Nonlinear Finite Element Analysis for shear strength and behavior of Reinforced Concrete T-Beam with Openings in Both Web and Flange by ANSYS 14.5

● **Zana Abdalla Aziz**[1] - MSc ●
Serwan Khurshid Rafiq[2]- Assist. Prof.
[1,2]University of Sulaimani, College of Engineering, Civil Engineering Department
zana.aziz@univsul.edu.iq, serwan.rafiq@univsul.edu.iq

Received: 06/12/2018 / Accepted: 27/06/2019 / Published: 22/12/2019
DOI Link: DOI Link: https://sites.google.com/a/univsul.edu.iq/sjes/issues/vol6no4/sjes-10112

Abstract

In this study, a three-dimensional T-beam consisting of circular openings in web and/or in the flange with variable distances from the support is analyzed numerically. The beam is simulated and analyzed non-linearly by using computer software of ANSYS V.14.5. In the simulation, the calibration for the model is carried out by taking the effects of openings, including their numbers and locations in the beam, on the behavior of the beams in general and their shear strength in particular after comparing the results with the experimental work. Thirteen cases are studied for investigating crack patterns and load capacity accompanied with graphing load-displacement envelope for each case. From these in thirteen cases, a case is control beam which is penetrated with holes. The rest of the samples, however, contain openings in their webs and/or flanges with variable distances from the support. A parametric study is carried out on high strength concrete to compare it with normal concrete.

After the calibration, the numerical results of the load-displacement curve, crack pattern and ultimate load significantly matches the results obtained from experimental works. The results show a substantial decrease of load carrying capacity by up to 11.7% with a decrease in openings distance from support from d (effective depth of the T-beam) to (d/3). However, the capacity of the beam to carry load increases by 17.6% by reducing the space between the openings and the support to (d/4).

Keywords: ANSYS (Finite Element Analysis), Openings in both flange and web, Reinforced concrete T-beams, Shear strength and behavior.

1- Introduction

In most reinforced concrete buildings, openings at structural elements are needed, to an installation of ducts and pipes for sanitation, heating, ventilation, air-conditioning, electricity, telephone and computer networks and other mechanical equipment. Passing these ducts through an opening in the beam, instead of placing them underneath of the beam, lead to a most saving in cost, especially in multistory buildings [1].

There is a lack of specific guidelines in building codes of practice (ACI 2012, ECP-203), although they contain detailed treatment of openings in floor slabs.

S. Amiriet al (2011) [2], tested nine simply supported concrete beams consisting of circular openings with varying diameters simulated by a three-dimensional nonlinear finite element method using ANSYS 10.0. All beams had an identical cross section of 100 mm × 250 mm and 2000 mm in length with the circular opening in seven diameters: 150 mm, 130 mm, 120 mm, 110 mm, 100 mm, 80 mm and 60 mm and an equivalent square opening with 133 mm in width. The beams were simulated to obtain the load-deflection behavior and compared with the solidconcrete beam. The results obtained from this study showed that the performance of the beams with circular openings with diameter less than 0.48D (D is depth of the beam web) has no effect on the ultimate load capacity of the Rectangular section beams.

R. B. Hafiz et al(2014)[3],tested simply supported RC beams consisting of circular openings with varying diameters of (60, 80, 100, 110, 120, 150) mm in 3-D nonlinear finite element method using ANSYS 10.0. The result shown that RC rectangular beams with circular openings of diameter less than 44% of the depth of beam (D) has no effect on the ultimate load capacity but circular openings with diameter more than 44% of D reduces the ultimate load capacity at least 34.29%.

Somes and Corley (1974)[4], tested a series continuous beams and they obtained from their test that circular opening may be considered as large when its diameter exceeds 0.25 times the depth of the web because introduction of such openings reduces the strength of the beam, and also Somes and Corley (1974) indicated that when a small opening is constructed in the web of a beam, with unreinforced in shear, the failure mode remains the same as that of a solid beam [2].

Hanson (1969)[5], tested a series of reinforced concrete T-beams with square and circular openings in the web and found that an opening located adjacent to the support have no effect in strength.

Mansur et al(1991) [6], tested eight reinforced concrete continuous beams, each containing a large transverse opening. Their results showed that an increase in the depth of opening from 140 mm to 220 mm led to a reduction in load capacity from 240 kN to 180 kN.

Amin et al(2017) [1], tested five beam column joints. All specimens consist of beam had a (T-cross section) total depth of 400 mm, flange thickness of 60 mm, flange width of 350 mm, and web width of 150 mm and 1500mm clear span from the column face. The main column had a rectangular cross section of 350 mm depth, 250 mm width, and 2000 mm clear height. Two of the RC beam column joints, which have a square opening (170mm X 170mm) located at clear distances from the column face 170 mm and 340 mm, other two RC beam column joints, which has a rectangular opening (170mm X 340mm)located at clear distances from the column face 170 mm and 340 mm. the result that they obtained from the study were Changing the opening location from 170 mm to 340 mm, lowered the energy dissipation capacity, the ultimate load, corresponding displacement, and the stiffness degradation of the beam column joint by up to 11.11%, 8.7%, 13.75%, 9.33%, respectively, and changing the aspect ratio of opening from 1 to 2, lowered the energy dissipation capacity, the ultimate load, the corresponding displacement, and the stiffness degradation of beam column joint up to 5.6%, 2.4%, 13.44%, 27.32%.and 3.3%, respectively.

2- Objective of the research

The aim of this study is to investigate the effects of number and location of openings on the shear strength and behavior of the beams using none linear finite element analysis by using ANSYS 14.5 software.

