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Flexural Behavior of Rectangular Double Hollow Flange Cold-Formed Steel I-beam

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Abstract: This research experimentally investigates the flexural behavior of rectangular hollow flange cold-formed steel I-beam (RHFCFSIB) under two concentrated loads at the same distance from the support. All specimens were at a constant clear span of (L=1500mm), a constant beam specifications (t=4mm) web, flange thickness (h=300mm) for beam's depth, and flange width of (b_f=150mm). The connecting distance between the bolts, i.e., connects the web to the flanges, was (L/6), and eight stiffeners for each beam were placed under the load bearing points and at the support points on each side. The experimental program included assembling the parts to make beams and testing four specimens under two-point loads. The major parameters adopted in the current research included the flange depth, i.e., h_f=30,60,90, and 120mm. The results showed that the beam with a flange depth of 30 mm had a higher ultimate load than other beams; however, it was the highest beam deflection. The beam with a flange depth of 120mm was the best section as a flexural member. The ultimate capacity of this beam increased by 15.34% and 6.4% compared to beams with flange depths of 60mm and 90mm and decreased by 12.9% compared to a beam with a flange depth of 30 mm. The maximum deflection at beam mid-span with a flange depth of 120 mm decreased by 53.8%, 44%, and 19.94% compared to beams with flange depths of 30 mm, 60mm, and 90mm, respectively. Therefore, the flange depth significantly influenced the flexural behavior by increasing the flange depth. Also, the ultimate capacity increased, and the deflection was reduced. The main conclusions drawn from the study were discussed and summarized. The research showed that the Hollow flanged sections gave the best results for flexural behavior.

سلوك الانحناء لعتب حديد مشكل على البارد ذات شفة مزدوجة مستطيلة مجوفة

علياء صلاح فلاح [1] ، نجلاء حميد الشريف [1]
[1] قسم الهندسة المدنية/ كلية الهندسة / جامعة بابل.

الخلاصة

كرس هذا البحث لاستقصاء سلوك الانحناء لأعتاب من الحديد المشكلة على البارد ذات شفاه مستطيلة مجوفة تحت تأثير تحميل مركز بنقطتين على مسافات متساوية من المساند. جميع العينات لها نفس طول الامتداد الصافي للعتب بين المساند(١٥٠٠ملم) ونفس السمك للويب والشفاه (٤ملم) ونفس عمق العتب (٣٠٠ملم) ونفس عرض الشفة (١٥٠ملم) وكانت مسافة الربط بين البراغي التي تربط الويب بالشفاه(ل/٦) وثمانية مقاطع تقوية لكل عتب وضعت تحت نقاط تحميل الحمل وفي نقاط المساند من كل جهة. يتضمن البرنامج التجريبي تجميع الاجزاء لعمل الاعتاب وفحص أربع عينات تتضمن المتغيرات الرئيسية المعتمدة في هذا البحث عمق الشفاه (٣٠, ٦٠, ٩٠, ١٢٠) ملم. أظهرت النتائج ان العتب ذات عمق شفاه (٣٠ملم) أكثر الاعتاب لتحمل الاحمال مقارنة مع الاعتاب الاخرى ولكنه كان اكثرهن انحراف عمودي . كان العتب ذو عمق شفاه(١٢٠ملم) افضل الاعتاب كعتب انحناء, حيث زادت قابلية تحمله بنسبة ١٥,٣٤٪ و ٦,٤٪ عند مقارنته مع الاعتاب ذو اعماق شفاه (٦٠,٩٠) ملم على التوالي وقلت بنسبة١٢,٩٪ مقارنة مع عتب ذو عمق شفاه (٣٠) ملم, وقل الانحراف العمودي بنسبة (٥٣,٨ %,٤٤٪ و١٩,٩٤٪) عند مقارنته مع الاعتاب ذو اعماق شفاه (٣٠, ,٦٠ ,٩٠) ملم على التوالي. تمت مناقشة وتلخيص الاستنتاجات الرئيسية المستخلصة من الدراسة. أظهر البحث أن الأجزاء ذات الحواف المجوفة أعطت أفضل النتائج لسلوك الانثناء .

