



EXPERIMENTAL AND THEORETICAL EVALUATION FOR EFFECT OF OPENINGS LOCATION ON SHEAR STRENGTH OF RC BEAMS

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Abstract: This paper discusses the structural behavior of reinforced concrete rectangular beams which have transverse opening in the web under the effect of single point loading. The location of the openings is the major variable adopted in this paper, while, the other variables are kept constant for all tested specimens. The experimental part includes poured and test of four (100x150x750mm) beam specimens with different locations openings. The experimental results indicated that the ultimate strengths are decreased (12%), (22%) and (41%) for beams containing opening at distance (L/2), (L/3) and (L/6) from the edge respectively. Also, the change in openings locations from center toward the edge lead to decrease the carrying capacity for about (29%). In order to study more thoroughly the performance of tested beams, a nonlinear analysis using ANSYS (Version-11) finite element program is used. The analytical results indicated that the load-deflection response, ultimate loads, and crack pattern are in good agreement with the experimental results.

Keywords: *Opening, Shear Strength, Reinforced Concrete Beam, Finite element, ANSYS*

تقييم عملي و نظري لتاثير موقع الفتحات على مقاومة القص للعتبات الخرسانية المسلحة

الخلاصة: يناقش هذا البحث السلوك الإنشائي للعتبات الخرسانية المسلحة المستطيلة التي تحوي على فتحات بالاتجاه العرضي للوترة تحت تأثير حمل مركز. ان المتغير الرئيسي المعتمد في هذا البحث هو موقع الفتحات، بينما تم الإبقاء على المتغيرات الأخرى ثابتة لكل العتبات المفحوصة. تضمن الجزء المختبري صب وفحص أربعة عتبات خرسانية مسلحة بأبعاد (100x150x750ملم) تحوي على فتحات بمواقع مختلفة. اشارت النتائج المختبرية الى أن المقاومة القصوى انخفضت بمقدار (12%)، (22%) و (41%) للعتبات الحاوية على فتحات تبعد مسافة (L/2) و (L/3) و (L/6) من الحافة على التوالي. ان تغيير مواقع الفتحات من المركز نحو الحافة ادى إلى انخفاض التحمل الأقصى بحدود (29%). لدراسة النماذج المفحوصة بشموليه أكثر، استخدم التحليل اللاخطي باستخدام برنامج العناصر المحددة (ANSYS) الإصدار-11. اشارت النتائج التحليلية أن استجابة الانحراف-الحمل، الحمل الأقصى، وشكل الشق في توافق جيد مع النتائج المختبرية.

1. Introduction

Sometimes, in building construction, utility ducts and pipes are accommodated in the space above the false ceiling. Passing these ducts through openings in the floor beams eliminates a significant amount of dead space and results in a more compact economical design, however, the effect of openings on the strength and behavior of the beams must be considered, Fig. 1. Including transverse openings in the web of a reinforced concrete beams reduced stiffness, and alters the simple beam behavior to a more complex one. Therefore, while providing a large opening, the effects on ultimate and service load behaviors of the

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beam must be properly accounted for in design. Passing these ducts through vertical (or transverse) openings in the floor beams leads to a reduction in the dead space and results in a more compact design multiplied by the number of stories can represent a substantial saving in total height, length of air-conditioning and electrical ducts, plumbing risers, walls and partition surfaces, and overall load on the foundation. The reduced stiffness of the beam may also give rise to excessive deflection under service load and result in a considerable redistribution of internal forces and moments in a continuous beam unless special reinforcement is provided in sufficient quantity with proper detailing, the strength and serviceability of such a beam may be seriously affected.



Figure1. Industrial Building (Openings through Stem of Beam)

Since the strength of concrete in tension is considerably lower than its strength in compression, design for shear becomes of major importance in all types of concrete structures. Generally, shear mode of failures are divided into four categories of failure and depends mainly on shear span to effective depth ratio [1]. The possible modes of failure are shear-tension failure; shear-compression failure; flexural failure; and arch-rib failure. Several researches are interest in transverse openings (web openings) in the rectangular floor beams under the effect of flexural or torsion loads [2, 3]. Shear behavior of reinforced concrete T-Beams contains vertical opening (Flange openings), also studied [4].

This paper discusses the structural behavior of reinforced concrete beam which have transverse opening in the web and subjected to shear.

2. Experimental Study

2.1. Experimental Program

Tests were carried out on four rectangular shaped beams, simply supported under the effect of single point loading. All beam specimens were reinforced with tension (flexural) bars at bottom. To eliminate the shear resisting contribution of stirrups and to ensure the specimens to fail in shear mode of failure, the tested beams were made without shear reinforcement (stirrups). The location of opening was the major variable in this research. The span, cross-section, concrete strength and reinforcement were kept constant for all tested specimens. To evaluate the compressive strength of concrete, the experimental program consists, also, cast and test of a series of control specimens (cubes).

2.2. Beam Specimens Details

The nominal dimensions of tested beams are shown in Fig. 2. The overall length was (750 mm), while, the overall depth and width are (150mm) and (100 mm) respectively. All beam specimens were reinforced with (3 ϕ 10 mm) tension (flexural) bars at bottom (with clear cover of 20mm) without shear reinforcement.