3- Finite element analysis

Finite element method (FEM) is a numerical method for solving a differential or integral equations and obtaining approximate solutions to a wide variety of engineering problems. It has been applied to a number of physical problems, where the governing differential equations are available. The method essentially consists of assuming the continuous function for the solution and obtaining the parameters of the functions in a manner that reduces the error in the solution[7]. ANSYS is a general purpose software, used to simulate interactions of all disciplines of physics, structural, vibration, fluid dynamics, heat transfer and electromagnetic for engineers[8].In this work, a three-dimensional finite element modeling by using ANSYS 14.5 software has been made. Materials idealization and the elements used to build these models are listed below:

3-1. Elements type

An element Solid65 used for 3-D modeling of solids is used to model the concrete. This element has eight nodes as shown in Fig. (1)with three degrees of freedom at each node translations in the nodal x, y, and z directions. The element is capable of plastic deformation, cracking in three orthogonal directions, and crushing [8].

The modulus of elasticity of concrete was calculated by equation 1[9].

$$E_c = 4700\sqrt{f_c'} \quad \text{------------------------} \quad (1)$$

The ANSYS program requires the uniaxial stress-strain relationship for concrete in compression. The simplified compressive uniaxial stress-strain curve as shown in Fig. (2) was adopted [10]

Numerical expressions, equations 2[11]had been used to construct the uniaxial compressive stress-strain curve for concrete.

$$f = \frac{E_c \varepsilon}{1 + \left(\frac{\varepsilon}{\varepsilon_o}\right)^2} \quad \text{---------} (2)$$

Where:

$$\varepsilon_o = \frac{2f'c}{E_c}$$

$$E_c = \frac{f}{\varepsilon}$$

f = Stress at any strain ε.

ε = Strain at stress f.

ε_o=Strain at the ultimate compressive strength f'c.

LINK180 element is used to model steel reinforcement. This element is a 3-D spar element and it has two nodes as shown in Fig. (3)with three degrees of freedom translations in the x, y, and z directions. This element is capable of plastic deformation.

The steel stress-strain relation used is shown in Fig. (4) which exhibits an initial linear elastic portion, a strain-hardening range in which stress again increases with strain. The extent of the yield plateau is a function of the tensile strength of steel[12]

Where:

$E_w=0.1E_s$ ------------- (3)

Es = Modulus of elasticity of steel bar, 200000 MPa

Ew = The tangent modulus of steel after yielding, MPa

εs = Strain in steel bar.

εyo = Strain in steel bar at yield point.

σs =Stress in steel bar.

SOLID185 element used for 3-D modeling of solid structures is used to model the steel plate. It is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element exhibits plasticity, stress stiffening, creep, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elasto-plastic materials, and fully incompressible hyper-elastic materials[8].

3-2. T-Beams geometry and material properties

The reinforced concrete T-Beams tested by Kawani, et al [13] are chosen to be model and study their behavior using the described method. The geometry of the T-beam with the reinforcement details and material properties as reported are shown in Figs. (5, and 6), and Table (1).

The testing program of Kawani, et al (13)consisted of thirteen reinforced concrete T-beams with opening in both the web and the flange under central point load in the structural laboratory. Their specimens were T- shape in cross section, for all beams span and steel reinforcements were kept constant. The main variables in their study are the location and number of 50 mm diameter openings in both the web and the flange, as shown in Table (2). All specimens had a constant T-shape cross section of [Length (L) = 2000 mm, width of flange (bf) =350 mm, depth of the flange (hf) = 70 mm, width of the web (bw) = 150 mm, total depth of the beam (h) =350 mm]. As shown in Fig. (5 and 6).

3-3. Finite element investigation

From the testing program of Kawani, et al [13], Eight RC T-beams were selected for the theoretical study with ANSYS 14.5 (i.e. A1, A2, A5, A6, A9, A10, A11, and A12), and were modeled as solid. All the models had a constant T-shape cross section of [Length (L) = 2000 mm, width of flange (bf) =350 mm, depth of the flange (hf) = 70 mm, width of the web (bw) = 150 mm, total depth of the beam (h) =350 mm]. The bottom reinforcement are 3-dia.20mm,and the reinforcement at top of the beam is 4-dia.10mm, as shown in the fig. (5), same as in the experimental study. All models were simulated same as their samples in the experimental study, respectively. The summary of inputs is given in Table (3).

To show the effect of concrete strength (fc') on its behavior, another sample (A12) was modeled with higher fc' about 40MPa.

To show the effect of location of the opening adjacent to the support, other three samples were modeled same as A2 with opening in web in different distance from the support, as shown in Table (4).

Where: d= effective depth.

4- Analysis results and discussion:

The test results of Kawani, et al [13] showed that the samples failed in shear, while the ANSYS models beam also failed in shear too with same crack pattern, indicating close agreement with the experimental ultimate load, see Table (5).

4-1. Crack pattern

Kawani, et al [13]investigated the effects of opening of the T beams after producing (50mm) diameter of circle opening in web and/or in flange, these beams had been tested under a mid-span vertical loading, increase in the applied load caused the existing inclined shear cracks to propagate slowly accompanied by the formation of new inclined cracks parallel to the initial cracks in the shear span. After that new inclined cracks were formed parallel to the line joining the loads and the support points. Failure was defined as the load level at which the load could no longer be increased. Some minor secondary cracks also formed before failure.

