Experimental And Numerical Study Of Replacing Pattern Of Steel Reinforcement In Tabular Steel-UHPC Composite Beams

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ABSTRACT:

The present paper included a study, trying to develop a new type of structural elements, a composite hollow beam containing a hollow steel box, which is fully encased in concrete by investigating its flexural behavior experimentally and numerically. The tensile longitudinal reinforcement will replace by pushing down the box location to be an equivalent of them. This encased hollow steel section was chosen to take advantage of its hollow core to reduce the amount of costed UHPC mix , which is a quality mutation in the concrete technology and fairly expensive. Several experimental mixtures were made in order to obtain a cubic compressive strength of 143 MPa in order to classify the concrete as ultra-high performance concrete. Several shapes and locations of steel hollow sections were used in the study as variables, in different situations, positions and presence and absence of longitudinal reinforcement. The results showed that composite hollow beams show flexural capacity and stiffness higher (118-127)% and (69.7-94.3)% respectively than non-composite solid beam. The numerical study show a good convergence between the numerical and experimental results for the same specimens, where the percentage of differences between the experimental and numerical results ranged between (3.5− 8.8)%.

KEY WORDS: Hallow Core, composite beams, ultra high performance, Deflection and longitudinal opening.

دراسة تجريبية وعددية لاستبدال نمط تقوية الصلب في الحزم المركبة ذات الصلب UHPC .

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ميسان ، الجامعة.

ملخص:

تضمنت الورقة الحالية دراسة ، تحاول تطوير نوع جديد من العناصر الإنشائية ، شعاع مجوف مركب يحتوي على صندوق فولاذي مجوف ، ومغطى بالكامل بالخرسانة من خلال التحقيق في سلوكه الانحنائي بشكل تجريبي وعددي. سيتم استبدال التعزيز الطولي للشد عن طريق دفع موقع الصندوق ليكون معادلاً له. تم اختيار قسم الصلب المجوف المغطى هذا للاستفادة من جوهره المجوف لتقليل كمية مزيج UHPC الذي تم تكلفته ، والذي يعد طفرة عالية الجودة في تكنولوجيا الخرسانة ومكلفة للغاية. تم تصنيع العديد من المخاليط التجريبية من أجل الحصول على قوة ضغط مكعبة قدرها ١٤٣ ميجا باسكال من أجل تصنيف الخرسانة على أنها خرسانة عالية الأداء. تم استخدام عدة أشكال ومواقع لأقسام الصلب المجوفة في الدراسة كمتغيرات ، في مواقف مختلفة ، والمواقف والوجود وغياب التعزيز الطولي. أظهرت النتائج أن الحزم المجوفة المركبة تظهر قدرة الانحناء وصلابة أعلى (١١٨–١٢٧) ٪ و (٦٩,٧–٩٤,٣) ٪ على التوالي من الشعاع الصلب غير المركب. أظهرت الدراسة العددية وجود تقارب جيد بين النتائج العددية والتجريبية لنفس العينات ، حيث تراوحت نسبة الاختلافات بين النتائج التجريبية والعددية بين (٣,٥ – ٨,٨ ٪) .

الكلمات الرئيسية: والحزم المركبة ، والأداء الفائق ، والانحراف ، والانفتاح الطولي.

- **INTRODUCTION**

Ultra high performance concrete (UHPC) is considered to be an advanced technology in concrete buildings. It has superior properties as a high strength in compression, tensile, durability and ductility compared than conventional concrete. The main drawbacks of this type of concrete is its high cost because of the lack of materials locally. In order to obtain a higher flexural capacity in sections using this type of concrete, which is characterized by a higher compressive strength, should be used a high quantity of longitudinal steel reinforcement enough to reach the balance between the compressive and tensile forces at the beginning of loading stage. Therefore, this report suggests to use the principle of composite section through using a type of steel section to take an advantage of its tensile strength and to take an economic advantage of its hollow core to reduce the amount of high-price UHPC materials.

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- **LITERATURE REVIEW AND PREVIOUS STUDIES**

• On composite sections:

In the research of many published researches we found that this type of steel-hollow sections (CFST) has not been used recently as a composite section encased in concrete fully or partially.But we have found many numerical and experimental studies studying on the ultimate strength on the traditional type of composite sections that was mentioned in Eurocodes **[1]**, **[2]**, **[3]**&**[4]**, with different variables.Which consists of encasing a steel w-section in the concrete as shown in **Fig. 1** below.

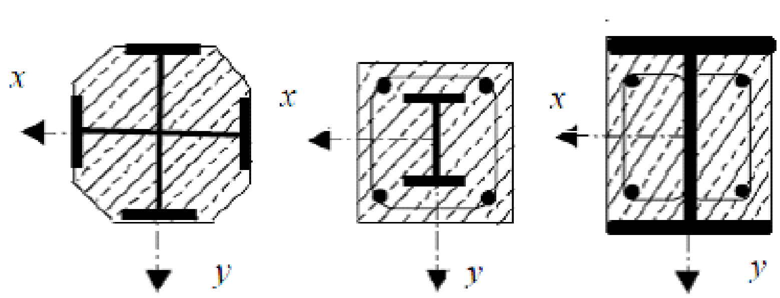


Fig. 1:. Typical composite cross-sections encased members.

***Neelima Khare and V. S. Shingade 2016*[5]**Investigated an experimental research on flexural and shear behavior of fully-encased composite beams. Their study showed a comparison between the use of longitudinal steel rebars as a major reinforcement and the use of encased rolled steel-section as a major reinforcement. As shown in **fig.2** below.Through the load-deflection curve shown in the figure below, they noted that the use of the encasing of rolled steel-section (type A and C) as a main reinforcement was better than the use of the traditional reinforcing steel rebars as a main reinforcement (type N), as the curves of the composite-section shows a high increase in the ultimate strength and less deflection resulting from loads.

Table 1 Parameters for experimental tests, by **Neelima Khare and V. S. Shingade 2016**.

Type of Beam	N	A	C
Bottom Reinforcement	2 # 12	2 # ISA 20 × 20 × 3	3 # Channels 20 × 7 × 3
Area of tension reinforcement (mm^2)	226	224	252
Top reinforcement	2#8	2#8	2#8
Stirrups	2 legged 8 mm dia	2 legged 8 mm dia	2 legged 8 mm dia
Stirrups Spacing (mm)	50 & 100	50 & 100	50 & 100
No. of samples casted	6 nos.	6 nos.	6 nos.

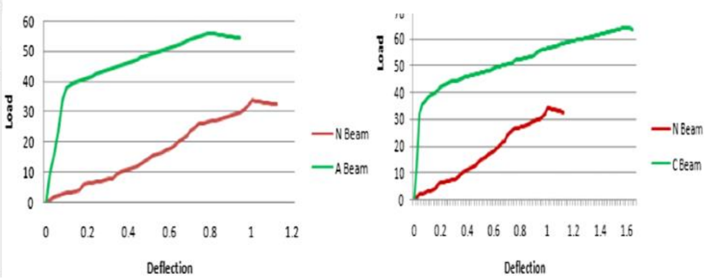


Fig.2:Overall view of the model, by Ahmed Youssef Kamal, 2015.

***Neelima Khare and V. S. Shingade 2016* [6]** Investigated the removal of the shear reinforcement from the composite beams to study its behavior under the influence of flexural and shear forces, with the presence and absence of shear reinforcement. The variables for the experimental investigation were (B1: Beam with Normal i.e. Conventional steel reinforcement, B2: Beams with rolled steel Angle sections as reinforcement and B3: Beams with rolled steel Channel sections as reinforcement). The experimental results showed that the crack width increases markedly if the shear reinforcement is not used compared to beams with shear reinforcement. composite beams without shear reinforcement, failed as a result of concrete crushing in a diagonal tension.

