Al-Azhar University Civil Engineering Research Magazine (CERM)
Vol. (45) No. (1) January 2023

Finite element simulation of reinforced concrete (RC) slabs strengthened with ultra-high performance fiber concrete (UHPFC) layers using Ansys 19

Israa.A. Mahrous[1], Mahmoud.M. Elsayed [2], Laila.M. abdel-Hafez [3], Yasser.R. Tawfic [4]

[1] PHD candidates, Faculty of Engineering, Minia University, Minia Egypt
[2]Assistant professor, Faculty of Engineering, Fayoum University,Fayoum, Egypt
[3] professor, Faculty of Engineering, Minia University, Minia, Egypt
[4] professor, Faculty of Engineering, Minia University, Minia, Egypt

ملخص البحث :

في هذا البحث تم عمل دراسة تحليليه باستخدام برنامج الانسز لعينات تم صبها معمليا لدراسة مدى تأثير استخدام الخرسانة فائقة الاداء في تحسين مقاومه القص الثاقب الذى يحدث في البلاطات المسلحة المسطحة وذلك باستخدام طريقتين ربط مختلفة الطريقة الاولى عباره عن ربط بلاطه من الخرسانة فائقة الاجهاد مع البلاطة المسطحة باستخدام جوايط حديد سمك 12مم والطريقة الثانية صب الخرسانة فائقة الاجهاد على أسطح مختلفة للبلاطة المسطحة المراد تدعيمها بعد تخشين السطح مع الاختيار المناسب لكل طريقه من طرق الربط في البرنامج وايضا تم دراسة عده عوامل اخرى منها زياده سمك الخرسانة فائقة الاجهاد وزياده نسبه الالياف بها وايضا وضع شبكه من حديد التسليح بسمك 6 مم داخل طبقه الخرسانة لنرى مدى تأثير كل عامل على خصائص البلاطات الخرسانية المسلحة .النتائج اثبتت ان تدعيم البلاطات باستخدام الخرسانة فائقة الاجهاد يحسن من خصائصها الميكانيكية ويزيد من مقاومتها للقص الثاقب .

Abstract:

To show analytically the effect of the ultra-high performance fiber concrete (UHPFC) layer on improving the punching shear stress of RC flat slabs, a finite element simulation was performed using ANSYS 19 for seven models investigated experimentally [1]. One RC slab considers a control specimen with normal concrete. Six RC slabs with normal concrete (NC) strengthening by UHPFC layer with a study of different parameters such as a different technique for strengthening, increasing thickness of UHPFC layer and steel fibers content in UHPFC mixture. The analytical results showed an agreement with an experimental one. Increasing the thickness of the UHPFC layer affects positively more than increasing steel fiber content in the UHPFC mixture, increasing punching shear capacity from 27.14% to

37.81 and toughness from 86.45%to 92.76%. Increasing steel fiber content in the UHPFC mixture and using (RFT) increased the ductility of strengthened RC slabs.

Key Words: punching shear strength, RC slabs, UHPFC, ANSYS

1. Introduction

Many numerical researches have been done to show solutions for punching shear failure which is the most important problem occurred in the flat slab. Collapse due to punching shear occurs quickly without warning. A powerful tool for simulating the nonlinear structural behavior of reinforced continuous RC structural members at all stages of loading up until failure is a finite element (FE) model that has been tested. Application for strengthening techniques by FE have been done to help in delaying the failure and give alarming before the collapse to increase the possibility be the failure not brittle. It's necessary to investigate new techniques for disentangling the problem of punching shear failure, using different materials such as fiber- reinforced polymer (FRP) [2-4], steel plates [5], carbon fiber-reinforced polymer (CFRP) [6-9], fabric reinforced cementations mortar (FRCM) [10] ,composite mater [11]. It was concluded from the results that load carrying capacity for all strengthened slabs is increased compared to the un-strengthened slab and showed an agreement with experimental studies made to show the validity of using a finite element. The width, length, and thickness of the fiber plat used have a positive effect on the ultimate load. Additionally, using steel plates has improved the slab system's stiffness, ductility, and energy absorption, switching the failure mechanism from punching shear failure to flexural failure. Recently, researches have been done to benefit from using ultrahigh-performance fiber-reinforced concrete (UHPFC) in strengthening RC structures with normal concrete (NC) [12-14] which showed that results from using FE models have good agreement with experimental results done to ensure the effectiveness of UHPFC in strengthening the punching shear strength of reinforced concrete (R.C) flat slabs.