All the experimental samples failed due to shear failure at a load of (136, 100, 136, 124, 132, 108, 140, and 116) kN for (A_1, A_2, A_5, A_6, A_9, A_{10}, A_{11}, and A_{12}), respectively, while the remaining ANSYS models for (A_1, A_2, A_5, A_6, A_9, A_{10}, A_{11}, and A_{12}) were failed in shear failure too at a load of (120, 102, 140, 130, 120, 90, 140, and 110), respectively, and there were some flexure cracks generated at mid span extended to the steel bars and stopped there due to the steel resistance. The ratio of the predicted shear capacity to the value of the experimental ultimate shear were (0.85, 1.02, 1.03, 1.05, 0.91, 0.83, 1, and 0.95), for (A_1, A_2, A_5, A_6, A_9, A_{10}, A_{11}, and A_{12}) respectively. The finite element results showed good agreement with the experimental results throughout the entire range of behavior. All the experimental and ANSYS samples failed in shear failure because there were have not any transverse steel bars for shear resistance, and if comparing the crack pattern of experimental tested beams with the nonlinear analysis using ANSYS software gives a good agreement with the crack pattern. See Fig. (7-14).

4-2. Load deflection response of beams

Load – deflection curves for the tested beams are shown in Figs.(15) through (22).Each one of these curves is initiated in a linear form with a constant slope. After cracking, the load deflection response takes a nonlinear form with a varying slope. Good agreement was obtained in the pre and post cracking stages of behavior.

Moreover, the load – deflection curves obtained from the finite element model is steeper than the load deflection curve attained from the experiments in pre-cracking and post cracking stages due to producing micro cracks from drying shrinkage of concrete beams before testing, which reduces the bond strength between the steel reinforcement and the concrete, whereas it has assumed a full bond in the finite element model.

4-3. Effect of concrete compressive strength

To study the effect of using high strength concrete on the behavior of T- beam with opening, different values of f ′c were taken in the numerical test. These values were 35, 40, 50, 60 and 70 MPa Fig. (23). Shows that the both cracking moment, post cracking stiffness were increased by increasing f ′cup to 10 MPa.

For the sample A_{12} with higher fc', its result showed that with increasing the strength of the concrete to (35, 40, 50, 60, and 70) MPa, ultimate load increased and the samples failed at (144kN, 162kN, 180kN, 206kN, and 235kN) respectively, and stiffness would increase. As shown in Fig. (23).

4-4. Effect of opening

To study the effect of the changing distance of opening from the support a beam with adjacent opening to the support were selected as shown in Table (5), the result shown that with decreasing distance of the opening from the support about (d) distance to (d/2, and d/3) distance, the load capacity decreased to (97kN, and 90kN), respectively, while for the opening located (d/4) distance from the support, the load capacity increased to (120kN) due to resistance of the reaction of the support. As shown in Table (5).

5- Conclusions

1- Non-linear finite element modeling by ANSYS 14.5 is able to simulate and analyze shear strength and behavior of reinforced concrete T-beam with openings.
2- The numerical results are in a harmony with the experimental results including ultimate load carrying capacity, crack pattern, and load displacement curve.
3- Increasing the strength of concrete with opening, increases shear strength and stiffness of the T section beam.
4- An opening at a location adjacent to the support about (equal and less than d/4), has no more effect on the load capacity of the T-beam.
5- Producing opening decrease shear resistance of T- beam.
6- Opening in the web have more effective than opening in the flange on the load capacity, when opening producing in the web at d-distance from the support, the load capacity was decreased about 27%, while opening in the flange at the same distance, load capacity decreased about 7.14%.
7- Producingtwo opening in both sides of the supports, have no more effect on load capacity of the T-beam corresponding to one opening.

References

1- Amin Saleh, M. Hamad, Sherif Elzeny, S.K.Elwan and A. Deifalla.," The Behavior of RC Exterior Beam-Column Joint with Nearby Beam Unreinforced Web Opening under Cyclic Loading – Experimental Study ", IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), Volume 14, Issue 4 Ver. VII (Jul. - Aug. 2017), PP 22-30
2- Soroush Amiri, Reza Masoudnia, "Investigation of the opening Effects on the Behavior of Concrete Beams without Additional Reinforcement in Opening Region Using Fem Method", Australian Journal of Basic and Applied Sciences, Vol.5, No.5, pp. 617-627,2011.
3- Rezwana Binte Hafiz, Shaiba Ahmed, Saikat Barua, Sharmin Reza Chowdhury, "Effects of Opening on the Behavior of Reinforced Concrete Beam", IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), Volume 11, Issue 2 Ver. VII (Mar-Apr. 2014), PP 52-61,www.iosrjournals.org.
4- Somes, N.F. and W.G. Corley, 1974. "Circular openings in webs of continuous beams". American Concrete Institute. Detroit, MI, pp: 359-398.
5- Hanson, J.M., 1969. "Square openings in webs of continuous joists". Portland cement Association, pp: l-14.
6- Mansur, M.A., Y.F. Lee, K.H. Tan and S.L. Lee, 1991. "Test on RC continuous beams with openings". Journal of Structural Engineering, 117(6): 1593-1605.
7- Tobeia, S. B., "Behavior of Corbels Strengthened with Carbon Fiber Reinforced Polymers (CFRP) – Numerical Study"; Eng. & Tech Journal; Vol.32, PartA, NO.10, 2014.
8- ANSYS, Inc., "ANSYS Help", Release 14.5.
9- ACI Committee 318. Building Code Requirements for Reinforced Concrete, ACI 3 18-14, American Concrete Institute, Detroit, 315 p. 2014.
10- Kachlakev Damian and Thomas Miller, "Finite element modeling of reinforced concrete structures strengthened with FRP laminates", Technical Report, Oregon Department of Transportation, pp.99, May 2001.
11- Gere, I.M. and Timoshenko, S.P., "Mechanics of material", PWS Publishing Company, Boston, Massachusetts. 1997.
12- Cervenka, V., Eligehausen, R. and Pulkl, R., "Sbeta-Computer Program for Nonlinear Finite Element Analysis of Reinforced Concrete Structures", Report 90/1, Institute of Building Materials, University of Stultgort, 1990.
13- Yousif Y. Q. K., Jalal A. S., Mahdi O. H., " Shear Strength and Behavior of Reinforced Concrete T-Beam with Openings in Both Web and Flange", Journal of Zankoy Sulaimani Part-A- (Pure and Applied Sciences), Vol.19, part A, No.1, 2017.

