Bending Behavior of Steel Circular Hollow Sections with Openings

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Abstract:-

Steel circular hollow sections have been widely used in many engineering applications as a structural members. This paper presents a study about the bending behavior of circular steel tubes through a series of bending tests in order to study and examine the influence of presence of openings on the structural behavior and the bending properties of these sections. The experimental program comprised testing of four specimens with diameter, thickness and length equal to 101.6, 3 and 1500 mm respectively. The tested steel specimens having yield stress of 290 MPa and the ultimate stress of 350 MPa. The results of the experimental work showed that the presence of openings in the specimens reduced their stiffness and ductility significantly and effected on the structural collapse of these specimens. In addition, the presence of one, two or three openings in the pure bending region of the specimens didn't effect on their yield and ultimate strength capacity.

1. Introduction

In recent years, Steel Circular Hollow sections (CHS) use increased significantly in many applications such as structural, architectural and mechanical engineering. The circular hollow sections have many excellent structural characteristics especially with regard to their resistance for torsion, bending and compression loadings in different directions as a result of the uniform distribution of the steel about the neutral axis, which leads to good performance of these sections [2]. In addition, the closed shape for these sections and absence of the sharp corners give best protection against corrosion and thus reduce the costs of protection compared with the open sections [1, 3, 6].

The multi-storey buildings are imposed by the limitations of height depending on the zoning regulations, economic consideration and the esthetic and functional requirements that meet the needs of these buildings. The ability to meet these requirements is an important consideration in the building or framing system selection [4, 5].

Provision of openings in structural steel beams becomes necessary for passing the utilities through beams such as the air conditioning and pipelines and thus help to reduce the storey height. A reduction of building height decreases the external surface and internal volume of the buildings, which leads to reduce the costs of operation and maintenance as well as the construction costs therefore, the provision of beams with openings becomes an acceptable in the practices of engineering and eliminates the probability of working holes in the inappropriate places.

To study the bending behavior of steel circular hollow specimens, four simply supported specimens has been tested in this study. For these four specimens, the pure bending is generated between two loading points. These specimens were used with same length, diameter and thickness but the main variable was the number and the presence locations of the openings along the specimens as listed in **Table 1.** All openings in the specimens were square shape and with rib length equal to 50 mm as shown in **Fig 1.**

Table 1. Dimensions of the specimens

Spec. designation	t (mm)	D (mm)	L (mm)	Opening description
BT1	3	101.6	1500	Without openings
BT4	3	101.6	1500	With one opening at the specimen center
BT5	3	101.6	1500	With two openings at the specimen loading points
BT6	3	101.6	1500	With three openings at the specimen center and loading points

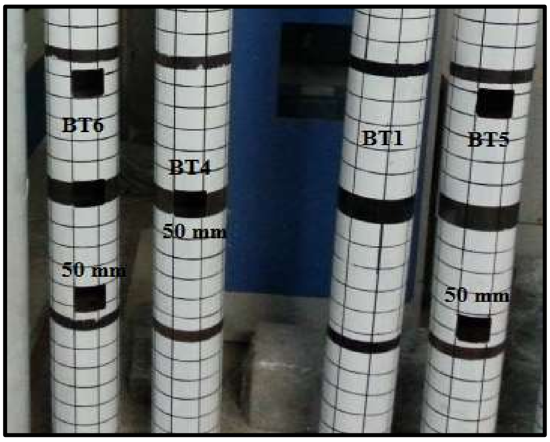


Fig 1. Specimens BT1, BT4, BT5 and BT6.

2. Experimental study:

2.1 Circular hollow specimens

In this experimental work, it was necessary to make special circumstances at the loading points in order to improve the specimen bending capacity and prevent the early appearance of the local buckling at the specimen loading points. Therefore, four machined rings were used at supports and loading points locations.

2.2 Experimental setup

The setup of the tested specimens is shown in **Fig 2,** the specimen was placed between two supports and the vertical load was applied in the center of the specimen by using the hydraulic jack. This load was transferred equally to the specimen loading points through the spreader beam.

Three dial gauges with accurately 0.01 mm were used for measuring the vertical displacement at various locations. One of these dial gauges was put at the mid-span section while the remaining dial gauges were put at the loading points.