الكلمات الدالة: المقاطع المشكلة على البارد، الحمل المثني، الحمل حسب نسبة الوزن، الأمان، الحمل الرأسي والفعالية من حيث التكلفة

1.INTRODUCTION

Cold-formed Steel's (CFS) advantages include extremely light weight, capacity to use standard joining techniques, dimensional stability, manufacturing flexibility, simplicity in handling and transport, and economy [1]. In the building industry, on railroad coaches, and for vehicle bodies, cold-formed steel sections are applied. These sections are made from flat steel formed into rolls or press brakes using steel sheets, plates, and strips when applying the brakes. Steel sheet or strip thickness Cold-formed steel structural components are generally 0.5 to 6 mm thick. Cold-formed steel parts are lighter and less expensive than hot-rolled steel equivalents (various shapes of cold-formed steel sections). The three most popular forms of cold-formed steel sections are C-channel, Z-section, and I-section. Due to their thinness, these sections often display several complicated buckling modes creating contemporary cold-formed steel sections with hollow tubes and flanges. With this component, the enhanced strength-to-weight ratio of classic cold-formed steel is paired with the reliability of hot-rolled steel [2]. Here is a summary of recent research regarding cold-formed hollow sections' behavior. Gardner et al. [3] experimentally compared cold-formed and hot-rolled steel hollow sections to test how the two ways affect the materials' reaction and the structures' behavior. Two sections had "geometric defects" of similar sizes, while cold-formed sections were found to have significant "residual stresses" due to bending . Moreover, the corner of the cold-formed sections was indicated with strength improvements. The shear behavior of a rectangular hollow flange channel beam (RHFCB) with rivet fastening was investigated by Keerthan and Mahendran [4], see Fig. 1. A total of twenty-four shear tests were conducted with basic supports and RHFCB specimens until failure was achieved. The specimens' web shear buckling performance and post-buckling strength were both enhanced when the rectangular hollow flanges were presented.

Fig. 1 Rivet Fastened Rectangular Hollow Flange Channel Beam [4].

Under localized pressures, Gao et al. [5] analyzed and modeled the bending behavior of a concrete-filled pentagonal flange beam (CFPFB). The numerical model predicted a difference in bending capacity of less than 10%. For a unique high-strength concrete-filled tubular flange beam, Gao et al. [6] theoretically and numerically produced a design formula for buckling resistance (HS-CFTFB). The experimental and computational LTB behavior of HS-CFTFBs examined by Gao et al. [6] suggested that including an infill concrete may resist flange deformation [7]. Web distortion affected the flexural strength of triangular hollow flange beams (THFBs) under uniform bending, and this effect was described by a simple formula in the work of Pi and Trahair [8] on the lateral-distortion buckling of hollow flange beams (HFBs). Tondini and Morbioli [9] investigated the bending behavior of cold-formed RHFGs using experimental and computational methods. The LTB and lateral distortional buckling of the RHFGs were studied by Hassanein et al. [10,11]. They discovered web distortion was readily apparent in constructions with medium to high span widths. Additionally, they revealed that the moment-gradient factor of RHFGs was personalized by the web's thickness and number of sides. [12]. According to Kim and Sause's [13] study on the LTB of CFTFGs, web distortion can drastically reduce flexural strength even in beams with minimal stiffeners. The part moment capacity of RHFGs was formed by Nilakshi and Mahendran [14,15] using a four-point loading test and numerical analysis. According to the studies above, the section moment capacity of TFBs is significantly underestimated by current design requirements. The buckling behavior of TFBs is also clearly altered by the tubular flange. In their research of the mechanical behavior of bolted connections for built-up I-shaped columns comprised of two-lipped channels, Tang and Ma [16] found that the load-bearing ability significantly reduced when the longitudinal bolt spacing was greater than half the span. From finite element analysis, Salih and Mohammed [17] found that the absence of an opening significantly affected the ultimate load capacity.

