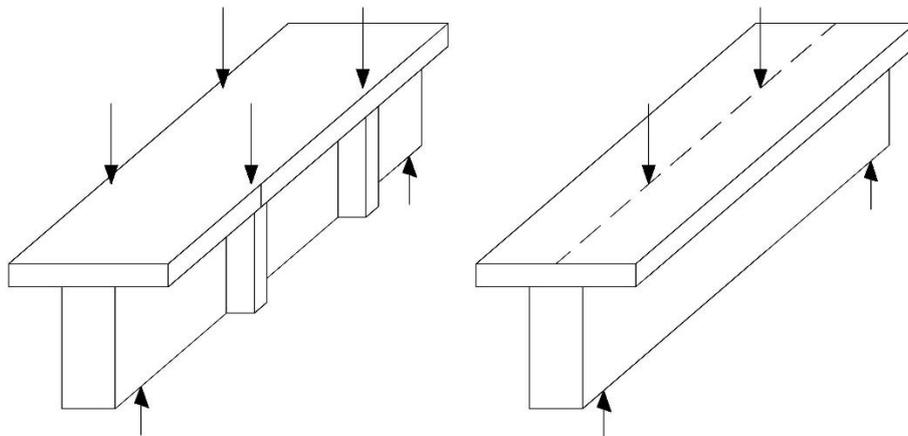
[Giuseppe and Giovanni \(2012\)](#) in their investigation, 20 reinforced concrete deep beams with an opening were loaded up to failure for  $a/H$  ratio equal to 0.27. The govern parameters were the position of the opening and reinforcement quantity. The researchers have tested two different opening locations and four type of different arrangements of horizontal and vertical reinforcement. The analytical results of different methods were compared with the experimental results. Results shows that the effect of the hole depends on its position in the beam the benefit of the presence of reinforcement depends on its arrangement.

A very few studies were focusing on studying the deep beams were investigated with loads applied through and supported by columns (Rogowsky et al. 1986; Foster and Gilbert, 1998; Lu et al. 2012).

Tan et al. (2011) studied the effect of inclined web reinforcement in deep beams with rectangular web openings shape, and his model include a strut and tie model to investigate the strength of tested beams.

## 2. BEAM MODEL GEOMETRY

The analysis of model have included several model listed in table (1) deep beams. The tested beams were T beam section area. All the model with Shear Span/effective depth ratios ( $a/d$ ) =1, length (L) equal to 1320 mm, total height (h) =400mm and web thickness ( $W_b$ ) =150mm. Ten of the beams have central intersecting members with the same overall depths of the beams. The flange width is (450mm). The geometry details with dimensions of the beams are shown in Fig. 1, Fig. 2, Fig. 3, Fig. 4 and Fig. 5 some of model was subjected to indirect loading and other subject to direct load. Four point load schematic was adopted. The model have web opening, the size of opening is (100 \*100) mm. Fig. 1 shows loading type of beams, direct and indirect loading Yousif (2016).



**Fig. 1. Indirect and direct loading T- beam.**

Table 1 shows the name and explanation of used model symbols, this research consider same name and models were adopted in Yousif (2016).

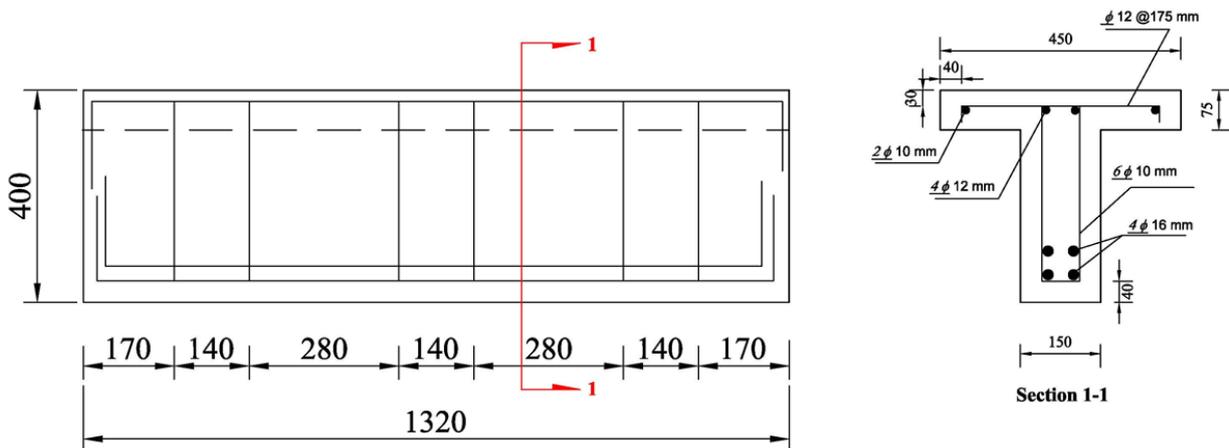
**Table 1. Symbol of model.**

Model No.	Details
DVT	Direct load –T shape
IT	Indirect Load – T shape
ITV	Indirect Load – T shape with vertical reinforcement
ITVO2	Indirect Load – T shape with vertical reinforcement and opening in web of beam
ITVHO2	Indirect Load – T shape with vertical and horizontal reinforcement and opening in web of beam

The experimental test program of geometry properties material of model conducted by [Yousif \(2016\)](#), these properties and are listed in [Table 2](#).