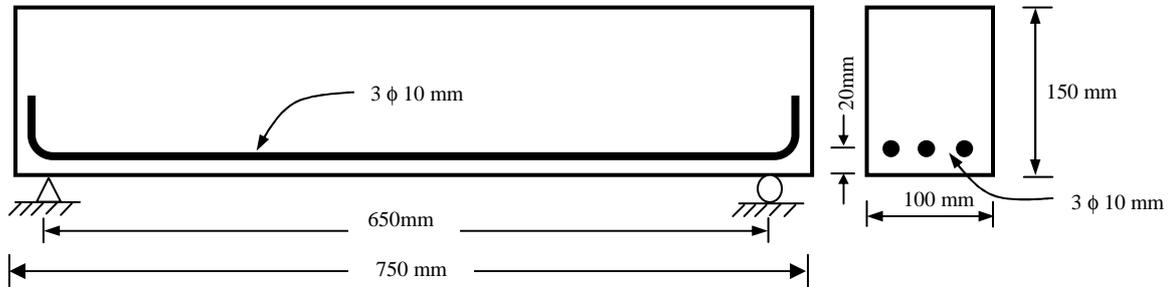


Figure 2. Dimensions of Tested Beams

The first beam specimen is poured without any opening, and the others are poured with circular opening (50mm) diameter at different locations (Mid-span, L/3 and L/6). Table 1. shows the details of tested beams, the locations of openings are shown in Fig. 3.

Table1. Beams Designation and Details

Beam Designation	Dimensions (mm)			Reinforcement	Opening Location**
	b_w	h	l		
(SB-1)*	100	150	750	3 ϕ 10 mm	Without opening
SB-2					L/2
SB-3					L/3
SB-4					L/6

*Reference Beam

**Measured from Support

** Diameter of Opening is (50mm)

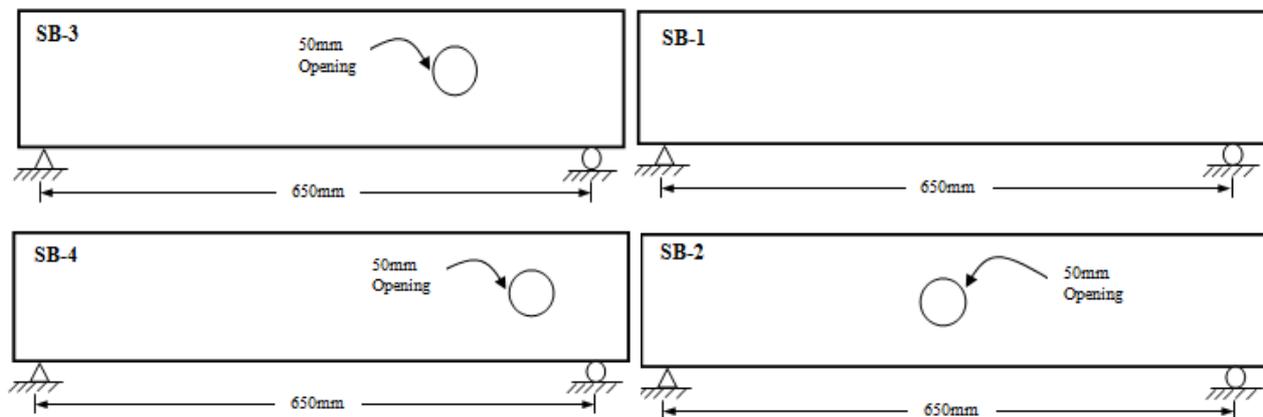


Figure3. Location of Openings

2.3. Materials

In manufacturing the beam and control specimens, local construction materials are used (except steel bars); properties and description of used materials are reported and presented in Table 2.

Table 2. Description of Construction Materials

Material	Descriptions
Cement*	Ordinary Portland Cement (Type I)
Sand**	Natural sand from Al-Ukhaider region with maximum size of (4.75mm)
Gravel**	Crushed gravel with maximum size of (20mm)
Reinforcing Bars	(ϕ 10 mm) deformed steel bars, having (410 MPa) yield strength (f_y)***
Water	Clean tap water (Used for Both Mixing and Curing)

* Conform with Iraqi specification No. 45/1989[5]. ** Conform with Iraqi specification No. 45/1984[6].

*** Average of three specimens (Each 400 mm length)

2.4. Concrete Mix design

One concrete mix was used in this work; the concrete mix proportions are reported and presented in Table 3. It was found that the used mix produces good workability and uniform mixing of concrete without segregation.

Table 3. Proportions of Concrete Mix

Parameter	Quantity
Water/cement ratio	0.40
Water (Liter)	168
Cement (kg/m^3)	420
Fine Aggregate (kg/m^3)	600
Coarse Aggregate (kg/m^3)	1200

2.5. Molds

Two wooden molds, (100x150x750) mm dimensions, were used to poured beam specimens. The molds were manufactured with (18mm) thick plywood base and two movable sides. The sides were fixed to the base by screws. When the mixing process was completed, the beam and control specimens were then cast in three layers and compacted by a table vibrator (external vibrator) to shake the mix and consolidate it into the molds. The surface of the concrete (top face of control specimen and side face of beam specimens) was leveled off and finished with a trowel, Fig. 4. Then, the specimens were covered with a nylon sheet to prevent evaporation of water. It may be noted that, to ensure that it would be easy to remove the samples when the concrete hardened, the inner faces of the molds was oiled.