***Ahmed Youssef Kamal, 2015* [7]** Investigated the effect of the positions of upper steel-flange in fully-encased beams, on composite beam's capacity. Twenty simply supported composite encased beams as shown in **Fig.3** , loaded in the mid-spans by concentrated loads. The variables were divided into four groups by a variable for the steel section's width divided by concrete section's width, (v= bs/b) of 0.33, 0.5,0.67 and 0.86. Each group has a variable normalized height (g = hf/hs) of 0, 0.25, 0.5, 0.75 and 1 in addition to a control beam (reinforced concrete beam without steel section) that is studied and analyzed by the author. The author concluded that the ultimate capacity of fully encased composite beams is very high. The increase in the width of steel section showed an increase in the capacity of the composite beams with steel I-section. And more reliably than the composite beams containing inverted steel T-section for the same width of composite beams. He also concluded that the presence of the upper steel flange in composite section delayed the initiation of concrete crushing. It has also been concluded that the lowering the position of steel section towards the tension zone will delay the initiation of concrete cracks. He also concluded that the full encasing of a steel I-section in the concrete increases the capacity higher than encasing inverted steel T-section.

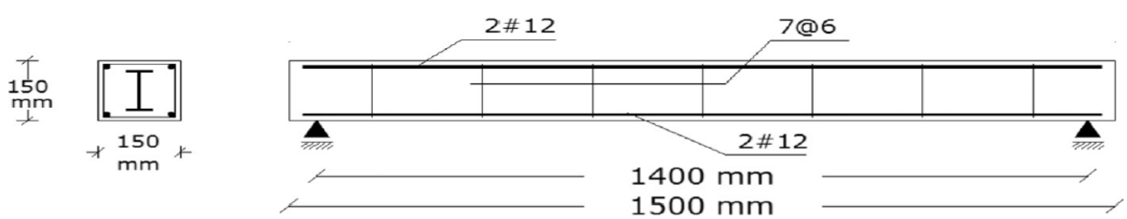


Fig.3:Overall view of the model, by Ahmed Youssef Kamal, 2015.

V. Kvocˇa´ka and L. Draba, 2012 **[8]** Define their system of partially-encased composite beams as shown in **Fig.4**. Their system consists of encasing the web of steel-section into the reinforced concrete, and connecting the concrete with the steel section by shear connectors. This means that concrete and steel section in partially encased composite beams can be considered as a one-unite if connecting them with shear connectors, which leads to increased the capacity and rigidity.

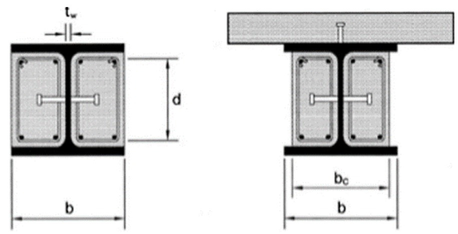


Fig.4:Typical cross sections of partially-encased beams, by V. Kvocˇa´ ka and L. Draba, 2012.

Ammar A., Saad N., and Wael S, 2012 **[9]** Investigated the ultimate capacity of fully encased composite beams. They studied the effect of increasing the steel-section area in the composite beams. They concluded that increasing of steel sections lead to increase the capacity of fully encased composite beams.

AISC 2010,**[10]**Two types of composite sections were included in this specification. Chapter 1: Includes the fully encased composite beams which depend on the natural bonding between the concrete and steel section to ensure the composite action. It also includes other types of composite sections consisting of steel section attached to concrete slab using different type of shear connectors headed studs and channels.

• **On UHPC mixture**:

UHPC has a compressive strength up to 150 MPa, and a flexural strength up to 10 mpa at 28 days. the concept of UHPC was developed firstly by Richard and Cheyrezy in 1990s at Bouygues Laboratory in France **[11]**. Later, the ductile property of UHPC beams were improved with the addition of steel fibers by Oh **[12]** and Ashour et al. **[13]**. As well as the increasing flexural and shear capacity were investigated by and the resistance of the goat Campione **[14]**, and by Lim et al. **[15]** respectively. The mechanical properties of UHPC in the presence or absence of steel fiber using locally available materials were investigated by Wille et al. **[16]**. He used silica powder (glass powder) as well as silica fume and fine sand to increase the reactivity. Allena and Newtson **[17]** presented a paper on using moist curing for UHPC and gained compressive strength (149.5Mpa) for fiber UHPC and (141.2Mpa) for plain UHPC. they conducted that plain UHPC is lower by 6% than fiber UHPC in compression strength

- **EXPERIMENTAL PROGRAM:**

3.1 Scope of Work

In this paper, an attempt was made to investigate the possibility of using steel hollow sections (CFST) in composite section by fully-encased in ultra-high performance concrete UHPC to benefit from its structural steel properties as a composite section with concrete and from its hollow core in economically benefit in reducing amount of required concrete in the section especially when an expensive concrete mix such as ultra-high performance concrete UHPC used. This hollow core may also can be used as a service segment in the building. The present work contains flexural behavior investigating of four experimental specimens to determine the usefulness of these steel hollow sections and then investigating them numerically. The numerical program included modeling nine numerical models with different variables of these steel hollow sections with presence and absence of a longitudinal reinforcement by removing it and lowering steel box position to be equivalent to longitudinal reinforcement. Details of experimental variables are shown in **Table 1**, while **Table 2** shows the details of numerical case studies in three group with different shape of steel hollow section. The used concrete mix was ultra high performance concrete mixture UHPC, which is relatively expensive, to reach the desired goal in the research by achieving economic benefit in this type of sections by reducing the amount of concrete by steel hollow core with maintaining its structural strength. **Table 2** below show comparison between solid and composite hollow beam with & without reinforcement with different shape of encased steel sections.

Table 1: geometry details of the experimental tested beams

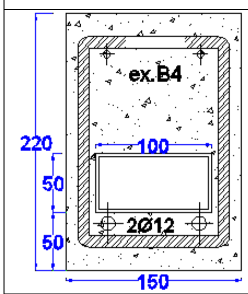
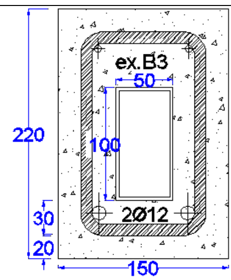
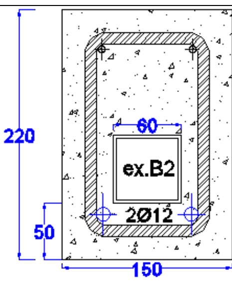
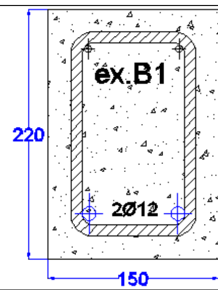
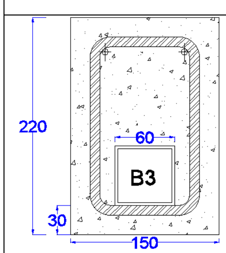
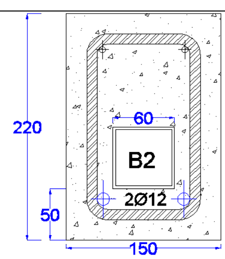
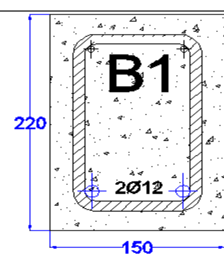
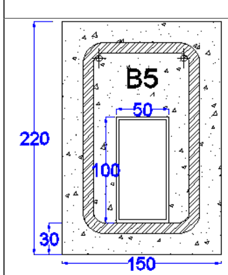
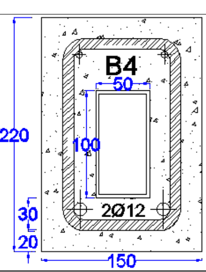
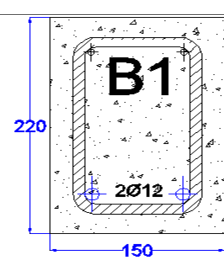
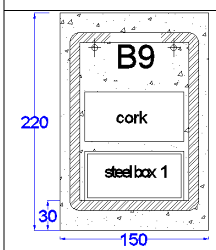
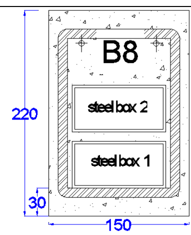
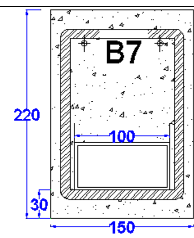
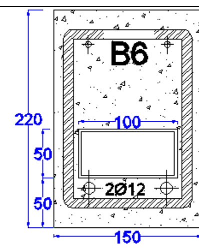
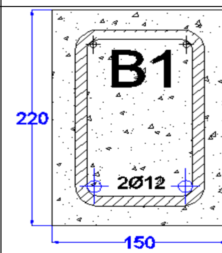
Experimental tested beams Group				Name of group
				Cross-section