**Table 2. Beam model properties [Yousif \(2016\)](#).**

Beam No.	a/h	Ln/h	$f_{cu}$	$f_t$
DTV	1.0	2.45	21	2.1
IT	1.0	2.45	22.8	2.25
ITV	1.0	2.45	22.8	2.25
ITVO2	1.0	2.45	26.9	2.65
ITVHO2	1.0	2.45	26.9	2.65

**Fig. 2. T-Beam with direct load (DT).**

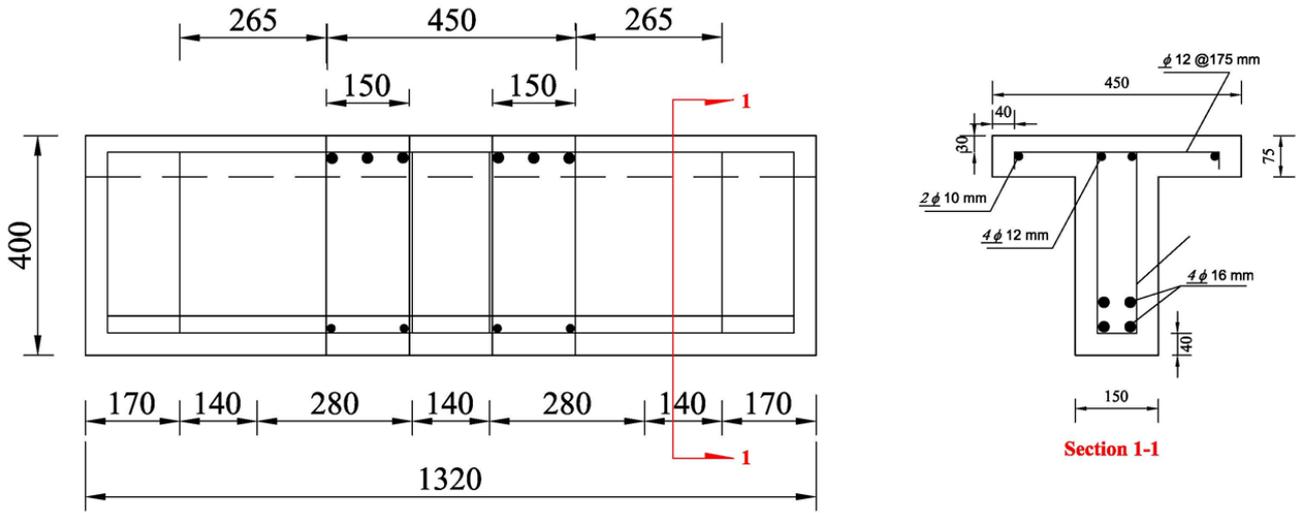


Fig. 3.T-Beam with indirect load (IT).

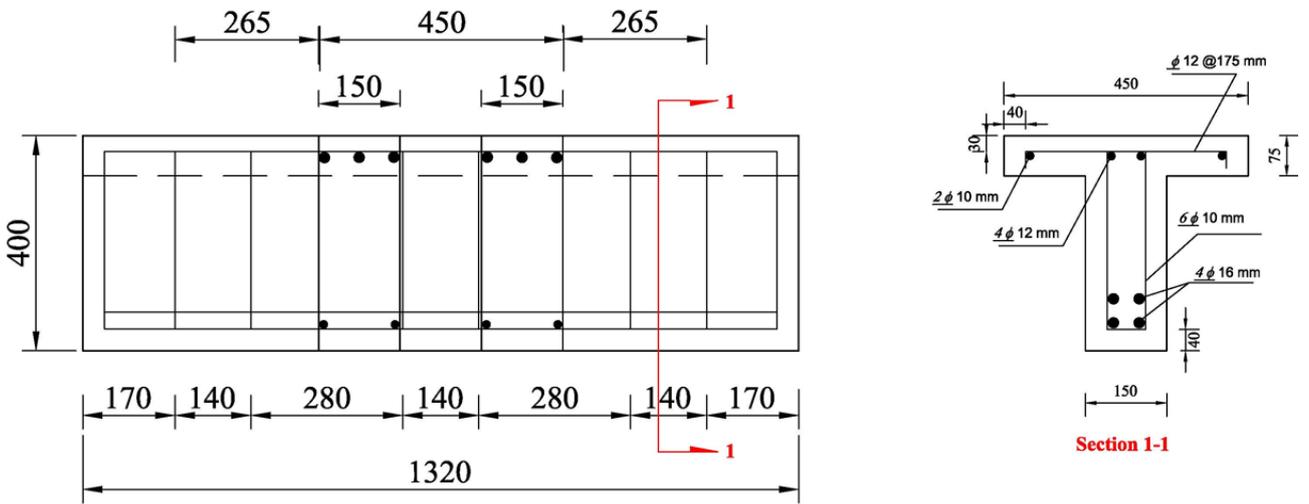


Fig. 4. T-Beam with indirect load (ITV).

