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The Effect of Opening Size and Location on the Performance of Reinforced Concrete T-Beams under Pure Torque

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ABSTRACT

In modern buildings, transverse openings are often used in order to pass the pipes of health services, electrical cables or air conditioning ducts and other prepuce. The presence of these openings leads to a weakening of the beam so it must work to investigate the behavior of these beams in order to know how the presence of openings affects beam resistance. In this research, the behavior of reinforced concrete T-beams with circular openings exposed to pure torsional moment is studied. The experimental program involves testing of five beams with same dimensions and reinforcements. One of them is solid beam and used as reference for comparison with other beams with an opening and the other four T- beams containing circular openings of deferent dimension(100 and 150) and location(Lc/2 and Lc/3). Practical results show that the T-beam with circular openings of diameter (100mm) with different locations (Lc/2 and Lc/3), where Lc is the clear span of the beam, have an ultimate torsional capacity lower than that for solid beam by about (23% and 30%) respectively. The increase of the openings size causes a significant decrease in torsional capacity, where the beams with circular openings of diameter (150mm) with different locations (Lc/2 and Lc/3) have an ultimate torsional capacity lower than that for solid beam by about (56 % and 61%) respectively. Practical results show also that the presence of circular openings with diameter of 47% and 71% from the total depth increases the angle of twist significantly as compared with reference beam for the same applied torque level.

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تأثير حجم وموقع الفتحة على اداء العتبات الخرسانية المسلحة ذات المقطع T تحت عزم اللي الصافي

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الخلاصة

في المباني الحديثة ، غالبًا ما تستخدم الفتحات المستعرضة لتمرير أنابيب الخدمات الصحية والكابلات الكهربائية أو قنوات تكييف الهواء وغيرها من الاغراض. يؤدي وجود هذه الفتحات إلى إضعاف العتبات، لذلك يجب أن يتم العمل على دراسة سلوك هذه العتبات من أجل معرفة معرفه مدى تأثير وجود الفتحات على مقاومة العتبة. في هذا البحث ، تتم دراسة سلوك العتبات الخرسانية بشكل T ذات الفتحات الدائرية المعرضة لعزم الالتواء الصافي. يتضمن البرنامج التجريبي اختبار خمس عتبات ذات أبعاد وتسليح متساوي, واحده منها هي عتبة صلدة استخدمت كمرجع للمقارنة مع العتبات الحاوية على فتحات. العتبات الأربعة الأخرى هي عتبات حاوية على فتحات دائرية بأحجام ومواقع مختلفة. تشير النتائج العملية إلى أن العتبات الخرسانية المسلحة بشكل T الحاوية على فتحات دائرية ذات قطر (100 ملم) في مواقع مختلفة (Lc /2 و Lc /3) لها قابلية التواء قصوى منخفضة بحوالي (23٪ و 30٪) مقارنةً بقابلية التواء العتبة المرجعية. ان زيادة حجم الفتحات يسبب نقصان ملحوظ في قابلية الالتواء. حيث ان العتبة الحاوية على فتحة دائرية بقطر 150 ملم وبمواقع مختلفة (lc/2 و lc/3) اعطت قابلية التواء اقل بمقدار (56 % و 61 %) مقارنة بقابلية التواء العتبة المرجعية. تظهر النتائج العملية أيضًا وجود فتحات دائرية بقطر 47٪ و 71٪ من العمق الكلي تزيد من زاوية الالتواء بشكل كبير بالمقارنة مع العتبة المرجعية لنفس مستوى العزم المسلط.

الكلمات الدالة: فتحة دائرية, حجم الفتحة, موقع الفتحة, العتبات بشكل T , اللي .

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1. INTRODUCTION

The torque determination is one of the most important types of loads that must be taken into consideration when designing the concrete structure because the structural elements that are subjected to torsional moment have dangerous and uncontrolled failure and give no attention before failure.

The effect of torsional moment is quite significant in structures like L-beams, curved beams in plane, ring beams to support circular water tanks, curved balconies or other similar structures having curved boundaries.