Table 2: geometry details of the numerical case study models

composite hollow beam without rein.	Composite hollowbeam with rein.	Solid beam (control)	Type of beam
			GR.1 Using Square (60*60)mm² Steel box
			GR.2 Using Vertical

			rectangular (50*100)mm² Steel box

Composite hollow beam with steel and cork box	Composite hollow beam with 2-steel box	composite hollow beam without rein.	composite hollow beam with rein.	Solid beam (control)	Type of beam
					GR.3 Using Horizonal rectangular (50*100)mm² Steel box

3.1 Specimen preparation

All the UHPC beams were with actual dimensions overall depth, width and length (220, 150 and 1500)mm respectively, clear span was 1400 mm. All of beams were reinforced with two 2 mm diameter bars at top and 12 mm bars at bottom and 10 mm diameter stirrups spaced at 60 mm center to center the specimens preparation **Fig. 5.**

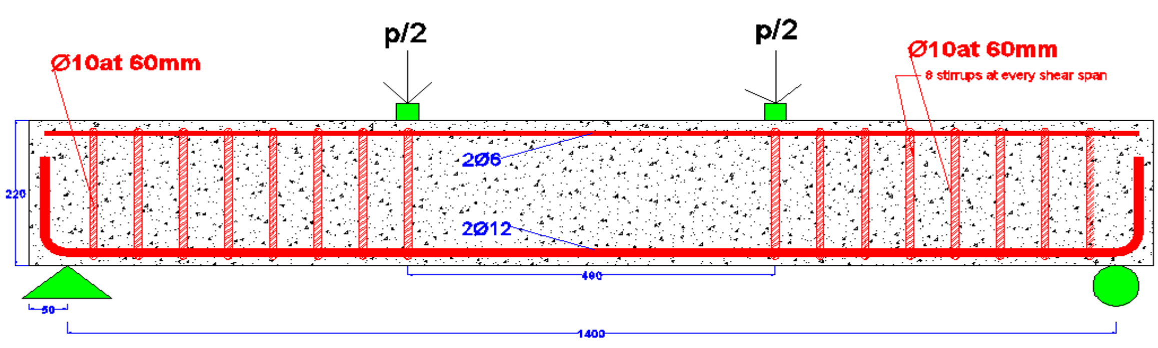


Fig.5: Flexural test and geometry (for control beam).

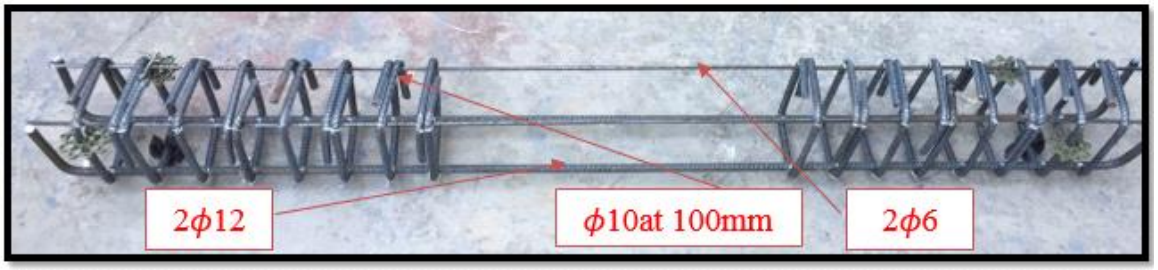


Fig.6: Experimental Reinforcement details

- **Materials**

- **Materials used in the UHPC mix**:

Among the attempts to develop concrete technology, the biggest concern is for the ultra high performance concrete UHPC. This mixture considered one of the most expensive concrete for lack of materials locally. In this work, some of its materials were imported from China. This mixture consists of (cement, silica fume, fine sand, steel fibers, water and Superplasticiser as high range water reducer). The process of properties testing for these materials was carried out at the University of Missan – Laboratory Engineering College. The used cement was ordinary Portland cement type-2. it was tested physically and chemically according to Iraqi standard No.5/1984 **[18]**. Physical and chemical properties are listed in the **Table 3**&**Table 4**. The fine sand was imported from DCP company and the maximum granular gradient was not exceeded 600μm. Results of its granular gradient testing were conforms to B.S. specification No. 882/1992 **[19,20]**as shown in **Fig.7**. Used steel fiber used was straight type as shown in **Fig.8** and its features shown in the **Table 5**. The used silica fume was a gray densified grade 920 D, it is imported from Al Khaim Company in UAE, its physical properties are shown in **appendix B**. The plasticizer used in the mixture was PC 260, imported from DCP company, conforming to ASTM C494-99 **[21]** type A and G as shown in **Appendix A.**

Table 3: Chemical Composition of used Cement

Oxide composition	Abbreviation	Content (percent) By weight	Limit of Iraqi specification No.5/1984
Lime	CaO	63.96	---
Silica	SiO_2	21.32	---
Alumina	AL_2O_3	4.58	---
Iron Oxide	Fe_2O_3	3.25	---
Sulphate	SO_3	2.48	< 2.8%
Magnesia	MgO	2.75	≤ 5%
Loss on Ignition	L.O.I	3.46	≤ 4%
Insoluble residue	I.R	1.07	≤1.5%
Lime saturation factor	L.S.F	0.97	0.66-1.02
Main compounds (Bogue's equations)			
Tricalcium Silicate	C_3S	50.69	---
Di Calcium Silicate	C_2S	18.28	---
Tri Calcium Aluminate	C_3A	8.14	---
Tetra Calcium Alumina Ferrite	C_4AF	9.89	---

Table 4: Physical Properties of the Cement

Physical properties	Test result	Limits of Iraqi Specification NO.5/1984	ASTM C150
Fineness Using Blain Air Permeability Apparatus (m^2/kg)	384	≥230	≥280
Setting time Using Victa's Method			
Initial (hrs: min.)	2:00	≥ 0:45 min	
Final (hrs: min.)	3:45	≤ 10 hrs	
Soundness Using Autoclave Method	0.22	< 0.8	
Compressive strength of mortar	20.8	≥15	≥12
3Days, MPa	27.4	≥23	≥10
7Days, MPa	34.7		
28 Days ,MPa			

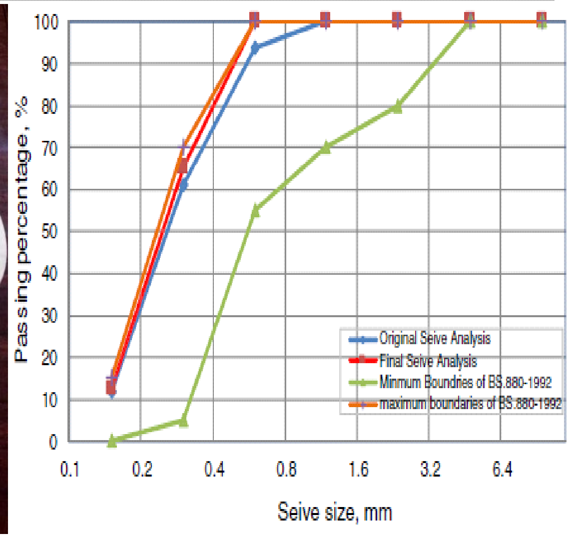


Fig.8: Sample of used steel fibers. **Fig.7:** Grading of fine sand

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Table 5: Characteristic of Used Steel Fibers

Modulus of Elasticity (GPa)	Tensile strength (MPa)	Diameter of Fiber (mm)	Length of fiber (mm)	Density (kg/m^3)	Type of steel fiber
210	***2600***	***0.175***	***13***	***7800***	*Straight*

- **UHPC Mixing proportion**

So far, there is no specification for the mix design of ultra high-performance concrete UHPC mixture, so it depends on the researchers' experience in determining its mixing proportions. In present research, several experimental attempts were made to reach a target compressive strength up to 150 Mpa. Experimental experiments showed that mixture containing the highest proportion of fine materials (cement+silica fume) and the lowest proportion of water and superplasticizer give higher compressive strength.The mixture proportions that gave a close result to the target compressive strength are shown in **Fig.9** below. The mechanical properties of these mixtures included testing cubes 100 mm and three cylinders 100 × 200 mm dimensions for compressive strength (fcu and f'c), three cylinders for the splitting tensile strength (f't), three 100 × 100 × 500 prisms for Modulus of rupture (f'r). all its test results and mode of failures are shown in **Fig.10**.