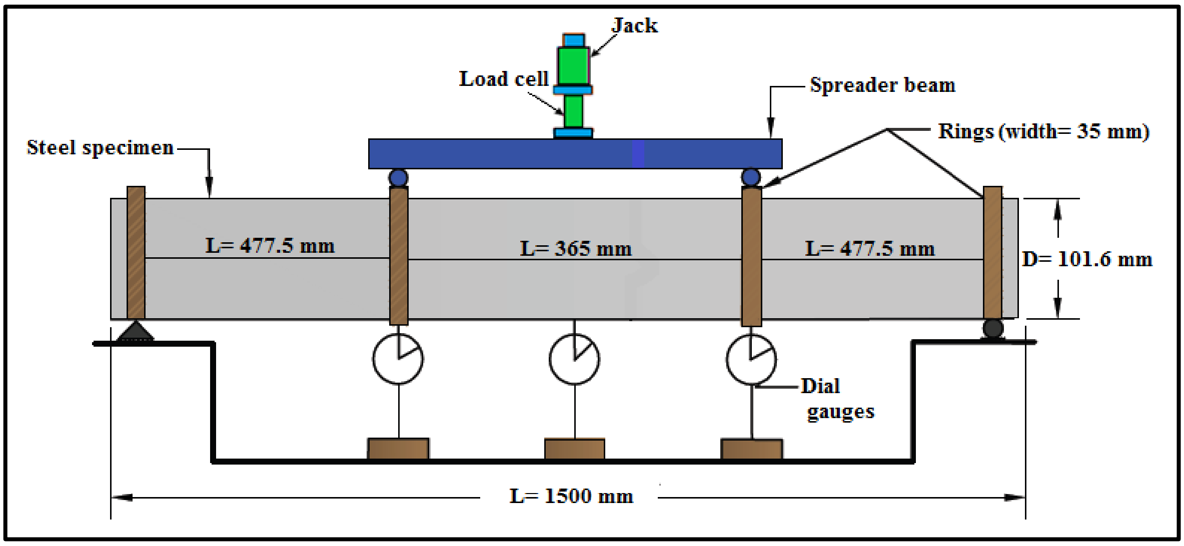


Fig 2. Schematic view of the test device and dial gauges distribution

3. Experimental results:

3.1 Load-Deflection curve of test specimens

From **Fig. 3** it could be noted that the tested specimens went through different stages when loaded gradually and which are as follows:

1- The elastic stage:

For the specimens BT1, BT4, BT5 and BT6, the elastic stage started from the beginning of loading to yield load equaled to 45, 40, 41 and 40 kN respectively and is characterized by linear relationship between the applied load and the specimen deflection.

In this stage, all specimens have very similar behavior with very close values of the yield load and yield deflection as shown in **Fig 3.** From this **Fig**, it can be noted that the presence of openings in the specimens didn’t have significant effect on the elastic stage for these specimens.

2- The ovalisation stage:

This stage represents the beginning of the specimen plastic behavior.

Here, a little increase occurred in the applied loads compared with the high increase in the specimen deflection and this continued until it was reaching to the ultimate load. The strength capacity of the specimens BT4, BT5 and BT6 were governed by the plastic deformation which occurred as a result of the moment capacity and the shear force at the openings, this moment capacity of the specimens decreased at the openings as a result of the occurrence of a high reduction in the moment contribution of these specimens therefore, the ultimate load values of the specimens BT4, BT4 and BT6 decreased by 17.88%, 19.71% and 14.23% respectively compared with the reference specimen BT1.

From this **Fig**, it can be noted that the presence of the openings effected significantly on the ovalisation stage through reduction the strain hardening capacity that led to a significant reduction in the specimens stresses redistribution compared with the reference specimen BT1.