Menna, D.W,and A.S. Genikomsou [15, 16] proved with a numerical study that it's essential to strengthen RC flat slab with a thin layer of ultra-high-performance fiber-reinforced concrete (UHPFRC). The punching shear capacity increases as the UHPFRC layer's thickness increases, when the UHPFRC layer's thickness rises, the displacement at the maximum resistance decreases. Applying a UHPFRC layer just to the critical areas of a slab may be more efficient and cost-effective and the ductility of the slab is increased. A more ductile connection is provided by UHPFRC .It can also screen the concrete slab from chemical percolation and the impact that could otherwise lead to reinforcement deterioration and corrosion.

2. Finite element model development

2.1 Geometry of the developed FE models

The RC slab's sizes were 100 mm thick, 1000 mm long, and 1000 mm wide. The column stud measured 100x100 mm and extended 150 mm above the compression face of the slab. Five longitudinal high tensile steel bars, each with a diameter of 12 mm, were the main reinforcement for RC slabs. The columns had Φ12at each corner. One of the specimens is un- strengthened RC slab (control RC slab) and the other RC slabs are strengthened by UHPFC according to different parametric studies. **Fig1** shows ANSYS numerical model for RC slabs, to take advantage of the symmetry in geometry and loading, only a fourth of each panel form is examined using the necessary boundary conditions. A finite element analysis includes meshing a model with volumes, regions, lines, and important points. The model is divided up into many small parts, and to produce precise results, the full size of the RC slabs is taken into account when building models with a mesh size of 50 mm. Strengthened models are divided into three groups shown in **Table 1**, based on a parametric study explained as follows:

- Strengthening scheme: two different techniques for strengthening RC slabs were used first one was strengthening by UHPFC laminates using an anchorage system (Φ12 for each anchor) for bonding, and the second technique strengthening by casting UHPFC mortar on different roughened positions of RC slabs.
- Strengthening zone (tension zone (ten) or compression zone (comp)).
- Thickness of UHPFC layer: (30, 50) mm.
-Adding longitudinal reinforcement (RFT) into UHPFC layer (R-UHPFC) mild steel five longitudinal mild tensile steel bars, each with a diameter of 6 mm.
- Steel fiber content in UHPFC matrix (1.5, 3) %.

