Behavior of Prestressed Concrete Beams in the Presence of Opening Before and After Tensioning of Cables

Ahmed Mohamed Abd Elregal, Ata El-Kareim Shoeib *, & Samir M. Ahmed**
* *Professor, Civil Engineering Department, Helwan University, Egypt*
** *Lecturer , Civil Engineering Department, Shorouk Academy, Egypt*

ABSTRACT

In modern construction, after the completion of the concrete structure, there are many openings and Ducts necessary for many services . the openings in the prestressed concrete beams became an important parameters must be studied. In this work, the behavior of prestressed concrete beams with opening was experimentaly and theortically studied. The effect of opening size, timing of created openings, and type of section are the main paramters The experimental study consists of six prestressed concrete beams with rectangular cross-section, sized 200 mm (width) x 400 mm (height) x 4000 mm (length) were manufactured, one of them with T- Section (total width of Flange 600 mm). by using ANSYS program, the size of opening after validation model was studied.

Keywords; prestressed concrete beams, opening size, (rectangular & T- sections) beams.

1- Literature Review

Literature Review was divided into two parts. In the first part, a brief clarification on the behavior, properties of prestressed concrete and the openings in the concrete while in the second part, to provide a detailed review of the body of literature related to Studing the Behavior of Prestressed Concrete Beams in the Presence of Opening Before and After Tensioning of Cables in its entirety would be too immense to address in this thesis. However, there are many good references that can be used.

Figure (1) shows The Difference between Reinforced & Prestressed Concrete

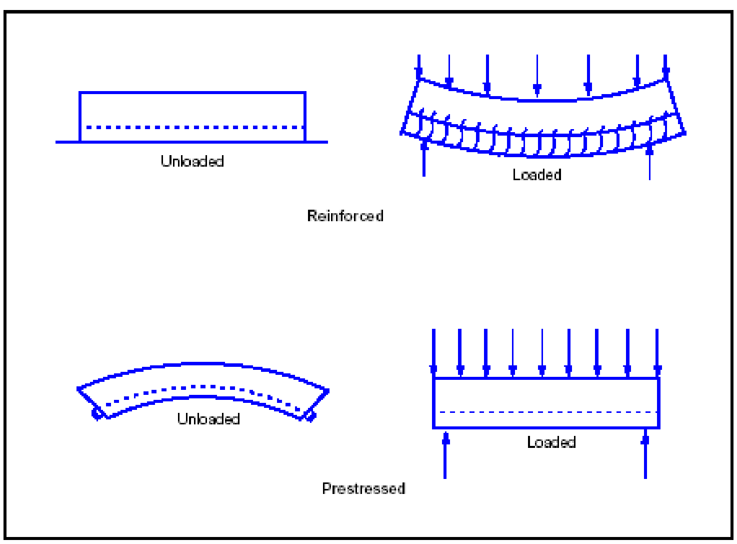


Figure (1): Difference between Reinforced & Prestressed Concrete

Prestressing is a technique used for known values of stresses in a structural member before the applications of full or live load. Pre-stressed concrete is reinforced concrete in which the steel reinforcement has been tensioned against the concrete. These stresses are induced by tensioning the high tensile strands, wires or rods, and then anchored to the member being Prestressed, by mechanical means. A load applied to a prestressed concrete member with bonded tendons induces equal strains in the concrete and adjacent tendon. This compatibility of strains between the concrete and tendon is a basic design assumption in calculations for stress and strain in prestressed sections. Prestressing may be essential for the functionality or the stability of a structure; it may simplify the connections and improves the performance by increasing stiffness or limiting cracking. Prestressed concrete having following applications.

1. In structural Member, where the span length is very high with low rises and low structural height, the application of Reinforced Cement Concrete shall be virtually impractical. In such a case, Prestressing is used to achieve a light weight, elegant looking and much economical structure with high durability. Prestressing, therefore, is widely used for long span beams and Bridges.

2. In building structure also, prestressing method is very effectively used to achieve lighter beams and slabs; thus reducing their dead load considerably as compared to R.C.C. Structures. Application of Prestressing in building construction also facilitates a larger span between the columns, thus reduces the number of columns. This also makes the structure more versatile for interior planning.

3. Prestressing is also very widely used in the construction of Mega Structures like Containment Wall of Nuclear Reactors, LNG Storage Tanks, Cement Silos, Chimneys, Dams and Rock Anchors etc.

Transverse openings in beams may be of different shapes and sizes. Prentzas (1968), in his extensive experimental study, considered openings of circular, rectangular, diamond, triangular, trapezoidal and even irregular shapes, as shown Fig. (2). Although numerous shapes of openings are possible, circular and rectangular openings are the most common ones. Circular openings are required accommodate service pipes, such as for plumbing and electrical supply. On the other hand, air-conditioning ducts are generally rectangular in shape, and they are accommodated in rectangular openings through beams. Sometimes the comers of rectangular opening are rounded off with the intention of reducing possible stress concentration at sharp comers, thereby improving the cracking behavior of the beam in service..

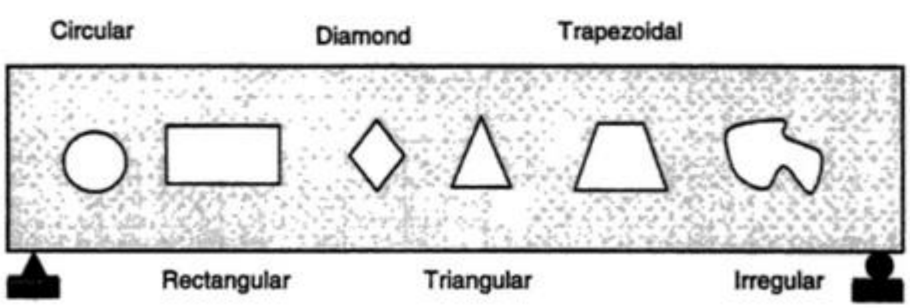


Figure (2): Opening Shapes Considered by Prentzas (1968)