Figure 4. Poured of Beam Specimens

2.6. Test Measurements and Instrumentation

Hydraulic universal testing machine (MFL system) was used to test the beams specimens as well as control specimens. Central deflection has been measured by means of (0.01mm) accuracy dial gauge (ELE type) and (30mm) capacity. The dial gauges were placed underneath the bottom face of each span at mid. Beam profile and loading arrangement are shown in Fig. 5.

2.7. Concrete Mixing and Placing (Pouring)

2.7.1. Concrete Mixer and Vibrating Table

The concrete was mixed by using a horizontal rotary mixer with (0.19 m³) capacity. While, vibrating table are used to vibrate the beam specimens as well as control specimens. The vibrating table consists of (1.0x1.5m) table made of (10mm) thick steel plate. The source of vibration was a rapidly rotating eccentric weight which makes the table vibrates with a simple harmonic motion.

2.7.2. Curing and Age of Testing

After (24) hours, the beam specimens and control specimens were stripped from the molds and cured (kept) in water bath for (28) days with almost constant laboratory temperature. Before (24) hours from the date of testing, they were taken out of the water bath and tested in accordance with the standard specifications.

2.8. Test Results of Control Specimens

Test results of mechanical properties of control specimens (compressive strength) are summarized in Table 4. Compressive strength for cubes (f_{cu}) was carried out on concrete in accordance with BSI 881-116 [7] with standard cubes (150x150x150 mm). The cubes were loaded uniaxially by the universal compressive machine up to failure.

Table 4. Mechanical Properties of Concrete

Property (MPa)	Value (MPa)
Cube compressive strength (f_{cu}) *	30
Cylinder compressive strength (f_c') **	25.5

*Average of six samples. ** $f_c' = 0.82f_{cu}$

2.9. Test Procedure

All beam specimens were tested using universal testing machine (MFL system) with monotonic loading to ultimate states. The tested beams were simply supported over an effective span of (650mm) and loaded with a single-point load; Fig. 5 shows the setup of beam specimens. The beams have been tested at ages of (28) days. The beam specimens were placed on the testing machine and adjusted so that the centerline, supports, point load and dial gauge were in their correct or best locations. Loading was applied slowly in successive increments. At the end of each load increment, observations and measurements were recorded for the mid-span deflection and crack development and propagation on the beam surface. When the beams reached advanced stage of loading, smaller increments were applied until failure. They fail abruptly without warning (sudden failure) and the diagonal cracks that develop becomes wider and as a result, the load indicator stopped recording anymore and the deflections increased very fast without any increase in applied load. The developments of cracks (crack pattern) were marked with a pencil at each load increment.

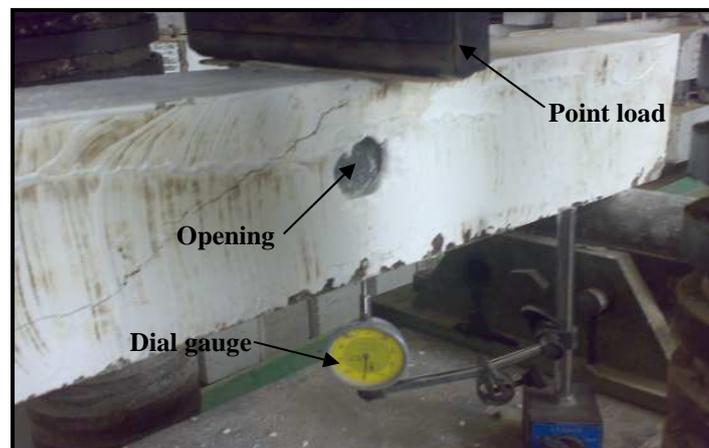


Figure (5) Beam Specimen Setup

3. Numerical Study

In order to study more thoroughly the performance of tested beams, ANSYS (Version-11) [8] finite element program is used to analyze two selected beam specimens, (SB-1) and (SB-3). A nonlinear three dimensional brick element (SOLID-65) in ANSYS is used to model the concrete. The solid element has eight nodes with three degrees of freedom at each node, translations in the nodal x, y and z-directions. The element is capable of plastic deformation and cracking in three orthogonal directions. A discrete axial element (LINK-8 in ANSYS) is

used to model the steel reinforcement. Two nodes are required for this element; at each node, three degrees of freedom exist identical to those for the brick element. To avoid stress concentration, (10x50x100mm) steel plate, modeled by using (SOLID-45 in ANSYS), is added at the load locations. The element has eight nodes with three degrees of freedom at each node, translations in the nodal x, y and z-directions.