In the past, the torsion was not taken into account when designing the concrete structures. It was found that, the torsion stresses were included in the factor of safety of designed members. After discovering the ultimate strength design method, torsion has been given a special importance. Torsion design standard first appeared in the ACI building code in 1971[1].

According to Somes and Corley [2], the circular opening may be considered small when its diameter less than 0.25 of the height of the web while, the opening may be considered large when the diameter more than 0.25 times the height of the web.

Nilesh and Patel [3] studied experimentally the effect of small circular openings on the shear and flexural ultimate strength of reinforced concrete beam. The main factors of the study are the opening size and opening location. The experiment work consists of five beams, the first beam is solid and used as reference for comparison with other beams with an opening, two beams have openings of 110mm (0.55D) and 90mm (0.45D) at L/8 distance from the support, the last two beams have openings as mentioned above at L/4 distance. The tested results showed that the increase of the opening diameter caused the increase in reduction of ultimate strength by 60.11% and 32.19% for beams with diameter of openings 110 and 90 mm respectively. For opening location at L/8 compared with solid beam. While for beams with opening at locations L/4 the reduction was 48.14% and 24.14% for 110 and 90 mm diameter of opening, respectively compared with the solid beam.

Oukaili and Al- Shammari [4] investigate the finite element analysis of reinforced concrete T-beams with multiple web openings under impact loading. The research includes three-dimensional finite element analysis using ANSYS 12.1 program for 12 beams with circular openings different in size and the position of opening from loading point. The result elucidates that the beams with circular opening with radian 22% of beam depth has less effect on the deflection of beam, the increase in the opening size to 35% and 57% of beam depth increases the deflection at center by 23% and 43% respectively. Besides, the results showed that when the opening go away for a distance equal or more than 1.5D from the loading point Do not give effect on the deflection of beam contain opening.

Abdulrahman and Rashid [5] present an experimental work conducted to study the behavior of the reinforced RPC T-beams with openings. The work includes testing of seven reinforced reactive powder concrete RPC T-beams, one beam is solid beam used as a reference and the other six beams, were beams with circular and square openings in different location from the support (Lc/2, Lc/3 and Lc/4).

The test results showed that the presence of openings in the beams web caused a reduction in the ultimate load carrying capacity by about (10-55)% depending on shape and location of opening, where beams with square and circular openings have average ultimate load carrying capacity lower by 36% and 29% respectively compared with the control beams. The results also showed that the presence of the openings in the shear region led to a decrease in ultimate load carrying capacity about 38% to 49% for opening of opening at (Lc/3 and Lc/4) respectively. While the presence of openings in the flexural region led to a decrease in the ultimate load carrying capacity rate of 11%.

Taha and Rasha [6] investigate the effect of web openings on the structural behavior of RC beams subjected to pure torsion by experimental and analytical studies. The experimental program includes seven RC beams under pure torsion with constant clear span 1800mm and constant beams width 150 mm. the main variables in the research are opening number, spacing between stirrups, and the depth of beams. One of them act as control beam and the other six beams divided into three groups ,the main variable of the first group is number of openings (one and two openings), for the second group is spacing between stirrups (100 and 167), and for third is beams depth(350 and 400).

The results obtained from the research showed that the increase of openings number or spacing between stirrups of the beams exposed to torsional moment decrease the ultimate torsional capacity .On the other hand, the result showed that the increase in the depth of beam increases the ultimate torsional capacity

2. BEAMS DETAILS

The tested beams were designed according to ACI318M-14 specification code, The dimensions of the tested beams were 1800 mm in overall length, thick of flange 60 mm, width of flange 350 mm, width of web 120 mm and 210 mm depth of web. Fig. 1 shows the details of the tested beams