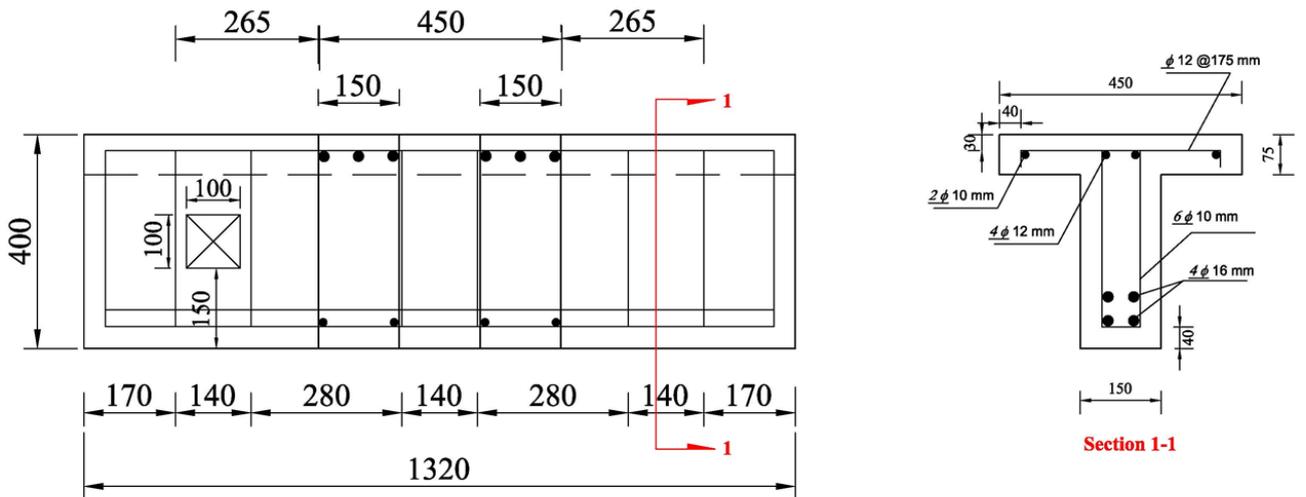


Fig. 5. T-Beam with indirect load with web opening vertical reinforced (ITVO2).