3.1. Materials Properties

3.1.1. Concrete

For the finite element models, compressive uniaxial stress-strain relationship for concrete is described by a multilinear isotropic stress-strain curve. The failure surface is defined by a total of five strength parameters, but it can also be specified by a minimum of two constants (f_t and f_c') with the other three referred as given by Willam and Warnke criterion [9]. The shear transfer coefficient (β_o) for open cracks and (β_c) for closed cracks, representing conditions of the crack face and determining the amount of shear transferred across the cracks, are used in many studies ranging from (0.0) to (1.0). In this study, (β_o) is assumed to be (0.2) and (β_c) (0.25). In tension, the stress-strain curve for concrete is assumed to be linearly elastic up to the ultimate tensile strength. The tension stiffening of concrete after cracking is represented by providing a linearly descending branch. Smear cracking approach is utilized to model the cracking of concrete. For finite element analysis, Poisson's ratio for concrete is assumed to be (0.2). The adopted empirical equation of ACI-318[10] Committee is used to determine the modulus of elasticity and tensile strength of concrete in the modeling of finite elements, as shown in Table 5.

Table (5) Modulus of Elasticity and Tensile Strength Adopted in FEA

Concrete Type	Empirical Equation	f_c' (MPa)	Value (MPa)
NSC	$E_c = 4700\sqrt{f_c'}$	25.5	$E_c = 23734$
	$f_t = 0.62(f_c')^{0.5}$		$f_t = 3.53$

3.1.2. Steel Reinforcement and Steel Plates

The uniaxial stress-strain relation for steel is idealized as a bilinear curve with Von-Mises yield criterion, representing the elastic-plastic behavior with strain hardening. This relation is assumed to be identical in tension and compression as shown in Fig. 6. In the present work, the strain hardening modulus (E_T) is assumed to be (0.03 E_s). This value is selected to avoid convergence problems during iteration. The steel plates are assumed to be linear elastic materials. An elastic modulus equal to (200GPa) and Poisson's ratio of (0.3) are used for the plates and the steel reinforcement

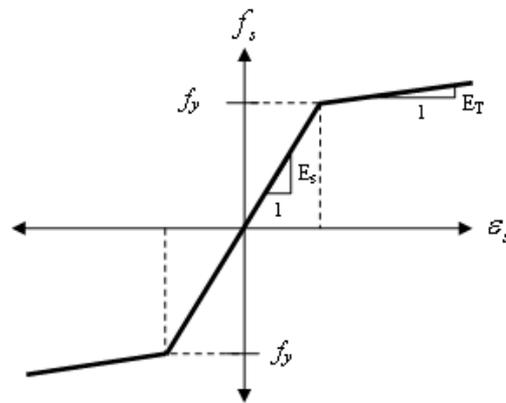


Figure 6. Modeling of Reinforcing Bars

3.2. Finite Element Modeling

The actual dimensions of the tested beams are shown in Fig. 2. Due to simple geometry of the tested beams, and due to vary locations of openings, entire model of beam is used for the finite element modeling, Fig. 7

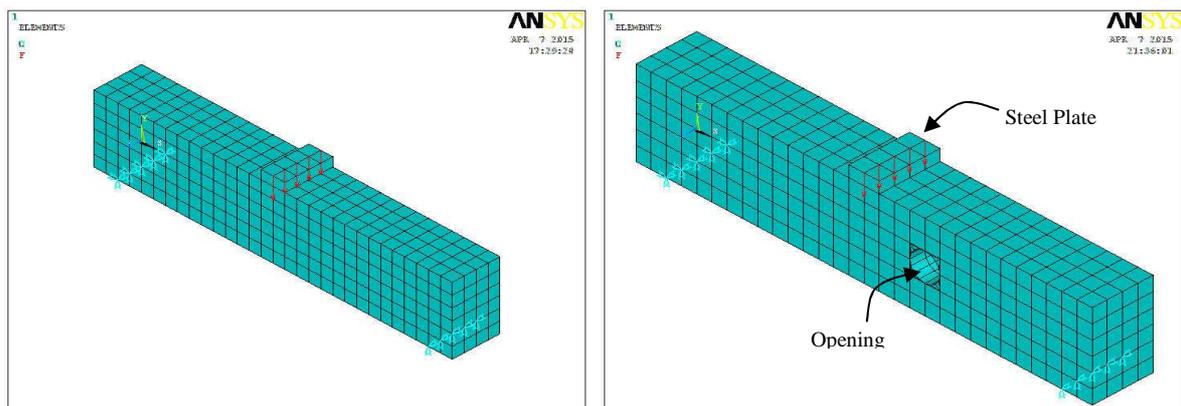


Figure 7. Mesh of the Concrete and Steel Plate

It may be noted that, the origin point of coordinates lie in one corners and only one loading plate are provided at the top of stub (column) to prevent load concentration. As an initial step, the beams, plates and supports are modeled as areas, then volumes (solid elements).

3.2.1. Finite Element Meshing

After creating of volumes, a finite element analysis requires meshing of the model. In other words, the model is divided into a number of small elements, and after loading, the stresses and strains are calculated at integration points of these small elements. To obtain good results, the mesh is set up such that square (or rectangular) elements are created, Fig. 7. In the early attempt (before spreading the load by using steel plates) and due to load concentration on concrete elements, crushing of the concrete started to develop in elements

located directly under loads. Subsequently, adjacent concrete elements crushed within few load steps. As a result, the model showed a large displacement, the solution diverged and finally, the finite element model failed prematurely. Therefore, to prevent this premature failure phenomenon, steel plates are used under load.