2. EXPERIMENTAL PROGRAM

Cold-formed steel (CFS) sections are common sections to resist bending resulting from applied loads. In this research, the flexural behavior of a group of samples consisting of cold-formed steel I-beams with hollow rectangular flanges of different sizes was studied. Also, the effect of these hollow flanges on the flexural behavior, the extent of improvement from the resistance of the sections to bending, reducing the deflection, and comparing them with each other were studied. Table 1 shows the description of the specimens. Table 2 details the four beam specimens tested in this research. The types of stiffener configurations are shown in Table 3.

Table 1 The Description of Specimens

Specimen Identification	Description
A30	CFS I-beam with rectangular hollow flange (h_f=30mm)
A60	CFS I-beam with rectangular hollow flange (h_f=60mm)
A90	CFS I-beam with rectangular hollow flange (h_f=90mm)
A120	CFS I-beam with rectangular hollow flange (h_f=120mm)

Table 2 The Dimensions of Specimens

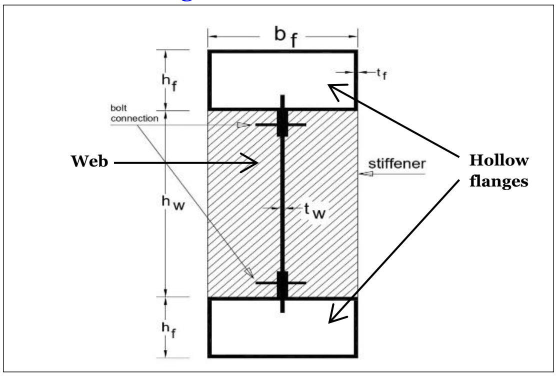
Specimen identification	H mm	h_f mm	h_w mm	b_f mm	t_f mm	t_w mm	Location of Connection
A30	300	30	240	150	4	4	L\6
A60	300	60	180	150	4	4	L\6
A90	300	90	120	150	4	4	L\6
A120	300	120	60	150	4	4	L\6

Table 3 Details of Stiffeners

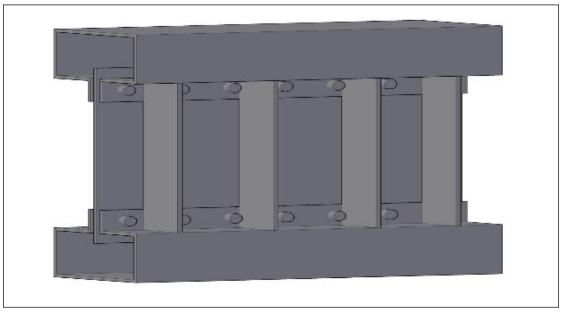
Specimen identification	Stiffener length, mm	Stiffener width, mm	Thickness mm
A30	240	69	4
A60	180	69	4
A90	120	69	4
A120	60	69	4

3. SECTION SPECIFICATION

The experimental research considered sections with varying hollow flange depths and locations of bolt connections. Two characteristics of the four types of rectangular hollow flange cold-formed steel beams were studied, i.e., thickness (4 mm) and bolt connection location at (L/6) from the support. The length and breadth of I-sections are governed by their section specifications, including thickness and total depth, as well as IS 811-1987: Code of Practice for Cold-formed Light Gauge Structural Steel Sections. The thickness of the beam (t = 4 mm), the flange width (b_f = 150 mm), the flange depth (h_f = 30, 60, 90, and 120 mm), the overall depth of the beam (h = 300 mm), and the connecting position between web and flange at (L/ 6) for a total span of 1500mm was the section specifications for the I-Sections utilized for the experimental research. The specimen's details are shown in Fig. 2.