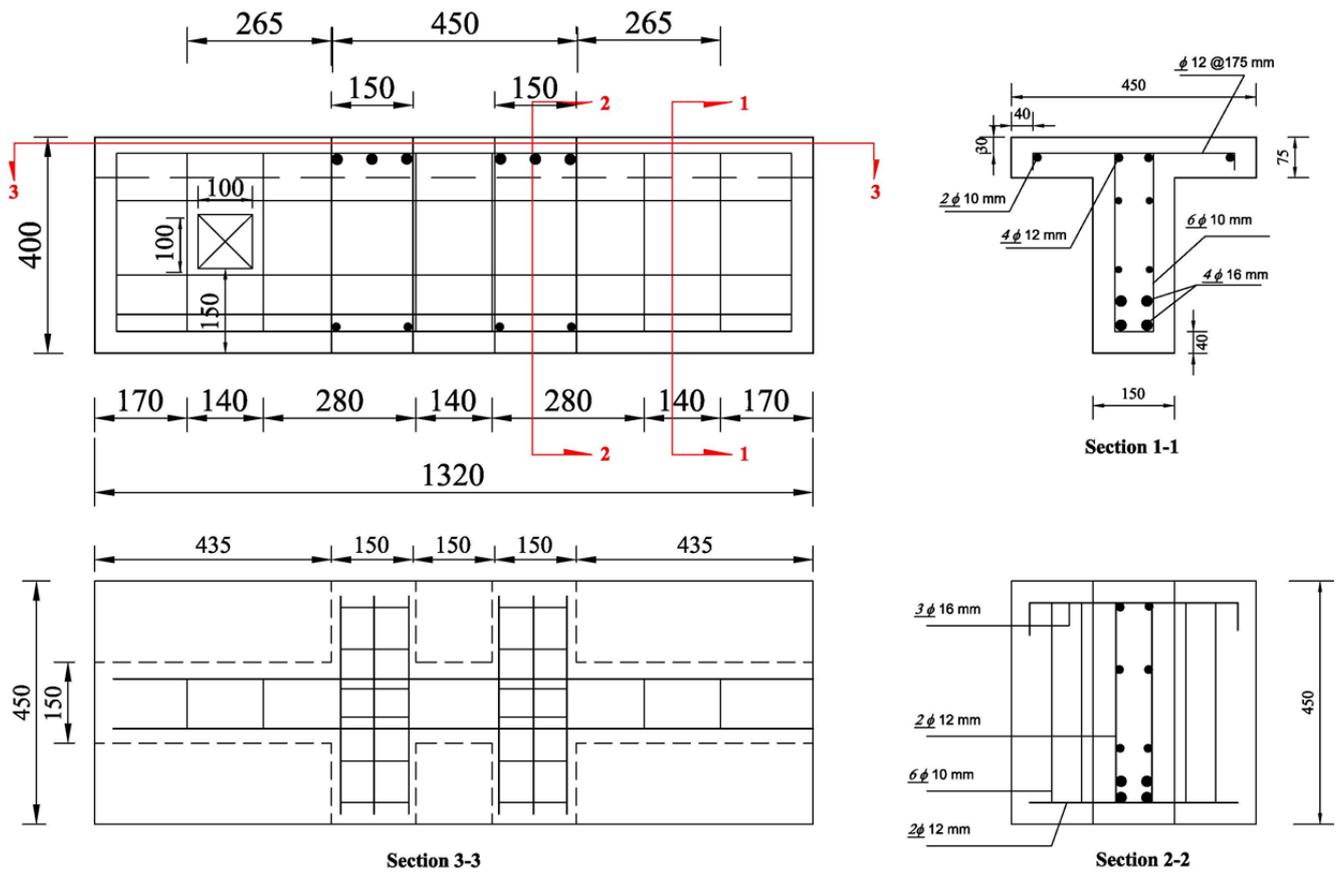


Fig. 6. T- Beam with indirect load with web opening (horizontal and vertical Reinf.) (ITVHO2).

### 3. FINITE ELEMENT MODEL SIMULATION

ANSYS software have been used in this research to simulate the models. 3D beam model adopted to represent the geometric and material nonlinear behavior reinforced concrete beam.

The geometry details of beam models was taken according to [Yousif \(2016\)](#) as described in section (2).

The concrete element was modeled by using the 8-noded brick elements (SOLID 65). Eight nodes with three degrees of freedom at each node, translation in the x, y, and z directions. This element have the capability of predicting cracks in tension and in three orthogonal directions, crushing in compression, and plastic deformation [ANSYS \(2007\)](#).

The steel bars, were modeled using element type (LINK8). This element can be used to model trusses, sagging cables, links, springs, etc. The 3-D spar element is a uniaxial tension compression element with three degrees of freedom at each node: translations of the Nonlinear Analysis of simply supported beam.

#### 4. MATERIAL PROPERTIES.

##### 4.1. CONCRETE IN COMPRESSION AND TENSION

The stress –strain curve of concrete was used in this research to represent the linear (elastic) and nonlinear (plastic) behavior of concrete. The concrete is assumed to be homogeneous and isotropic. The relationship of stress-strain curve of concrete in compressive (uniaxial) for concrete modeling is predicted from the following equations as shown in Fig. 7a ACI (1999):

$$f_c = \varepsilon E_c \quad \text{for} \quad 0 \leq \varepsilon \leq \varepsilon_1$$

$$f_c = \varepsilon E_c / (1 + (\varepsilon/\varepsilon_0)^2) \quad \text{for} \quad \varepsilon_1 \leq \varepsilon \leq \varepsilon_0$$

$$\varepsilon_0 = 2 f_c / E_c \quad \text{for} \quad \varepsilon_0 \leq \varepsilon \leq \varepsilon_{cu}$$

Where:

$f_c$  = stress at any strain  $\varepsilon$ , N/mm<sup>2</sup>,

$\varepsilon_0$  = strain at the ultimate compressive strength  $f_c'$ .

$\varepsilon_{cu}$  = ultimate compressive strain,

$\varepsilon_1$  = strain corresponding to  $0.3 f_c'$

The multi-linear isotropic stress- strain requires the first point of the curve to be defined according to Hooke's law:

$$E = \sigma / \varepsilon$$

$$\sigma = 0.3 f_c'$$

The stress–strain relationship for concrete in tension assumes that the tensile stress increases linearly with an increase in tensile strain up to concrete cracking. After concrete cracking, the tensile stress decreases linearly to zero as the concrete softens. The bond between the concrete and reinforcing bars was simulated approximately by the tension stiffening model, which defines the stress–strain relationship for concrete in tension after cracking. Fig. 7b present the relationship between stress and strain of concrete in tension.

Fig. 7 showing the constitutive curves of concrete in compression and tension used in this research.

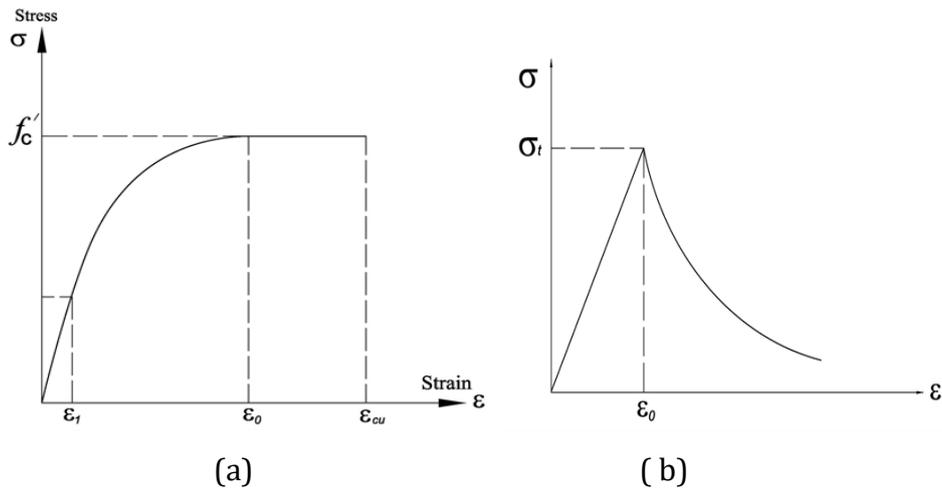


Fig. 7. Stress-strain curve of concrete (a-compression , b-Tension).