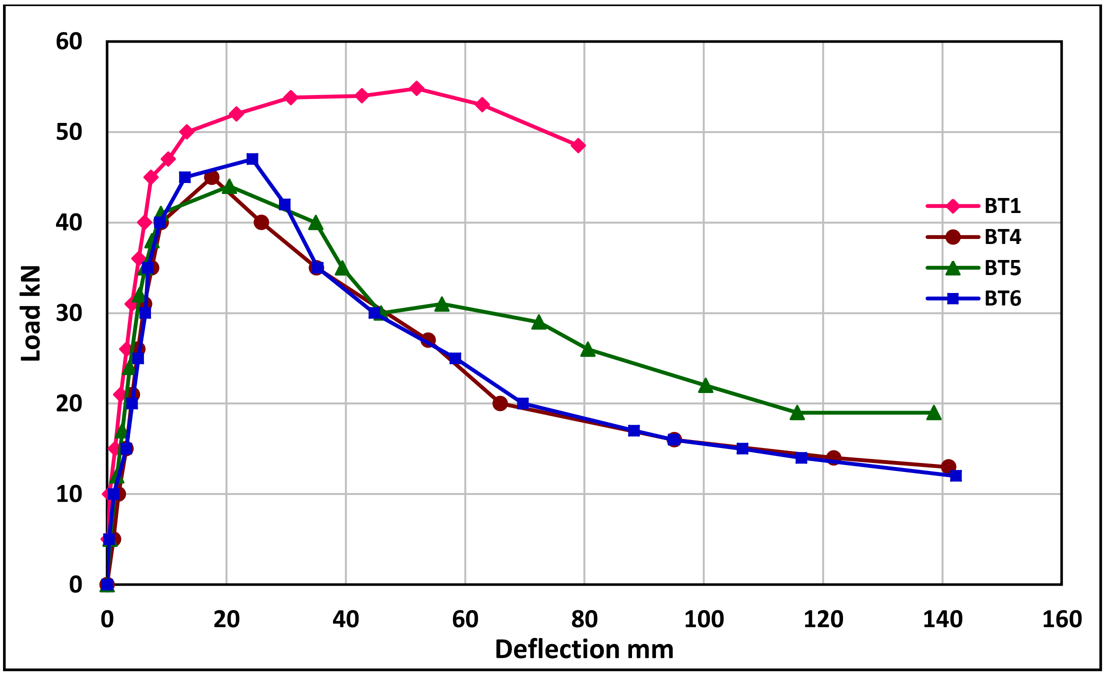


Fig 3. Load-mid span deflection curve of specimens.

3- The structural collapse stage:

From **Fig. 3**, it can be seen that the loads capacity for tested specimens dropped after the ultimate load that accompanied by increasing the dial gauge readings which led to the descending part in load- mid span deflection. This refers to the structural collapse stage. The collapse of the reference specimen BT1 began through very smooth kink forming in the compression part at pure bending region. Continuation the specimen loading worked to increase its deflection and gradual growth of this kink and thus caused the local buckling at the specimen top surface. This local buckling effected on the entire specimen and led to the formation of two folds, one of them at the top surface and exposure to compression deformation and the other in bottom surface and exposure to tension deformation, finally this led to the global buckling failure mode as shown in **Fig. 4.**

This stage began when the arrival of the specimens BT4, BT5 and BT6 to the ultimate load by exposure all specimen elements that situated above and below the opening to high stresses. The specimen elements below the openings are exposed to tension stress which led to the occurrence of yielding, while the elements above the openings are exposed to compression stress and this led to the occurrence of buckling.

The collapse of the specimen BT4 began by the occurrence of high plastification at the top surface of the openings as a result of exposure to a high compression which led to the kink formation in this surface while continuing to apply loads.

After that, this kink has evolved into the local buckling and moved from the top surface of the opening to the top surface of the specimen causing the formation of two folds, one in the top surface and the other in the bottom surface and finally led to the global buckling failure mode as shown in **Fig.** 5.

Fig 4. Structural failure of the specimen BT1.

While the collapse of the specimen BT5 began by the fold formation in the top surface of the specimen at opening in the left loading point.

The continuation of the specimen loading after the ultimate load has led to increase the amplitude and height of the fold without the occurrence of transmission to other places as shown in **Fig. 6.** Finally, this fold caused the local buckling failure in the specimen compression part.

The collapse of the specimen BT6 began by exposure the top surface of the central opening to large compression accompanied by a large deformation as a result of the occurrence of yielding which followed by buckling. Continuing to apply loads on this specimen caused the local buckling formation and after that moved from the central opening to the specimen top surface, causing the formation of two folds worked to increase the specimen curvature and eventually led to the global buckling failure as shown in **Fig**.7.