With regard to the size of openings, many researchers use the terms small and large without any definition or clear-cut demarcation line Mansur and Hasnat (1979) have defined openings circular, square, or nearly square in shape as small openings, whereas, according to Somes and Corley (1974), a circular opening may be considered as large when its diameter exceeds 0.25 times the depth of the beam web However, the authors consider that the essence of classifying an opening as either small or large les in the structural response of the beam. When the opening is small enough to maintain the beam-type behavior or, in other words, he usual beam theory apples, then the opening may be termed a small opening When beam-type behavior ceases to exist due to the provision of openings, then the opening may be classified as a large opening According to the above criterion, the definition of an opening being small or large depends on the type of loading For example, the opening segment is subject to pure bending, then beam theory may be assumed to be applicable up to a length of the compression chord beyond which instability failure takes place. Similarity, for a beam subject to combined bending and shear, test data reported in the literature (Prentzas, 1968 Mansur et al, 1985, 1990; Nasser et al, 1967) have shown that the beam-type behavior transforms into a Vierendeel truss action as the size of opening is increased. Some guidelines for identifying whether an opening is large or small are given in subsequent chapters when dealing with different types of loading and load combinations

2- Direction for Present objective

The literature review suggested that Studing the Behavior of Prestressed Concrete Beams in the Presence of Opening Before and After Tensioning of Cables was indeed feasible. It was decided to use ANSYS as the FE modeling package.A Prestressed concrete beam with reinforcing steel modeled discretely will be developed with results compared to the experimental work. The load-deflection response of the experimental beam will be compared to analytical predictions to calibrate the FE model for further use. A second analysis of a prestressed concrete beam will also be studied. The different stages of the response of a prestressed concrete beam are computed using FEA and compared to results generated using hand computations.

3-Experimental work

In this part, the tested specimens' details and preparation and studied parameters were presented. And also, the test setup was described as follows

3.1 Details of Tested Specimens and Parametric Study

The experimental study consists of two Prestressed Concrete beams with rectangular cross-section, sized 200 mm (width) x 400 mm (height) x 4000 mm (length) were manufactured. T- Section (total width of Flange 600 mm).Using Compressive Strength 40 Mpa.

The First Beam is (Control Beam) Rec. Section (Dimension 200 * 400 * 4000) mm Without any Opening.The Second Beam is Rec Section (Dimension 200 * 400 * 4000) mm with Opening (100 * 100) mm AT Mid Span Before Tensioning of Cable.

Figure (3) shows The Reinforcment details for the Prestressed beam, Figure (4) shows The Dimensions of B1 & B2, Figure (5) shows The Tset Setup for the Prestressed beam.

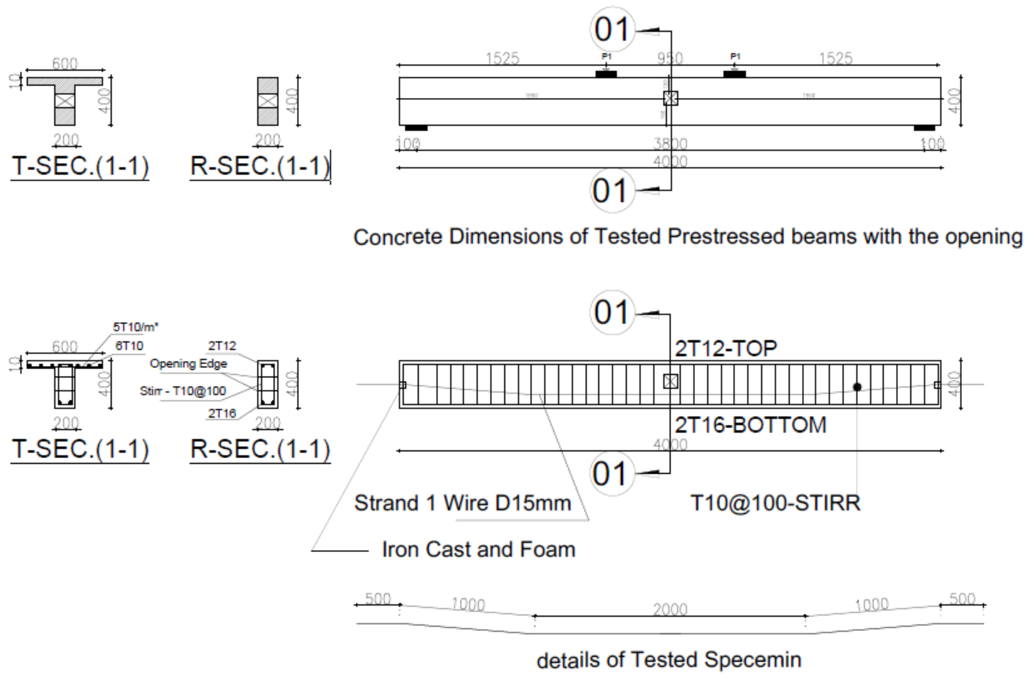
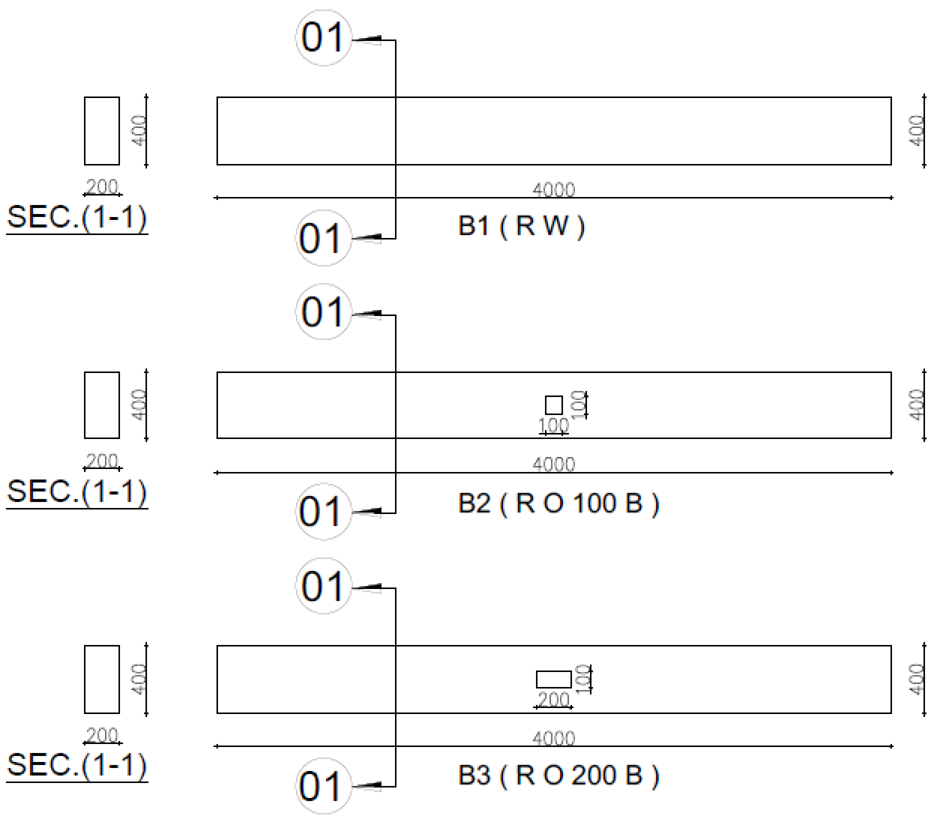