(a) 2-D Side View of Section



(b) Three-Dimensional Section

Fig. 2 Specimens' Details

4. DEVELOPMENT AND RESEARCH

4.1. Test Specimens

Room-temperature steel was cold-formed from steel sheets with a thickness of 4 mm. The specimens were subsequently shaped into I shapes using one of Cold roll forming and press braking are the two procedures existing. The cold roll forming method was utilized to produce the I-section in this study. The thickness of a cold-formed steel sheet of the necessary length was bent into two channels and two angles using a press braking machine. These channels and angles were joined to make a rectangular hollow flange, as seen in Fig. 3. This technique was used to create a rectangular hollow flange cold-formed steel I-beam out of two rectangular flanges bolted to a web.

Fig. 3 Fabricated Test Specimens

4.2. Loading Condition

To load the beam, two loads were symmetrically positioned between the supports. Four critical points were along the beam's span, i.e., two end supports and two loading points. Therefore, it can bend the beam in four different directions. This technique is known as four-point bending. As shown in Fig. 4, the space between the loads was 500 mm, whereas the distance between the two supports was obviously 1500 mm . Four-point bending had a homogeneous bending moment, and there was no shear force between the loading points; thus, it led to pure bending loading.

4.3. Supporting Conditions

The press braking method was adopted to fabricate a rectangular hollow flange cold-formed steel I-beam from two hollow flanges and a web connected by bolts at various positions from the support. Fig. 4 depicts a simply supported rectangular hollow flange cold-formed steel I-beam with a roller at one end and a pinned connection at the other. The span length of all the beams was maintained at 1500 mm with support at 100 mm.

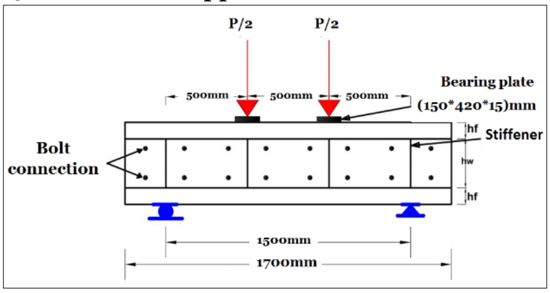


Fig. 4 Loading and Support Conditions.

4.4. Limiting Criteria

The limited criterion is a normalized scale or value that compares the results of different sections to see how well they work on a single scale. The load-ultimate capacities of the sections in this article were compared using deflection as a standard metric. The deflection limit was given as span/300 in the BS 5950-5: 1998. Code of Practice for the Design of the Cold-Formed Narrow Gauge Sections.

5. RESULTS AND DISCUSSION

Flexural beams were tested on four types of specimens using universal testing equipment with a 600kN capacity and adjustable supports long enough for the required span. The obtained load and deflection are measured, recorded, and extrapolated as necessary. The specimen's deformation was measured using the disc gauge. The disc gauge was positioned in the middle of the bottom beam to measure the section deflection, as seen in Fig. 5. It was also positioned directly under the point load at the bottom of the beam to measure deflection in this region. As the load was gradually raised by the hydraulic jack, the cold-formed beam started to deflect, and local buckling happened toward the bottom of the load.

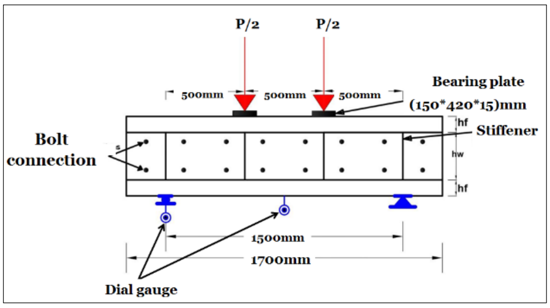


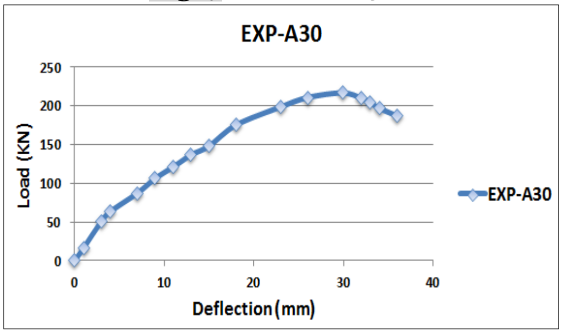
Fig. 5 Location of Dial Gauge.