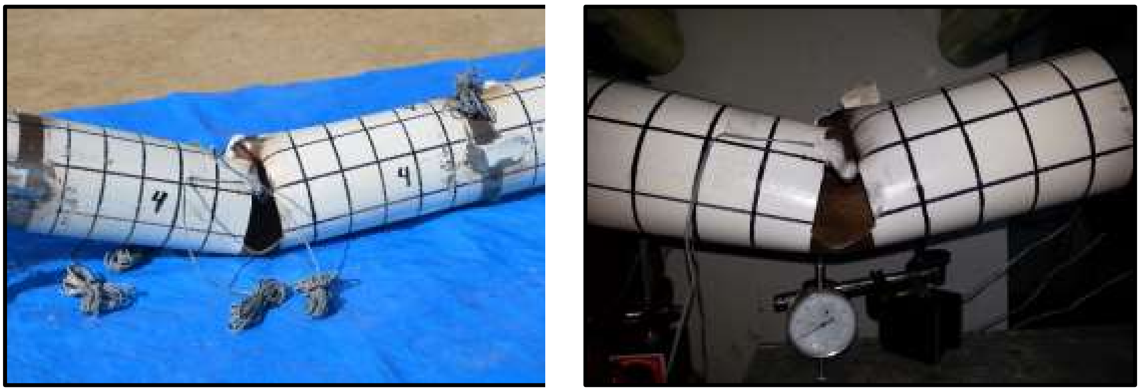


Fig 5. Structural failure of the specimen BT4.

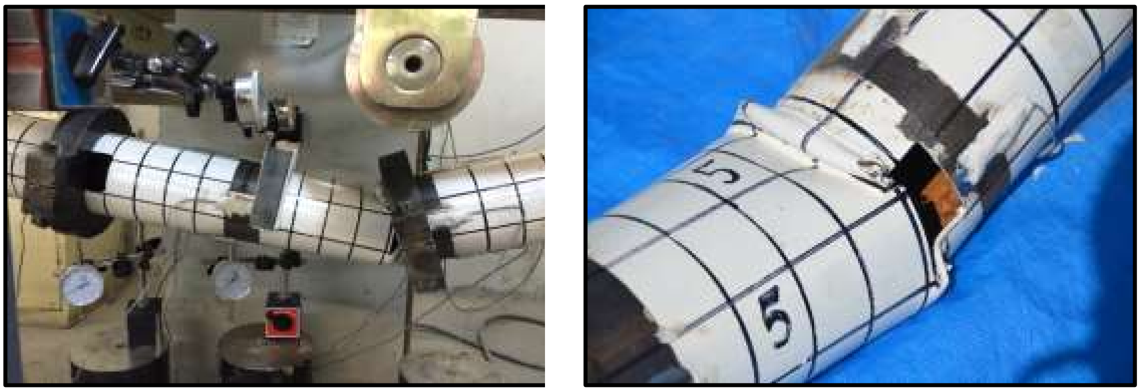


Fig 6. Structural failure of the specimen BT5.

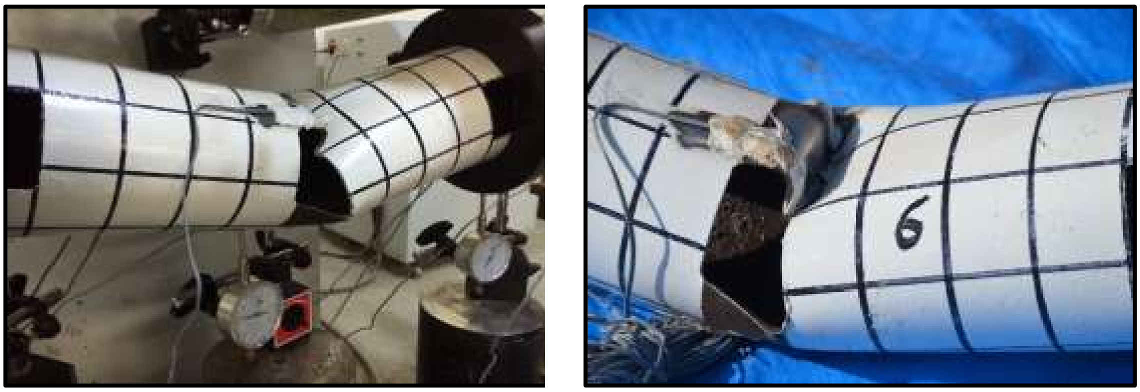


Fig 7. Structural failure of the specimen BT6.