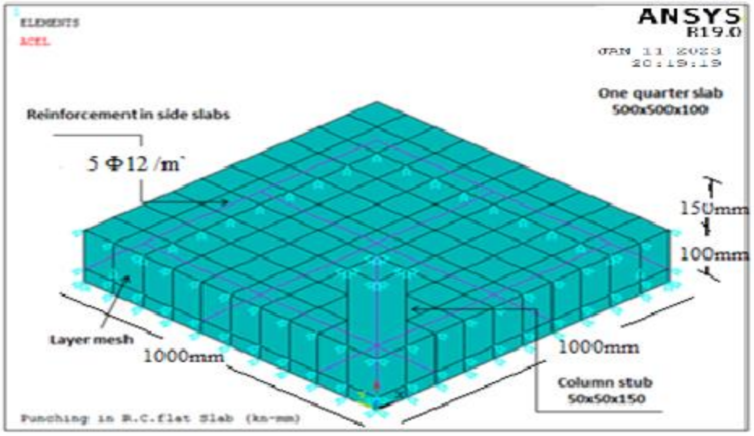


Fig.1: ANSYS numerical model for RC slabs

Table 1

Shows description of RC slab model

	Model	**Strengthening scheme**	**Zone**	**Thickness of UHPFC layer**	**Steel fibers content**	**RFT**
	S_0	**RC control slab**				
Group 1	S_1	Laminate	Ten	30	1.5%	------
	S_2	Casting	Ten	30	1.5%	------
	S_3	Casting	Ten	30	1.5%	5Ø6/m`
	S_4	Casting	Comp	30	1.5%	-----
	S_5	Casting	Comp+ Column head	30	1.5%	-----
	S_6	Casting	Column head	30	1.5%	-----
Group 2	S_1'	Laminate	Ten	30	3%	-----
	S_2'	Casting	Ten	30	3%	-----
	S_3'	Casting	Ten	30	3%	5Ø6/m`
	S_4'	Casting	Comp	30	3%	-----
	S_5'	Casting	Comp+ Column head	30	3%	-----
Group 3	S_1''	Laminate	Ten	50	1.5%	----
	S_2''	Casting	Ten	50	1.5%	----
	S_3''	Casting	Ten	50	1.5%	5Ø6/m`
	S_4''	Casting	Comp	50	1.5%	-----
	S_5''	Casting	Comp+ column head	50	1.5%	-----

2.2 Elements type [17]

The used elements in this model are Solid65 and Link180.

- Concrete (normal concrete and UHPFC)

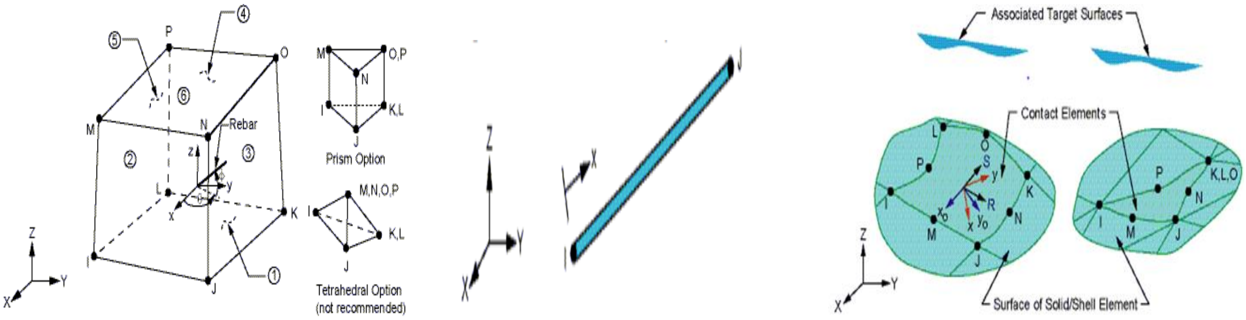
SOLID65 is used to represent solids in three dimensions, either with or without reinforcing bars. It has eight nodes, of which each has three degrees of freedom (translations in the X, Y, and Z directions). The solid has the ability to crack under tension and to crush under compression. The coordinate system of SOLID65 and the locations of the nodes are shown in **Fig 2.a.**

- Reinforcing steel bars

The longitudinal reinforcement is modeled using a 3D link element called Link180. It is possible to describe trusses, sagging cables, linkages, springs, etc. using this element. With three degrees of freedom in the nodal x, y, and z axes, this 3-D spar element is a uniaxial tension-compression element. Both compression-only (gap) and tension-only (cable) modes are provided. Link 180's coordinate system and node locations are shown in **Fig 2.b.**