التحليل اللاخطي بالعناصر المحددة لايجاد مقاومة القص للعتبات الخرسانية المسلحة ذات مقطع (T) الحاوية على فتحات دائرية في الشفة العليا و النصل (الجذع)

زانا عبدالله عزيز[1] - ماجستير
د. سيروان خورشيد رفيق[2] - استاذ مساعد
[1،2] جامعة السليمانية - كلية الهندسة - قسم الهندسة المدنية

المستخلص

هذه الدراسة عرضت تحليل العتبات الخرسانية المسلحة ذات مقطع (T)الحاوية على فتحات دائرية في الشفة العليا و/او النصل (الجذع) بمسافات متغيرة من المساند. تم محاكاة و تحلبل العتبات بشكل غير خطى بطريقة العناصر المحددة باستخدام برنامج الكومبيوتر (ANSYS 14.5). بالمحاكاة تم معايرة التموذج المقترح للدراسة على اساس تاثير الفتحات متضمنا عدد الفتحات وموقعها للنماذج المفحوصة على تصرف العتبات الخرسانية يشكل عام وعلى مقاومة القص للنماذج وخاصة النماذج المفحوصة فى المختير . تم معايرة النموذج المقترح للدراسة على اساس تاثير الفتحات على مقاومة القص متظمنا عدد الفتحات وموقعها فى العتبة الخرسانية .تم دراسة ثلاثة عشر عتبة خرسانية من حيث مخطط التشقق ومخطط الاحمال الازاحة وقابلية التحمل لكل عتبة خرسانية ومقارنتها مع النتائج العملية.

بعد معايرة النموذج المقترح فى هذه الدراسة مع النموذج العملى، اشارت النتائج التحليلية للعتبات الخرسانية ان استجابة مخططات الحمل - الانحراف ، الحمل الاقصى. و شكل الشقق المحسوبة بطريقة العناصر المحددة فى توافق جيد مع النتائج المختبرية . حيث اشارت النتائج المختبرية مع تقليل بعد مسافة الفتحات فى العتبات الخرسانية المسلحة ذات مقطع (T) الحاوية على فتحات دائرية من المسند من (d) لحد (d/3) تنخفض المقاومه القصوى لحد مقدار (11.7 %) للعتبات الخرسانية بينما تحمل العتبات الخرسانية المسلحة تزداد بنسبة 17.6 % عند تقليل المسافة بين الفتحه والمسند من (d) الى (d/4).

الكلمات المفتاحية : العتبات الخرسانية المسلحة ذات مقطع (T)، مقاومة القص وسلوكِ الفتحات الدائرية في الشفة العليا والنصل (الجذع) ، وANSYS .

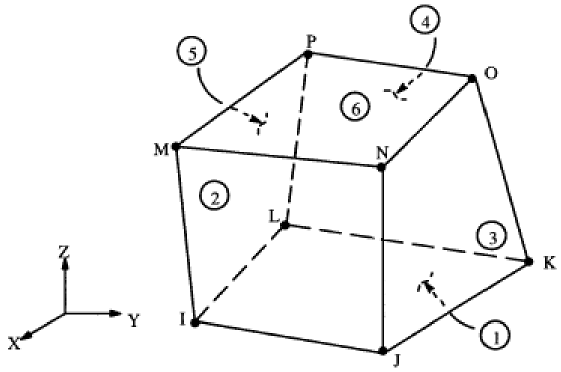


Fig.(1) : Solid 65- 3D reinforced concrete solid [8].

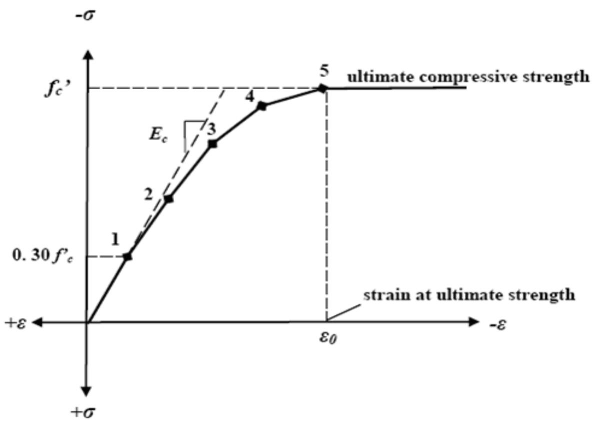


Fig.(2) : Simplified compressive uniaxial stress-strain curve for concrete[10].

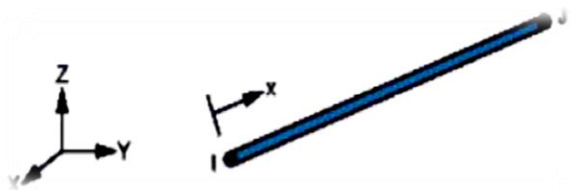


Fig. (3) : LINK180 element [8].