Figure (3): The Reinforcment details for the Prestressed beam



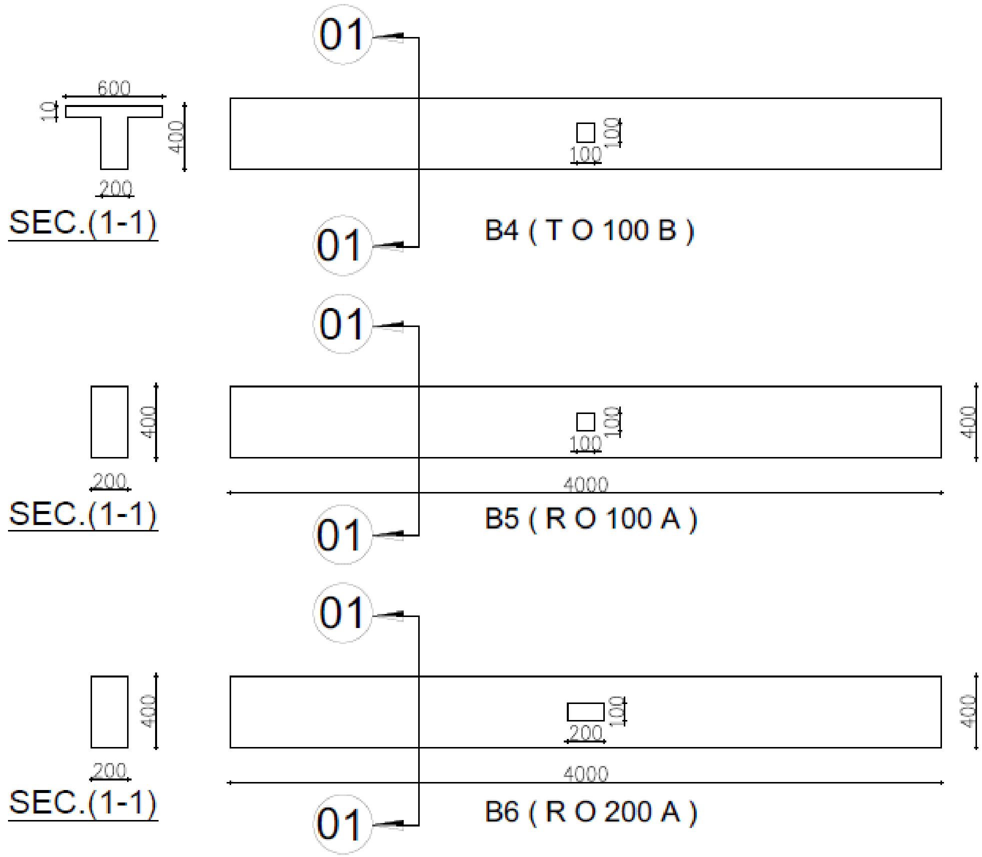


Figure (4): The The Dimensions of B1 & B2

Figure (5): The Test Setup for the Prestressed beam.

R: Rec-Section **& T:** T-Section **& W:** Without Opening **& O:** Opening **& 100 :** Opening Dimension (100 * 100)mm & **200 :** Opening Dimension (200 * 100)mm **& B:** Before Tensioning **& A:** After Tensioning

3.2 Samples Preparation

Concrete has been prepared to test in El-Mostafa ready Mix Concrete In New Capital Administration, The Specimens Were Poured at The Station in the Site the characteristics of the materials used in this research are discussed in this chapter.

Figure 6: Preparation of tested samples Reinforcement

3.3 Mix Design

Specimens have Same compressive strength The characteristic compressive strengths are 40 MPa. Table (1) presents the ratio of each material by weight for 1 m^3 of concrete to get the desired strength.

Table (1): Mix Design Ratios

Coarse aggregate (kg)	Fine aggregate (kg)	Cement (kg)	Water (liter)	Silica fume (kg)	Super-plastizer (liter)	Average Comp. Strength after 7 days MPa	Average Comp. Strength after 28 days MPa
1000	500	425	170	50	5	41.5	48.26

The mixing was done by the ready mixer, and the Specimens were poured through the pump. The time of arrival of the concrete Car from the station to the Specimens site was about 10 minutes, due to the location of the ready-Mix station is near from the Specimens.

The concrete was cast in the molds and cured by covering the specimens with moist burlap sheets until testing. Six concrete cubes with dimension 150x150x150 mm were cast from The Concrete Car Figure (4). The cubes were Submerged in water until day of testing. Compressive strength of the tested cubes ranged after 7 Days between 38.4 and 41.5 Mpa (Three Cubes) . And after 28 Days between 48 and 49.3 Mpa (Three Cubes). Table (2) showed the compressive strength for every Cube. table (1) showed The Results by The Ready Mix Concrete after 7 Days & The Results by The Ready Mix Concrete after 28 Days.

3.4 Test Setup and Testing

A steel frame setup for testing the beams was constructed (Mataria Faculty of Engineering, Helwan University), as shown in Figure (7). It consisted of I-beams resting on four steel columns to support the Tested Prestressed beams during loading. The distance between supports for tested Prestressed beams is 3.80 m. Loading was undertaken using a hydraulic jack connecting with the pump to two points by Plate 950 mm at the center of the beam. The steel I-beam was attached to the strong concrete floor. The applied loads were recorded from the connected monitor to the hydraulic pump. The tested

Prestressed beams' vertical displacement was recorded using .The beam is supported at four joints. The clear span of the tested Beam is 3800mm. A digital load cell with a capacity of 550 kN and an accuracy of 0.1 kN was adopted to measure the applied load .Five LVDT, one at the middle of the beam and the others at a distance equal to 500 & 1250 mm from each edge of the Prestressed beam. A strain gauges were used to read the strain of steel and concrete , one for the main steel bar at mid-span, the other strains were used at Compersion Zone of the tested beam , under the openings & diagonal around the opening of the tested specimens. The strain gauge locations have been illustrated from Figure (7) for the tested specimens.