3.2.2. Loads and Boundary Conditions

Displacement boundary conditions are needed to constrain the model for obtaining a unique solution. To ensure that the model acts the same way as the experimental beams, boundary conditions need to be applied at the support location. For each support, of beam, one support is to be modeled as a hinge and the other one is modeled as a rollers.

The external load was applied on a steel plate across the entire centerline of the steel plate; thus, the external applied load was represented by the equivalent nodal forces on the top nodes of the same place of plate. Since the steel plate had four divisions in transverse direction (Z-direction), the equivalent force at each node on the plate becomes $(P/5)$ of the actual applied force (assuming equally distributed of applied load).

The application of the loads up to failure was done incrementally as required by the Newton-Raphson procedure. Therefore, total applied load was divided into a series of load increments (load steps). Within each load step, maximum of (50) iterations were permitted. At certain stages in the analysis, load step size was varied from large (at points of linearity in the response) to small (when cracking and steel yielding occurred). In all cases, convergence was achieved before reaching the maximum (50) iteration.

Failure for each of the models is defined when the solution for a minimum load increment still does not converge (convergence fails). The program then gives a message specifying that the models have a significantly large deflection (rigid body motion).

4. Results and Discussion

4.1. Experimental Results

As mentioned before, the main objectives of this study are to examine or assess the shear behavior of reinforced concrete beams containing openings at different locations.

During the experimental work, ultimate loads, load versus deflection at mid-span for each beam were recorded. Photographs for the tested beams are taken to show the crack pattern and some other details. The recorded data, general behavior and test observations are reported as well as recognizing the effects of adopted parameters on the shear behavior.

4.1.1. General Behavior

Photographs of the tested beams are shown in Fig. 8 and test results are given in Table 6. All beams of this category were designed to fail in shear, which was characterized by sudden failure and diagonal wide cracks which extended from supports towards the load or openings locations.

The general behavior of the tested beams can be described as follows:

At early stages of loading, small vertical deflection initiated in the mid span of tested beams, with further loading, one diagonal crack extended upwards and became wider in shear

span. The crack propagated faster and reached the compression face (near applied load openings), where crushing of the concrete near the positions of applied loads had occurred due to high concentrated stresses under load and presence of weak locations in the beam (openings).

As expected, the main cracks (diagonal cracks) for all tested beams commenced at the shear span and all beams exhibited sudden failure. It may be noted that, at failure, some parts of tested beams were crushed and subjected to defragmentation, this may be due to high concentrated stresses and absence of vertical steel reinforcement to hold these parts in the transverse direction.

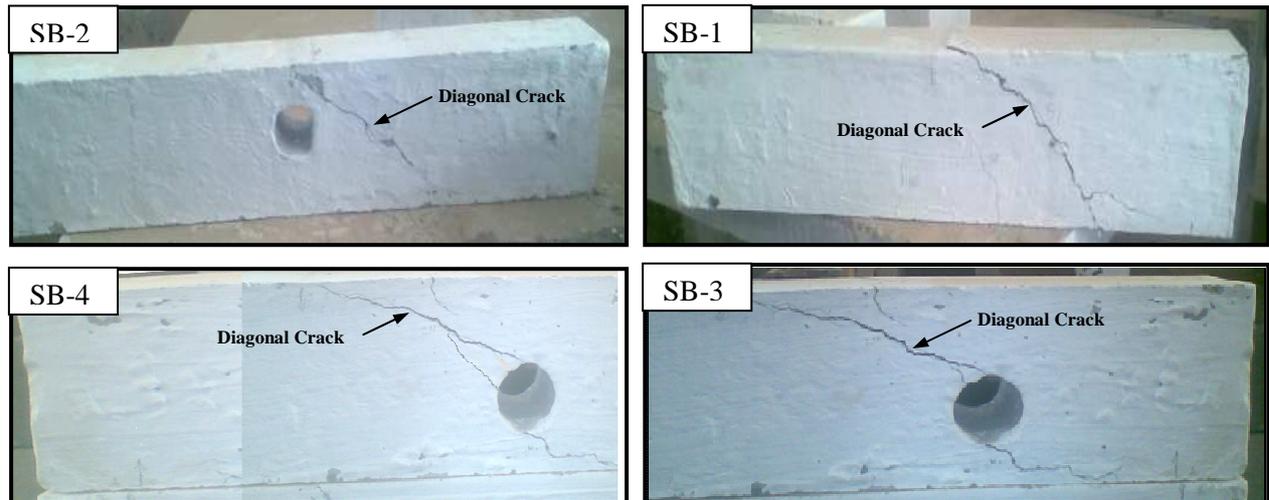


Figure .8 Crack Patterns Tested Beams

4.1.2. Mode of Failure

The appearance of the cracks reflects the failure mode for the tested beams. The experimental evidences show that the diagonal cracks extended horizontally along the tension reinforcement and eventually, the failure took place due to diagonal tension cracks were formed diagonally and moved up and towards the position of loading point, this mode of failure called “Shear-Tension” failure, as shown in Fig. 8.