Fig.9: Mix Proportions, result compressive strength (fcu(

Fig.10: Test results of mechanical properties.

3.2.3. Steel materials

• Steel hollow sections

two types of hollow steel sections used in this research as shown in Fig. (4), the first was square hollow section (60*60)mm², and the second was rectangular hollow section (50*100)mm². Thickness of all steel sections was (2.8mm). The physical properties of these sections were tested according to ASTM A370-05**[22]**, to determine the yield stress and ultimate strength. The result of average yield stress was (fy =320mpa) and ultimate stress was (fu=600mpa).

• Steel reinforcement

In this research, a four size of steel reinforcement was used (ϕ6, ϕ10 , 12ϕ & ϕ16). all of steel reinforcement tested in University of Technology using the testing machine SANS 1000 kN according to B.S.4449/1997 **[23]**, the properties of these steel reinforcement are shown in Table 2.

• Stud Shear Connectors

Stud shear connectors were used to achieve full composite interaction between Concrete and steel hollow sections together by resisting shear flow forces during the loading.

Fig. (5) shows the welding process of the shear connectors.

Fig. 11:the welding of the shear connectors on steel hollow section.

3.2.4 molds of experimental program

In this work, four wooden mold were designed for the experimental models. Three of them were made of openings on both sides of the mold for the steel box to be fixed and installed to prevent movement during the casting process as shown in fig.4.

Fig. 11:Prepare molds before casting.

- **NUMERICAL INVESTIGATION**

A three dimensional model was modeled bythe widely used commercial program ANSYS. A three-dimensional model of the beams was modeling and analyzed by ANSYS software. Full interaction behavior was assumed between the steel section and the surrounding concrete in the numerical modeling, because the internal slip was not observed during the testing.

4.1 Description of the model

The Solid beam, non-composite hollow and composite hollow beams with a clear span of 1400 mm having simply supported end are modeled using ANSYS program. In order to reduce the wasted time, half the tested concrete beam (750 mm) was used for the modeling by used the benefit of the symmetry in the geometry, the properties of the materials and the symmetry in the loadings. the modeling of the concrete was done by used three dimensional brick element, and it is designation in ANSYS15 (solid 65 element), The geometry shape of this element consists of eight corner nodes and each corner accepts displacements in three directions (u, v and w in x, y and z direction respectively). As well as solid 65 element contains the option for plastic deformation (cracking) in three orthogonal directions. the longitudinal steel reinforcement were modeled by using 2-node discrete (link180 element). To overcome the concentration of stresses during the modeling when applying the load on the concrete, steel plates are used at the support and at the loading area. These steel plates and the steel hollow box are modeled using (solid185) element. And this element has eight nodes and each of these nodes have three degrees of freedom in three directions (x, y and z).

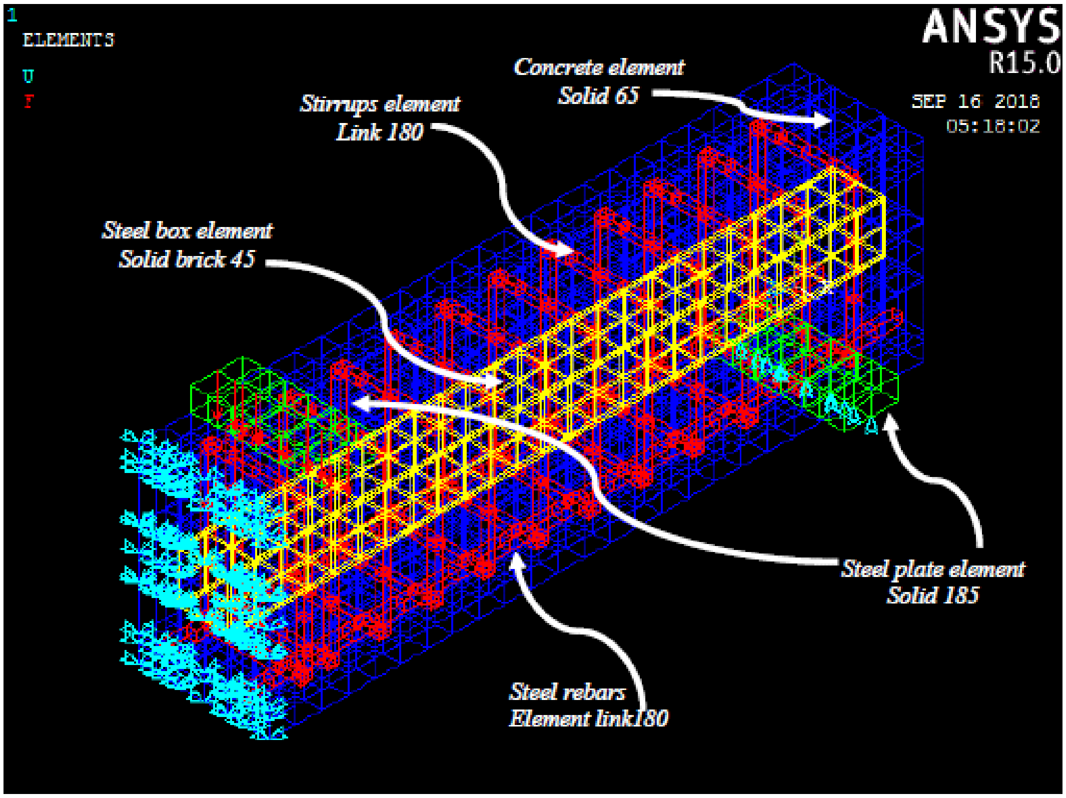


Fig.13: Typical details of FE mesh used for the analysis of concrete composite hollow beams.

- **RESULTS AND DISCUSSIONS**

5.1 Test setup and instrumentation

After the end of the treatment period for the test beams, they painted by white color to facilitate the viewing of the cracks, and then transferred to the test machine to applied the load by two loading points in the center of the specimen to investigate its flexural behavior. Each specimen was supported from the ends by two-steel rollers bearing on steel supports. The loading was performed by a hydraulic jack that was recently calibrated to provide the required load. Dial gauge is installed in the center of the specimen to measure displacement.