Figure (7): Experimental setup (photo).

4-THEORETICAL ANALYSIS

The ability of common structural analysis tools to predict the performance of the tested beams was investigated in order to provide practicing engineers with information about their respective reliability. Linear and non-linear finite element analysis methods. This chapter were Comparison between the Experimental Results with theoretical equations of different Codes.

4-1 Nonlinear Finite Element Analysis.

The considered beams behaved nonlinearly mainly due to the material nonlinearity of the elastic plastic steel reinforcement bars and the linear pseudo plastic and brittle behavior of concrete.

This method of analysis is currently considered as the state of the art for analyzing reinforced concrete structures. However, the use of this sophisticated tool is complicated by the need to choose several controlling parameters, which are usually chosen based on previous experience in correlating the results of the finite element analysis to real experimental results similar to the ones to be analyzed.

In addition to reproducing the behavior of the tested beams, the nonlinear analyses were performed in order to study the effect of the strengthening of the beams with and without openings The analysis was done using the finite element package ANSYS.

ANSYS is a generalpurpose finite element modeling package that can be used to solve a wide variety of problems, including heat transfer,static and dynamic structural analysis (both linear and non-linear), and fluid problems.

The Finite Element Method (FEM) involves dividing the complex domain into finite elements and uses variation concepts to construct an approximation of the solution. There are two types of analysis: 2-D modeling and 3-D modeling. A 2-D modeling is simple, can be run on normal computers but may give less accurate results on some applications. However, a 3-D modeling produces more accurate results while sacrificing the ability to run effectively on all but the fastest computers. Within each of these modeling schemes, numerous algorithms (functions) can be inserted to make the system behave linearly or non-linearly. Linear systems are far less complex and generally do not take into account plastic deformation. Non-linear systems do account for plastic deformation, and many also are capable of analyze a material all the way to fracture.

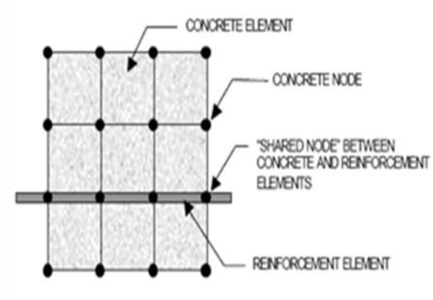
Modeling of reinforced concrete in ANSYS starts by choosing one of three methods that can be used to model steel reinforcement in finite element models. These methods are (Figure (8) 1) discrete method; 2) embedded method; and 3) smeared method.

In the discrete method, reinforcement is modeled using bar or beam elements connected to the concrete mesh nodes. As a result, there are shared nodes between the concrete mesh and the reinforcement mesh, as shown in Figure (8)a. Also, since the reinforcement is superimposed in the concrete mesh, concrete exists in the same regions occupied by the reinforcement.

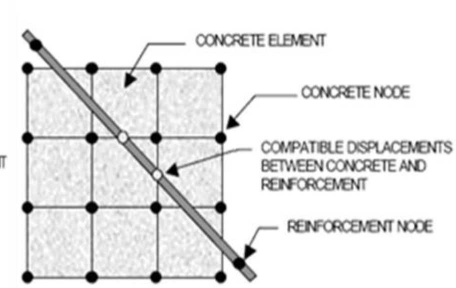
To overcome mesh dependency in the discrete model, the embedded formulation allows independent choice of concrete mesh, as shown in Figure (8) b. In the embedded method, the stiffness of the reinforcing elements is evaluated independently from the concrete elements, but the element is built into the concrete mesh in such a way that its displacements are compatible with those of surrounding concrete elements. That is, the concrete elements and their intersection points with each reinforcement segment are identified and used to establish the nodal locations of the reinforcement elements.

In the smeared method, it is assumed that reinforcement is uniformly spread throughout the concrete element in a defined region of the finite element mesh. This approach is used for large-scale models where the reinforcement does not significantly contribution to the overall response of the structure (Figure 8-c).

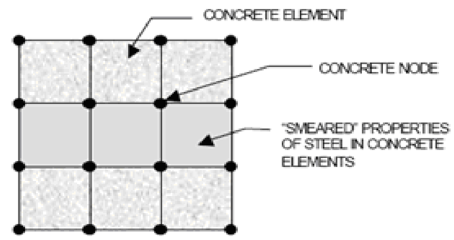
For this research work, the discrete method was chosen to model steel reinforcement in the finite element model of reinforced concrete beam. The finite element model itself can be created in ANSYS using command prompt line input, the Graphical User Interface (GUI), or ANSYS Parametric Design Language (APDL). APDL was used for creating the models in this paper.



a) discrete method



b) embedded method

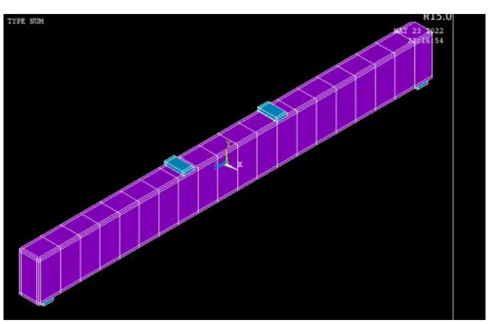
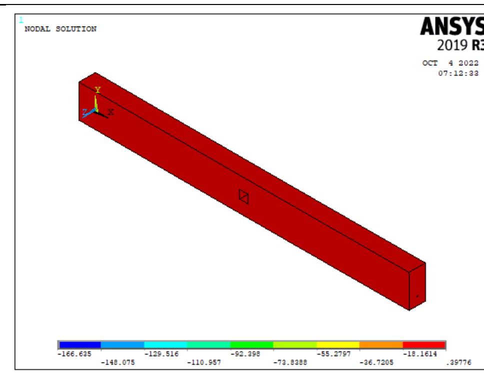


c) smeared method

Figure 8: Reinforcement modeling methods (ANSYS)

4-2 Modeling

The solid element, SOLID65, was used to model the concrete, the 3D spar Link180 element was used to model the steel bars (Bottom , Top and Stirrups) and The Prestressed Cable and the Link185 element, was used to model The Supports for the beams and the Link186 element, was used to model The steel plates. The model of the control slab is shown in **Figure** 9.

	
a) Link elements for steel bars& steel plates	b) solid elements for concrete
Figure (9): The model of the control beam used in the nonlinear analysis	

4-3 Material Properties

The parabolic uniaxial stress strain curve given in ECP 203 was used to represent the behaviour of concrete in compression. The modulus of elasticity and the tensile strength of concrete were calculated using the ECP-203. The elastic plastic uniaxial stress strain model given in the ECP-203 was used to model steel.