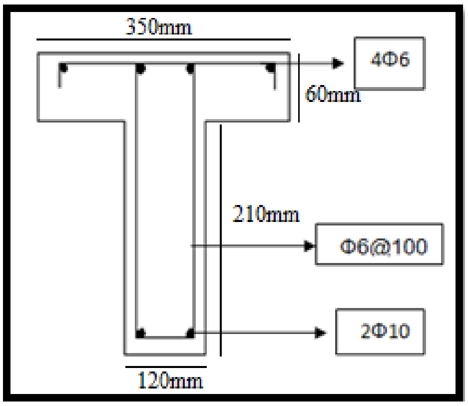

Fig. 1. Details of the beam

3. EXPERIMENTAL PROGRAM

The main objective of this research is to investigate the torsional behavior of reinforced concrete T-beams with circular openings. Five high performance reinforced concrete T-beams have been cast and tested under pure torsion. One of them is a solid beam used as reference beam and the other four beams are beams with circular openings with different size and location. Table 1 shows the Specimen Details.

The results adopted to determine the behavior of beams containing circular openings are the cracking torque, ultimate torque, angle of twist, strain in transverse reinforcement, toughness and stiffness of the beams.

Table 1
The specimen details

Beams designation	Opening details (mm)	Location (mm)
CON	Without	-------
BMS	100 mm	Lc/2
BTS	100 mm	Lc/3
BML	150 mm	Lc/2
BTL	150 mm	Lc/3

In order to make it easy to recognize the description of each beam, abbreviations of words have been used. So the letter “B” refer to the beam, and the second letter “M and T” will refer to the location of opening that is mid of clear span and one third of clear span measured from the support, respectively. While the third letter “S and L” will refer to opening size that is small (of a diameter of 100 mm) and large (of a diameter of 150 mm) opening, respectively.

4. CONSTITUENT OF THE CONCRETE MIX

Four trial mixes are done to choose the mixture used in casting concrete T-beams, The mixtures are casted into (100 * 200) mm cylinders and tested with a 7-day period. The materials proportions adopted in casting are listed in Table 2.

4.1 Cement

Ordinary Portland cement type (I) manufactured in Iraq is used .The physical and chemical properties of cement are conformed to the Iraqi Specification No.5/1984 [7]

4.2 Fine Aggregate

Natural sand (AL-Ukhaidher) is used for producing concrete mixture. The grading of this sand type is stratifying the Iraqi Specification No.45/1984 [8].

4.3 Coarse Aggregate

Crushed gravel is used in the concrete mixture. The maximum size of gravel is 10mm. The aggregate is washed, and then stored in a saturated dry surface condition before using. The coarse aggregate grading is identical to the requirements of Iraqi specification No. 45/1984

4.4 Water

Ordinary tap water was relied upon in casting and curing

4.5 Superplasticizer (S.P.)

A polycarboxylic ether based on (Gleniume-51) is used as high range water reducer to reduce water content in concrete mix and to improve the mechanic properties of the mixture. The properties of the super plasticizer are conform to the requirements of ASTM C494 [9]

Table 2
Properties of concrete mix

Cement kg/m3	Sand kg/m^3	Gravel kg/m^3	Water Kg/m^3	S.P L/m^3	w/c
600	664	996	168	4	0.28

5. CASTING PROCEDURE

Process of mixing and casting is done in several stages. Nine cylinders (150 * 300) mm, three cubic (150 * 150) mm and three prism (100 *100* 500)mm have been casted with the concrete beam. Mixing process is conducted by using rotary mixer (with 0.19 m^3 capacity). Fig 2 shows the casting process.

6. TEST SETUP

The device that has been approved for testing is located at Al- Mustansiriya University, Faculty of Engineering – structure Laboratory, but the device is designed to apply loads at different points along the specimen span and cannot apply loads outside the specimen level. That is, it cannot apply twisting moment, the supports are also fixed and cannot rotate to allow the specimen to twist. Therefore, it is necessary to convert the Universal device by adding two T-shaped steel frame with (12) mm steel plates that work to hold the edges of the beam completely as shown in Fig 3. Each frame is connected (in opposite direction) to a 500 mm steel arm that is vertical along beam span. The two ends of the steel arms are connected with a steel girder of 3000 mm long. So that the forces applied from the device are divided on both sides of the beam, this force is transmitted from both sides of the steel arm to the beam in the form of twisting moment in opposite directions. The supports also modified to rotate and allow the specimen to twist. The idea of this testing process was mentioned by Zararis and Penelis [10].