4.1.3. Ultimate Shear Strength (V_u)

The recorded ultimate loads of the tested beams are presented in Table 6. As expected, test results show that the reference beam (SB-1) has the maximum ultimate strength in comparison with the rest beams. This may be due to absence of any leak (openings) in the web. As shown in Table 6, the ultimate shear strength decreased when the opening location moved toward of and close up to the edge (support). For the tested beam SB-4 (which have opening near the support), the ultimate shear strength decreased by (41%) this due to passing of the crack's direction through the circular opening. So when an opening faced it the crack grew larger and consequently the sudden failure occurred.

For the tested beam SB-2 (which have opening at the center), the ultimate shear strength decreased by (12%), the presence of opening didn't help the cracks to extend easily (the

direction of cracks is far away from the opening position) and as a results, the shear strength didn't decreased significantly.

Table6. Ultimate Shear Strength of Tested Beams

Beam Designation	Opening location	P_u (kN)	V_u (kN)**	$(V_u)_i/(V_u)_R$
(SB-1)*	Without Opening	41	20.5	1.0
SB-2	L/2	36	18	0.88
SB-3	L/3	32	16	0.78
SB-4	L/6	24	12	0.59

*Reference Beam ** $V_u = P_u/2$

4.1.4. Effect of Openings on Ultimate Strength

As shown in Table 6, presence of openings leads to decreases the stiffness of tested beams due to removed concrete parts, and this leads to decrease in carrying capacity. Due to abrupt changes in the sectional configuration, opening corners are subject to high stress concentration that may lead to reduction in stiffness of the tested beam and produced cracking and excessive deflection, Fig. 9.

As shown in Table 6, when the opening shifted from (L/2) to (L/3) (see SB-2 and SB-3), the ultimate shear strength decreased from (12%) to (22%). When the openings shifted towards the support (from (L/2) to (L/3)), rapid progressive of cracks were take place due to passing of openings directly within the path of diagonal cracks. The decreasing in ultimate load was (41%) for tested beam (SB-4) when shifted more toward the support. This means that the location of openings affected significantly on ultimate capacity of tested beams.

4.1.5. Deflections

Load-deflection curves of the tested beams at mid-span at all stages of loading up to failure are constructed and shown in Fig. 9. As shown, at the beginning, all curves were identical and the tested beams exhibited linear behavior and the initial change of slope of the load-deflection curves occurred between (5 kN to 15kN), which may be indicated the first crack loads. Beyond the first crack loading, each beam behaved in a certain manner.

Behavior of reference Beam (SB-1) exhibited greater loads and deflections in comparison with the other beams. This beam had the greatest stiffness due to absent of openings. Load-deflection curves for the tested beams (SB-2, SB-3 and SB-4) exhibits smooth increase in both applied loads and deflections. Presence of openings caused decreasing in the load carrying capacity beyond the first cracking and this was reflected on the corresponding deflections. For tested beams (SB-1 and SB-2), slight increase in ultimate deflection of beam (SB-2) was observed by comparing with (SB-1). This is may be due to presence of opening in the beam (SB-2) which leads to decreasing of beam stiffness and as a result, slight increases in deflection take place.

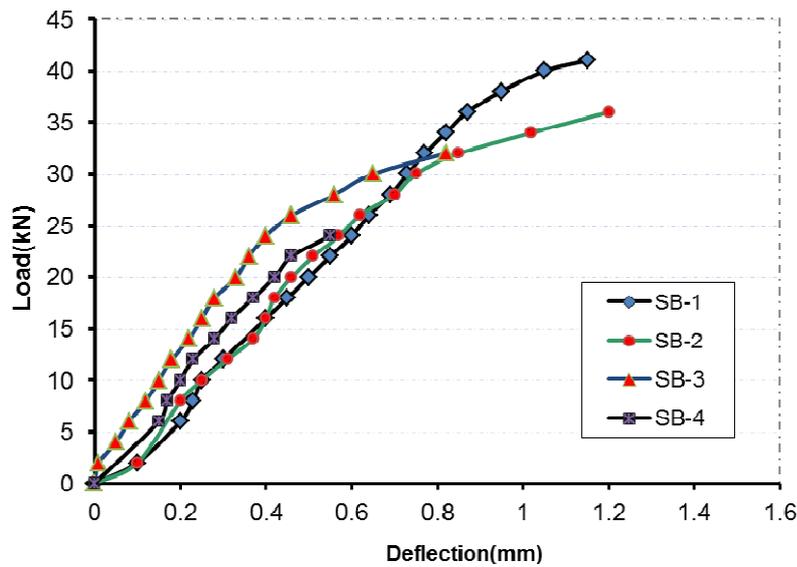


Figure 9. Load-Deflection Relationship of Tested Beams

4.2. Finite Element Results

4.2.1. Load-Deflection Curves

Deflections (Vertical displacements) are measured at mid-span at the center of the bottom face of the beams, in y-direction (U_y). Deflected shape of finite element beam model due to the vertical load is shown in Fig. 10. The load versus deflection curves obtained from the numerical study together with the experimental tests are presented and compared in Fig. 11 and Fig. 12, for tested beams (SB-1) and (SB-3) respectively. In general, it can be noted from the load-deflection curves that the finite element analyses agree well with the experimental results throughout the entire range of behavior. When comparing with the experimental values, all the numerical models show relatively large capacity at the ultimate stage.