5.1. Beam A30 with Hollow Flange (h_f=30mm)

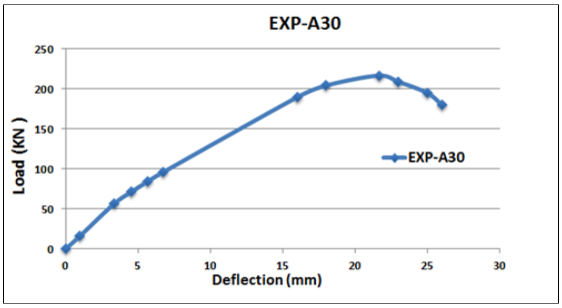
This beam consisted of two rectangular hollow flanges and one web. The depth of each flange was 30mm, and the web was 240mm. The location of the bolt connection between the two flanges and the web was at L/6, and the length of the span was 1500mm.

Fig. 6 Laboratory Testing on A30.

Fig. 7 Failure of A30.



(a) Load-Deflection Curve at Mid-Span for A30.



(b) Load-Deflection Curve Under Point Load for A30.

Fig. 8 Load- Deflection Curve for Specimen A30.

The ultimate load supported by the A30 section was 217kN, and the beam deflected (29.89 and 21.64) mm at mid-span and under point load, respectively.

5.2. Beam A60 with Hollow Flange (h_f=60mm)

This beam consisted of two rectangular hollow flanges and one web. The depth of each flange was 60mm, and the web was 180mm. The location of the bolt connection between the two flanges and the web was at L/6, and the length of the span was 1500mm.

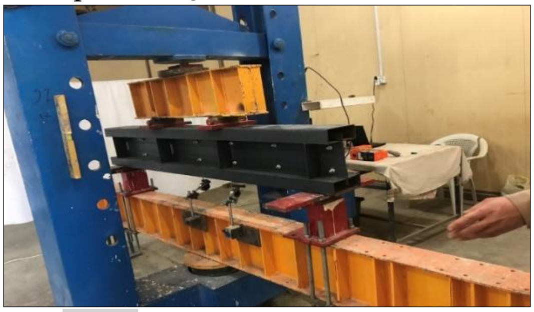
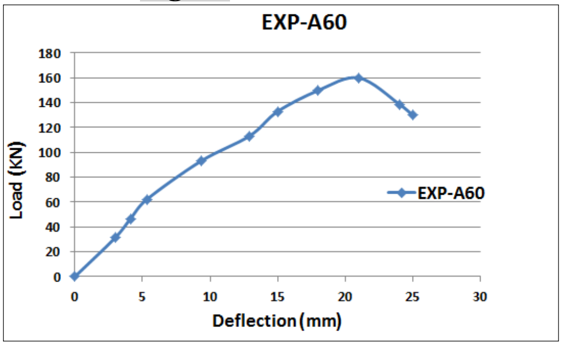
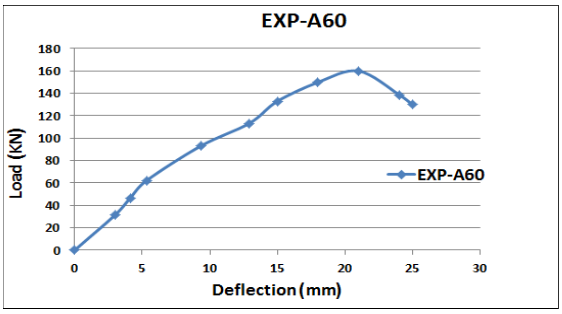


Fig. 9 Laboratory Testing on A60.

Fig. 10 Failure of A60.