6.1 Angle of Twist and Reinforcement Strain Measurements

To measure angle of twist (rotation), the amount of vertical deflection in the flange due to the applied torsion is measured using 0.01 accuracy dial gages. Dial gages are fixed in the two ends of the beam. The deflection obtained from dial gage reading is divided on the horizontal distance to measure angle of twisting using the equation;

Angle of twist (θ) = tan-1(dial gauge reading /175)

Where 175mm represent the distance from center of cross section to the location of dial gauge

Two strain gauge has been fixed in each beam to measure the strain in the reinforcement. The type of strain gauge used in steel reinforcement is (KFH-20-120-C1-11L1M2R 120 20) and the type of the data logger is (TML/TC-32K).

Strain gauge has been fixed on the two sides of beam on the first stirrups adjacent to twisting arm at mid of tension zone of the stirrup.

Fig. 2. Casting procedure

(a) **(b)**

Fig. 3(a) and (b). Procedure of applying torque mentioned by Zararis and Penelis

7. TEST RESULTS AND DISCUSSION

7.1 Mechanical Properties of Hardened Concrete

Table 3
Mechanical properties of hardened concrete

Dry density of concrete kg/m^3	Cubic Compressive Strength "fcu" (MPa)	Cylinders Compressive Strength "fc'"(MPa)	Modulus of Rupture (MPa)	Splitting Tensile Strength (MPa)	Modulus of Elasticity(MPa)
2865	69	63	4.72	5.22	37731

7.2 Torsional Capacity and Angle of Twist

Torsional capacity and twisting angle measured in two stages: cracking torsional capacity and ultimate torsional capacity. Table 4 shows the percentage of decrease in cracking and ultimate torque.

Table 4
Results of cracking and ultimate torque

Beam Designation	Tcr (kN.m)	Percent of Decrease in Tcr (%)	Tu (kN.m)	Percent of Decrease in Tu (%)	Max. Angle of Twist (rad)
CON	15	----	29.75	----	0.03277
BMS	11.5	23	23	23	0.03228
BTS	8.75	42	20.75	30	0.0456
BML	6.25	55	13.25	56	0.0388
BTL	5	67	11.5	61	0.0584

T= (Pu/2)*Am
Where Am represent the distance from center of cross section to the point of apply load =0.5***m***

7.2.1 Effect of Opening

In general, the presence of web opening in the transverse region of beam reduces the beams torque capacity and increases the angle of twist for the same value of torsion because of reduction in cross sectional transverse area which means smaller sections that resist the applied torque, also because of concentration of shear stress distribution. Also the presence of openings makes change in the behavior of beam because the reduction in polar moment of inertia leads to decrease in the torsional rigidity. Fig.4 shows the torque-angle of twist relationship for all tested beams

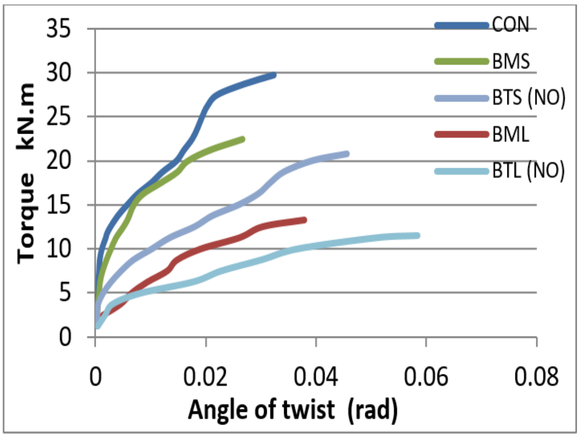

Fig. 4. Torque-angle of twist relationship for all beams

The symbols "no and fo" indicate the side at which the twisting angle is measured "near to the opening and far from the opening" for beams containing openings in one-third of the clear space.