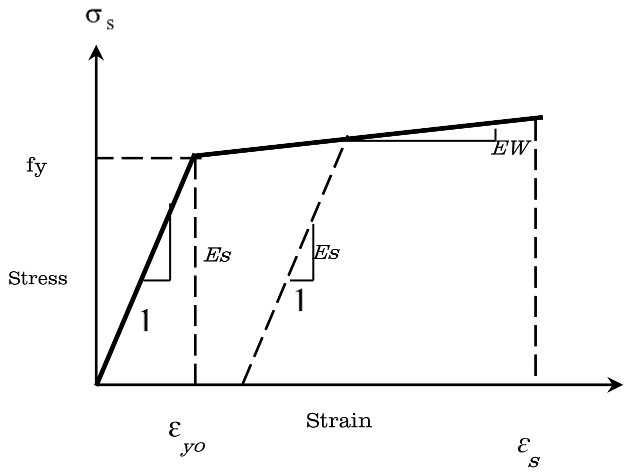


Fig. (4) : Stress-strain curve for steel bar.[12]

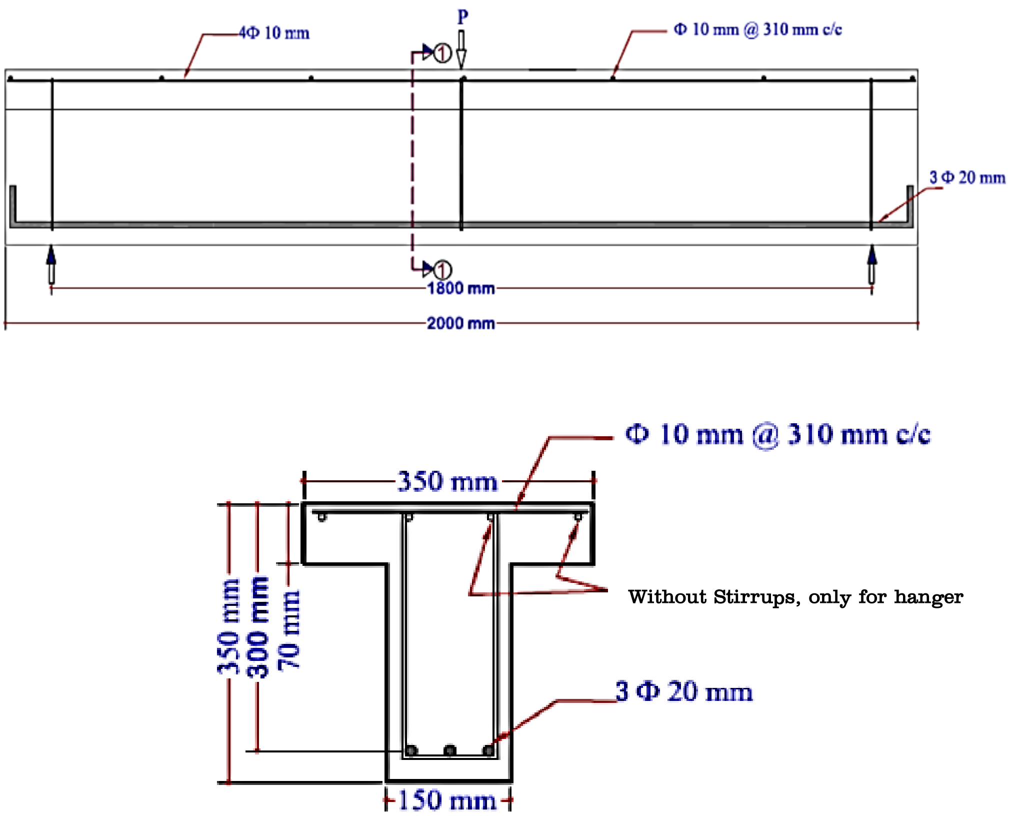


Fig. (5) : Control T-Beam[13], section 1-1.

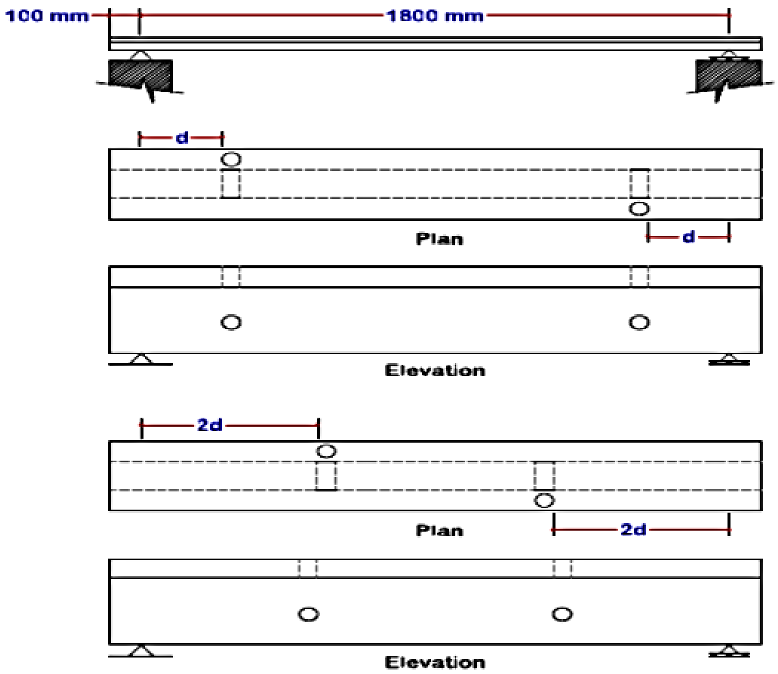
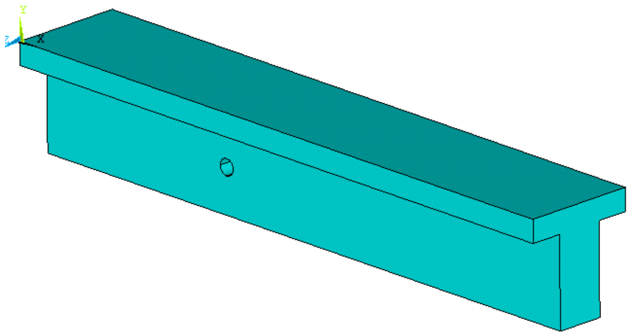


Fig. (6) : T-Beam with opening [13].