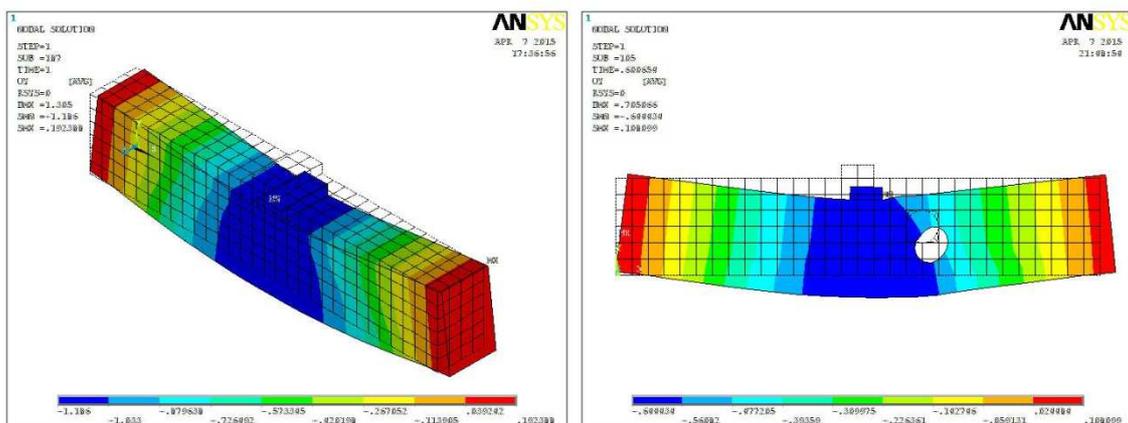


Figure 10. Deflected Shape of Beam Model

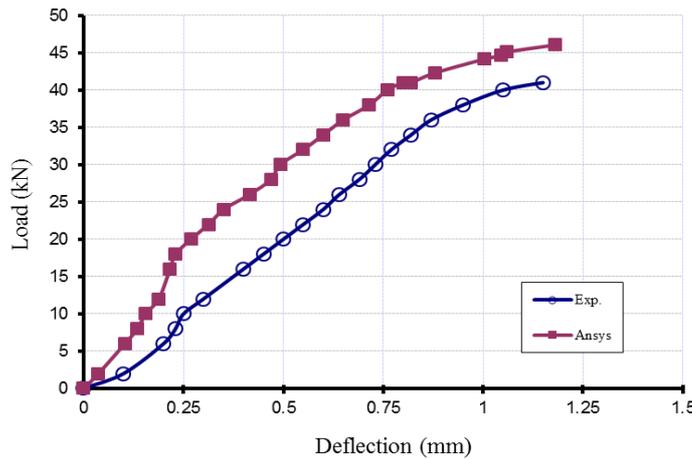


Figure 11. Load-Deflection Relationship for Beam (SB-1)

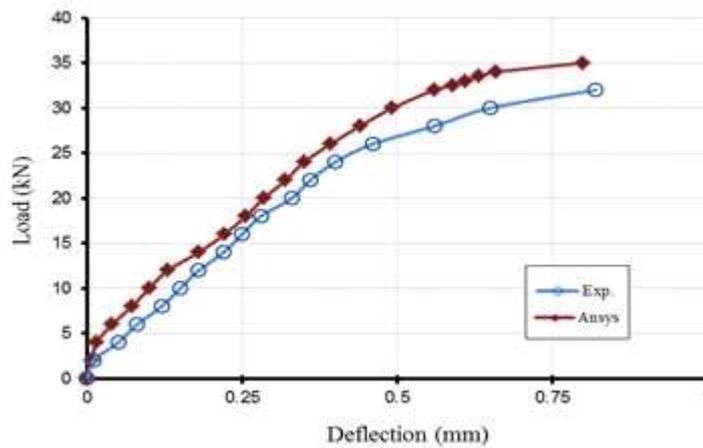


Figure 12. Load-Deflection Relationship for Beam (SB-3)

4.2.2. Ultimate Loads

Table 8 shows the comparison between the ultimate loads of the experimental (tested) beams, $(P_u)_{EXP.}$, and the final loads from the finite element models, $(P_u)_{FEM}$.

The final loads for the finite element models are the last applied load steps before the solution starts to diverge due to numerous cracks and large deflections. As shown in Table 8, the ultimate loads obtained from numerical model agree well with the corresponding values of the experimental (tested) beams.