7.2.1.1 Effect of Opening Location

Location of web opening affects the behavior, strength and angle of twist of reinforced concrete T- beam where the specimen with central opening have greater resistance against torque and lower angle of twist than specimen with opening in the third of clear span. This means that the eccentricity of web opening affects the capacity and angle of twist of the beams. Fig.5 and Fig.6 shows the effect of opening location on torque-angle of twist relationship for beams.

7.2.1.2 Effect of Opening Size

From observation of the results listed in Table 3, it can be concluded that the opening web size has the greatest effect on the behavior and strength of reinforced concrete T- beam against pure torsion at cracking and maximum torque due to a reduction in the web area. Fig.7 and Fig.8 shows the effect of opening size on torque-angle of twist relationship for beams.

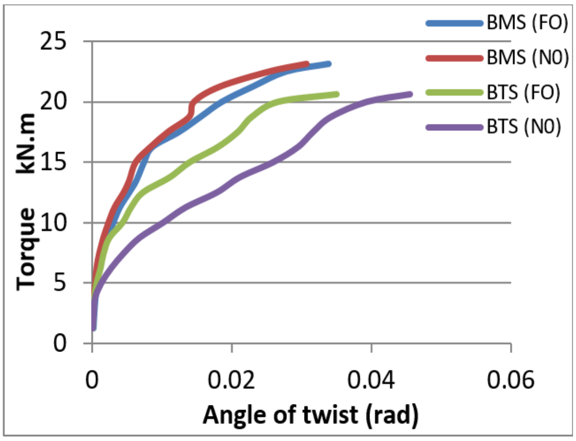

Fig. 5. Torque-angle of twist relationship for beams (BMS) and (BTS)

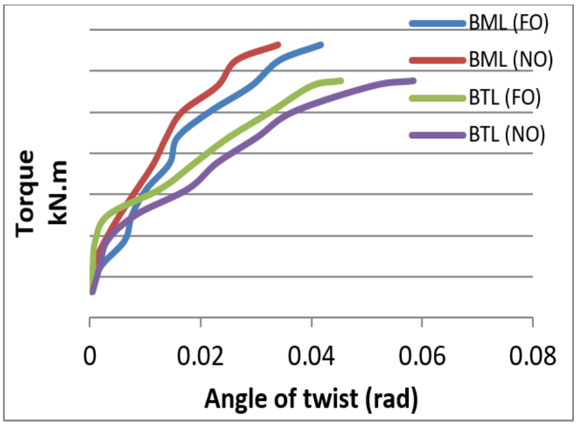

Fig. 6. Torque-angle of twist relationship for beams (BML) and (BTL)

7.3 Reinforcement Strain (measured at both ends of beam)

Before first crack, all beams behave linearly, beyond this point, there were clearly disturbance for values of strain for all beam specimens. At ultimate stage, all values of strain for beam specimens are positive (tension). The Maximum strain for beam specimens (Con), (BMS), (BTS), (BML), (BTL), are (3871*10-6), (1921*10^{-6}), (2385 *10^{-6}), (2130 *10^{-6}), (1995 *10^{-6}), respectively.

From the obtained result it can be concluded that, the stirrup strains for beam specimens (Con), have the largest strain value that exceeds the yield strain value which equal to 3300 *10^{-6}, this means, it is reached to yield strain before the other specimens. Fig. 9. Shows torque - strain relationship for all beams.

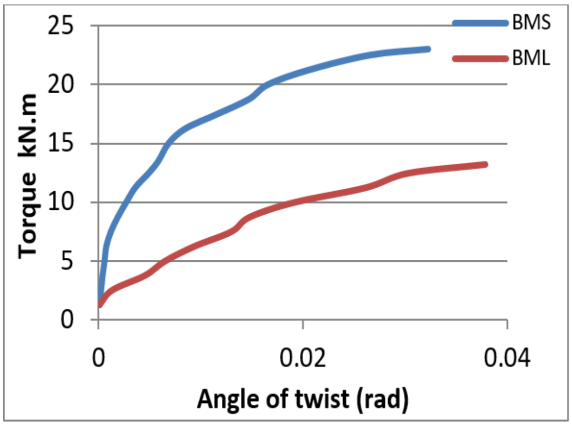

Fig. 7. Torque-angle of twist relationship for beams (BMS) and (BML)