#### 4.2. REINFORCEMENT PROPERTIES

A perfect-plastic stress-strain curve model was adopted in this research to simulate the behavior of the steel reinforcement. The parameters including yielding strength  $f_y$ , modulus of elasticity  $E_s$ , (Table 2) and Poisson’s ratio  $\nu = 0.2$  are used to define this model. The stress–strain curve relationship is shown in Fig. 8, according to the formulas:

$$f_s = E_s \cdot \epsilon_s \quad \epsilon_s \leq \epsilon_{sy}$$

$$f_s = f_{sy} \quad \epsilon_s > \epsilon_{sy}$$

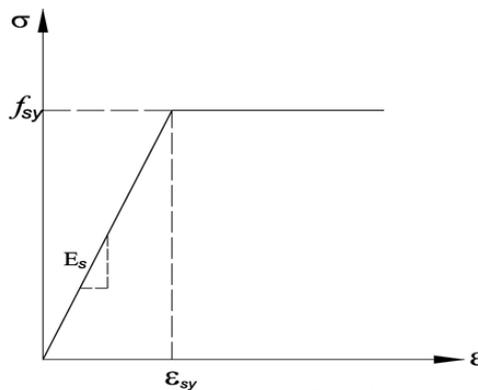


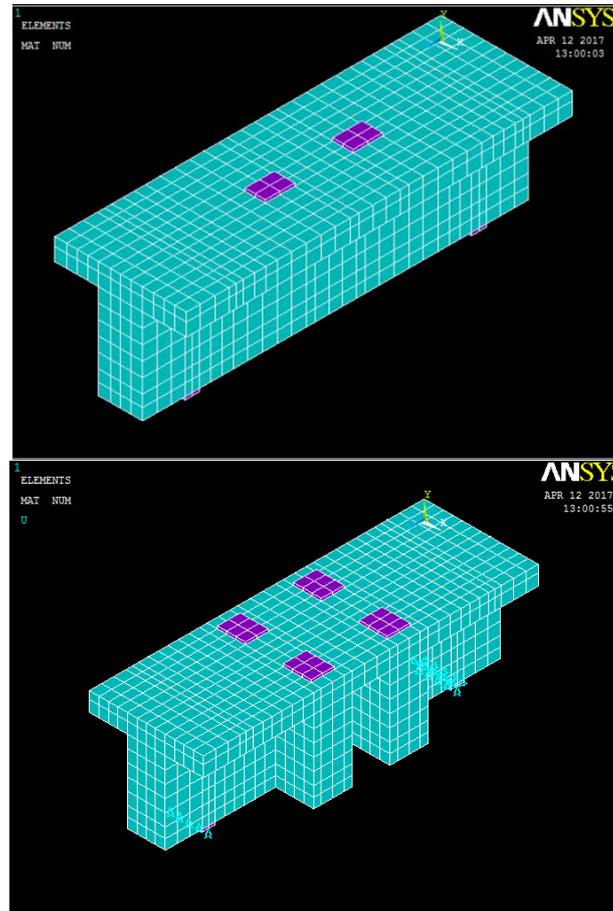
Fig. 8. Stress-Strain curve of steel bar.

Nonlinear structural analysis need to use a suitable type of convergence criterion to terminate the iterative process when the solution is considered to be sufficiently accurate. Most convergence criteria used to be applied to get the equilibrium is displacement, out of forces, and internal energy ANSYS (2007). In this study force convergence criteria was adopted.

#### 4.3. MODELING OF T-BEAMS

The models were adopted in this research depend on the same geometry and reinforcement details in Yousif (2016).

The specimens were modeled as 3D and the dimensions of the sections were chosen to match those being used in the experimental tests of the experiment. Full length model have been used as shown in Fig. 9.



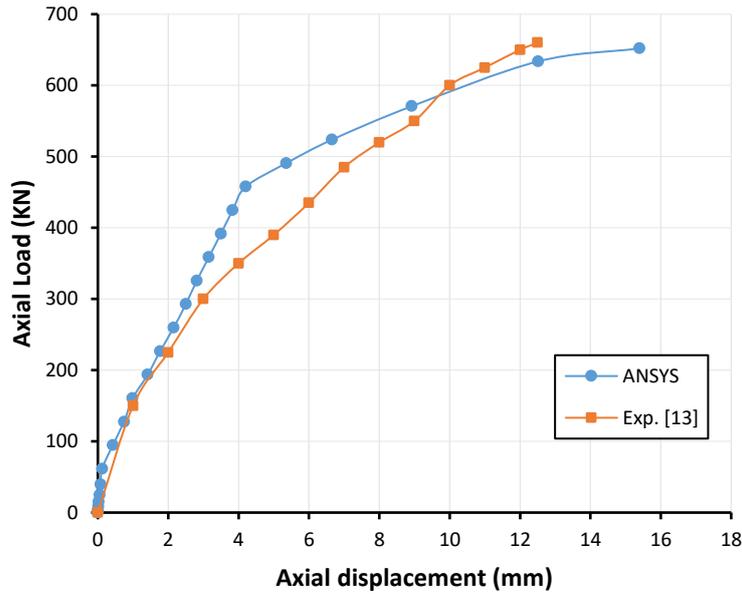
**Fig. 9. FEM ANSYS model of DVT and ITV.**

The support was modeled as a roller in one side and a hinge in other. The load was applied as a pressure on steel plate area were modeled using solid 45 elements.

