International Conference on Advances in Structural and Geotechnical Engineering

ICASGE'19

25-28 March 2019, Hurghada, Egypt

Paper title

Experimental and numerical study on RC beams with Stay-In-Place GFRP Forms

K.M. El-sayed[1], H.M.Refaat [2], E.A.Radwan [3]

[1] *Assoc. Prof. Civil Engineering Department, Faculty of Engineering in Benha, Benha, Egypt, E-mail:Khelsayed@hotmail.com*

[2] *Assoc. Prof. Civil Engineering Department, Faculty of Engineering in Benha, Benha, Egypt, E-mail:hala.abusafa@bhit.bu.edu.eg*

[3] *PHD Student Civil Engineering Department, Faculty of Engineering in Benha, Benha, Egypt, E-mail:Braaemad@yahoo.com*

ABSTRACT

The present study concerned with studying the flexural behavior of RC beams with stay in place (SIP) forms, which can be used as a novel construction technology. Eight specimens were prepared, five of them with SIP form and three specimens were prepared conventionally. The specimens were tested in flexure under four-point bending loads. All the specimens had hollow unreinforced longitudinal PVC tube, located at tension side to reduce specimen weight. The used SIP forms were made from glass fiber reinforced polymer (GFRP). The GFRP forms were extended at compressive side forming hooks in order to enhance their bond with concrete and, also, to avoid a premature lateral local buckling. The forms were provided, also, with lateral clips GFRP to improve their bond with concrete, and to avoid a premature lateral buckling. The tested specimens can be divided into three groups. The first group contains three specimens, which prepared conventionally (without SIP forms) with different reinforcement steel bars (10, 12 or 16 mm diameter) at tension side. The second group includes three specimens similar to those of the first group but with SIP forms. The third group contains two specimens similar to the first specimen of the second group but they were strengthened at tension side with additional longitudinal sheets of carbon fiber reinforced polymer (CFRP) or glass fiber reinforced polymer (GFRP) in order to increase their flexural resistance.

The experimental results included ultimate load, load-deflection and load-strain relationships. The cracking behavior and failure mode were observed and recorded. The experimental results showed a significant improvement in the flexural behavior of the tested specimens with SIP forms compared to the corresponding conventional ones.

The tested specimens were simulated numerically using ANSYS (version 15). The numerical values of ultimate load were almost higher than the corresponding experimental value; up to 18%.

Keywords: RC beams, Flexure failure, Stay-in-place forms, Fiber Reinforced Polymer.

ظهرت في الآونة الأخيرة أنظمة إنشائية لتستخدم في إنشاءات المستقبل بدلا من الأنظمة الإنشائية الحالية ومنها الفرم الباقية في المكان المصنوعة من البوليمرات المسلحة بالالياف لما لها من سهولة وسرعة في التنفيذ فضلا علي المقاومة العالية لكافة الاجهادات المطلوبة بعناصر المباني السكنية وغيرها مما حدا بنا لدراسة السلوك الانحنائي للكمرات الخرسانية المسلحة المصبوبة بالفرم الباقية في المكان من خلال اختبارات معملية ودراسة تحليلية لعدد ثمان كمرات بإبعاد ١٦٠ مم عرض٢٨٠مم ارتفاع وطول ٢٥٠٠مم تم اختبارها جميعا من خلال حمل علي اربع نقاط تحميل مقسمة إلي ثلاثة مراحل الأولي تحتوي علي ثلاث كمرات بدون فرم وتسليح من سيخين قطر ١٠مم ناحية الضغط وسيخين قطر ١٠مم و١٢مم و١٦مم علي الترتيب ناحية الشد والثانية تحتوي علي ثلاث كمرات تشابه المرحلة الاولي ولكن تم صبها في الفرم الباقية في المكان التي تم تصنيعها في المعمل باستخدام قالب بطريقة الضغط وثلاث طبقات من الألياف الزجاجية وزن 420 جم/م2 ومادة جامعة من الايبوكسى اما المرحلة الثالثة فهي لكمرتين مثل الكمرة الأولي من المرحلة الثانية و تم تقويتها باستخدام ثلاثة طبقات من الياف الزجاج والكربون علي الترتيب اختبرت وتم توقيع العلاقة بين الحمل والترخيم حتي الكسر لكل عينة كما تم عمل نموذج عددي علي الحاسب الآلي باستخدام برنامج ANSYS - version 2015 وأسفرت النتائج عن فرق بين النتائج المعملية التحليلية بمقدار ١٨%.

1. INTRODUCTION

Recently, the evolution of stay-in-place FRP forms has given a great hope for the future structures owing to its ability to carry higher loads, where the FRP forms have a considerable capacity to resist stresses instead of or beside to the conventional steel reinforcement. For RC beams, SIP forms contribute to resist bending moments and shearing forces. In addition, this type of beams has the advantage of rapid execution, saving in construction equipment and being more economic as regards the expenses of labor required for the construction. Moreover, the it allows smaller cross sections than the conventional RC beams, which reduce the dead loads of the structure and consequently less columns and foundation cost.

Reviewing the previous researches in this aspect, it's obvious that studying the flexural behavior of concrete beams using stay in place FRP forms hasn't been effectively done in a manner that makes its application easy and overcome the disadvantages of use, especially, lateral buckling of the FRP form flanges.

Hart Noah Honickman (2008) provided a study on eight concrete slabs and nine girders constructed using pultruded GFRP sections as SIP formworks. No tension steel reinforcement was used. All specimens were tested in four-point monotonic uniaxial bending. Four adhesive and mechanical bond mechanisms were explored to accomplish composite action. The most effective mechanism, considering structural performance and ease of fabrication, was wet adhesive bonding of fresh concrete to GFRP. Although failure was by debonding, no slip was observed prior to failure.

Olivier Remy (2012) investigated a newly developed fiber reinforced cement composite; a Glass Fiber Reinforced Inorganic Phosphate Cement Composite or GFR.IPC. The main objective of this study was to demonstrate the structural potential of GFR.IPC composite and its possible use in future building applications. GFR.IPC composite was used to produce an innovative lightweight SIP forms. Two new concepts for formwork elements were proposed: one for beams (Beam.Box), and one for slabs. Both systems were designed for residential housing and more in specific within the scope of renovation and retrofitting. This work illustrated the structural feasibility of the Beam.Box concept. A reduction of more than 50% by weight was observed compared to the use of traditional forming techniques and traditional reinforcement.

Mark Stewart Nelson et al. (2013), carried out an experimental investigation on ten bridge deck sections, which composed of Fiber Reinforced Polymer (FRP) composite ribbed panels, acting as both permanent formwork and bottom slab reinforcement. Several critical parameters were examined, namely: varying of the width of the deck specimens relative to their spans, and varying interface bond condition, concrete strength and loading location on the deck. Varying concrete strength from 17 MPa to 42 MPa in identical decks resulted in 20% increased capacity but did not influence stiffness. Applying adhesive bond at FRP–concrete interface to create a fully composite section increased the deck strength and initial stiffness by 30% and 73%, respectively. In decks with adhesive bond, loading directly above the FRP splice resulted in a 20% lower strength than loading half-way between splices. This is an opposite trend to that observed in decks without adhesive bond.

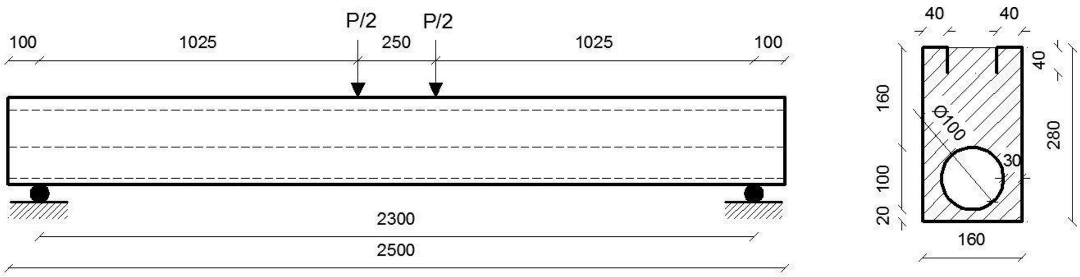
2. EXPERIMENTAL PROGRAM

An experimental program was carried out to assess the potential of using stay-in-place FRP form in improving the flexural behavior of RC beams. All the tested specimens were half-scale simply supported beams. The dimensions of the tested specimens were chosen in order to fail due to flexure.