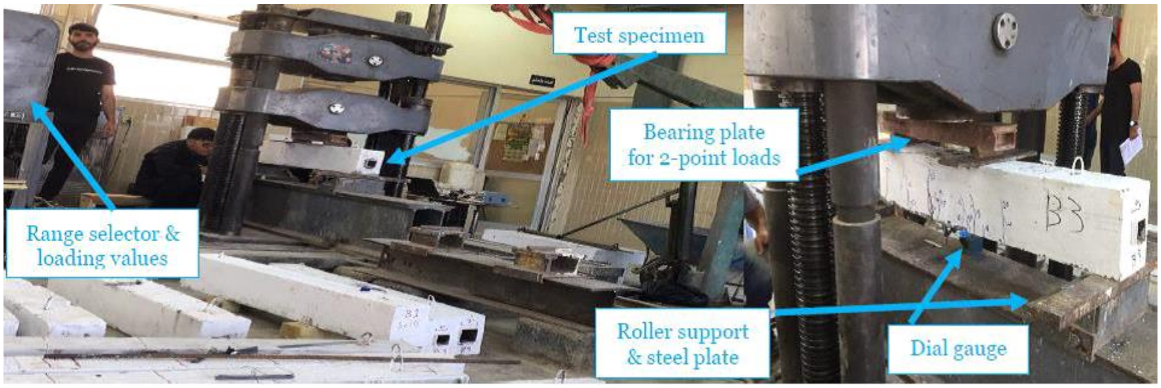


Fig.14: test setup of the experimental study.

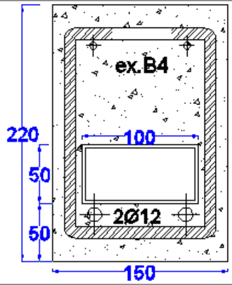
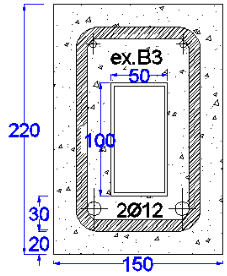
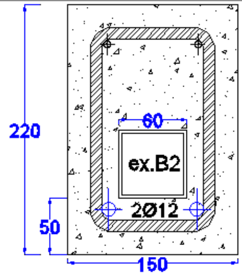
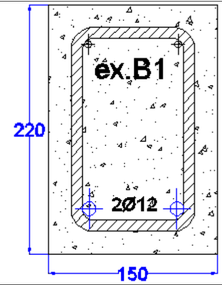
5.2 Ultimate load and moment capacity

- **For Experimental Beams**

The ultimate load and moment capacity of the experimental tested beams are shown in **Table 6**. It can be observed that flexural resistance of the composite hollow beams is generally higher than the corresponding non-composite beam. It is very clear that the reason for the resistance increase is to due to encased steel hollow section in the concrete. For specimens (exp.B1) and (exp.B2), a moment and load capacity increase of 118% when square steel box with geometric properties [A=(60*60)mm² and I=108,0000 mm4] encased in concrete, while this increase jumped to 122.7% when rectangular steel box with geometric properties [A=(50*100)mm² and I=416,6666 mm4] encased in concrete in (exp.B3) and it is explained by the effect of moment inertial of rectangular box higher than square box. While the increase jumped to 127.2% when horizontal rectangular box encased in concrete in (exp.B4). This result is explained by the horizontal position of the rectangular steel box providing an increase in the amount of steel material below the section higher than other steel hollow sections.

Table 6:Ultimate load and Moment capacity of the tested beams.

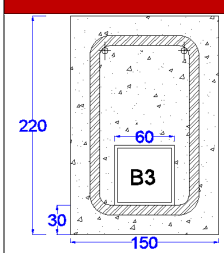
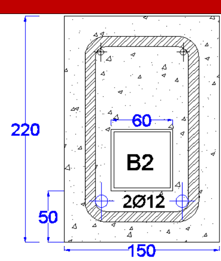
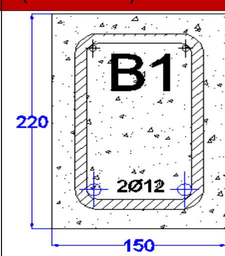
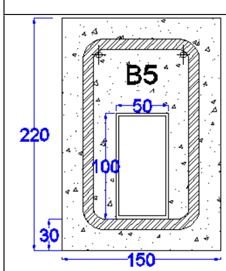
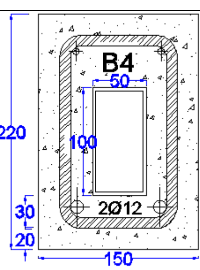
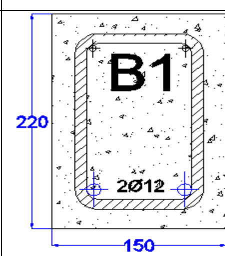
Experimental tested beams Group	Group Name

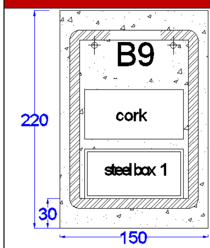
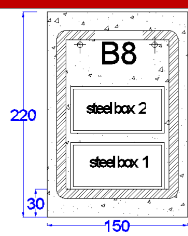
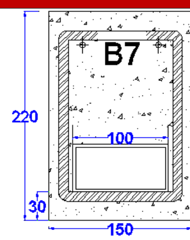
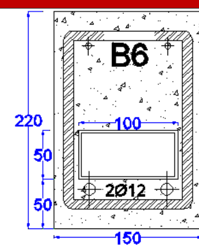
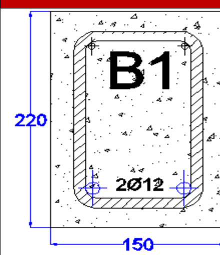
				Cross-section
250 kN	245 kN	240 kN	110 kN	Load capacity
58.3 kN.m	55.9 kN.m	55.9 kN.m	25.6 Kn.m	Moment capacity

- **FOR NUMERICAL CASE STUDIES MODELS**

In these models, a research was made to study the possibility of replacing the longitudinal reinforcement by steel hollow sections. These steel sections are further lowered below the section and leaving 30 mm as concrete cover. As shown in **Table 7**, the numerical models consist three types of beam. The fist one was non-composite solid beam (B1) as control specimen. The second type was composite hollow rein. beam contains steel hollow section located at (50mm) from the bottom fiber. The third type was composite hollow non-rein. Beam which is doesn't reinforce with any longitudinal rebars and replacing it by steel hollow section at (30mm) from bottom fiber. From the table it is noticed clearly that composite hollow beams capacities were higher than non-composite solid beam (B1). In GR.1 when using square box (60*60)mm² it is noticed that composite hollow rein. Beam (B2) shows capacities higher by 120% than solid beam (B1), and the composite hollow non-rein. Beam (B3) was higher by 52.8% than solid beam (B1). In GR.2 when rectangular steel box used the capacities of composite hollow rein. Beam (B4) was higher by 114% than solid beam (B1), and composite hollow non-rein. Beam (B5) was higher by 63.3% than (B1). In GR.3 when horizontal rectangular box was used. It is noticed clearly that composite hollow rein. Beam (B6) shows capacities higher by 138.5% than (B1), and composite hollow rein. Beam (B7) was higher by 81.5% than (B1). The composite hollow non-rein. Beam (B8) shows the higher capacities than all of the tested beams, and higher by 154.3% than solid beam (B1). And this is because the encasing of two-steel box inside the concrete.

Table 7: Ultimate load and Moment capacity of the tested beams.

composite hollow beam without rein.	composite hollow beam with rein.	Solid beam (control)	Type of beam
			GR.1 Using Square (60*60)mm² Steel box
174.3 kN	251 kN	114 kN	Load capacity
53.6 Kn.m	24.4 Kn.m	25.6 Kn.m	Moment capacity
			GR.2 Using Vertical rectangular (50*100)mm² Steel box
186.2 kN	244.9 kN	114 kN	Load capacity
67.6 kN.m	55.9 kN.m	25.6 Kn.m	Moment capacity

Composite hollow beam with steel and cork box	Composite hollow beam with 2-steel box	composite hollow beam without rein.	composite hollow beam with rein.	Solid beam (control)	Type of beam
					GR.3 Using Horizontal rectangular (50*100) mm² Steel box
214.4 kN	290 kN	207 kN	272 kN	114 kN	Load capacity
46.6 kN.m	57.1kN.m	55.7 kN.m	55.9 kN.m	53.6 Kn.m	Moment capacity

5.3Load – deflection relationship

- **For Experimental Beams**

The load-deflection curve of the tested beams shown in **Fig.15**. We note that all tested beams are identical at the beginning of loading but the non-composite solid beam (B1) at first crack load 70 kn is move away in the deflection direction and gives high deflections, indicating that concrete lost its resistance to tensile stresses. The curves of composite hollow beams with different steel boxes have differing ultimate loads from each other, but have almost the same deflection at failure.