## 5. FEM RESULTS

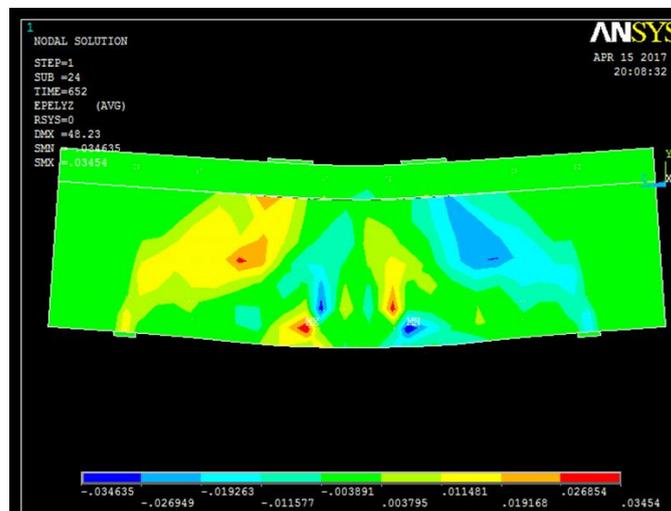
The deflection – load relation are obtained from FEM analysis of models shows the result are compatible with experimental result conducted by [Yousif \(2016\)](#).

[Fig. 10](#) shows the FEM results compared with experimental result of DVT model [Yousif \(2016\)](#). The deflection was obtained at the center of the beam, results shows there is a good agreement between the theoretical and experimental deflection of beam.



**Fig. 10. Deflection – load curve of DVT model.**

The contour strain of the concrete are shown in the Fig. 11, it's clear that the path n the point load and of concentration stresses is along the connect line between load point and the support. The FEM ANSYS deflection results versus applied load of beam model IT was compared with experimental results as shown Fig. 12. The diagonal cracks propagation shown in Fig. 13. The deflection –load relation of model of model IT are shown in Fig.14.



**Fig. 11. Contour strain of DVT model.**

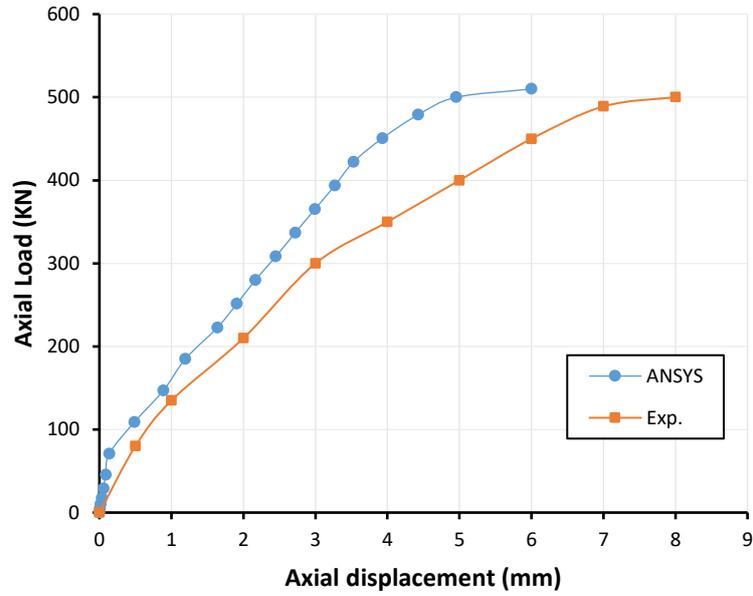
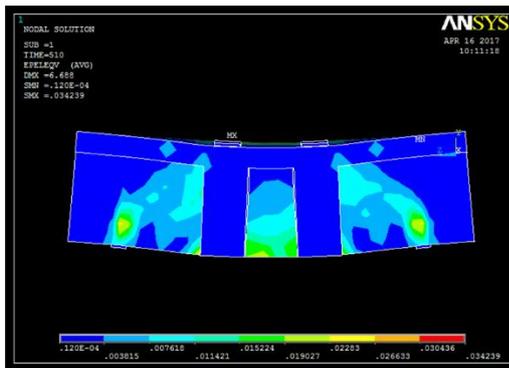


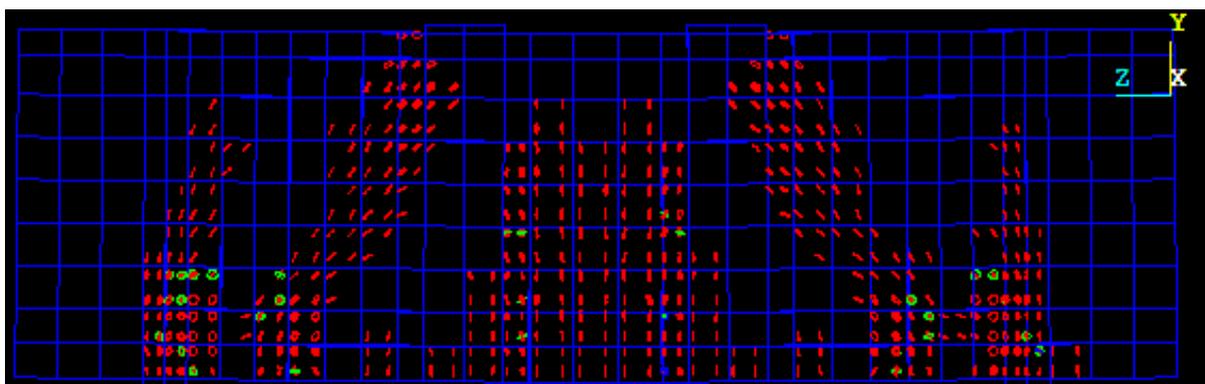
Fig. 12. Deflection – load curve of IT model.