2.1 Details of tested specimens

Eight RC beam specimens were prepared. All of them have the same dimensions (160 mm width, 280 mm height & 2500 length), as shown in Fig. 1. The tested specimens were designed to be simply supported with clear span 2300 mm. All the tested specimens were internally reinforced by steel bars. The compression side was reinforced by two longitudinal bars of 10 mm diameter, in all specimens, however the tension side had two longitudinal steel bars of different diameters (10, 12 and 16 mm), which is a parameter of study. The transversal reinforcement was stirrups of 8 mm diameter and 200 mm spacing. All the specimens had hollow unreinforced longitudinal PVC tube, of 100 mm diameter, and located at tension side in order to reduce the specimen weight. The used SIP forms were made from glass fiber reinforced polymer (GFRP) consisted of three layers of glass fiber fabrics. The GFRP forms were extended at compressive side forming hooks in order to enhance the bond between the forms and concrete and, also, to avoid a premature lateral local buckling in the GFRP form. All the specimens with SIP forms were provided with lateral clips made from GFRP strands of 8 mm diameter and 200 mm spacing, and located at the specimen middle height. These clips contribute in improving the bond between the forms and concrete, and to avoid a premature lateral buckling in GFRP forms.

The specimens are divided into three groups, as shown in Figs. (2 to 4) & Table 1. The first group contains three specimens (R 2Ø10, R 2Ø12 & R 2Ø16) which prepared conventionally (without SIP forms) with two longitudinal steel bars at tension side of 10, 12 and 16 mm diameter, respectively, as shown in Fig. 2. The second group includes three specimens (SIP 2Ø10, SIP 2Ø12 & SIP 2Ø16) which had SIP forms, and internally reinforced at tension side with two longitudinal steel bars of 10, 12 and 16 mm diameter, respectively, as shown in Fig. 3. The third group contains two specimens (SIP-R3C & SIP-R3G) which, also, prepared with SIP forms. To increase the flexural resistance of the specimens of this group, the lower side of the SIP forms were reinforced at its interior surface by three longitudinal sheets of carbon fiber reinforced polymer (CFRP) and glass fiber reinforced polymer (GFRP), respectively, as shown in Fig. 4.



imensions in mmAll d

Fig. 1: Dimensions of the tested specimens.

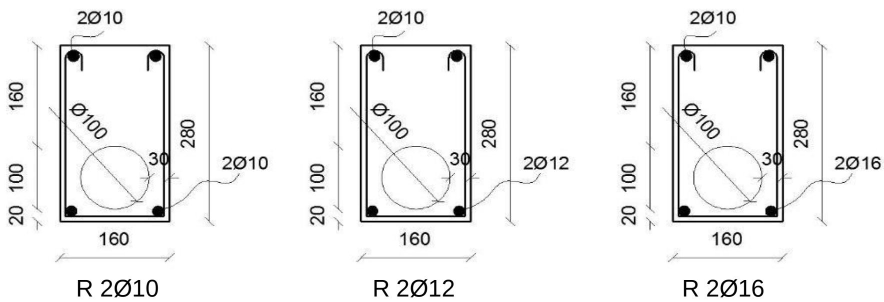


Fig. 2: The specimens of first group.

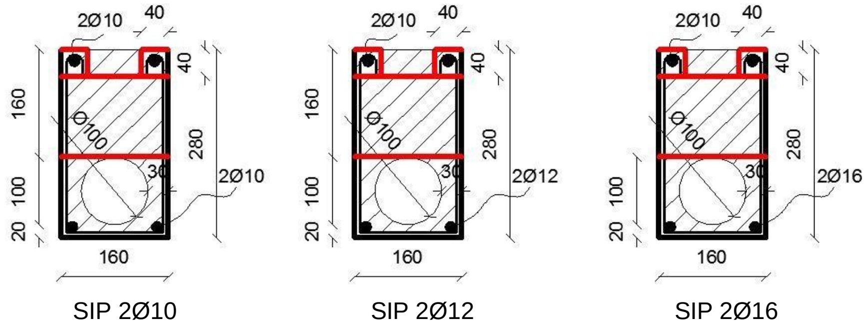


Fig. 3: The specimens of second group.

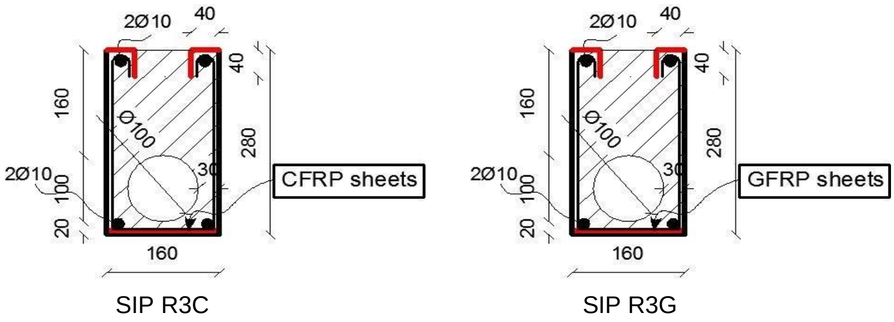


Fig. 4: The specimens of third group.

Table 1: The experimental test program.

Group	Specimen code	Specimens Description		
		form SIP Reinforcement	Bottom Reinforcement	Transversal reinforcement
No. 1	R 2Ø10	No SIP forms	2 Ø 10	5Ø8 Vl. S.mm 200 @ tirrups
	R 2Ø12		2 Ø 12	
	R 2Ø16		2 Ø 16	
No. 2	SIP 2Ø10	3 layers of Glass fiber sheets	2 Ø 10	5Ø8 Vl. Stirrups @ 200 mm. + 5Ø8 Hl. GFRP Clips @ 200 mm.
	SIP 2Ø12		2 Ø 12	
	SIP 2Ø16		2 Ø 16	
No. 3	SIP R3C		2 Ø 10 + 3 layers of carbon fiber sheets	
	SIP R3G		2 Ø 10 + 3 layers of glass fiber sheets	

2.2 Preparation of tested specimens

Stay-In-Place FRP Forms were fabricated in the Concrete Lab. of Faculty of Engineering in Benha. A special metallic mould was used to compress the GFRP forms, the mould was made from aluminum chequered plate, as shown in Fig. 5. All GFRP forms were produced using three layers of E-glass woven roving, sika wrap-hex 430 G from sika Egypt Company. The fiber was impregnated by unsaturated polyester with a peroxide hardener. Using a smooth surface of melamine wood covered by gel-coat, the FRP forms were produced by the aluminum mould successively. The GFRP forms were prepared to fulfill the required dimensions of the specimens. The GFRP forms were compressed then a hot light of metal halide lamb 400 watt is used for curing of GFRP composite. Some of the produced stay-in-place forms are shown in Fig. 6.

Concrete mix was placed to a depth of 20 mm then the PVC tube was installed, then the concrete placing was continued to fill all depth of the form. The concrete was vibrated mechanically and the concrete surface was finished. The specimens were left in the lab atmosphere until testing date.

Fig. 5: The aluminum chequered plate mouldused for manufacturing of FRP forms.

Fig. 6: The FRP forms used for stay-in-place RC beams.

3. MATERIAL PROPERTIES

3.1 Concrete

A trial mixes were prepared and a suitable mix was selected to get a target cubic compressive strength of 300 kg/cm2 after 28 days. The constituents of concrete mix and its proportions are presented in Table 2.

d its proportionsTable 2. The constituents of concrete mix an.

Compressive target strength (kg/cm^2)	Cement (Kg/m^3)	dolomite Crushed (Kg/m^3)	Sand (Kg/m^3)	Water (Liter/m^3)
300	350	1260	630	175

3.2 Glass fiber reinforced polymer (GFRP)

The stay-in-place GFRP forms were manufactured by using Sika Wrap Hex-430G® E-glass fibers, which is a product of Sika Company. The used polymer was unsaturated polyester. Sheets of the former glass fiber and, also, carbon fibers (Sika Wrap Hex-230C®, product of Sika Company) were used as an additional bottom reinforcement, installed at the inner surface of the forms. Epoxy Sikadur-330 was used as a polymer for the high strength carbon fiber. The Mechanical properties of the used fibers are given according to the manufacturer in Table 3.

Table 3: Mechanical properties of FRP.

Property	Sika Wrap Hex-430G®	Sika Wrap Hex-230C®
Fabric design thickness	0.17 mm	0.13 mm
Weight / Area	0.43 Kg/m^2	0.225 Kg/m^2
Tensile strength	2300 MPa	4300 MPa
Modulus of elasticity	76 GPa	238 GPa
Strain at failure	2.8%	1.8%

4. EST PROCEDURET

The experimental tests were carried out in the Concrete Lab. of the Faculty of Engineering in Benha. The loading system consisted of rigid reaction frame of 100 ton capacity and a hydraulic jack of 100 ton capacity, actuated by electrical pump. The specimens were prepared for testing as a simply supported beam under four-point loads, and over a clear span of 2300 mm. A spreader rigid steel beam was used to transfer the load to two concentrated loads of 250 mm spacing, centric to the beam mid span. Five linear variable differential transformers (LVDT) were installed to record the vertical deflections; at mid span, under concentrated loads, and near to supports, as shown in Fig. 7. Vertical deflections, first cracking load and ultimate failure load, were recorded. Also, propagation of cracks was marked after each load increment up to failure. The test set-up is illustrated in Fig. 8.