(a) Load-Deflection Curve at Mid-Span for A60.



(b) Load-Deflection Curve Under Point Load for A60.

Fig. 11 Load-Deflection Curve for Specimen A60.

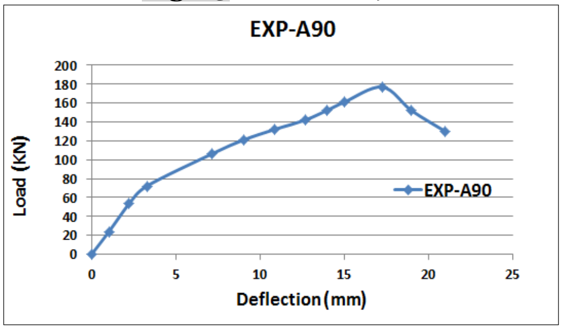
The ultimate load supported by the A60 section was 160kN, and the beam deflected (24.65 and 20.99) mm, at mid-span and under-point load, respectively.

5.3 Beam A90 with Hollow Flange (h_f=90mm)

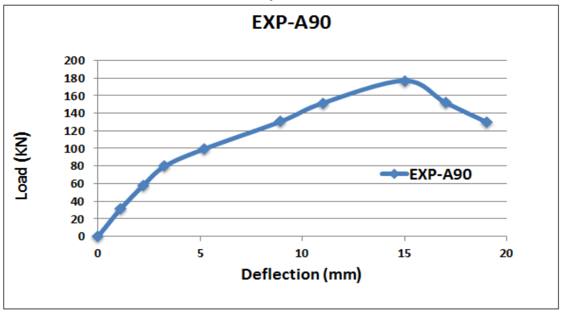
This beam consisted of two rectangular hollow flanges and one web. The depth of each flange was 90mm, and the web was 120mm. The location of the bolt connection between the two flanges and the web was at L/6, and the length of the span was 1500mm.

Fig. 12 Laboratory Testing on A90.

Fig. 13 Failure of A90.



(a) Load-Deflection Curve at Mid-Span for A90.



(b) Load-Deflection Curve Under Point Load for A90

Fig. 14 Load-Deflection Curve for Specimen A90.

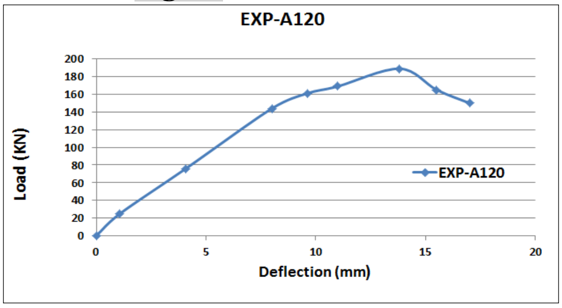
The ultimate load supported by the A90 section was 177kN. The beam deflected 17.25 and 14.99 mm at mid-span and under point load, respectively.

5.4 Beam A120 with Hollow Flange(h_f=120mm)

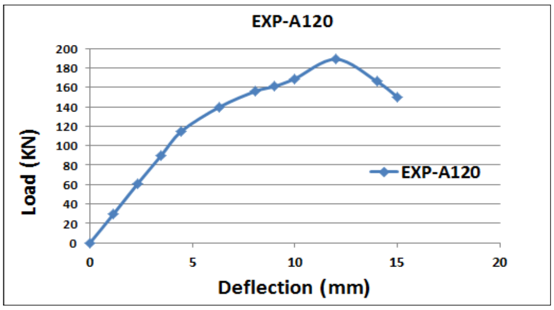
This beam consisted of two rectangular hollow flanges and one web. The depth of each flange was 120mm, and the web was 60mm. The location of the bolt connection between the two flanges and the web was at L/6, and the length of the span was 1500mm.

Fig. 15 Laboratory Testing on A120.

Fig. 16 Failure of A120.



(a) Load-Deflection Curve at Mid-Span for A120.