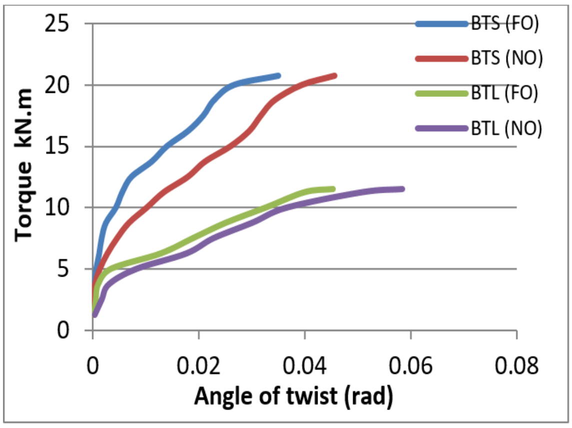

Fig. 8. Torque-angle of twist relationship for beams (BTS) and (BTL)

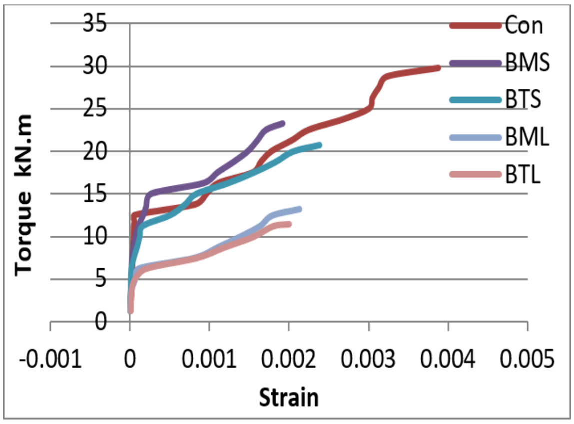

Fig. 9. Torque-strain relationship for all beams

7.4 Toughness

The toughness refers to the ability of the specimen to absorb the energy or can be defined as the energy required to break the specimen.

Toughness represents the area under the torque-angle of twist curve for each beam specimen, and it is measured by using Microsoft Office Excel. Table 5 shows toughness value of the tested beams.

Table 5
Toughness at failure

Beam Designation	Toughness*10^{-4} kN.m.rad
CON	9049.76
BMS	5809.61
BTS	6385.29
BML	3771.4
BTL	4743.57

7.5 Stiffness

Rotational stiffness can be defined as the ability of a body to resist deformation in response to any applied force and it is a function of material property (function of rigidity). Table 6 shows torsional stiffness of the tested beams.

Rotational stiffness (K) given by: $K = M/\Theta$ … (1)

Where:

M= the applied moment (kN.m).

Θ= the rotational twist angle (rad).

Table 6
Rotational stiffness at failure

Beam Designation	Stiffness at Failure (kN.m/rad)
CON	907
BMS	712
BTS	455
BML	341
BTL	196

8. FAILURE MECHANISM

The progress of cracks provided useful facts related to the failure mechanism of tested specimens. First crack of all beams specimens appeared at the weaker zone and after that it increased gradually. When the torque moment was increased, cracks appeared on each beam side and finally took the spiral shape with beam axis.

Concerning the beams that contain openings it have been observed that; the greatest cracking and failure occurs at the opening regardless of the size and location of the opening where in all cases, the greatest cracking and failure occurs at the opening because the presence of opening in transverse position is considered a weak area because of the reduction in cross sectional transverse area. Figures (9 to 13) show the failure modes for all tested beams specimens.

9. CONCLUSIONS

Based on the experimental results of the tested beams, the following conclusions are drawn:

1- The presence of circular opening with diameter of 100mm in the center of clear span reduces the torsional capacity of the beam by about 23 % as compared with reference beam.