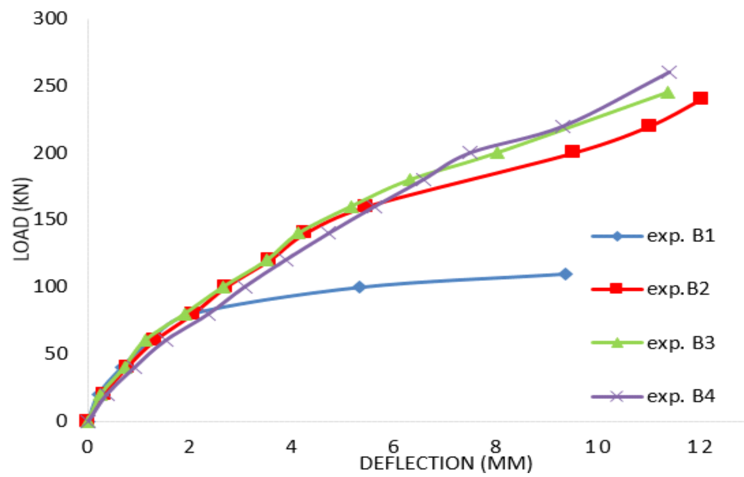


Fig.15: Load-deflection relationships of the experimental tested beams.

- **For Numerical Case Studies Models**

The deflection of all numerical case study models was measured in the mid-span of model under bottom surface for the comparing purpose. The deflection measurements may give a logical reasons for the model carrying capacity. load-deflection curves of all numerical models was divided into three groups as shown in the **Fig.16** below. It is noted that the non-composite solid model (control beam) in all comparisons gave a behavior far from other models in terms of maximum load and deflections was high compared with deflections of composite hollow models at specific loads. In GR.1, it observed clearly that (B2) model, which contains reinforced with longitudinal rebars, gave maximum load and less deflections compared to the rest models. But the model (B3) which has non-reinforced and removed longitudinal rebars from it and replaced it completely by lowering steel box location by 20 mm more than (B3), it gave less load and more deflection than (B2), but remains more better than non-composite solid reinforced model (B1). In GR.2, the composite reinforced model (B4) show maximum capacity and less deflections compared to the non-reinforced composite model (B5) , but the non-reinforced composite model still better in all respects than the normal reinforced solid model (B1). In GR.3, several details noticed, such that the non-reinforced model but contains two encased steel boxes (B8) gave higher capacity than others. The capacity of reinforced composite model contains one steel box (B6) higher than non-reinforced composite model (B7). But non-reinforced model, which was has steel box below and hollow core in the middle of section (B9) show us good properties compared to the reference solid model (B1). The structural property is by increasing capacity and economic property by decrease amount of used UHPC expensive mix.This (B9) model show a very large increase in the maximum-deflection compared to the rest of models due to the presence of the large hollow core which fabricated by cork in the center of the section, which led to reduction in the Moment of inertia of the section.

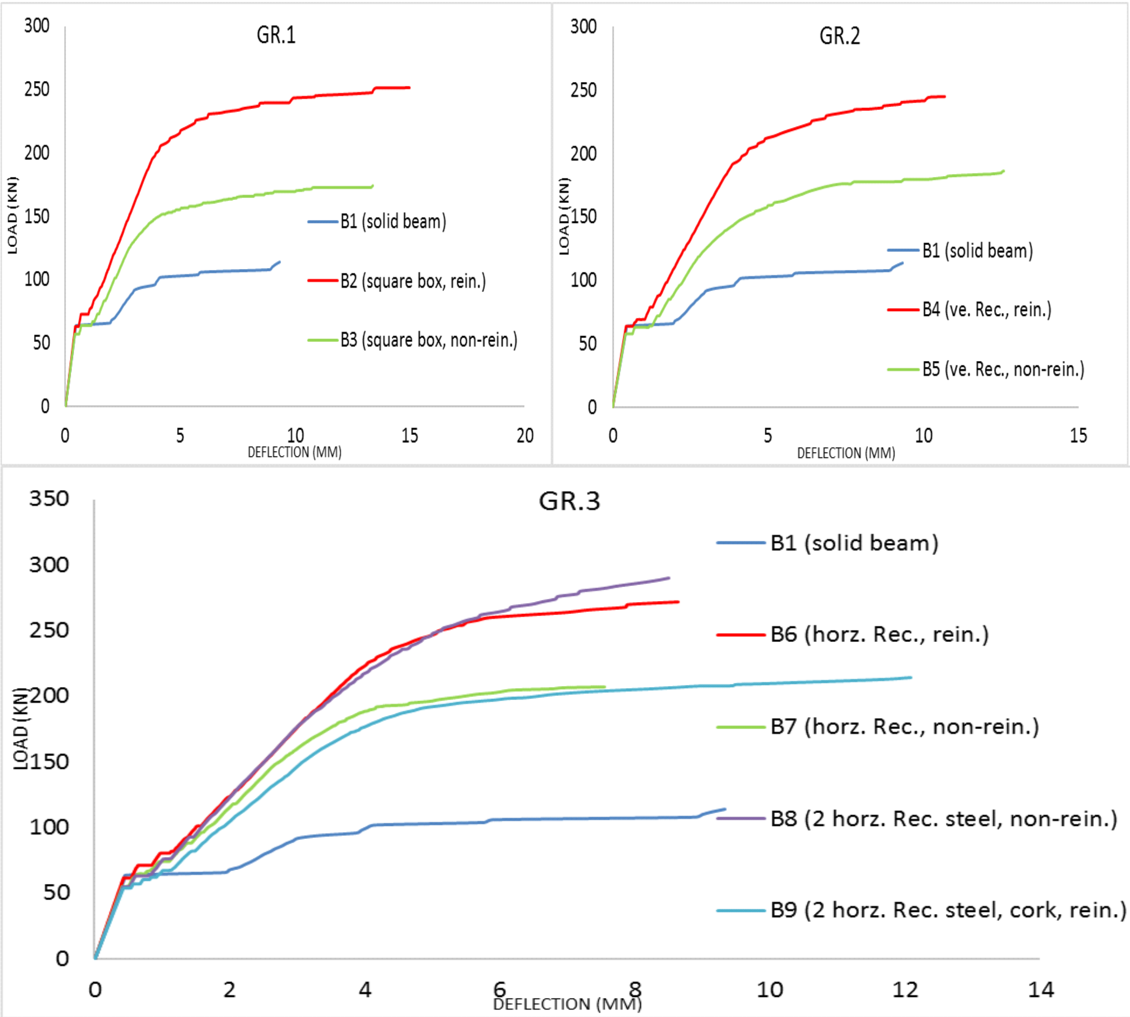


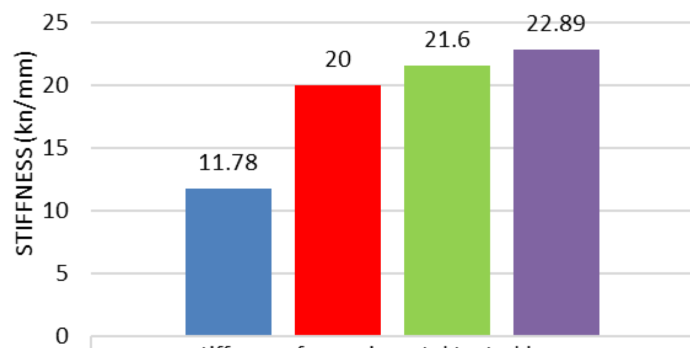
Fig.16: Load–deflection relationships of the numerical case studies.

5.4 STIFFNESS COMPARSIONS FOR THE TESTED BEAMS

Stiffness can be defined as the load required to cause one unit deflection. In this study, the stiffness values were calculated at the ultimate point stage by dividing the maximum load value on the maximum deflection value.