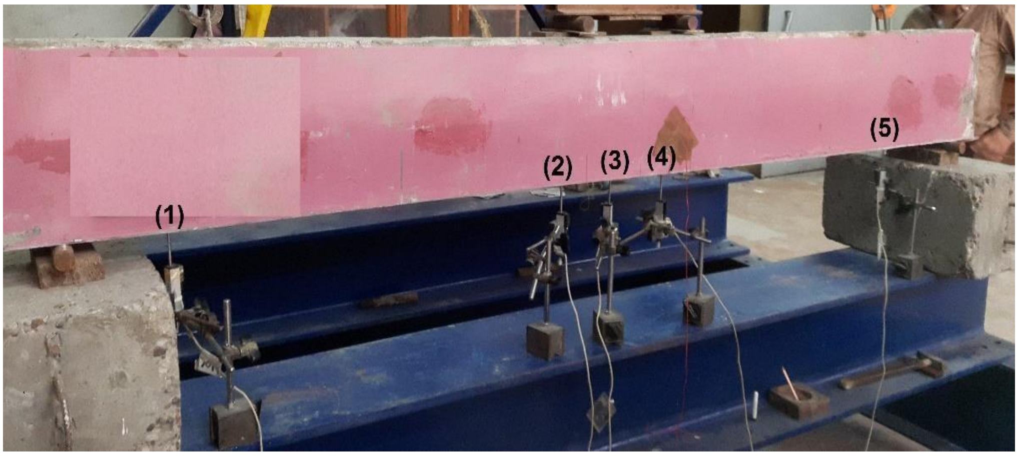


Fig. 7: LVDT locations .

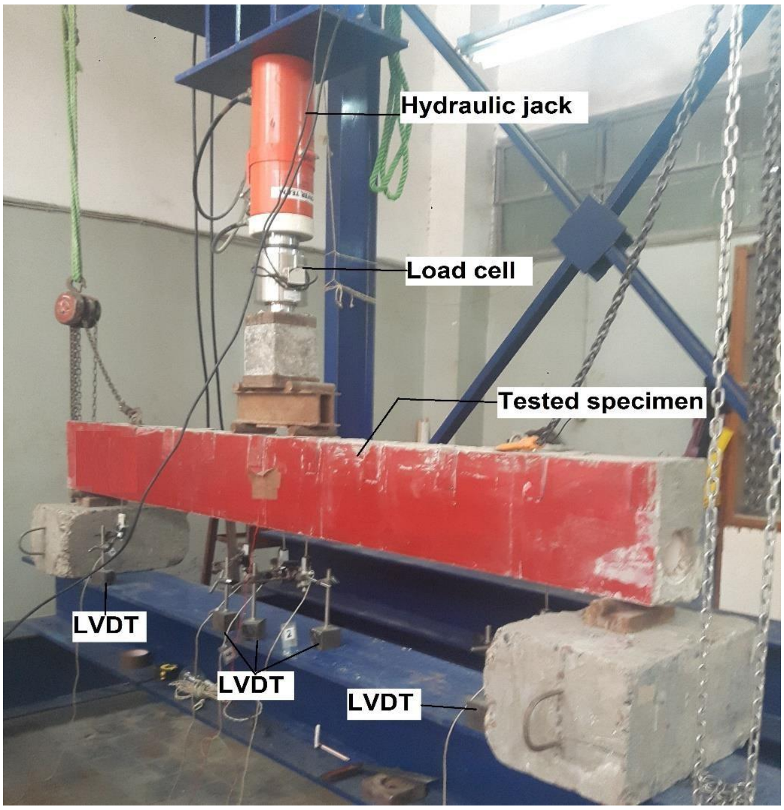


Fig. 8: Test set up.

5. ANALYSIS OF EXPERIMENTAL RESULTS AND DISCUSSION

The experimental tests provided various results which can assess the influence of SIP forms on the flexural behavior of the composite specimens. The load-deflection relationships illustrate the stiffness, strength and ductility of the tested specimens. Moreover, the recorded progress of cracking pattern recognizes the failure mode type of the different tested specimens. This section deals with analyze and discuss the obtained results in order to reveal the influence of each study parameter, and consequently conclude the contribution of SIP forms in improving the flexural behavior of tested specimens.

5.1 Load–deflection relationships

For all the tested specimens, the load deflection curve was plotted and the crack propagation was monitored and recorded. Comparisons between the results of different specimens were carried out to reveal the effect of the parameters considered in this study.

5.1.1 Effect of stay-in-place form

The using of stay in place form is the main parameter in this study. The experimental results of tested specimens with different reinforcement ratios were compared to evaluate the influence of using stay in place form on the flexural behavior of the tested specimens.

The effect of this parameter could be observed by comparing the behavior of three specimen pairs; specimens (R 2Ø10 & SIP 2Ø10), specimens (R 2Ø12 & SIP 2Ø12) and specimens (R 2Ø16 & SIP 2Ø16). The load-deflection curves of the reference specimens were clearly different compared to composite specimens (with SIP forms), as shown in Figs 9, 10 & 11. The reference specimens (R 2Ø10, R 2Ø12 & R 2Ø16) undergo three stages during testing, the first stage remains till cracking, then the second stage takes place till steel yielding, and finally the third stage continue after yielding till complete failure. However, the specimens with SIP forms (SIP 2Ø10, SIP 2Ø12 & SIP 2Ø16) undergo four different stages, the first and second stages have the same limits as defined for reference specimens, but the third stage starts after steel yielding and the FRP forms maintain resisting the tensile stresses till its rupture where a drop in the resistance is observed and, then, the fourth stage starts where the steel reinforcement in yield state maintains solely the acting load till the complete failure of the specimen. During the second stage the tested specimens with SIP forms had higher stiffness compared to reference specimens, by 67, 60 & 66%, respectively. Also, the specimens with SIP forms still had stiffness through the third stage while the stiffness of reference specimens was almost zero. Moreover, the ultimate load of the tested specimens with SIP forms was significantly higher than reference specimens, by 118, 80 & 52%, respectively.

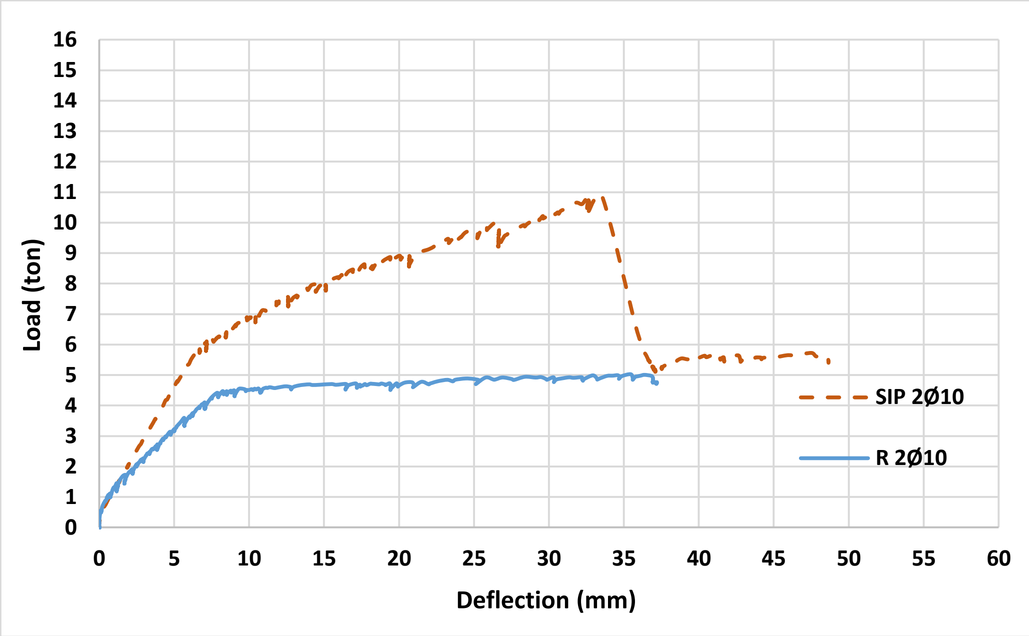


Fig. 9: Comparison between Load-Central deflection relationships of the specimens, (R 2Ø10 & SIP 2Ø10).