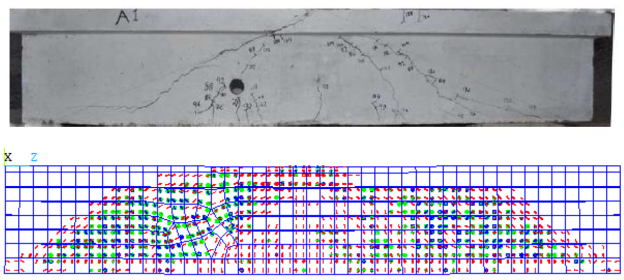
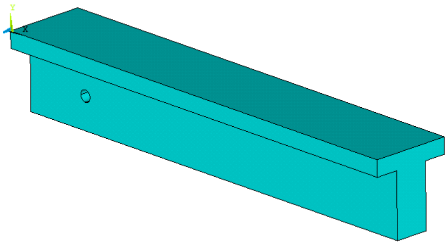


Fig. (7) : (Experimental [13] and ANSYS Sample (A1) crack pattern. (Source: Researcher)



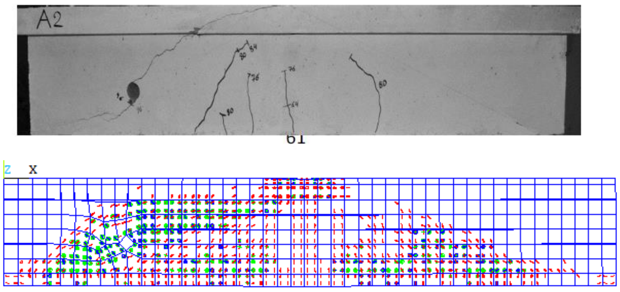


Fig. (8) : (Experimental [13]and ANSYS sample (A2) crack pattern. (Source: Researcher)

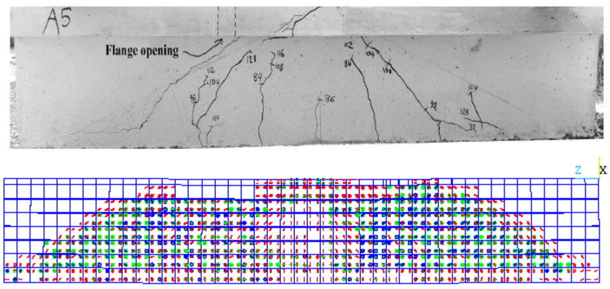


Fig. (9) : (Experimental [13]and ANSYS sample (A5) crack pattern. (Source: Researcher)

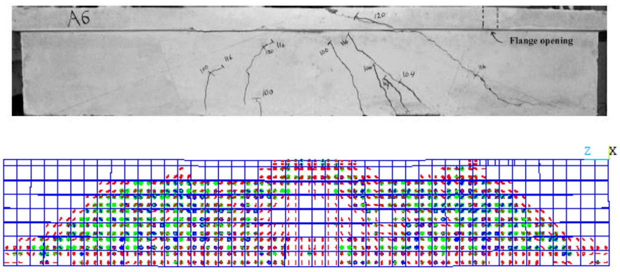


Fig. (10) : (Experimental [13]and ANSYS sample (A6) crack pattern. (Source: Researcher)

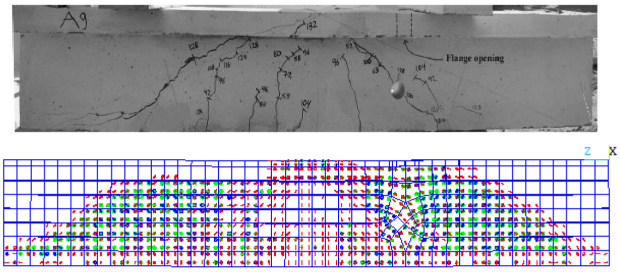


Fig. (11) : (Experimental [13]and ANSYS sample (A9) crack pattern. (Source: Researcher)

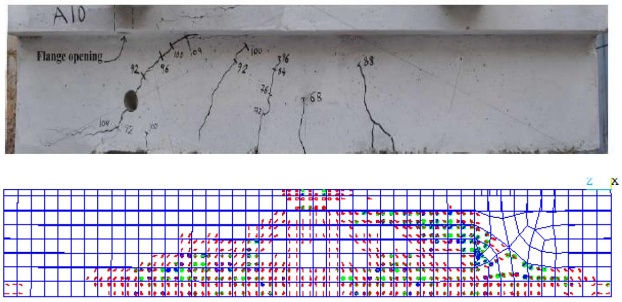


Fig. (12) : (Experimental [13]and ANSYS sample (A10) crack pattern. (Source: Researcher)