- **For Experimental Beams**

The values of stiffness for the experimental tested beams are shown in **Fig.17** below. A very significant increase observed in the stiffness for composite hollow beams higher than non-composite solid beams. The figure shows that the stiffness increased by 69.7% when square steel hollow box encased below the section in (exp.B2) higher than control solid beam (exp.B1). It is also noted that the use of a rectangular steel box in (exp.B3) instead of a square steel box in (exp.B2), leads to the increase in stiffness by 8% as a result of the difference in moment of inertia between the square and rectangular shape of steel hollow box. It is also noted that increasing the amount of steel material in the tension zone by placing the rectangular steel box horizontally in (exp.B4) led to a greater increase stiffness higher than all other experimental beams.



	stiffness of experimental tested beams
exp. B1 (solid beam)	11.78
exp.B2 (square box, rein.)	20
exp. B3 (ve. Rec. box, rein.)	21.6
exp. B4 (horz. Rec. box. rein.)	22.89

Fig.17: Stiffness values of the experimental tested beams.

- **For Numerical Case Studies Models**

The values of stiffness for the numerical cased studied models are listed in the **Fig.18** below. It is noted that stiffness of non-composite solid model (B1) less than the stiffness of composite models. It is also noted in GR.1 that the composite model, which contains square steel box and also reinforced with longitudinal rebars (B2) shows the larger stiffness than others. the stiffness of non-reinforced composite hollow beam (B3) was less than (B2) by 28.6%, but it is still greater than reinforced solid beam by 6.5%. In GR.2, which is considering studies the encasing of rectangular steel box, once with presence of a longitudinal reinforcement, and once again in the absence of longitudinal reinforcement by lowering steel box location by 20 mm. it is noted that the composite model (B5) which is not reinforced with longitudinal rebar is less than the reinforced composite model (B4) by 54.7% but larger than the reinforced solid model (B1) by 21.3%. In GR.3 it is noticed that the model (B8), which contains two-steel boxes at the bottom of section, shows the maximum stiffness among the models. And the economic model (B9), which contains one-steel box at the bottom and hollow core in the center of section by removed a large part of the concrete and removal longitudinal reinforcement shows a stiffness higher than non-composite solid model (B1) by 45.4%.

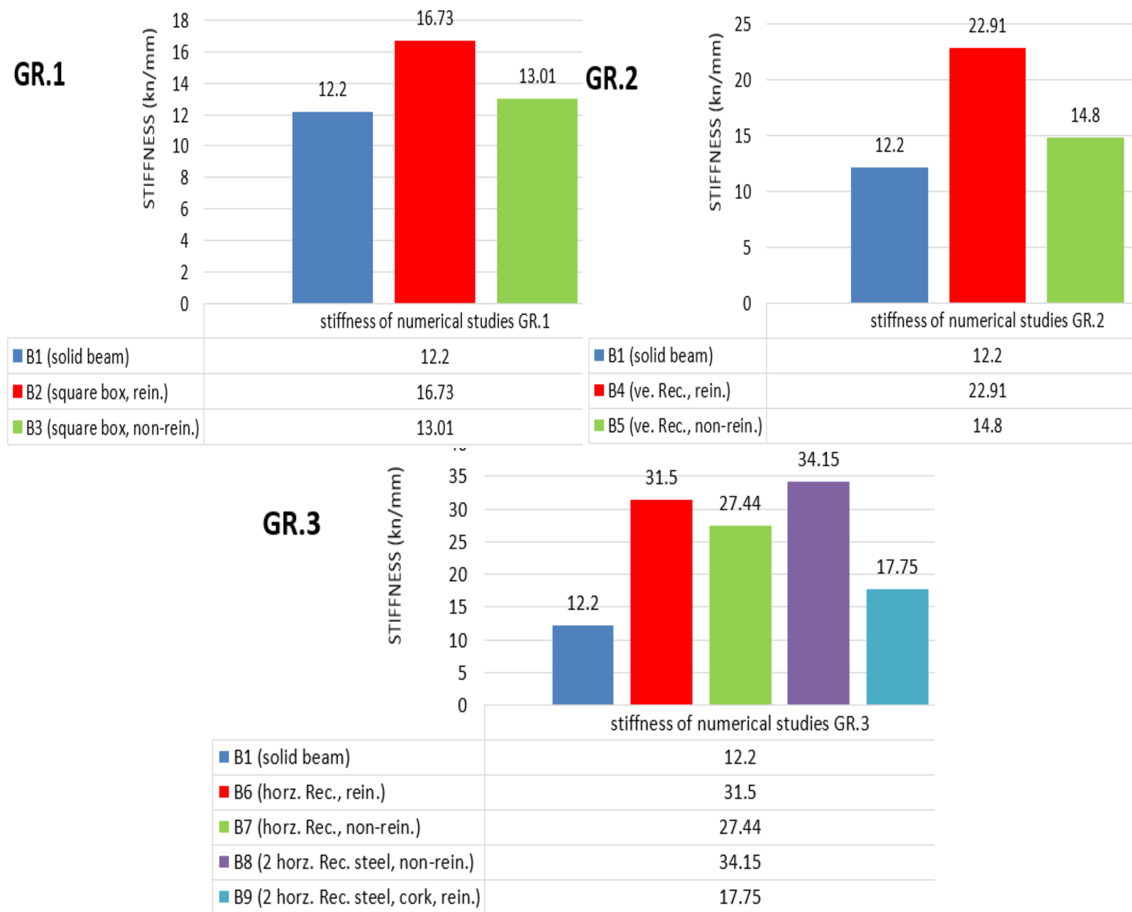


Fig.18:Stiffness values of the numerical case studies groups.

5.5 Comparison between analytical and experimental behavior

Validation of the all finite element models was carried out using experimental results. The experimental and numerical results showed very close affinity in all models. The convergence of experimental and numerical results will be summarized as follows:

- Ultimate load comparison between experimental and numerical analysis:

a comparison between the ultimate load values of the experimental and the numerical results, as shown in **Table 8** below, it is noted there is no significant change in the values between them.

Table 8: Analytical and experimental comparison at ultimate stage.

Ultimate load Pu (Kn)			Sample
%Difference	**Experimental**	**Analytical**	
3.5%	**110**	**114**	B1(solid beam)
4.5%	**240**	**251**	B2 (square box, rein.)
0.04%	**245**	**244.9**	B3 (ver. Rec. box, rein.)
8.8%	**250**	**272.1**	B4 (hor. Rec. box, rein.)

- Comparison between experimental and analytical load-deflection behavior of the tested beams.

The experimental and numerical results were compared in terms of the load-deflections curve of all the models. Very little difference was observed between the experimental and numerical results, where the numerical results of load-deflection curve had less deflections values than the experimental results.