- The contact surface

CONTA174 is used to simulate sliding and contact between deformable surfaces described by this element and a 3-D "target" surface (TARGE170). The element can be used in 3-D structural and coupled field contact analyses. It is defined by eight nodes (the underlying solid or shell element has mid-side nodes) as shown in **Fig 2.c**. It can degenerate to a six-node element depending on the shape of the underlying solid or shell elements. The behavior of the contact surface for the first bond technique between RC slabs with no roughness and UHPFC laminate was standard behavior which was the (sliding and separation) allowable between the two layers. While the surface contact between RC slabs and the UHPFC layer (casting) was rough behavior which (no sliding + separation) is allowable between the two layers. Additionally, the amount of the cohesion coefficient determines the permissible contact gap; as the cohesion coefficient increases, the contact gap decreases and shear stress transfer increases. The cohesion and friction coefficients must be specified so that the higher the values, the less probable sliding and contact gaps are, and the greater the shear stress transmission as a result. The cohesion coefficient was 0.01, and 0.02, and the friction coefficient was 0.3, and 0.35 for the first and second bond techniques, respectively, because it has better agreement with experimental results. **Fig.3** shows the contact surface between the RC slab and UHPFC layer at the tension zone of the RC slab.



a. The node locations and coordinate system of solid 65

b. The coordinate system and node locations for link 180

c. CONTA174 Geometry

Fig.2 Element type for concrete, reinforcing steel bars and contact surface

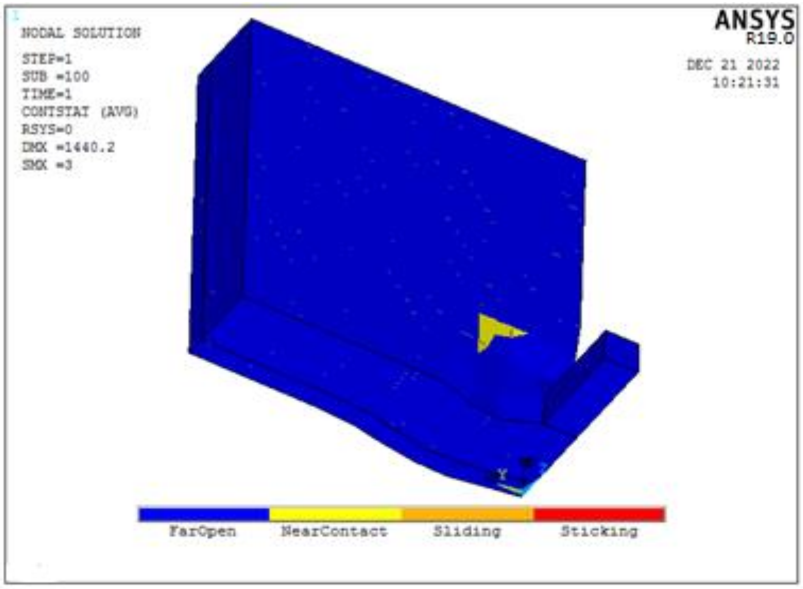