a- FEM model



b- Experimental model Yousif (2016)



c- Inclined shear cracks

Fig. 13. Concrete strain of IT model and crack propagation.

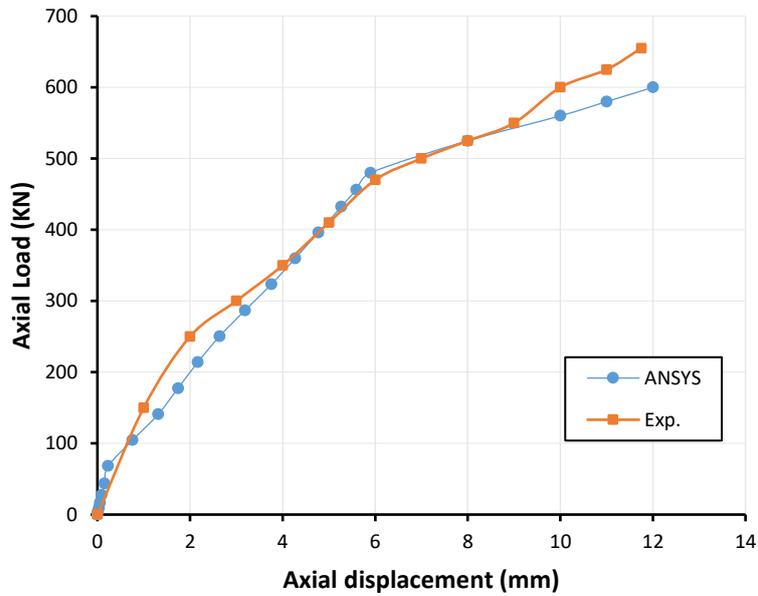


Fig. 14. Deflection – load curve of ITV.

Fig. 15 shows the FEM model with an open size (100 x 100 mm) with terminate the extension of reinforcing steel bar.

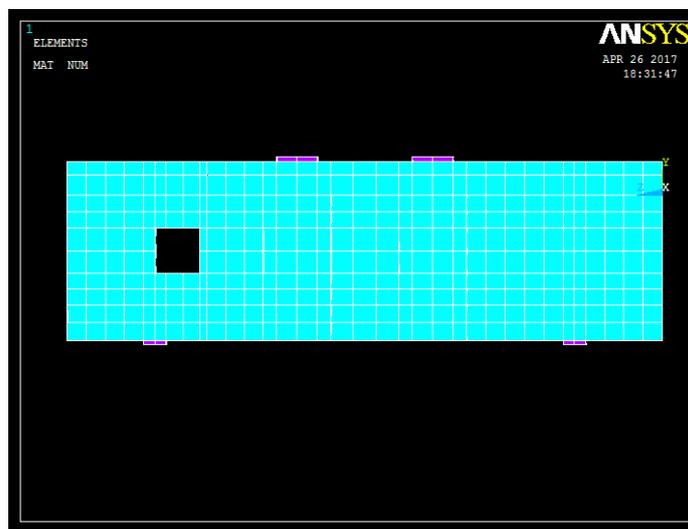
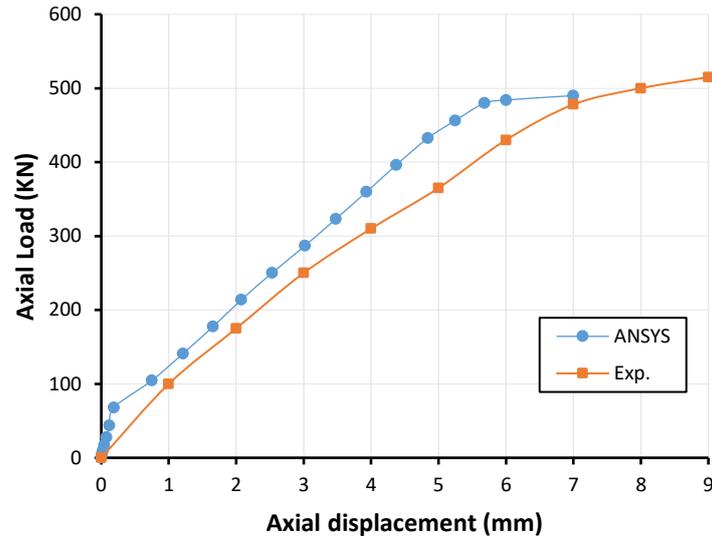
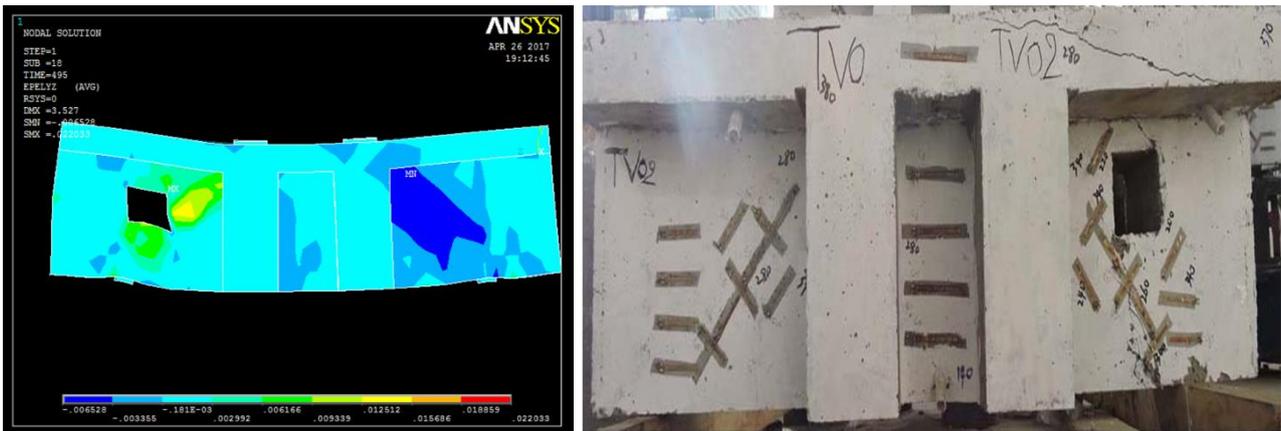