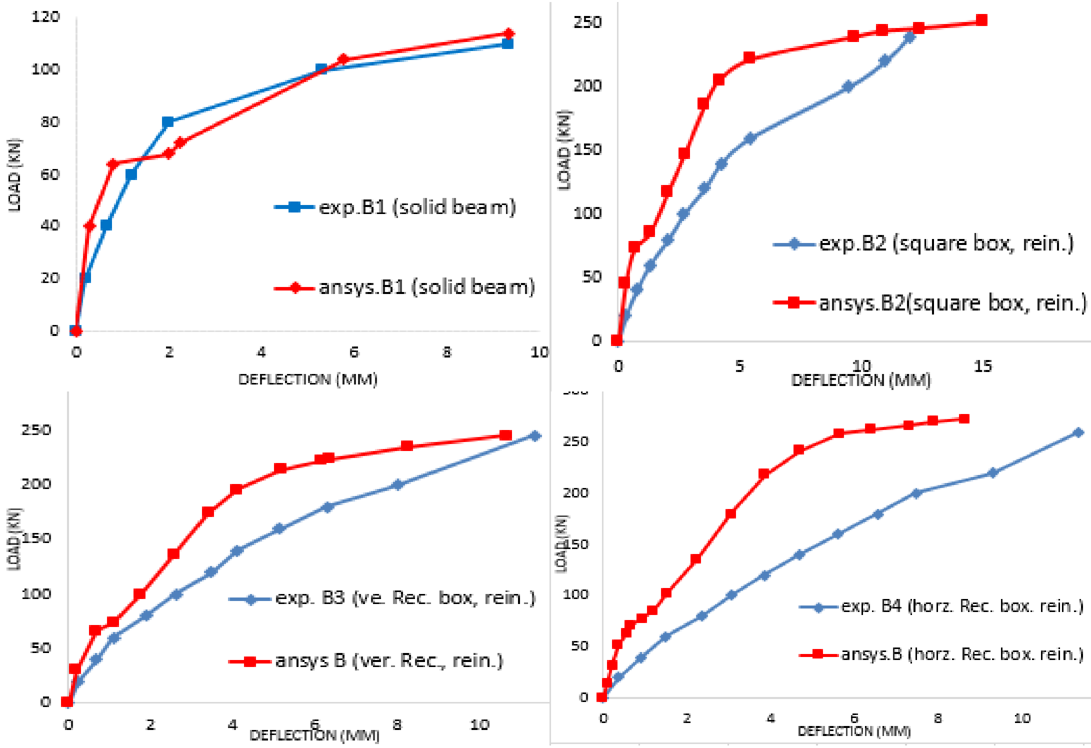


Fig.19: Comparison between experimental and analytical load-deflection behavior of the tested beams.

6. CONCLUSIONS

- In the experimental part, the composite hollow beams show resistance to bending forces higher than non-composite solid beam. As the composite hollow beam containing a square hollow section gave a flexural capacity and stiffness higher by 118% and 67% than the solid beam.
- In the experimental part, the composite hollow beam, which contains a rectangle steel box, show resistance to bending and stiffness higher by 2% and 8% than the composite hollow beam containing a square steel box, giving an impression of the effect of the steel section shape and its moment of inertia on the behavior of composite beam.
- In the experimental part, the composite hollow beam, which increased its of steel material section at the bottom of the section through encasing the rectangular steel

box horizontally, showed resistance to bending curvature and stiffness higher than other models.

- The finite element model has proved to be effective in terms of evaluating the ultimate load capacity and load-deflection behavior. It was found good correlations between what was modeled and the actual experimental results have been achieved.
- In the numerical part, the composite hollow beam model has been encased by square steel box show bending resistance and stiffness higher by 120% and 37% than solid beam model. Also, when the square steel box position was lowered and replaced with longitudinal reinforcement, it gave bending resistance and stiffness by 52.8% and 6.5% than the solid beam model.
- In the numerical part, the composite hollow beam model has been encased by rectangular steel box show bending resistance and stiffness higher by 114.8% and 87% than solid beam model. Also, when the rectangular steel box position was lowered and replaced with longitudinal reinforcement, it gave bending resistance and stiffness by 63.3% and 21.3% than the solid beam model.
- In the theoretical part, the model, which was encased with two-steel boxes in the section, gave bending resistance and stiffness higher by 154% and 179.9% than the solid beam model and also saving economic cost by reducing the amount of UHPC used material.
- In the theoretical part, the model that has been encased with horizontal rectangular box at the bottom of section instead of the longitudinal reinforcement and also a hollow core was done above it with the same dimensions by cork to reduce the amount of costly UHPC mix. It gave resistance to bending and stiffness higher by 88% and 45.4% than the solid beam.

- **REFERENCE**

- STN EN 1994–1–1: Eurocode 4: Design of Composite Steel and Concrete structures. Part 1–1: General Rules and Rules for Buildings.
- STN EN 1994–2: Eurocode 4: Design of Composite Steel and Concrete Structures. Part 2: General Rules and Rules for Bridges.
- STN EN 1992–1–1: Eurocode 2: Design of Concrete Structures. Part 1–1: General Rules and Rules for Buildings.
- STN EN 1993–1–1: Eurocode 3: Design of Steel Structures. Part 1–1: General Rules and Rules for Buildings.
- Neelima Khare, V.S. Shingade, Flexural and shear response of concrete encased steel beams, IJIRSET J. 5 (7) (2016) 13482–13491.
- Neelima Khare, V.S. Shingade, Experimental study on performance of composite beams with and without shear reinforcement, Int. J. Eng. Res. Develop. 12 (7) (2016) 10–16.
- Ahmed Youssef Kamal, Encased beam with variable upper steel flange position, Int. J. Appl. Innov. Eng. Manage. (IJAIEM) 4 (4) (2015) 60–66.
- V. Kvocˇa´ ka, L. Draba, Partially–encased composite thin–walled steel beams, Procedia Eng. 40 (2012) (2012) 91–95.
- A. Ammar, N. Saad, S. Wael, Strength and ductility of concrete encased composite beams, Eng. Tech. J. 30 (15) (2012).
- AISC, Specification for Structural Steel Buildings, American Institute of Steel Construction, Chicago, IL, 2010.
- Pierre Richard, Marcel Cheyrezy, Composition of reactive powder concretes,Cem. Concr. Res. 25 (7) (1995) 1501–1511.
- Byung Hwan Oh, Flexural analysis of reinforced concrete beams containing steel fibers, J. Struct. Eng. 118 (10) (1992) 2821–2835.
- Samir A. Ashour, Faisal F. Wafa, Flexural behavior of high–strength fiber reinforced concrete beams, Struct. J. 90 (3) (1993) 279–287.

- Giuseppe Campione, Maria Letizia Mangiavillano, Fibrous reinforced concrete beams in flexure: experimental investigation, analytical modelling and design considerations., Eng. Struct. 30 (11) (2008) 2970–2980.
- D.H. Lim, B.H. Oh, Experimental and theoretical investigation on the shear of steel fibre reinforced concrete beams, Eng. Struct. 21 (10) (1999) 937–944.
- Kay Wille, Antoine E. Naaman, Gustavo J. Parra-Montesinos, Ultra-High Performance Concrete with compressive strength exceeding 150 MPa (22ksi): a simpler way, ACI Mater. J. 108 (1) (2011).
- Srinivas Allena, Craig M. Newtson, Ultra-high strength concrete mixtures using local materials, J. Civil Eng. Arch. 5 (4) (2011).
- IQS 5/1984 " Portland cement Central Organization for Standardization and Quality Control Iraq" (in Arabic).
- B.S. 882. Specification for aggregates from Natural sourcesfor concrete. British Standards Institute; 1992.
- Iraqi Specification Limit. Aggregate from Natural Sources for Concrete, No.45/1984.
- ASTM C 494/C 494M – 1999. Standard Specification for Chemical Admixtures for Concrete, vol. 04.02; 1999. p. 1–9.
- ASTM A 370-05, "Standard Test Method and Definition for Mechanical Testing of Steel Products," 2005 Annual Book of ASTM Standards, Vol.01.01, ASTM, Philadelphia, PA., 2005.
- ASTM C78-02. Standard test method for flexural strength.

Appendix B. Chemical and Physical Requirements of Silica Fume ASTM C 1240-04 [21].

Requirement	Analysis %	Limit of specification requirement ASTM C1240
SiO_2	86.46[a]	>85.0
Moisture content	0.68[b]	<3.0
L.O.I	4.02[a]	<6.0
Percent retained on 45-μm (No. 325) Sieve, Max.	7	<10
Accelerated Pozzolanic Strength Activity Index with Portland Cement at 7 days, Min. Percent of Control	128.6	>105
Specific surface, Min, cm^2/g	210,000	>15

Appendix A. Technical Description of Flocrete PC 260*.

Chemical base	Modified polycarboxylates based polymer
Appearance/colors	Light yellow liquid
Freezing point	−7 °C approximately
Specific gravity@25 °C	1.1 ± 0.02
Air entrainment	Typically less than 2% additional air is entrained above control mix at normal dosages
Dosage	0.5–4.0 l/100 kg of binder
Storage condition/shelf life	12 months if stored at temperatures between 2 °C and 50 °C