From the overall behavior of the specimens BT4, BT5 and BT6, we note that the structural behavior and the yield and ultimate load values didn't affect by changing the number of openings in the pure bending region because the openings within each specimen are racing with each other in order to reach the ultimate load, and the opening that reaches firstly is controlling the specimen and causing the structural failure of it.

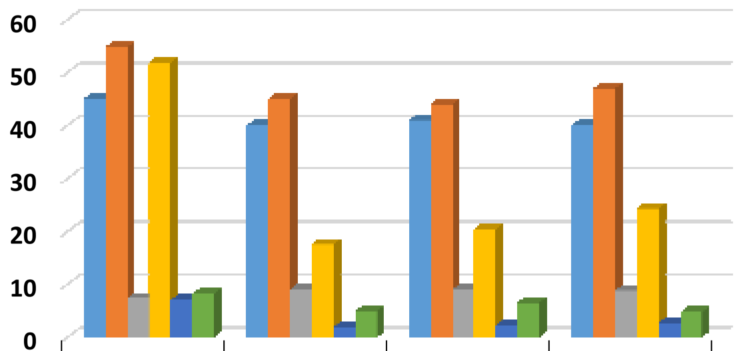
3.2 Ductility

Fig. 8 shows the ductility values of the specimens BT1, BT4, BT5 and BT6, which are obtained from the division of the ultimate deflection that registered in the mid-span of the specimen on the value of the yield deflection.

This **Fig** shows that the reference specimen BT1 has a higher value of ductility than other specimens up to 7.03 and it was due to the high value of the deflection at the ultimate load compared with the deflection value at the yield load and thus caused a gradual drop in the specimen loads capacity.

From this **Fig**, it is found that the presence of openings in the specimens BT4, BT5 and BT6 reduced their ductility significantly by 72.40%, 67.71% and 60.88% respectively compared with the reference specimen BT1.

This is due to the high reduction in the values of the ultimate deflection for these specimens, therefore it was observed sudden and rapid drop in the loads carrying capacity of these specimens when they reached to the ultimate load compared with the gradual drop of the reference specimen BT1 as shown in **Fig. 8.**



	BT1	BT4	BT5	BT6
Yield load kN	45	40	41	40
Ultimate load kN	54.8	45	44	47
Yield deflection Δy (mm)	7.38	9.07	9.03	8.85
Ultimate deflection Δu (mm)	51.88	17.57	20.48	24.35
Ductility Δu/Δy	7.03	1.94	2.27	2.75
Stiffness kN/mm	8.21	4.94	6.55	4.77

Fig 8. Test results of the specimens BT1, BT4, BT5 and BT6.

3.3 Stiffness

Stiffness is the specimen resistance to deformation and represent the ratio of applied load vs. mid-span deflection. **Fig. 8** also gives the values of the stiffness for the specimens BT1, BT4, BT5 and BT6. This **Fig** shows that the presence of openings in the specimens BT4, BT5 and BT6 reduced their stiffness by 39.83%, 20.22% and 41.90% respectively compared with the reference specimen BT1 as a result of the large deformation of these specimens.

From these stiffness values, we note that the central opening has the largest effect on the specimen stiffness from the other openings because this is the opening that controlled the specimen and caused its failure.

3.4 Deflection profile

Figs. 9 and 10. give a comparison of deflection profile for the specimens BT1, BT4, BT5 and BT6 at the yield and ultimate load.

From **Fig. 9** we note that at yield load, the specimens BT5 and BT6 showed the similar behavior through specimen loading processes. The maximum deflection of these specimens was at the left loading point and equaled to 10.20 and 9.51 mm respectively. While the maximum deflection of the specimen BT4 was at the specimen mid-span and reached 9.07 mm and it nearly equaled the mid-span deflection for the specimens BT5 and BT6.