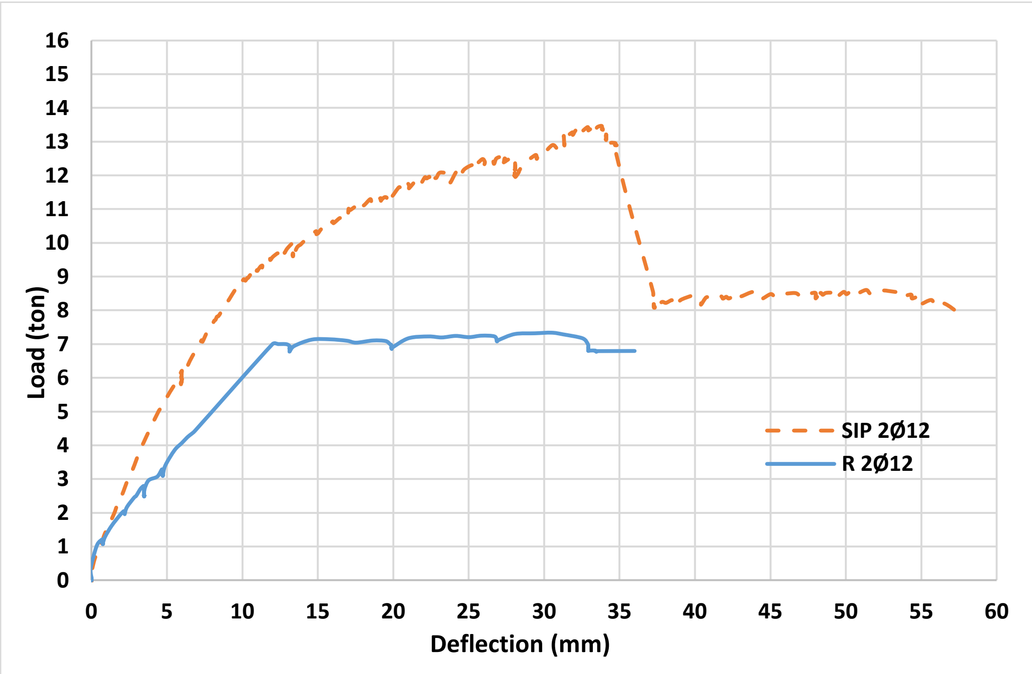


Fig. 10: Comparison between Load-Central deflection relationships of the specimens, (R 2Ø12 & SIP 2Ø12)

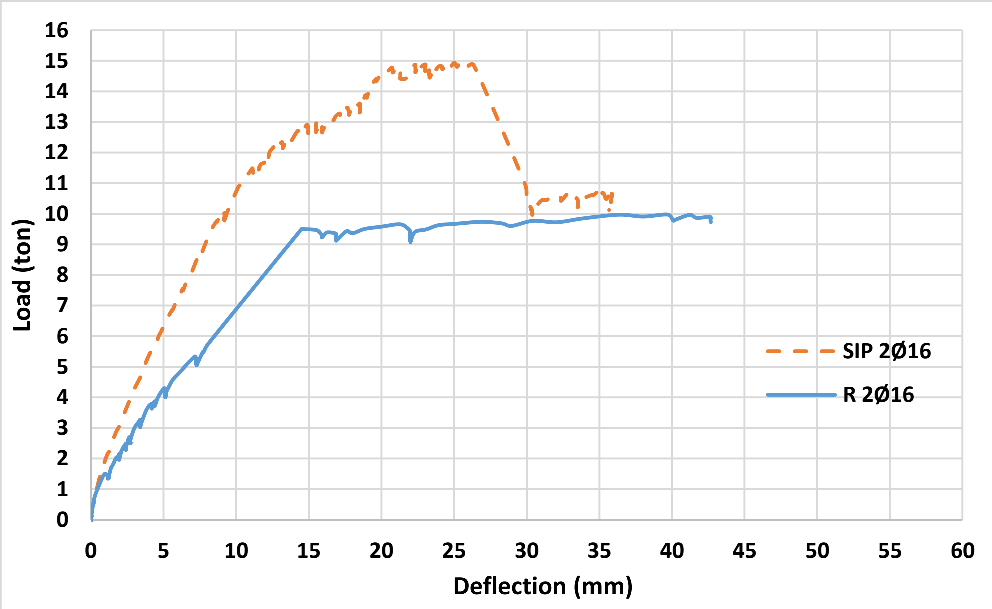


Fig. 11: Comparison between Load-Central deflection relationships of the specimens, (R 2Ø16 & SIP 2Ø16).

5.1.2 Effect of reinforcement steel ratio

The effect of this parameter could be observed by comparing between the behavior of reference specimens (R 2Ø10, R 2Ø12 & R 2Ø16) and, also, the specimens with SIP forms (SIP 2Ø10, SIP 2Ø12 & SIP 2Ø16). As expected, the increasing of reinforcement steel ratio at tension side lead to increase the ultimate load. In comparison with specimen R 2Ø10, the ultimate loads of specimens (R 2Ø12 & R 2Ø16) were higher by 47 & 96%, respectively, as shown in Fig. 12. Also, the ultimate loads of specimens (SIP 2Ø12 & SIP 2Ø16) were higher by 22 & 36%, respectively, than the corresponding value of specimen (SIP 2Ø10), as shown in Fig. 13. It is noticed that the effect of steel ratio was minor in specimens with SIP forms compared to reference specimens, the contribution of FRP forms in resisting the flexural load with reinforcement steel may explain these different effects.

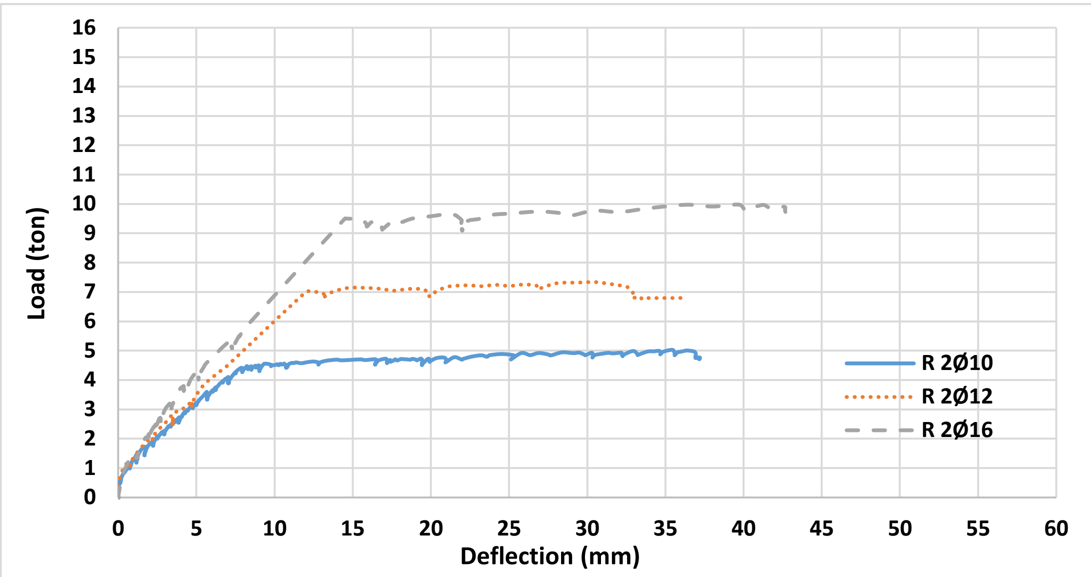


Fig. 12: Comparison between Load-Central deflection relationships of the reference specimens, (R 2Ø10, R 2Ø12 & R 2Ø16).