(b) Load-Deflection Curve Under Point Load for A120.

Fig. 17 Load-Deflection Curve for Specimen A120.

The ultimate load supported by the A120 section was 189kN, and the beam deflected 13.81 and& 14.99 mm at mid-span and under point load, respectively.

6. INTERPRETATION

The experiments were completed, and the findings were received. The parts were constructed with mild steel (Yield stress: 266.1MPa, Young's modulus: 200000MPa). According to the Code of Practice for the Design of Cold-Formed Narrow-Gauge Sections, the maximum permissible deflection was 5mm (**span/300**) (**BS 5950-5:1998**). The results of the four proposed sorts of sections are shown in Table 4. The load-to-weight ratio was used to calculate the section's efficiency. This ratio represents the amount of self-weight required to sustain each increase in the section's load-ultimate capacity; hence, the greater the ratio, the better the section's performance.

Table 4 the Outcomes of The Planned Specimens' Tests

Section type	Total applied load (KN)	Total weight of beams (Kg)	Efficiency %	Ductility	Stiffness ratio KN/mm	Modulus of toughness MPa*10⁹
A30	217	51.2	4.24	1.71	7.3	5039
A60	160	53.6	3	1.9	6.5	2626
A90	177	56.4	3.14	1.6	10.3	2185
A120	189	60	3.15	1.32	13.7	1853

Based on the load-to-weight ratio, the A30 beam prepared from "two rectangular hollow flanges" bolted to the web L/6 from the support and had a thickness of 4mm was more efficient than the other specimens.

7. CONCLUSION

This research focused on the bending responses of cold-formed beams having hollow rectangular flange sections. These findings were arrived at:

- When fabricating a hollow rectangular flanged CFS section, it is important to consider web buckling and web aspect ratio.
- The bending strength of a beam depends heavily on its yield stress besides its thickness, depth, and web aspect ratio.
- The failure mode of the beam with a flange depth of 30 mm was governed by the distortional buckling failure mode, perhaps because the depth of the web in this section was greater than the rest of the sections. As the cold-formed steel sections' depth increased, the sections were exposed to a higher rate of buckling than bending because the maximum stresses were concentrated in the compression flange. The concentration of these stresses led to distortional buckling. While the failure mode of beams with flange depths 30 mm,60mm, and 120mm was governed by bending failure.
- A beam with a flange depth of 30 mm was the most capable of carrying loads, as it carried a load of 217KN, and this was 26.7% higher than a beam with a flange depth of 60 mm, 18.43% higher than a beam with a flange depth of 90 mm, and 12.9% higher than beam with flange depth 120 mm because when the load increased, the web descended until it met the flange. As a result, the web gained more rigidity, making it bear more.
- In comparison to the beam with a flange depth of 60 mm, the percentage of load ultimate capability increased by 9.6% for the beam with a flange depth of 90 mm, 15.4% for the beam with a flange depth of 120 mm, and 6.4% for the beam with a flange depth of 120 mm compared with the beam with a flange depth of 90 mm.
- The beam deflection with a flange depth of 90 mm specimen decreased by 53.79% compared with the beam with a flange depth of 30 mm specimen, 43.97% with the beam with a flange depth of 60 mm specimen, and 19.94% with the beam with a flange depth of 90 mm specimen.
- It was shown that increasing the depth of a rectangular flange increased its ultimate capacity, decreased beam deflection, and increased the section's resistance to buckling. Therefore, the flange of an I-hollow beam was a better flexural member. Overall, the beam with a flange depth of 120 mm specimen outperforms the sections as a flexural component while being more reasonably priced.

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NOMENCLATURE

b_f	Flange width, mm
h	Beam's depth, mm
h_f	Depth of flange, mm
h_w	Depth of web, mm
L	Clear span, mm
t	Thickness of steel plate, mm

REFERENCES

[1] Sifan M, et al. **Flexural Behavior and Design of Hollow Flange Cold-Formed Steel Beam Filled with Lightweight Normal and Light Weight High Strength Concrete**. *Journal of Building Engineering* 2022; **48**:103878.