Fig. 15. FEM model of ITVO2.



**Fig. 16. Deflection – load curve of ITVO2.**

Fig. 16. Present the relation of deflection versus the applied load for model ITVO2 with opening while Fig. 17 shows the failure mode and crack propagation compared with experimental result of model ITVO2.



**a- FEM model**

**b- Experimental model Yousif (2016)**

**Fig. 17. Concrete strain of ITVO2 model and crack propagation.**

The beam failure in all deep beams models were in shear the cracks line observed extend between the point applied load and plate support. Elastic linear behavior were noticed in all analyzed deep beams. Mid-span cracks appears with gradually increasing load step at the bottom toward top of the beam while with increasing applied load ,inclined crack propagate extremely at shear span causing final failure. The failure in experimental work could be happen suddenly due to excessive inclined cracks for beam without web reinforcement and without a significant increase in crack Yousif (2016).

The inclined cracking load can be defined as the load causes the first major inclined crack in shear span while the ultimate load is the maximum load value can be applied to the reinforced concrete beam. The vertical web reinforcement in beam model does not showing significant change the first inclined cracking loads while there a clear effect for presence of web reinforcement on the ultimate load. Table 3 presents the experimental and FEM result of ultimate and inclined crack load of each model. When the applied load is increase, the mid-span deflection increases similarly for all analytical models and experimental beams. In general for all model, the deflection of beam model with horizontal and vertical web reinforcement less than the beam have only vertical web reinforcement. Existing the opening in web of deep beam show reduction in beam loading capacity.

**Table 3. The ultimate load and inclined cracked load of beams.**

Beam No.	Cracked Load Pcr (KN)		Ultimate applied Load (KN)	
	Exp. Yousif (2016)	FEM ANSYS	Exp. Yousif (2016)	FEM ANSYS
DTV	180	193.6	675	658
IT	160	149.8	500	510
ITV	200	182.2	640	620
ITVO2	200	183.0	480	495
ITVHO2	200	181.5	510	508

## 5. COMPARISON OF RESULTS

The test results, theoretical and FEM result of beams including Zsutty Equations Zsutty (1971) of deep beams were considered and it was founded a good agreement. Table 4 presents the comparison of FEM results, Experimental and Zusutty equation for ultimate load of adopted reinforced concrete beam.

**Table 4. Experimental and theoretical comparison of ultimate load different type of beam.**

Beams No.	Exp. Pu (kN)	Zusutty Eq. Pu (kN)	FEM Pu (kN)
	Yousif (2016)	Zsutty (1971)	
DTV	675	604.88	658
IT	500	197	510
ITV	640	322	620
ITVO2	480	--	495
ITVHO2	510	--	508

## 6. CONCLUSION

Based on the theoretical analysis and experimental test program results for reinforced concrete deep beams with and without web openings, directly and indirectly loaded, the following conclusions were concluded:

1. The expected failure was occurred in diagonal shear cracks same as in experimental tested models.
2. The reinforcement details of different model have clear effects of beam capacity and beam behavior.
3. The strengths of beam can be effectively enhanced for deep beams reinforced with both horizontal and vertical stirrups.
4. The existing of opening within the shear span reduce the load-carrying capacity of beam.
5. Experimentally and theoretically analysis approved that the existing of vertical stirrup reinforcement increase the ultimate load of beam capacity.
6. The deep beams analysis results with and without openings using ANSYS was shows a good agreement compared with experimental results with small difference observed for all tested and analyzed beams.

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