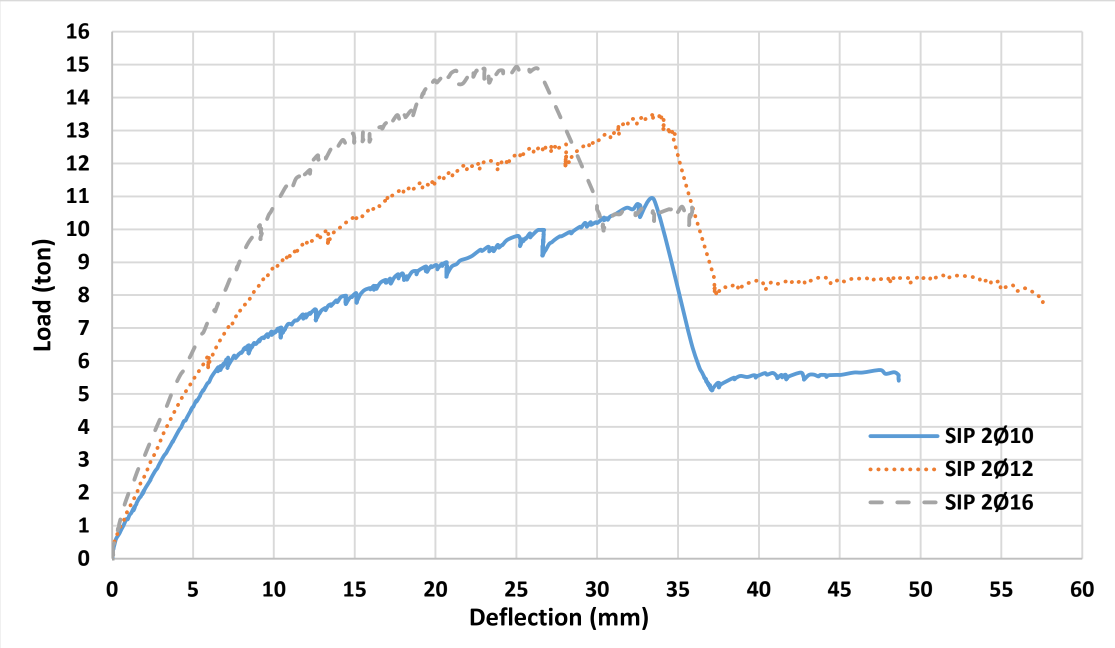


Fig.13: Comparison between Load-Central deflection relationships of the specimens with stay-in-place forms, (SIP 2Ø10, SIP 2Ø12 & SIP 2Ø16).

5.1.3 Effect of using FRP sheets as an additional tensile reinforcement

The effect of this parameter could be observed by studying the behavior of specimens (SIP 2Ø10 & SIP-R3C) and specimens (SIP 2Ø10 & SIP-R3G). The specimen (SIP-R3C) had the highest ultimate load and the lowest deflection at all loading levels due to strengthening the stay in place form by three layers of 100 mm width CFRP. In comparison with specimen (SIP 2Ø10), the ultimate load of (SIP 2Ø10) was higher by 36%, and the deflection was reduced by 81% at ultimate recorded load of specimen (SIP 2Ø10), as shown in Fig. 14. Also, the specimen (SIP-R3G) had higher ultimate load, by 21%, compared to specimen (SIP 2Ø10), as shown in Fig. 15. As expected, the effect of carbon fiber was higher than the glass fiber due to its higher strength and stiffness.

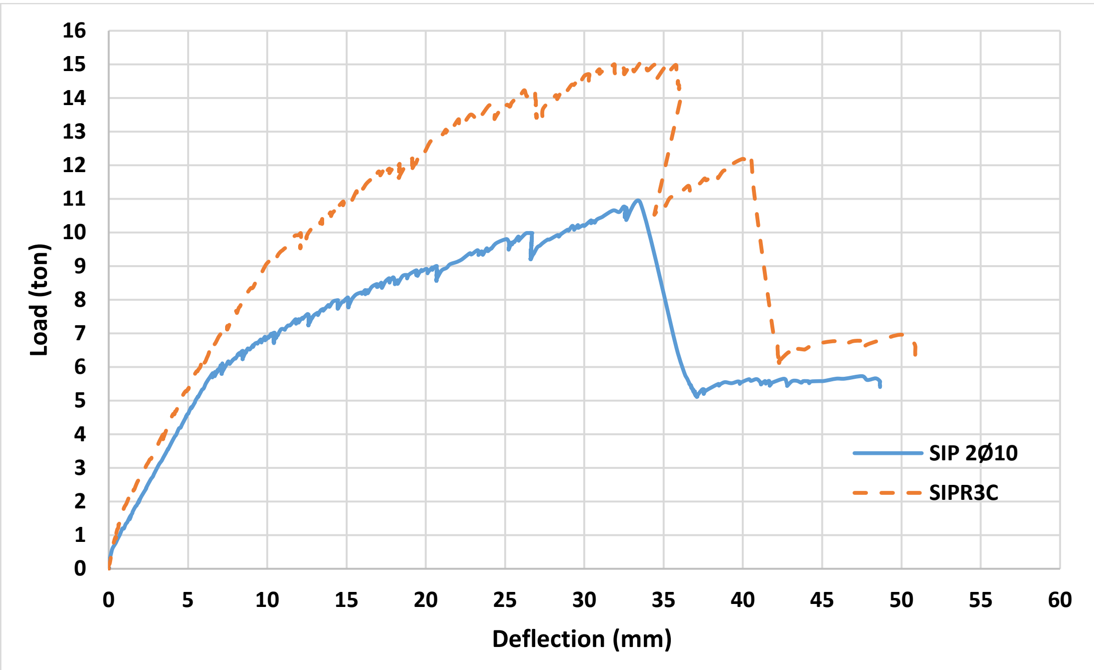


Fig. 14: Comparison between Load-Central deflection relationships of the specimens, (SIP 2Ø10 & SIP R3C).

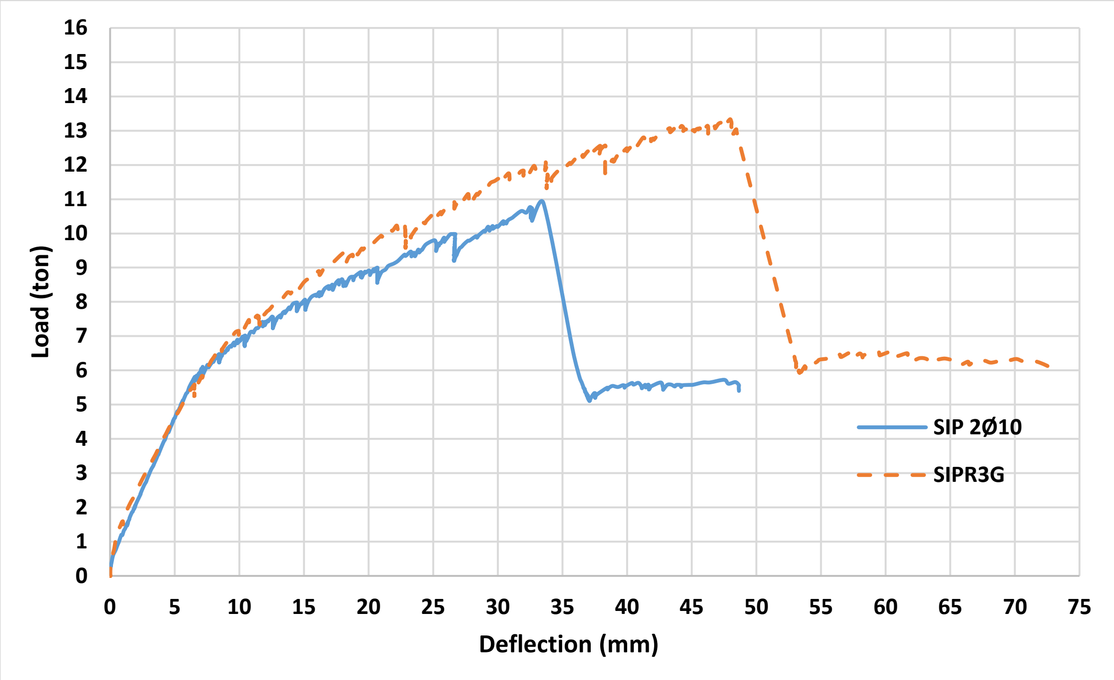


Fig. 15: Comparison between Load-Central deflection relationships of the specimens, (SIP 2Ø10 & SIP R3G).

5.2 Crackingand ultimate loads

Table.4 presents the deflection and load values at first cracking and at its ultimate value for all the tested specimens. The specimen SIP 2Ø16 had the highest ultimate load. As expected, the specimens with stay in place forms and reinforcement steel bars inside the beam had the highest ultimate load in comparison with the specimens with reinforcement steel bars only.

Table.4: Main results of the tested specimens .

Group	Specimen code	1ST Cracking		Ultimate	
		Load (ton)	ΔCr. (mm)	Load (ton)	ΔUl. (mm)
No. 1	R 2 Ø 10	0.7	0.40	5.00	36.00
	R 2 Ø 12	1.00	0.5	7.35	30.00
	R 2 Ø 16	1.40	1.2	9.80	40.00
No. 2	SIP 2 Ø 10	-	-	10.88	33.50
	SIP 2 Ø 12	-	-	13.25	34.10
	SIP 2 Ø 16	-	-	14.85	26.30
No. 3	SIPR R3C	-	-	14.75	36.20
	SIPR R3G	-	-	13.15	48.40

5.3 Cracking behavior and mode of failure

All the tested specimens were loaded until failure due to flexure. For all specimens, cracks propagation was monitored, and the plane of failure was observed to investigate the cracking and failure behavior. Two modes of failure are observed, the first one was flexure failure of specimens without stay in place forms, due to tension failure of reinforcement steel, as shown in Fig. 16. The second mode of failure was the rupture of FRP forms due to tensile stress accompanied to the bending moment, as shown in Fig.17. After the rupture of FRP SIP forms the reinforcement steel had reached its yield and sustained, solely, the acting loads. All the specimens with FRP SIP forms were failed due to the later mode of failure.