4-4 Validaton of the theoretical Nonlinear model

For validation of the ANSYS model , the determination of the parameters controlling the details of the concrete material model of SOLID65, such as tension stiffening and the shear retention across cracks of reinforced concrete, was empirically determined by finding the values achieving the best fit of the calculated load deflection curve of the control beam with the experimental one as shown in **Figure 10** .

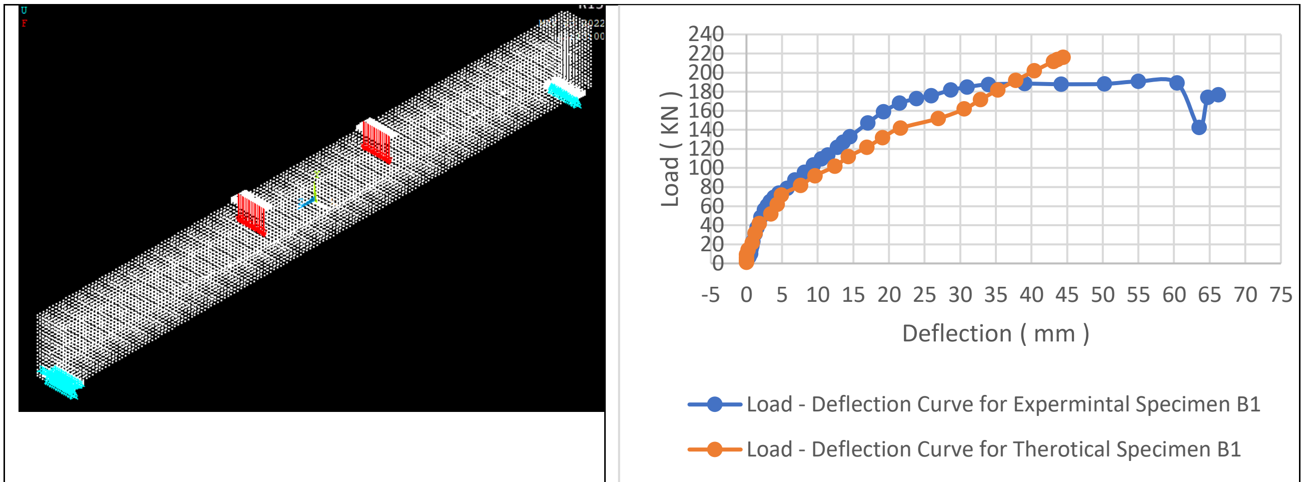
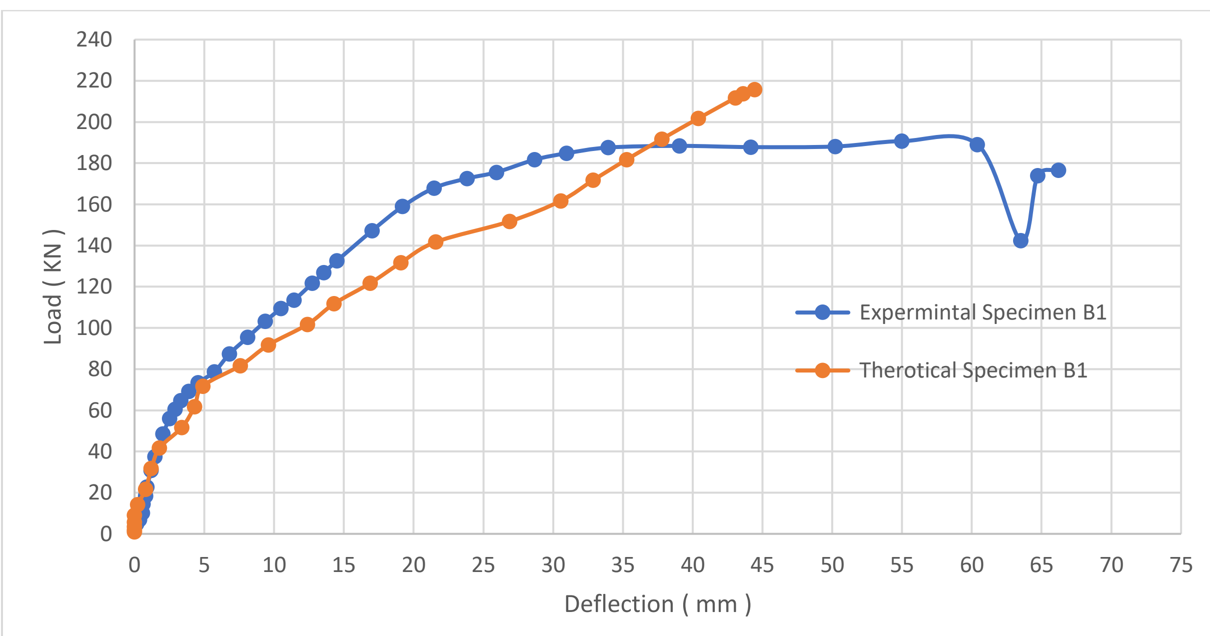


Figure 10: Validation of Theoretical load-deflection curves of control beam by comparing with experimental

It can be seen that, in general, the calculated curve matches the experimental one. However, it is relatively less rigid than the experimental curve, especially after cracking.

After verification of the model, the same model was used to analyze the other strengthened tested specimens. The load deflection curves of strengthened specmines with openings are given in **Figure 11**.