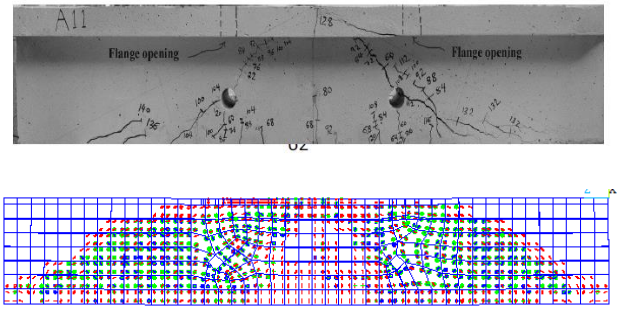


Fig. (13) : (Experimental [13]and ANSYS sample (A11) crack pattern. (Source: Researcher)

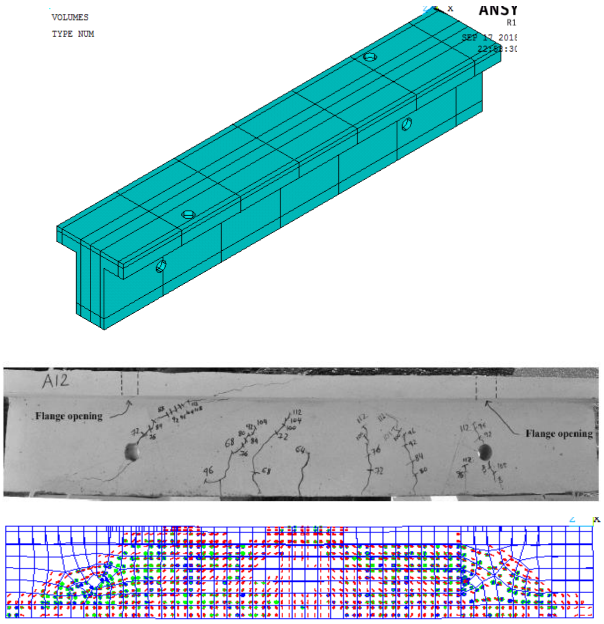


Fig. (14) : (Experimental [13]and ANSYS sample (A12) crack pattern. (Source: Researcher)

Table (1) : Properties of steel reinforcement bars.[13]

No.	Bar dia. (mm)	Yield strength, Fy, MPa	Ultimate strength fu, MPa
1	20	620	727
2	10	550	671

All the samples have fc'=30.04MPa, and fsp = 2.902MPa.

Table (2) : Samples with opening.[13]

Sample	No. of openings	Distance from the supports (mm)
A1	1 (in web)	600
A2	1 (in web)	300
A3	2 (in web)	600
A4	2 (in web)	300
A5	1 (in flange)	600
A6	1 (in flange)	300
A7	2 (in flange)	600
A8	2 (in flange)	300
A9	1 (in web), 1 (in flange)	600
A10	1 (in web), 1 (in flange)	300
A11	2 (in web),2 (in flange)	600
A12	2 (in web),2 (inflange)	300

Table (3) : Model material properties. (Source: Researcher)

Materials	Material model	Element type
Concrete	Linear isotropic Multilinear- isotropic Concrete	Solid 65
Steel Bar	Linear isotropic - Bilinear isotropic	Link180
Steel Plate	Linear isotropic	Solid 45

Table (4) : Opening located adjacent to the support. (Source: Researcher)

Sample	No. of openings	Distance from the supports (mm)
A2	1 (in web)	d/4
		d/3
		d/2
		d

Where: d= effective depth.

Table (5) : Experimental [13], and ANSYS results (Source: Researcher)

			Experimental Data		ANSYS Data		
samples	No. of openings	Distance from the supports (mm)	Failure load (kN)	Mode of failure	Failure load (kN)	Mode of failure	**ANS. / Exp. %**
A1	1 (in web)	600	136	Shear comp. Failure	120	Shear comp. Failure	0.85
A2	1 (in web)	300	100		102		1.02
A5	1 (in flange)	600	136		140		1.03
A6	1 (in flange)	300	124		130		1.05
A9	1 (in web),1 (in flange)	600	132		120		0.91
A10	1 (in web),1 (in flange)	300	108		90		0.83
A11	2 (in web),2 (in flange)	600	140		140		1
A12	2 (in web),2 (in flange)	300	116		110		0.95

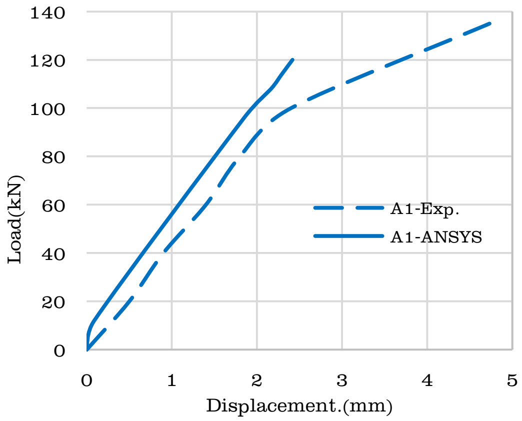


Fig. (15) : Load-displacement curves for A1sample. (Source: Researcher)

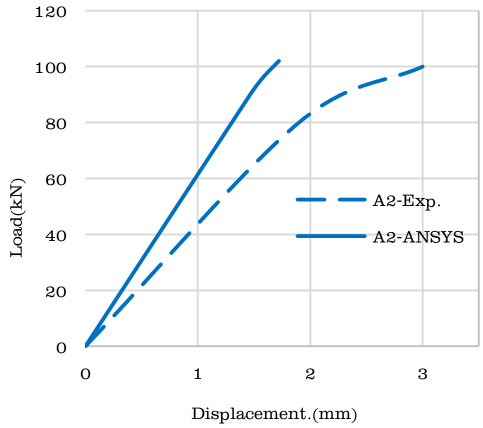


Fig. (16) : Load-displacement curves for A2 sample. (Source: Researcher)