Fig.16: Failure mode of specimen (R 2Ø12), the first mode.

Fig.17: Failure mode of the specimens with FRP SIP forms, the second mode.

6. FINITE ELEMENT ANALYSIS

In this part, the tested specimens were simulated using the finite element program (ANSYS, version 15). The numerical results of the simulated specimens were compared with the experimental results.

All the simulated models are simply-supported beams subjected to two-point loads. The concrete and resin are modeled with a higher order 3-D element named SOLID65. LINK180 is used to define reinforcing steel while SOLID185 is used to define FRP sheets and form. A fully bonded between FRP forms and concrete was assumed.

Five materials were used in modeling the specimens, which are: concrete, reinforcing steel (mild & high tensile steel), CFRP sheets, GFRP sheets and epoxy resin (Sikadur® 330). The compressive stress-strain relationship of concrete is considered to be linear from zero to one-half the ultimate compressive strength, the strain at the ultimate compressive strength ranges from 0.002 to 0.003 CFRP and GFRP strips were modeled by linear orthotropic material while epoxy Sikadur® 330 were modeled as linear isotropic material. Table. 5 presents the properties of the used material.

Table 5: The properties of the used materials.

Material	Compressive strength (MPa)	Tensile strength (MPa)	Poisson`s ratio	Modulus of Elasticity (GPa)
Concrete	30	2.8	0.2	20
Mild steel	--	320	0.3	210
High tensile steel	--	450	0.3	210
CFRP strips	--	4300	0.3	238
GFRP strips	--	2300	0.3	76

The obtained experimental results are compared with the numerical results, calculated from the finite element modeling. The experimental and numerical results of load versus mid-span deflection are compared for each specimen, as shown in Figs. (18 to 25). The typical deformed shape of the finite element models obtained by ANSYS is shown in Fig. 26. Also, Table. 6 presents a comparison between the numerical and experimental ultimate loads. It can be noticed that the ratio of the numerical ultimate load to experimental one is greater than 1.0, and up to 1.18, except one specimen (SIP-2Ø12) where the ratio is 0.92. So, the developed model almost predicts a higher ultimate load compared to the corresponding experimental value.

Table 6: Comparison between experimental and numerical results.

Specimen code	$P_{u,exp.}$	$P_{u,num.}$	$P_{u,num.}$ / $P_{u,exp.}$
R 2Ø10	5.00	5.90	1.18
R 2Ø12	7.35	7.45	1.01
R 2Ø16	9.80	10.40	1.06
SIP 2Ø10	10.88	12.00	1.10
SIP 2Ø12	13.25	12.20	0.92
SIP 2Ø16	14.85	15.60	1.05
SIP-RC3	14.75	16.80	1.13
SIP-RG3	13.15	13.60	1.03

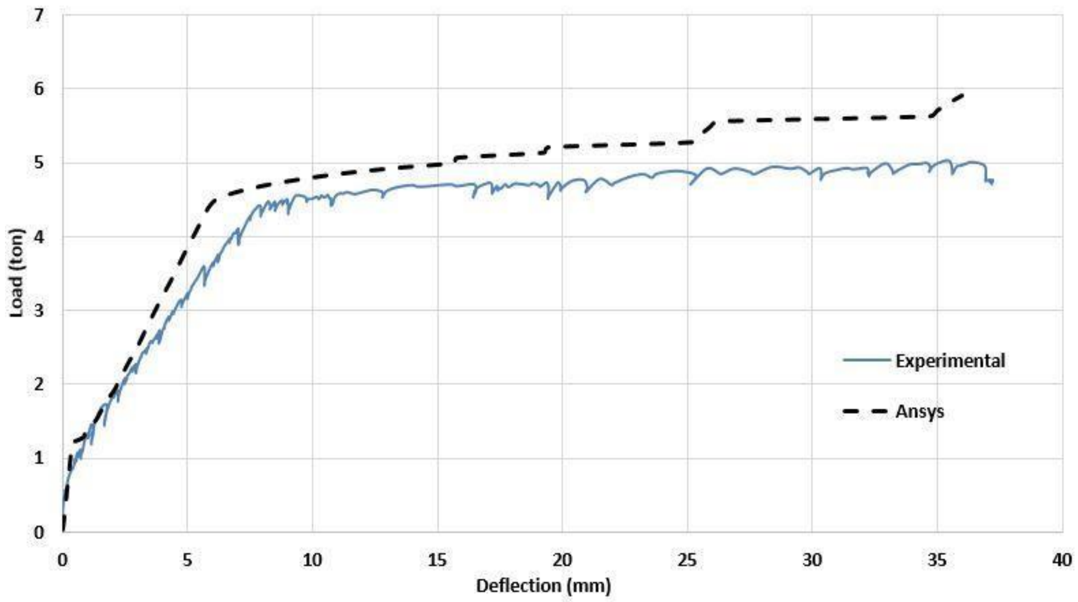


Fig. 18: Comparison between experimental & numerical load-deflection curves of tested specimen (R 2Ø10).

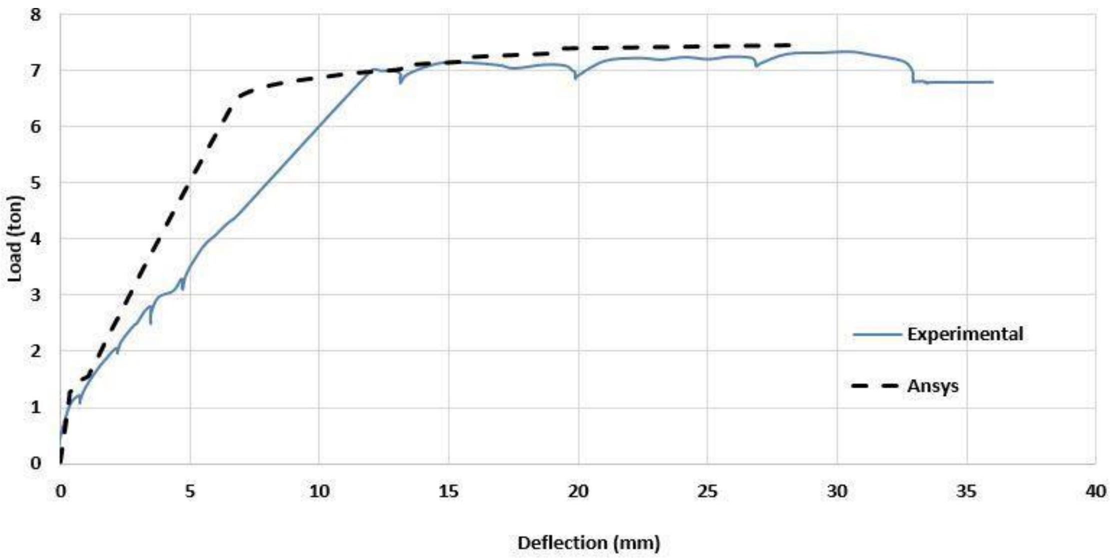


Fig. 19: Comparison between experimental & numerical load-deflection curves of tested specimen, (R 2Ø12).