Fig.3 Contact surface between RC slab and UHPFC layer at tension zone of RC slab

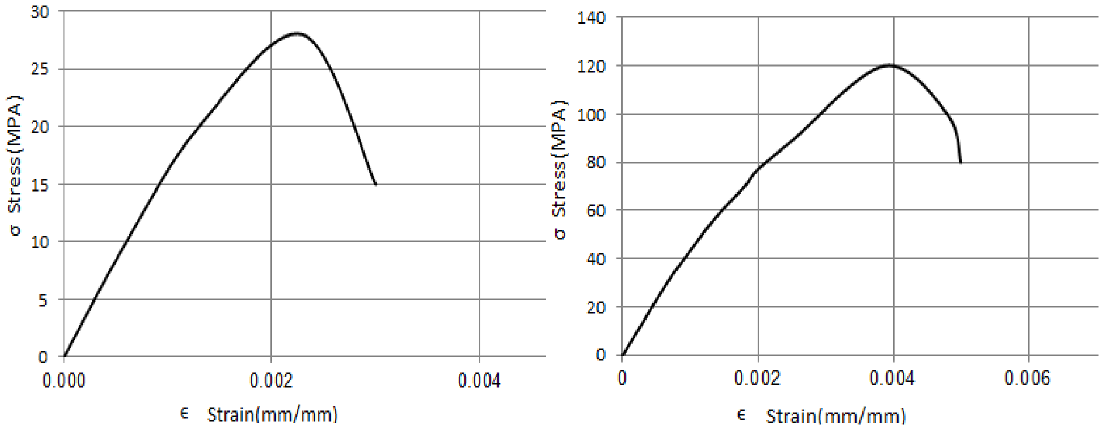
2.3 Material models

Definitions of the material models should be accurate and suitable for realistic nonlinear finite element studies of reinforced concrete structures. By entering the steel yield strength or the compressive strength of concrete, ANSYS automatically generates the material attributes. The following definitions are necessary for modeling a valid numerical model using ANSYS. Three types of a mixture (NC and UHPFC) and two types of longitudinal reinforcement (Ø6, Φ12) by mechanical properties were measured experimentally and mentioned in **Table 2** for each mixture. Open shear transfer coefficient equal 0.2, closed shear transfer coefficient equal 0.8 for NC and UHPFC Concrete. **Fig 4** presented stress–strain curves measured experimentally also for NC and UHPFC Vf (1.5%).

Table 2

Material properties and material parameters used for NSC slabs and UHPFC layers

Material	Element type	Material properties
NC	Solid 65	Elastic modulus (E_c) 22400 Compressive strength (fc`) 28 Mpa tensile stress (f_t) 3.1 Mpa Poisson's ratio (υ) 0.2
UHPFC Vf % (1.5%)	Solid 65	Elastic modulus (E_c) 46050 Compressive strength (fc`) 121 Mpa tensile stress (f_t) 9.2 Mpa Poisson's ratio (υ) 0.2
UHPFC Vf % (3%)	Solid 65	Elastic modulus (E_c) 46050 Compressive strength (fc`) 128.6 Mpa tensile stress (f_t) 9.3 Mpa Poisson's ratio (υ) 0.2
Longitudinal reinforcement Φ12	Link 180	Elastic modulus (Es) 200000 Yield stress (fy) 481Mpa Tensile Strength 653 Mpa Poisson's ratio (υ) 0.3
Longitudinal reinforcement Ø6	Link 180	Elastic modulus (Es) 198000 Yield stress (fy) 292Mpa Tensile Strength 387 Mpa Poisson's ratio (υ) 0.3



a. Stress –strain curve for NC

b. Stress –strain curve for UHPFC Vf (1.5%)