Fig. 10. Failure mode for beam Con

Fig. 11. Failure mode for beam BMS

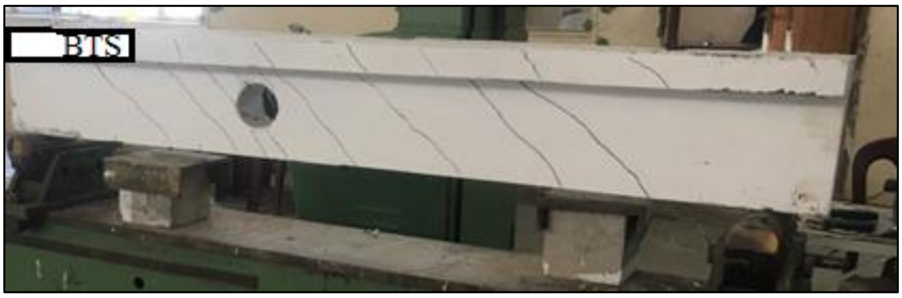

Fig. 12. Failure mode for beam BTS

Fig. 13. Failure mode for beam BML

Fig. 14. Failure mode for beam BTL

2- The presence of circular opening with diameter of 100 mm in the third of clear span reduces the torsional capacity of the beam by about 30 % as compared with reference beam

3- Increase of opening size leads to a significant reduction in first cracking load, ultimate load carrying capacity, stiffness and toughness of the beam where increasing the opening size to 150mm reduces the torsional capacity of the beams by about 56 % and 61% for opening location Lc/2 and Lc/3 respectively as compared with reference beam.

4- The presence of circular opening with diameter of 100 mm and 150 mm of the reinforced T-beams increases the angle of twist as compared with reference beam for the same torque level.

5- The best position of openings in beams exposed to torque are openings in the mid-span where the presence of opening in the third of clear span leads to reduction of first cracking load, ultimate load carrying capacity, stiffness, and toughness comparing with beam with opening in the mid-span

REFERENCE

[1] ACI Committee 318M. “Building Code Requirements for Structural Concrete and Commentary.” American Concrete Institute, Michigan, USA, (1971).

[2] Allam SM. Strengthening of RC Beams with Large Openings in the Shear Zone. *Alexandria Engineering Journal* 2005; **44** (1):59-78.

[3] Saksena N, Patel P. Experimental Study of Reinforced Concrete Beam with Web Openings. *International Journal of Advanced Engineering Research and Studies*-India 2013; **2** (3):66-68.

[4] Oukaili NK, Al-Shammari AH. Finite Element Analysis of Reinforced Concrete T-Beams with Multiple Web Opening Under Impact Loading. *Journal of Engineering*; 2014; **20** (6): 15-26.

[5] Abdulrahman MB, Rashid HM. Repairing of Reactive Powder Concrete T-Beams Containing Web Opening by CFRP Strips. *Tikrit Journal of Engineering Sciences* 2019; **26** (1): 9-19.

[6] Taha Abdo1 and Rasha Mabrouk1 (2017). Effect of Web Openings on the Structural Behavior of RC Beams Subjected to Pure Torsion. *MATEC Web of Conferences* 120, 01007.

[7] Iraqi Standard Specification No.5/1984: Portland cement

[8] Iraqi Standard Specification No. 45/1984: Aggregate from Natural Sources for Concrete and Construction

[9] ASTM C494-C494M/0 2105: Standard Specification for Chemical Admixtures for Concrete

[10] Zararis P. and Penelis G. (1986). "Reinforced Concrete T-Beams in Torsion and Bending", *ACI Journal*; No. 83-17.

[11] Abdulrahman MB, Mahmood SM. Strength of Reinforced Reactive Powder Concrete Hollow Beams. *Tikrit Journal of Engineering Sciences* 2019; **26** (2):15-22

[12] Abdul-Rahman MB, Ali AA, Younus AM. Effecting of Steel Fibers and Fly Ash on the Properties of Concrete. *Tikrit Journal of Engineering Sciences* 2018; **25** (4): 30-36.

[13] Abdulla, Aziz Ibrahim. "Thermal properties of sand modified resins used for bonding CFRP to concrete substrates." *International Journal of Sustainable Built Environment* 2016; 5(1): 176-182.