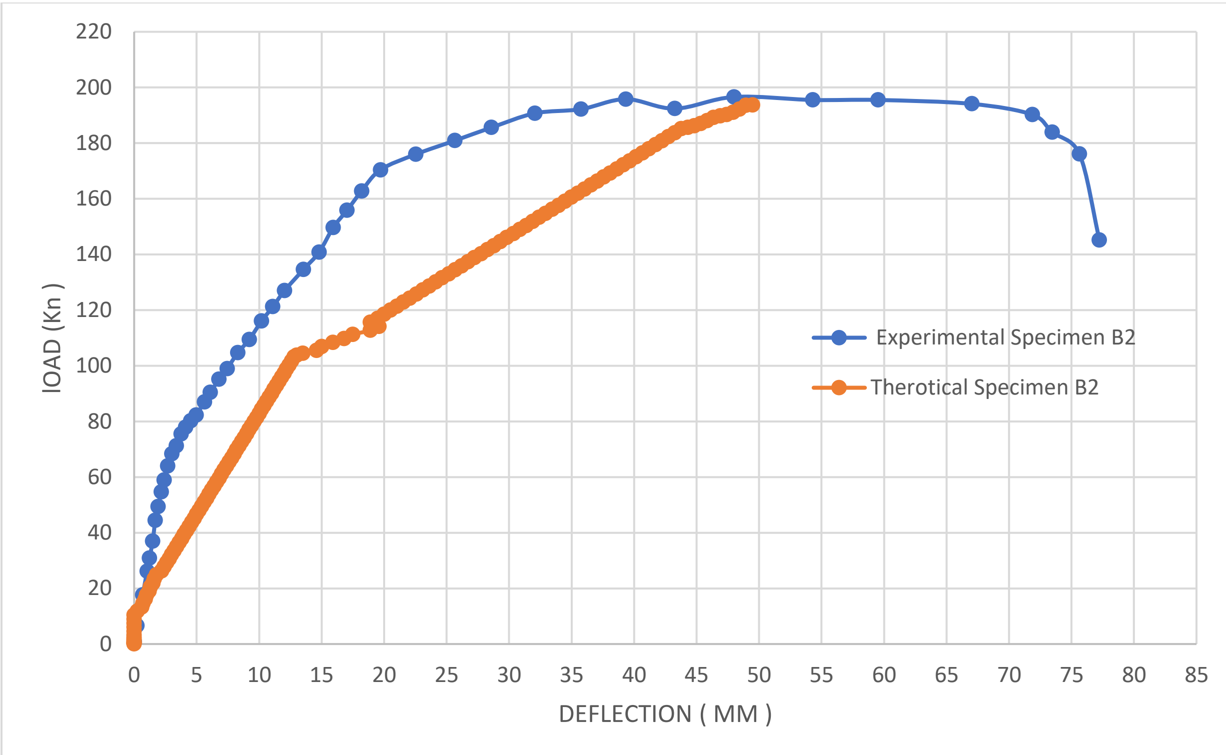


Figure 11: Comparsion between Theoretical & expermintal load-deflection curves of Tested beam

The effect of Presence of Opening on the Beam was studied on load deflection curve for specimens (B1 & B2) that are identical in compressive strength 40 MPa.
From Fig (11) it can be seen that the failure load was equal to 190.7 kN and 196.6 kN for B1 and B2 respectively. The failure load was increased by 3.09% at Presence of an Opening (100 * 100) mm At The Center of The Beam (B2) . compared to beam without any Opening. Also it was found that the deflection was equal to 55.006 mm and 48.009 mm for B1 and B2 respectively. The deflection decreased by 12.72 % at Presence of an Opening (100 * 100) mm At The Center of The Beam , it can be said that the Opening At The beams are Same ductile with beams without Opening But More Deflection Than Beams Witho utOpening. The reason may be due to effects of Opening At The Beam Make it decrease AT Deflection Due to Its Weakness in The Max. Moment.
From Fig (11) it was found Comparison Between B1 & B2 . in The Presence of Opening At The Beam the cracks width generally increase. And also, the number of cracks was increased .The failure mode for prestressed tested specimens not changed.

4-5 Study the paramters by theoretical Nonlinear model

Theoretical modifications were made to the control beam and virtual openings were made of their sizes a (30 * 10) mm & (40 * 10) mm & (50 * 10) mm , and they were modeled with the Ansys program as shown in the figure (12)
Some beams were also studied expermintally and theoretically, as the B3 beam, in which the dimensions of the Opening Dimensions 200 * 100 mm, as shown in the results

Figure (13) Also, on the study of changing the cross section of the tested beam from a rectangle to T- section, the results were shown as shown in Figure 14.