[2] Abou-Rayan AM, Khalil NN, Zaky AA. **Experimental Investigation on the Flexural Behavior of Steel Cold-Formed I-Beam with Strengthened Hollow Tubular Flanges.** *Thin-Walled Structures* 2020; **155**: 106971.

[3] Gardner L, Saari N, Wang F. **Comparative Experimental Study of Hot-Rolled and Cold-Formed**

Rectangular Hollow Sections. *Thin-Walled Structures* 2010; **48**(7): 495-507.

[4] Keethan P, Mahendran M. **Shear Tests of Rivet Fastened Rectangular Hollow Flange Channel Beam**. *Journal of Constructional Steel* 2016; **121**: 330-340.

[5] Gao F, Zhu HP, Zhang DH, Fang TS. **Experimental Investigation on Flexural Behavior of Concrete-Filled Pentagonal Flange Beam under Concentrated Loading**. *Thin - Walled Structures* 2014; **84**: 214-225.

[6] Gao F, Yang F, Liang H, Zhu H. **Numerical Study and Strength Model of Concrete-Filled High-Strength Tubular Flange Beam under Mid Span Load**. *Engineering Structures* 2021; **229**: 111654.

[7] Gao F, Yang F, Zhu H, Liang H. **Lateral-Torsional Buckling Behavior of Concrete-Filled High Strength Steel Tubular Flange Beams under Mid-Span Load**. *Journal of Constructional Steel Research* 2021; **176**: 106398.

[8] Pi YL, Trahair NS**. Lateral-Distortional Buckling of Hollow Flange Beams with Web Stiffeners**. *Journal of Structural Engineering, ASCE* 1997; **123**(6):695-702.

[9] Tondini N, Morbioli A. **Cross- Sectional Flexural Capacity of Cold-Formed Laterally-Restrained Steel Rectangular Hollow Flange Beams**. *Thin-Walled Structures* 2015; **95**: 196-207.

[10] Hassanein MF, Kharoob OF, EL Hadidy A. 4. **Lateral–Torsional Buckling of Hollow Tubular Flange Plate Girders with Slender Stiffened Webs**. *Thin-Walled Structures* 2013; **65**: 49-61.

[11] Hassanein MF, Silvertre N. **Lateral-Distortional Buckling of Hollow Tubular Flange Plate Girders with Slender Unstiffened Webs**. *Engineering Structures* 2013; **56**: 572-584 .

[12] Hassanein MF, Kharoob OF. **Flexural Strength of Hollow Tubular Flange Plate Girders with Slender Stiffened Webs under Mid-Span Concentrated Loads**. *Thin-Walled Structures* 2013; **69**: 18-28.

[13] Kim BG, Sause R. **Lateral Torsional Buckling Strength of Tubular Flange Girders**. *Journal of Structural Engineering* 2008; **134**(6): 902-910 .

[14] Perera N, Mahendran M. **Section Moment Capacity Tests of Hollow Flange Steel Plate Girders**. *Journal of Constructional Steel Research* 2018; **148**: 97-111.

[15] Perera N, Mahendran M. **Finite Element Analysis and Design for Section Moment Capacities of Hollow Flange Steel Plate Girders**. *Thin-Walled Structures* 2019; **135**: 356-375.

[16] Tang X, Ma H. **A Study on Bolted Connection of Built-Up I-Shaped Member Consisting of Double Thin-Walled Cold-Formed Lipped Channels**. *4th International Conference on Advances in Steel Structures* 2005 June 13-15; Shanghai, China; **1**: 523-528.

[17] Usamah MS, Abbas HM, Marwa ZK, Kamaran SA. **Finite Element Investigation of the Ultimate Capacity of Hollow-Flange Steel Girders with Web Openings**. *Diyala Journal of Engineering Sciences* 2022; **15**(2): 19-30.