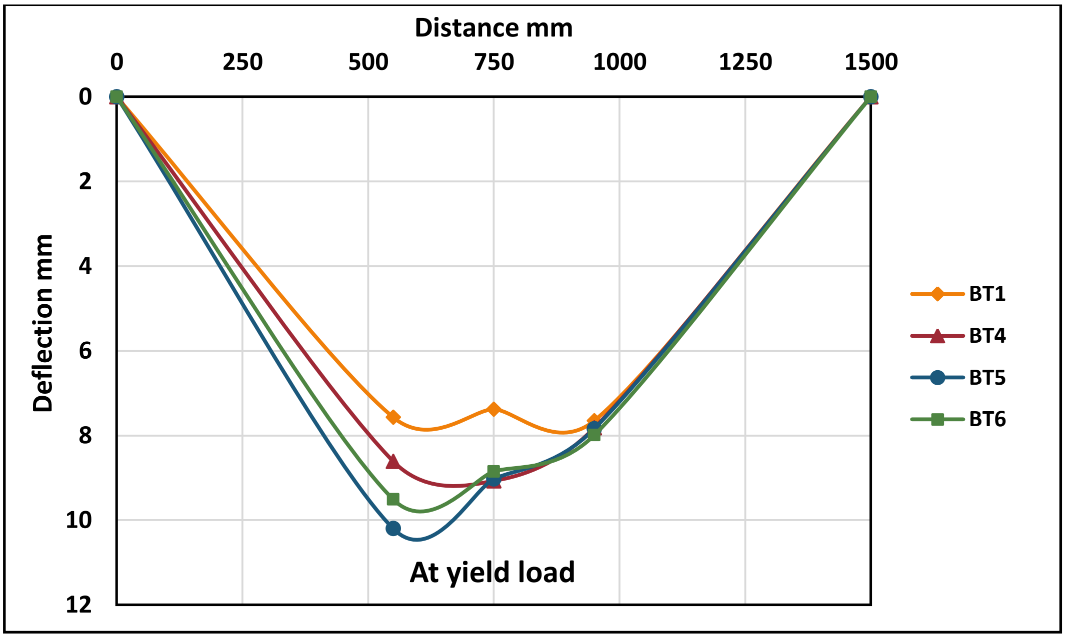


Fig 9. Deflection profile for the specimens BT1, BT4, BT5 and BT6 at yield load.

While at ultimate load, the specimens BT1, BT4 and BT6 showed the similar behavior but differed in their deflection values as shown in **Fig. 10**. The maximum deflection of the specimens BT4 and BT6 at this load was 34% and 47% respectively from the corresponding deflection of the reference specimen BT1.

At the same load, the specimen BT5 showed more response at the left loading point in which the specimen failure occurred and gave deflection at the mid-span reached to 40% from the maximum deflection of reference specimen BT1. While the reference specimen BT1 showed the most response at the mid-span compared with the remaining specimens and the value of maximum deflection for this specimen reached to 51.88 mm.

From this, we observe that the presence of openings reduced the ability of the specimens BT4, BT5 and BT6 to energy absorption and dissipation and thus reduced their resistance to fracture and finally accelerate the specimens failure unlike the specimen BT1 which characterized by its ability to resistance the failure.