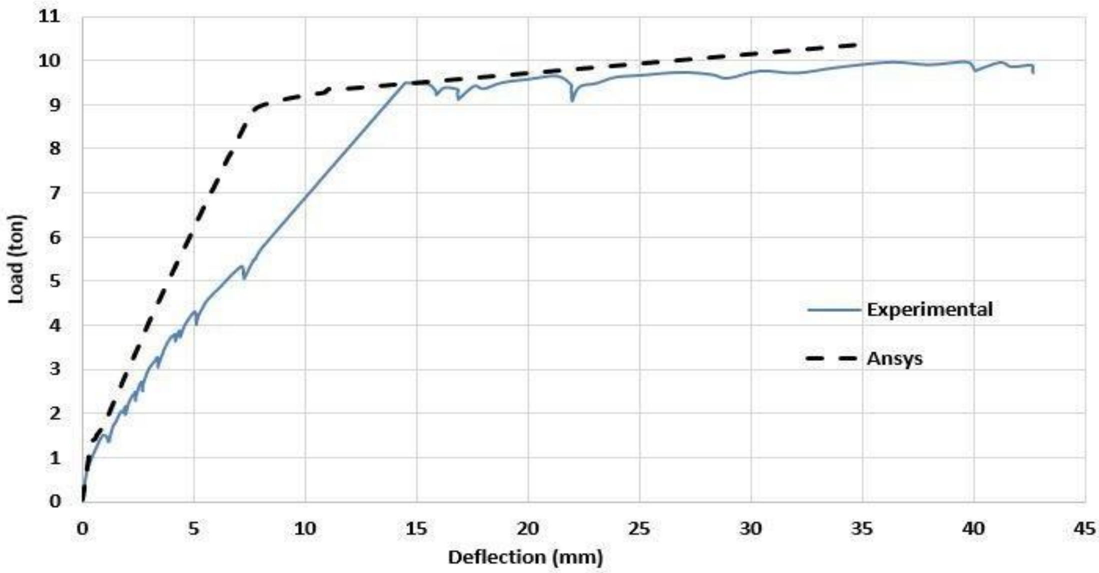


Fig. 20: Comparison between experimental & numerical load-deflection curves of tested specimen, (R 2Ø16).

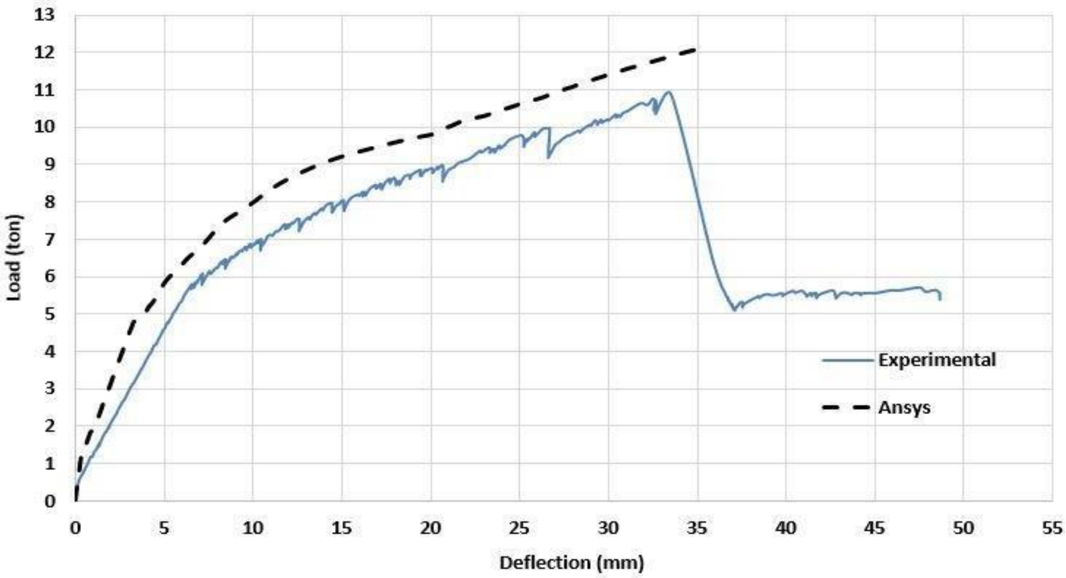


Fig. 21: Comparison between experimental & numerical load-deflection curves of tested specimen, (SIP 2Ø10).

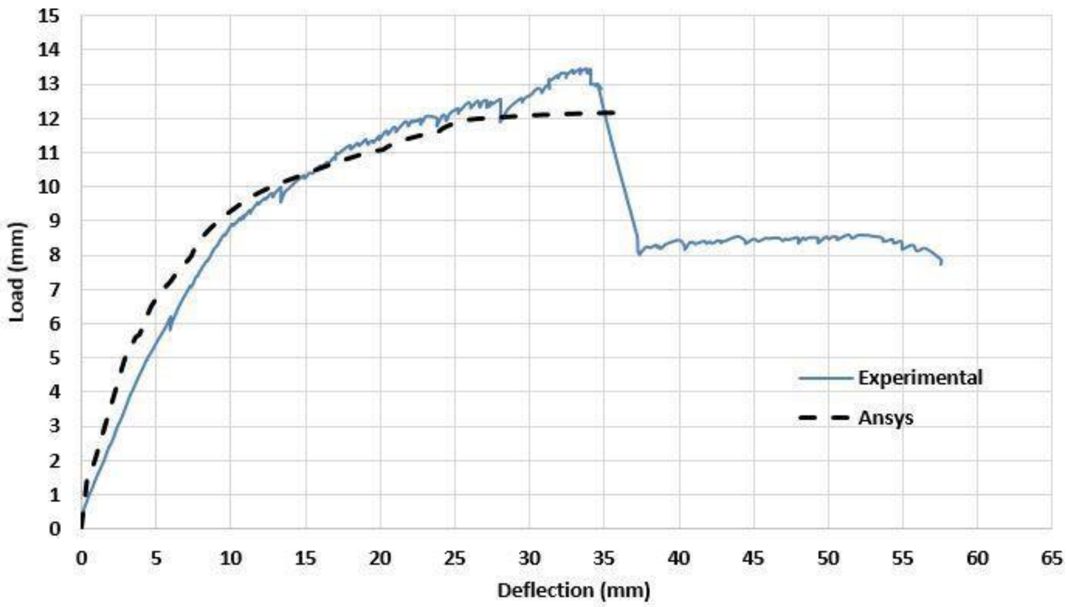


Fig. 22: Comparison between experimental & numerical load-deflection curves of tested specimen, (SIP 2Ø12).

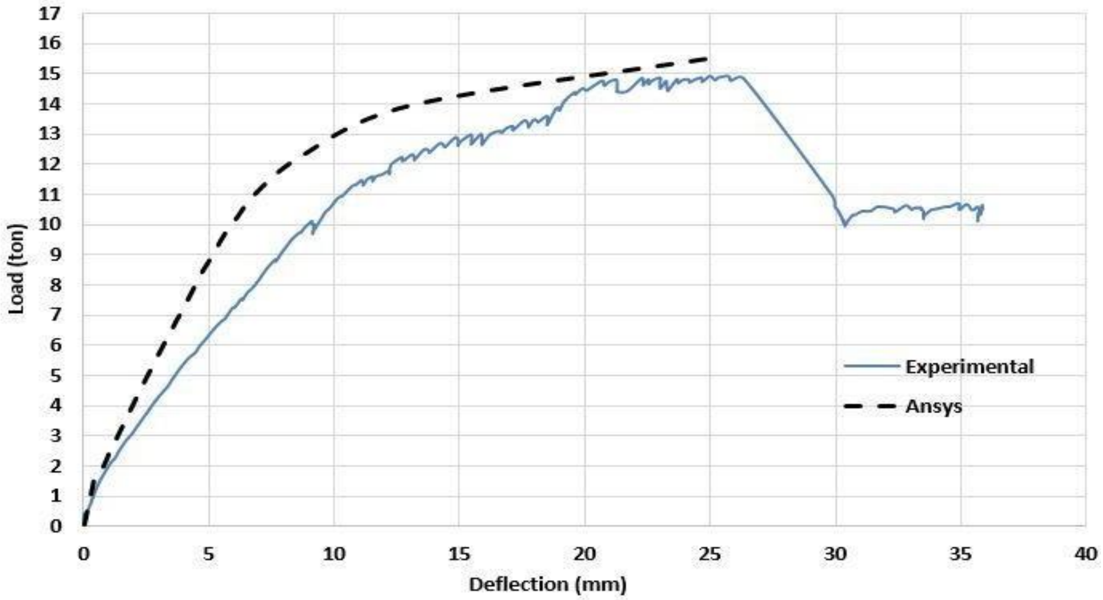


Fig. 23: Comparison between experimental & numerical load-deflection curves of tested specimen, (SIP 2Ø16)

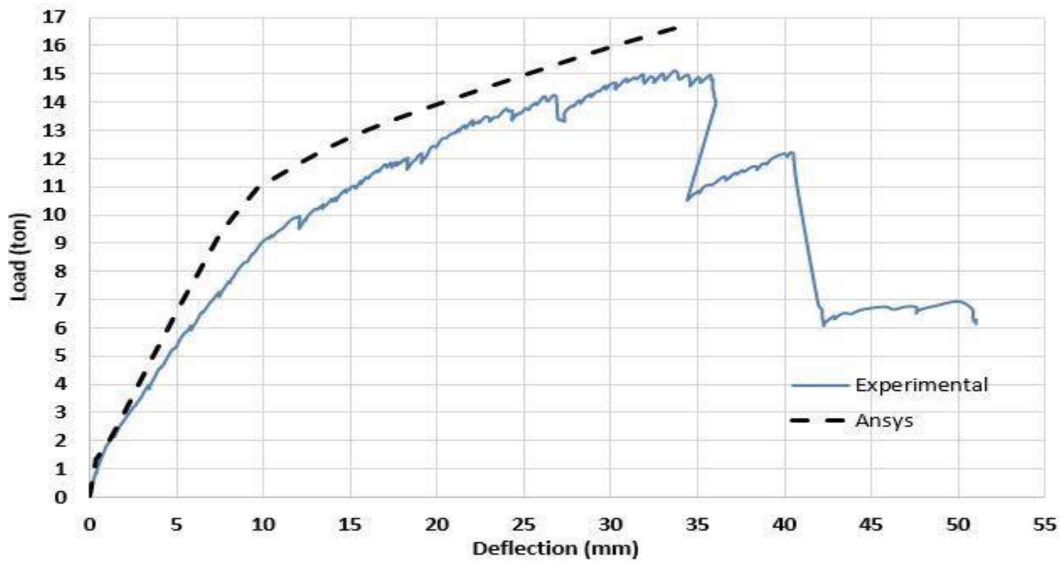


Fig. 24: Comparison between experimental & numerical load-deflection curves of tested specimen, (SIP R3C).