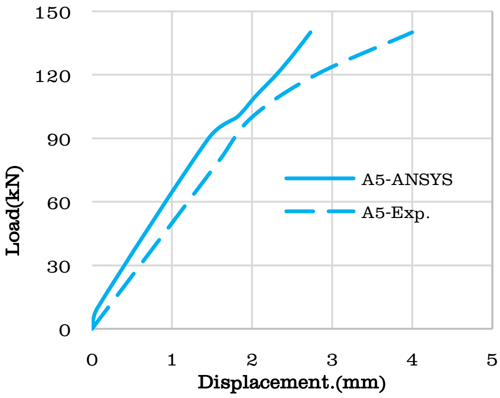


Fig. (17) : Load-displacement curves for A5sample. (Source: Researcher)

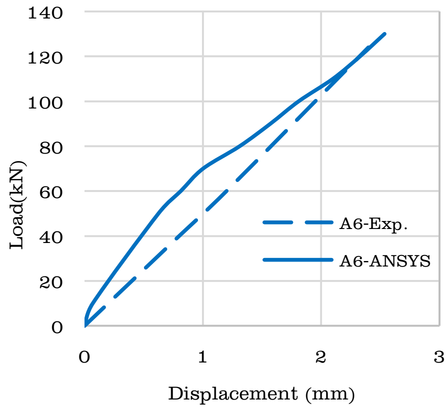


Fig. (18) : Load-displacement curves for A6 sample. (Source: Researcher)

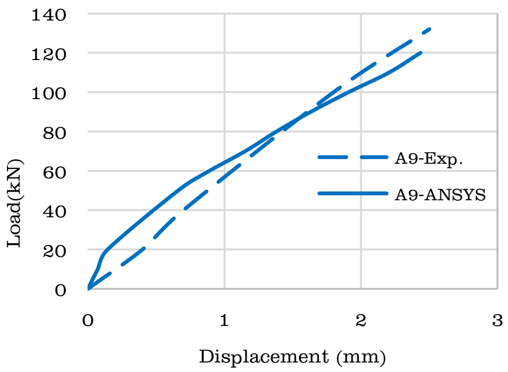


Fig. (19) : Load-displacement curves for A9 sample. (Source: Researcher)

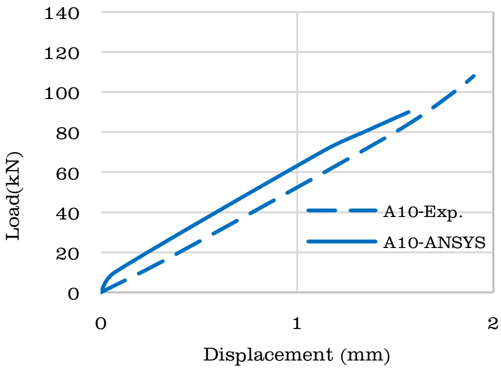


Fig. (20) : Load-displacement curves for A10 sample. (Source: Researcher)

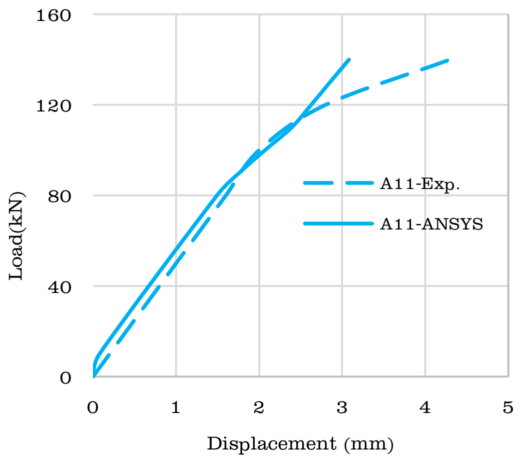


Fig. (21) : Load-displacement curves for A11 sample. (Source: Researcher)

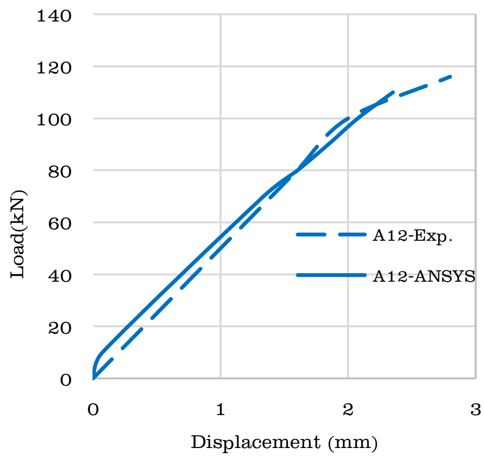


Fig. (22) : Load-displacement curves for A12 sample. (Source: Researcher)

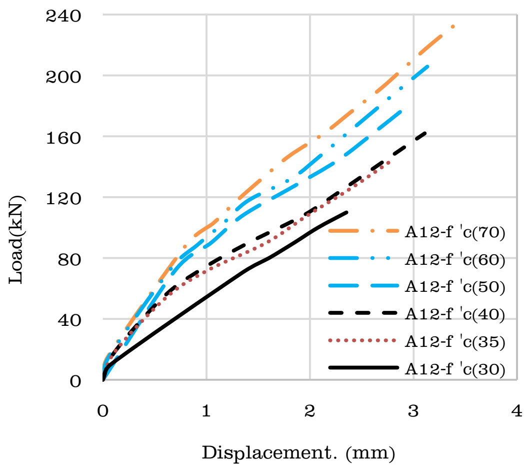


Fig. (23) : Load-displacement curves for A12-f 'c (30, 35, 40, 50, 60, & 70) MPa. (Source: Researcher)