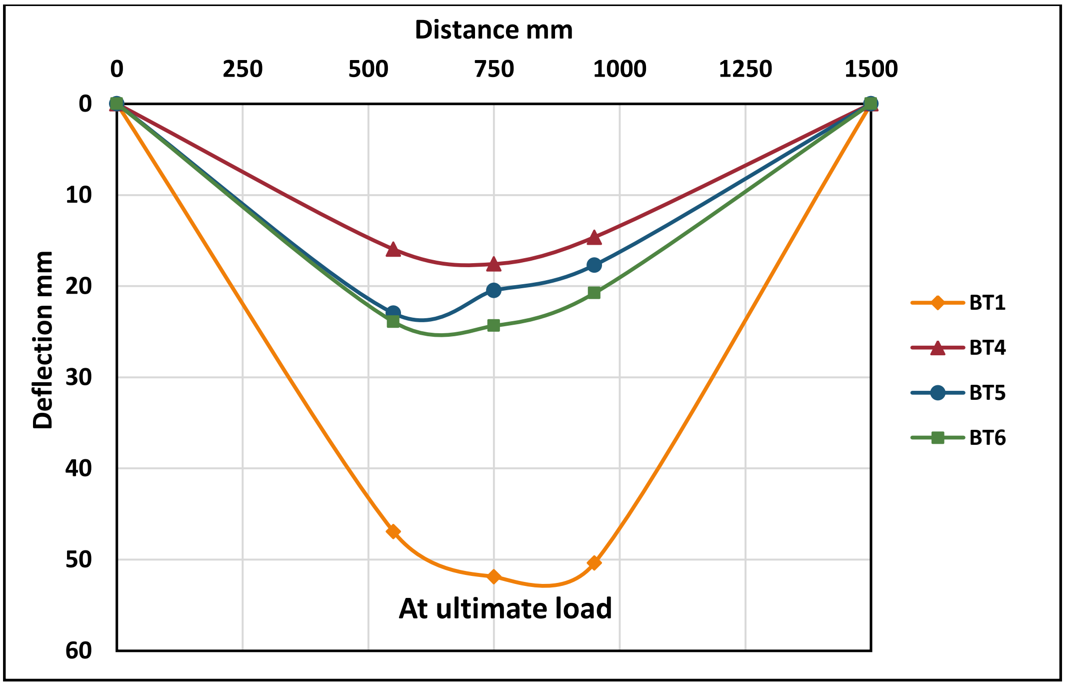


Fig 10. Deflection profile for the specimens BT1, BT4, BT5 and BT6 at ultimate load.

4. Summary and conclusion

This paper has displayed the results of the experimental study on the steel circular hollow specimens with openings under bending moment. A total of four specimens were tested with diameter, thickness and length equaled to 101.6, 3 and 1500 mm respectively in order to examine the influence of the presence of openings on the structural behavior and the bending properties of these specimens. Based on the analysis of the experimental data, the conclusion as the following:

1. The presence of openings reduces the ultimate strength capacity as a result of the low strain hardening capacity for the specimen.
2. The presence of openings decreases the specimen ductility significantly because of the low deflection at the ultimate load. This little ductility causes the sudden and rapid drop in the specimen loads carrying capacity when access to the ultimate load.
3. The presence of openings reduces the specimen stiffness as a result of the large deformation that occurs at the openings.
4. The presence of openings reduces the specimen ability to absorb and dissipate energy and accelerates its failure.
5. Change the number of openings at the pure bending region doesn't effect on the structural behavior and the yield and ultimate load values because only one opening is

reaching the ultimate load and controlling the specimen.

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سلوك الانثناء لمقاطع الحديد الدائرية المجوفة بوجود الفتحات

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الخلاصة

مقاطع الحديد الدائرية المجوفة استخدمت بشكل واسع في العديد من التطبيقات الهندسية كأعضاء هيكلية. الأبحاث المختبرية حول المقاطع الدائرية المجوفة عندما تتعرض لعزم الانثناء كانت قليلة. هذا البحث يقدم دراسة حول سلوك الانثناء لمقاطع الحديد الدائرية المجوفة من خلال سلسلة من فحوصات الانثناء من اجل دراسة وفحص تأثير وجود الفتحات على السلوك الهيكلي وخصائص الانثناء لهذه المقاطع. البرنامج العملي تضمن فحص اربع عينات بقطر وسمك وطول يساوي (101.6 , 3 , 1500 ملم) على التوالي. العينات المفحوصة تمتلك اجهاد خضوع يساوي 290 ميگا باسكال واجهاد اقصى يساوي 350 ميگا باسكال. نتائج العمل المختبري اضهرت أن وجود الفتحات في العينات قلل صلادتها ومطيليتها بشكل كبير وأثر على الانهيار الهيكلي لهذه العينات ، بالاضافة الى ان وجود فتحة واحدة او اثنتين او ثلاث في منطقة التحميل الوسطى للعينة لم يؤثر على سعة مقاومتها القصوى.