Table 8. Comparison between Experimental and Finite Element Ultimate Loads

Beam Designation	Ultimate Load (kN)		$\frac{(P_u)_{FEM}}{(P_u)_{EXP.}}$
	$(P_u)_{EXP.}$	$(P_u)_{FEM}$	
B-1	41	46	1.12
B-3	32	35	1.09

4.2.3. Crack Patterns

The ANSYS program records the crack pattern at each applied load step (after first crack). Crack patterns obtained from the finite element analysis and the failure modes of the experimental beams agree well, as shown in Fig. 13. The appearance of the cracks reflects the failure mode for the beams. The finite element model accurately predicts that the beams fail in shear and predicts that the inclined cracks formed in the shear span regions. The cracks are concentrated under load region and vanish diagonally towards the opening then toward beam supports.

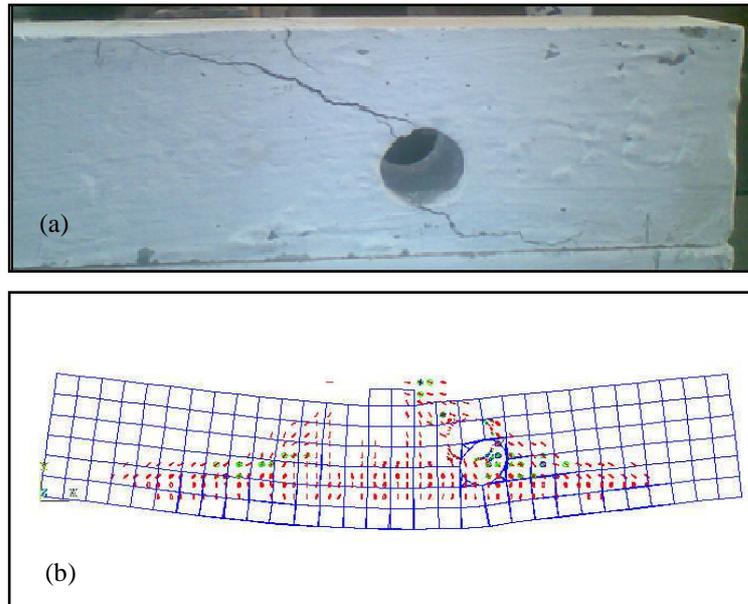


Figure 13. Crack Pattern, (a) Experimental Test, (b) FE model

5. Conclusions

Based on the results obtained from the experimental and theoretical work, the following conclusions are obtained:-

- 1- For tested beams with opening, the ultimate strengths were decreased (12%), (22%) and (41%) for beams containing opening at distance ($L/2$), ($L/3$) and ($L/6$) from the edge respectively. Also, the change in openings locations from the center toward the edge lead to decrease the carrying capacity for about (29%). Presence of openings lead to concentrated of stress around their hollow and caused decreasing in the load carrying capacity. As a result, when the location of web opening moved toward of edges (supports), the ultimate shear strength decreased.
- 2- In all tested beams, the crack path forced to passing through the weak locations (locations of openings). Therefore, in design, special details must be added at these locations.
- 3- Based on the finite element analysis by using ANSYS computer program (version 11.0), it can be concluded that the computational finite element models adopted in the current study are useful and adequate for analyzing tested beams. The finite element model used in the present work is able to simulate the behavior of all tested beams. The analytical tests carried out for all tested beams indicated that the load-deflection responses, ultimate loads behavior in concrete beams are in good agreement with the experimental results.

6. References

1. Wang. C. K. and Salmon, C. G.(1984). "*Reinforced Concrete Design*", 4th Edition, Harper International Edition, New York, USA, 947 pp.
2. Mansur, M.A.(2006). "*Design of Reinforced Concrete Beams with Web Openings*", Faculty of Civil Engineering, UniversitiTeknologi, 81310 UTM Skudai, Malaysia, (Proceeding of the 6th Asia-Pacific Structural Engineering and Construction Conference, Kuala Lumpur, Malaysia ,5-6 September, 2006).
3. Dainel H.R., and McMullen A.E. (1977)."*Torsion in Concrete Beams Containing an Opening*", Journal of the Structural Division, ASCE, Vol.103, No.ST3, PP. 607-617.
4. Aziz A. H. and Ajeel A.E. (2010). "*Effect of Existing Flange Openings and Cold Joints on Strength of RC T-beams*", Journal of Engineering, Baghdad University ,Vol. (16), No.(1), pp: 4535-4546,Baghdad.
5. Iraqi Specifications No. (5). (1984)."*Portland Cement*", the Iraqi Central Organization for Standardization and Quality Control, Baghdad-Iraq.
6. Iraqi Specifications No. (45). (1984). "*Aggregates from Natural Sources for Concrete and Building Construction*", the Iraqi Central Organization for Standardization and Quality Control, Baghdad-Iraq.
7. BS1881-116.(1983). "*Method for Determination of Compressive Strength of Concrete Cubes*", British Standards Institute, London.
8. "*ANSYS Manual*", Version (11.0).
9. Willam, K., and Warnke, E. (1975)."*Constitutive Model for the Triaxial Behavior of Concrete*", Proceedings, International Association for Bridge and Structural Engineering, Vol. (19), ISMES, pp. 174, Bergamo, Italy.
10. ACI Committee 318. (2008). "*Building Code Requirements for Structural Concrete (ACI 318-08 M) and commentary (318R-08)*", American Concrete Institute, Farmington Hills, MI, USA, 430pp.