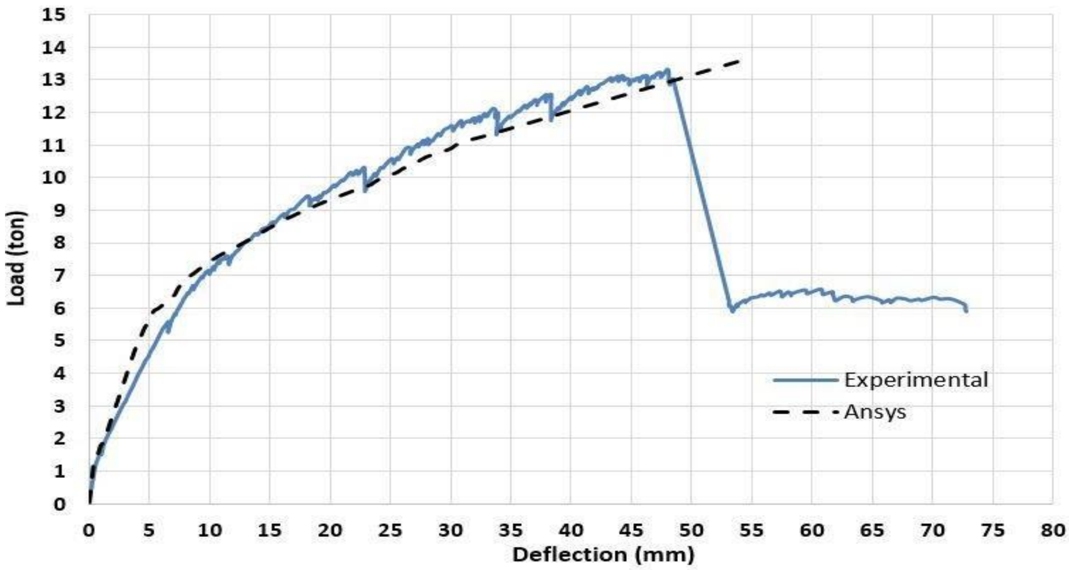


Fig. 25: Comparison between experimental & numerical load-deflection curves of tested specimen (SIP R3G).

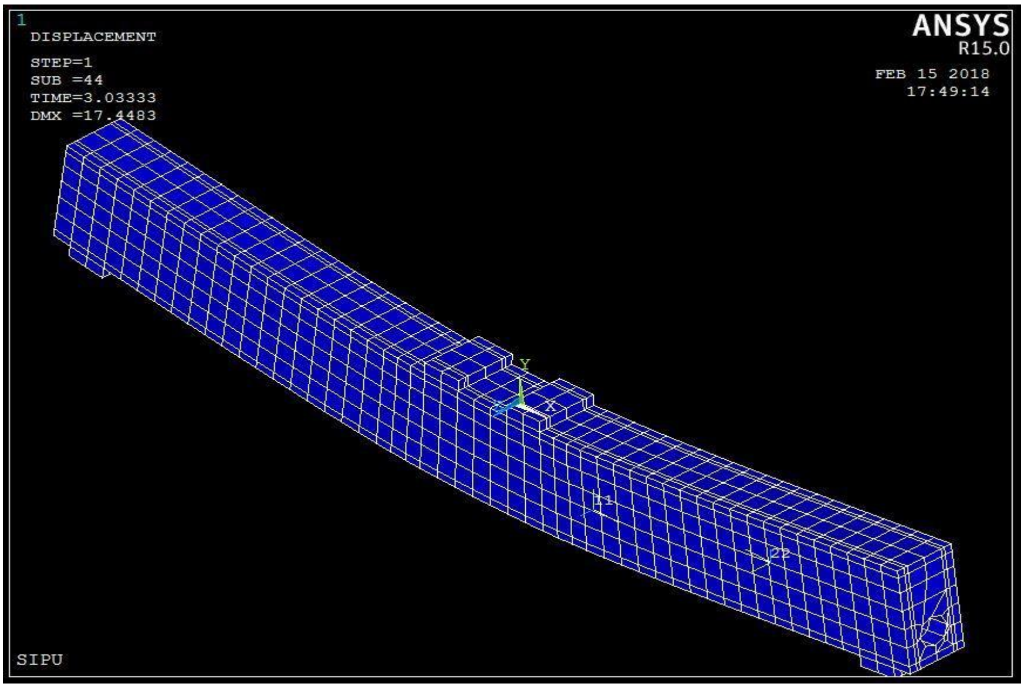


Fig. 26: Typical deformed shape of finite element model.

7. CONCLUSION

The main goal of the current research is examining the influence of using stay-in-place FRP form to improve the flexural resistance of hollow RC concrete beams. From the experimental results, the following conclusions could be drawn as below: -

- According to the experimental results obtained in this research, using stay-in-place FRP form has improved the structural performance of RC beams in terms of flexural stiffness by 60 to 67%, and the ultimate carrying capacity by 52 to 118%.
- After the rupture of FRP SIP forms the flexural resistance of the tested specimen drop suddenly but does not collapse completely where the steel reinforcement in yield state maintains, solely, the acting load till the complete failure of the specimen.
- The effect of reinforcement steel ratio was about 50% lesser in specimens with SIP forms compared to reference specimens, the contribution of FRP forms in resisting the flexural load with reinforcement steel may explain these different effects.
- Adding three layers of longitudinal CFRP & GFRP sheets to the SIP forms at tension side increased the flexural strength by 36 & 21%, respectively. Also, the deflection was reduced due to the additional FRP sheets.
- The reference specimens failed in tension due to steel yield, but the specimens with SIP FRP forms were failed firstly due to the rupture of FRP forms.
- According to the finite element model developed by ANSYS (version 15), to simulate the tested specimens, the ultimate load was almost higher than the corresponding experimental value, up to 18%.

8. LIST OF REFERENCE

Bakis C, Bank L, Brown V, Cosenza E, Davalos J, Lesko J, et al. "Fiber-reinforced polymer composite for construction – state of the art review. J compos constr ASCE 2003; 6(2):73-87.

Nelson M, Eldridge A, Fam A "The effect of splices and bond on performance of bridge deck with FRP stay-in-place forms at various boundary condition" Engineering structures 56; 2013; 509-516.

Honickman H, Nelson M, Fam A "Investigation into the bond of glass fiber reinforced polymer stay in place structural forms to concrete for decking application" Trans Res Rec 2009; 2131: 134-44.

Gai A, Darby A, Ibell T, Evernden M "Experimental investigation into a ductile FRP stay in place formwork system for concrete slabs" Construction and Building Materials; 2013; 49 1013-1023.

Goyel R, Mukherjee A, Goyel S "An investigation on bond between FRP stay in place formwork and concrete" Construction and Building Materials; 2016; 113; 741-751.

Honickman, H "Pultruded GFRP Sections as Stay in Place Structural open Formwork for Concrete Slabs and Girders", Queen`s university; Canada; Thesis 2008.

Remy, O "Lightweight Stay in place formwork: a concept for future building applications" Vrije universiteit brussel; PhD Thesis 2012.

Feng X, zou X, Wu Y, Wang J "FRP stay in place form and shear key connection for FRP-concrete hybrid beams/decks" composite structures; 2018; 192; 390-407.

Saleem S, Pimanmas A, Rattanapitikon W "Lateral response of PET FRP- confined concrete" Construction and Building Materials; 2018; 159; 741-751.