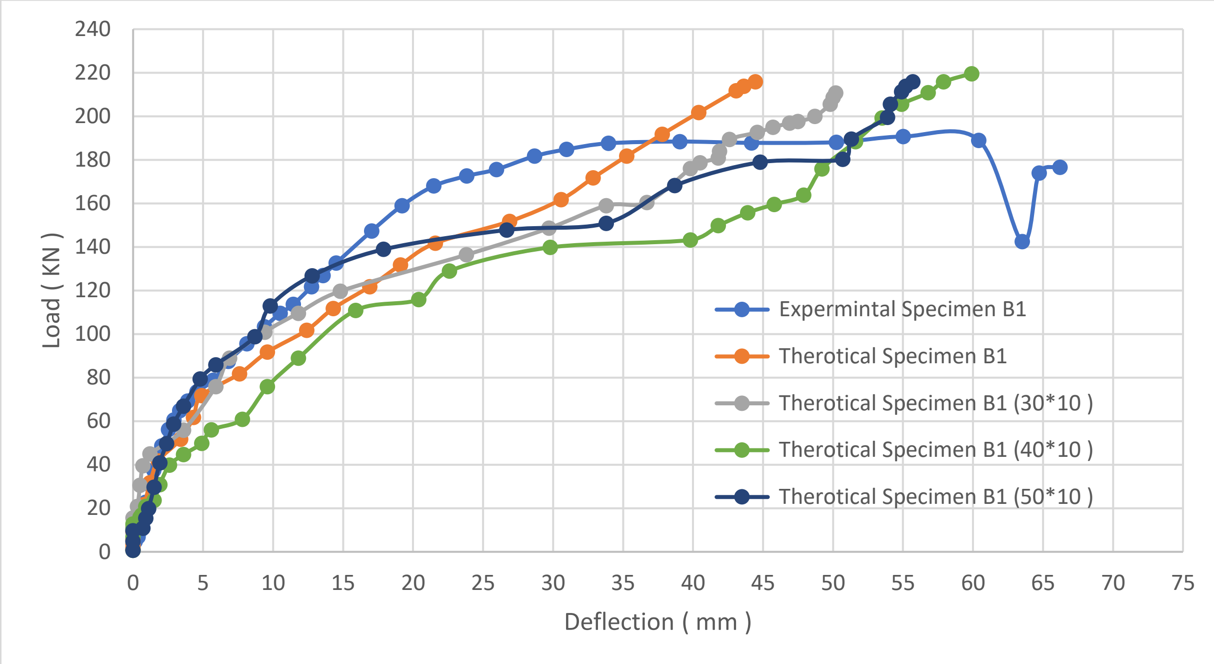


Figure (12): The Results of the virtual Beams

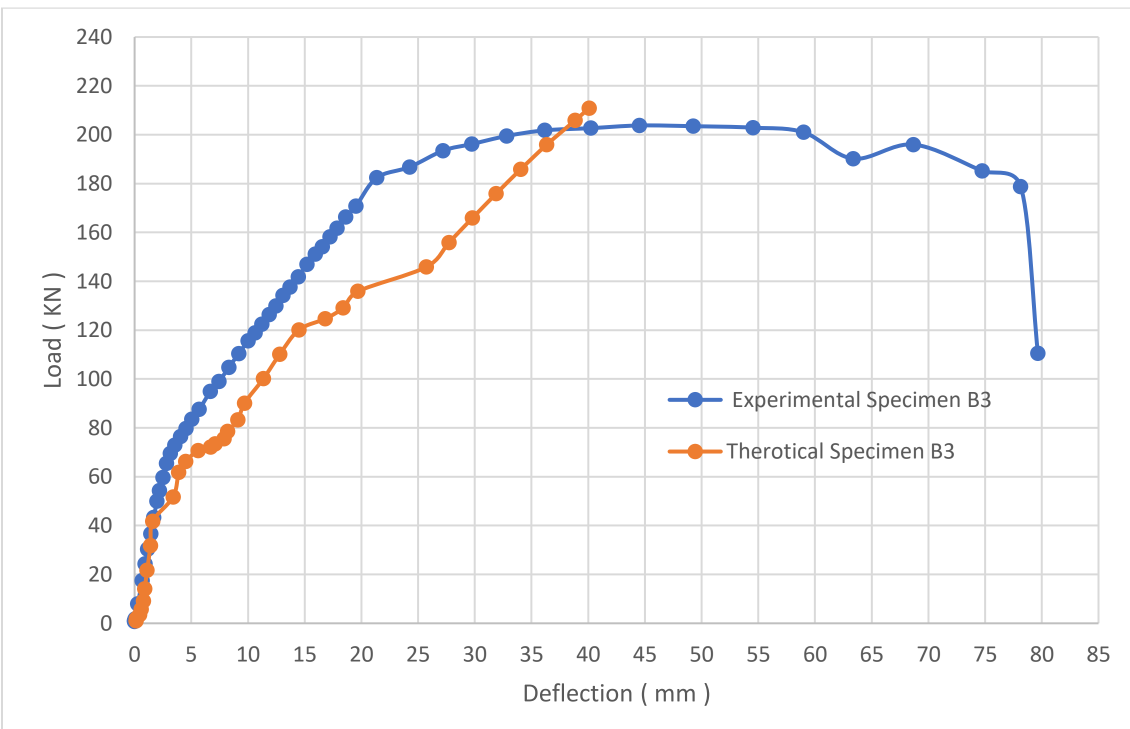


Figure (13): The Results of the Tested Beam (B3)

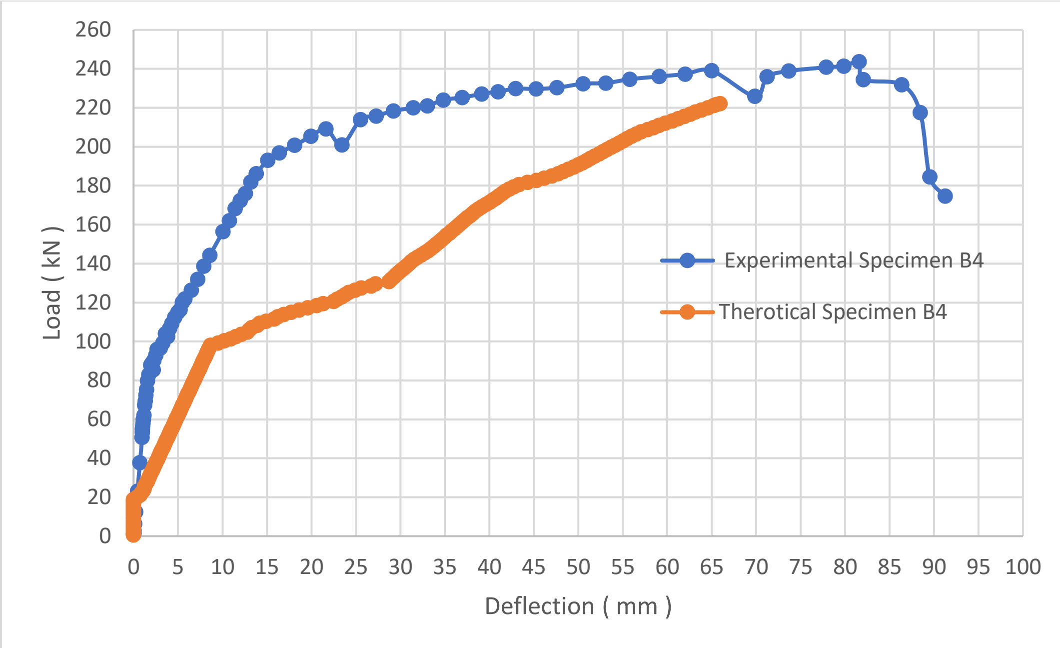


Figure (14): The Results of the Tested Beam (B4)

4-6 The Expermintal Results of the tested Beam

Table (2) presents the Test Results of Beams

Table (2): Test Results of Beams

Beam no.	**Crack load P_{cr} (KN)**	**Maximum load P_{max} (KN)**	**Max. Defl. Δ_a (mm)**	**Failure type**
B1 (R W)	78.8	190.7	55.006	Flexural
B2 (R O 100 B)	87	196.6	48.009	Flexural
B3 (R O 200 B)	76.5	203.8	44.532	Flexural
B4 (T O 100 B)	90.4	243.6	81.583	Flexural
B5 (R O 100 A)	74.4	198.3	45.555	Flexural
B6 (R O 200 A)	63.9	203.3	50.386	Flexural

5- CONCLUSION

From experimental and theoretical results, the following conclusions can be drawn:

1. **Effect of Presence The Opening** it can be said that the Opening At The beams are Same ductile with beams without Opening But More Deflection Than Beams Without Opening. the deflection was equal to 55.006 mm and 48.009 mm for B1 and B2 respectively. The deflection decreased by 12.72 % . The reason may be due to effects of Opening At The Beam Make it decrease AT Deflection Due to Its Weakness in The Max. Moment.
2. **Effect of The Opening Dimensions** it can be said that the The Larger of Opening Dimensions At The beams are More ductile Than beams Which its Dimensions are Smaller Than it. and Less Deflection Than Beams When The Opening are Larger Than others. the deflection was equal to 48.009 mm and 44.532 mm for B2 and B3 respectively. The deflection decreased by 7.24 % at Presence of an Opening (200 * 100) .The reason may be due to effects of Opening At The Beam Make it decrease AT Deflection Due to Its Weakness in The Max. Moment .
3. **Effect of The Cross-Section of the Specimen**. it can be said that the Change of Cross Section of the Beam with T- Section are More ductile Than beams Which its Section is Rectangular and More Deflection Than Rec. Section Beams . the deflection was equal to 48.009 mm and 81.583 mm for B2 and B4 respectively. The deflection increased by 69.932 % at The Beam Which has T- Cross Section The reason may be due to effects of Large Section At The Beam Make it increase AT Deflection Due to Its Increasing its Volume & Weight & Steel Weight. . That's Mean The Larger of Section Dimensions The More Deflection it will be.

6-REFERANCE

1- M.A. Mansur, Tan, S.L. Lee Collapse loads of RC beams with large openings ASCE J Struct Eng., 110 (11) (1984), PP. 2602-2610

2- Amiri, S., R. 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 Science, 5(5), 2011, 617-624.

3- Hanson, J.M., Square openings in webs of continuous joists, Portland Cement Association, 1969,pp: 1-14.

4- Somes, N.F. and W.G. Corley, Circular openings webs of continuous beams, American Concrete Institute, Detroit, MI, 1974, pp: 359-398.

5- Salam, S.A., Beams with openings under different stress conditions, Conference on Our World in Concrete and Structures, Singapore, 25-26 Ague, 1977, pp.: 259-267.

6- Siao, W.B. and S.F. Yap, Ultimate behavior of unstrengthen large openings made in existing concrete beams, Journal of the Institution of Engineers, 30(3), 1990, 51-57.

7- Abdulla, H.A., A.M. Torkeya, H.A, Haggagb and A.F. Abu-Amira, Design against cracking at openings in reinforced concrete beams strengthened with Composite Structures, 60, 2003, 196-204.

8- Mansur, M. A., "Ultimate Strength Design of Beams With Large Open ings," International Journal of Struc tures, V. 8, No. 2, 1988, PP. 107-125.

9- Mansur, M. A., Tan, K. H., Lee,Y. F., and Lee, S. L., “Piecewise Linear Behavior of RC Beams With Openings,” Journal of the Structural Division, American Society of Civil Engineers, V. 117, No. 6, 1991,pp. 1607-1621.
10- Barney, G. B., Corley, W. G., Hanson,J. M., and Parmelee, R. A., “Behavior and Design of Prestressed Concrete Beams With Large Web Openings,” PCI JOURNAL, V. 22, No.6, December 1977, pp. 32-6 1.
11- Dinakaran, V., and Sastry, M. K., “Behavior of Post-Tensioned Prestressed Concrete T-Beams With Large Web Openings,” Indian Concrete Journal,V. 58, No. 2, February 1984, pp. 34-38.
12- Kennedy, J. B., and Abdalla, H. A.,“Static Response of Prestressed Girders With Openings,” Journal of the Structural Division, American Society of Civil Engineers, V. 118, No. 2, February 1992, pp. 488-504.
13- Kennedy, J. B., and El-Laithy, A., “Cracking at Openings in Prestressed Beams at Transfer,” Journal of the Structural Division, American Society of Civil Engineers, V. 108, No. 6, 1982, pp. 1250-1265.
14- Hibbitt, H. D., Karisson, B. I., and Sorensen, E. P., ABAQUS Version 4-8, Finite Element Program, Hibbitt, Karisson & Sorensen, Inc., Provi dence, RI, 1989.
15- ACI Committee 318, “Building Code Requirements for Reinforced Concrete (ACI 318 89),” American Concrete Institute, Detroit, MI, 1989.
16- Lin, T. Y., and Burns, N. D., Design of Prestressed Concrete Structures, John Wiley & Sons, Inc, New York,NY, 1981.
17- Abdalla, H. A., and Kennedy, J. B., “Design of Prestressed Concrete Beams With Openings,” Journal of the Structural Division, American So ciety of Civil Engineers, V. 121, No. 5, May 1995, pp. 890-898.
18- Kennedy, J. B., Chami, S., and Grace, N. F., “Dynamic and Fatigue Responses of Prestressed Concrete Girders With Openings,” Canadian Journal of Civil Engineering, V. 17, No. 3,1990, pp. 460-470.
19- Abdalla, H. A., “Static and Dynamic Responses of Prestressed Concrete Beams With Openings,” Doctoral Thesis presented at University of Windsor at Windsor, Ontario, Canada, 1993.
20- El-Laithy, A., “Influence of Openingson the Behavior of Rectangular Post-Tensioned Prestressed Concrete Beams,” MS Thesis presented at University of Windsor at Windsor, On tario, Canada, 1978.
21- Collins, M. P., and Mitchell, D., Prestressed Concrete Structures, Prentice Hall, Englewood Cliffs, New Jersey,1991.
22- Metric Design Manual: Precast and Prestressed Concrete, Canadian Prestressed Concrete Institute, Ottawa,Canada, 1992.
23- Abdalla, H. A., and Kennedy, J. B.,“Dynamic Analysis of Prestressed Concrete Beams With Openings,” Journal of the Structural Division, American Society of Civil Engineers, V. 121,No. 7, July 1995, pp. 1058-1068.
24- Ahmed M. El-Basiouny, Hamed S. Askar, Mohamad E. El-Zoughiby, Experimental and numerical study on the performance of externally prestressed reinforced high strength concrete beams with openings, 2021, Mansoura University, Mansoura, Egypt.
25- Hamdy shehabeldin, Mohamed Husain, Hatem Gheith, Salah Abdel-Megeed, and Emadeldin Zaki., Behavior of Prestressed Concrete Beams with Openings in Shear Region, 2017, Faculty of Engineering, Zagazig University

26- Jia-Bin Ye| Jian Cai | Zhi-Liang Zuo | Qing-Jun Chen |Xu-Lin Tang | Xiaoqin Zhao, Numerical investigation on the shear behavior of prestressed concrete beams with small rectangular openings, 2020.
27- George B. Barney, John M. Hanson, Hatem Gheith, W. Gene Corley, and Richard A. Parmelee., Behavior and Design of Prestressed Concrete Beams With Large Web Openings,1977.