Fig 4 : Stress –strain curve for NSC and UHPFC

3. Results and discussion

- For group 1

3.1 Ultimate loads and ultimate deflection

Fig 5 shows the load-deflection curves for models. The control slab has failed quickly in a brittle way in punching shear, with no warning. (S_0) achieved punching shear capacity of 169.7KN at a deflection of 15.62 mm. the punching shear capacity of (S_1) which strengthened by 30mm UHPFC laminate was 180.84 KN , had the smallest increase in load compared with all strengthened slabs by 6.56 % because of the weak contact between two slabs. The deflection at the maximum load was 12.68 mm. When strengthened slab by casting 30mm UHPFC mortar thickness at the tension side of RC slabs (S_2) achieved punching shear capacity of 206.473 KN more than S_1 by 15.11 %. The deflection at the maximum load was 14.58 mm. Adding longitudinal reinforcements in UHPFC mortar to strengthen RC slabs (S_3) increased the punching shear capacity to 420.8 KN, more than using UHPFC mortar only without RFT S_2 by 126.3%, and reducing punching of RC slab by column. The deflection at the maximum load was 16.50mm. In the case of strengthened compression zone of RC slab by casting thickness of 30mm UHPFC mortar (S_4). The deflection was 9.88 mm at a maximum load of 257.37 KN which less than the deflection of the control slab by 36.74 %. It was observed that strengthened RC slabs at the compression zone achieved an increase in load more than strengthened RC slabs at tension zone S_2 by 30% due to increasing the effective depth. Added 80mm height of UHPFC column head around the column in addition to the 30mm UHPFC layer at compression side (S_5) increased load by 58.6% more than strengthened by UHPFC layer only at compression side (S_4). The deflection was 8.68 mm at a maximum load less than the deflection of the maximum load for (S_4). The result achieved also a decrease in deflection from the deflection of the control slab at maximum load by 44.43%. Strengthened with UHPFC column head only (S_6) achieved 222.90 KN maximum load with 15.02 mm deflection, and showed a slight increase in load compared with the control slab. It can be concluded that strengthening RC slab with the UHPFC column head around column and UHPFC laminate at tension zone didn't achieved much success in solving the problem of punching shear. Finally using UHPFC casting mortar on different roughed surfaces for strengthening RC slabs, in particular, gave very high results and high efficiency than using UHPFC laminate. Turns out it is important to use UHPFC with longitudinal reinforcement (R-UHPFC) to increase the punching shear strength and ductility. **Fig 6** shows the deformed shape of the models. Strengthening RC slabs with UHPFC achieved enhancement in punching shear capacity and reduce deflection at maximum load.

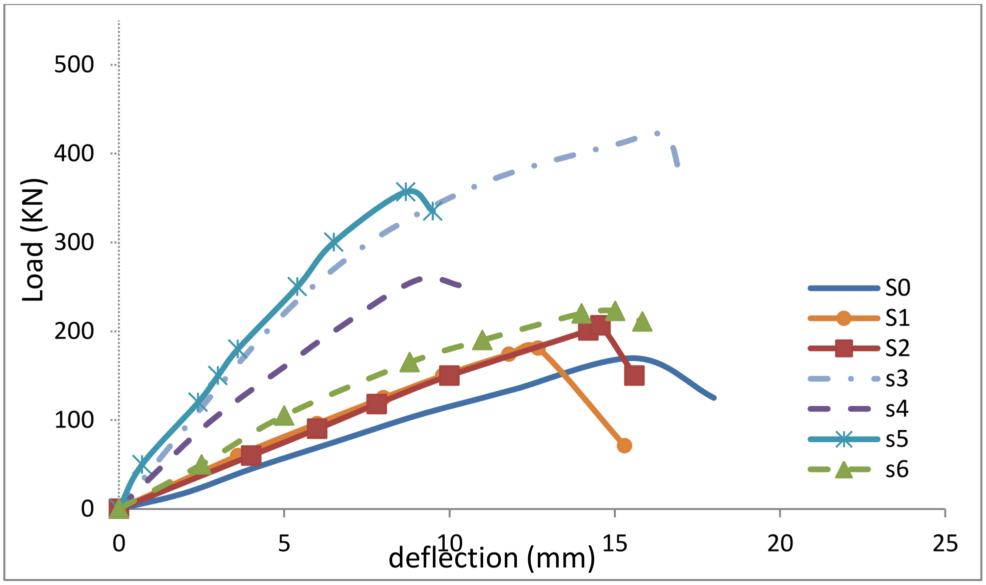
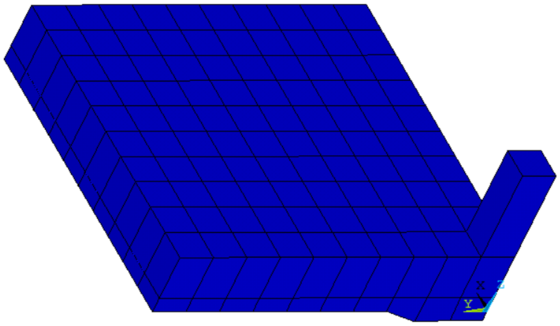
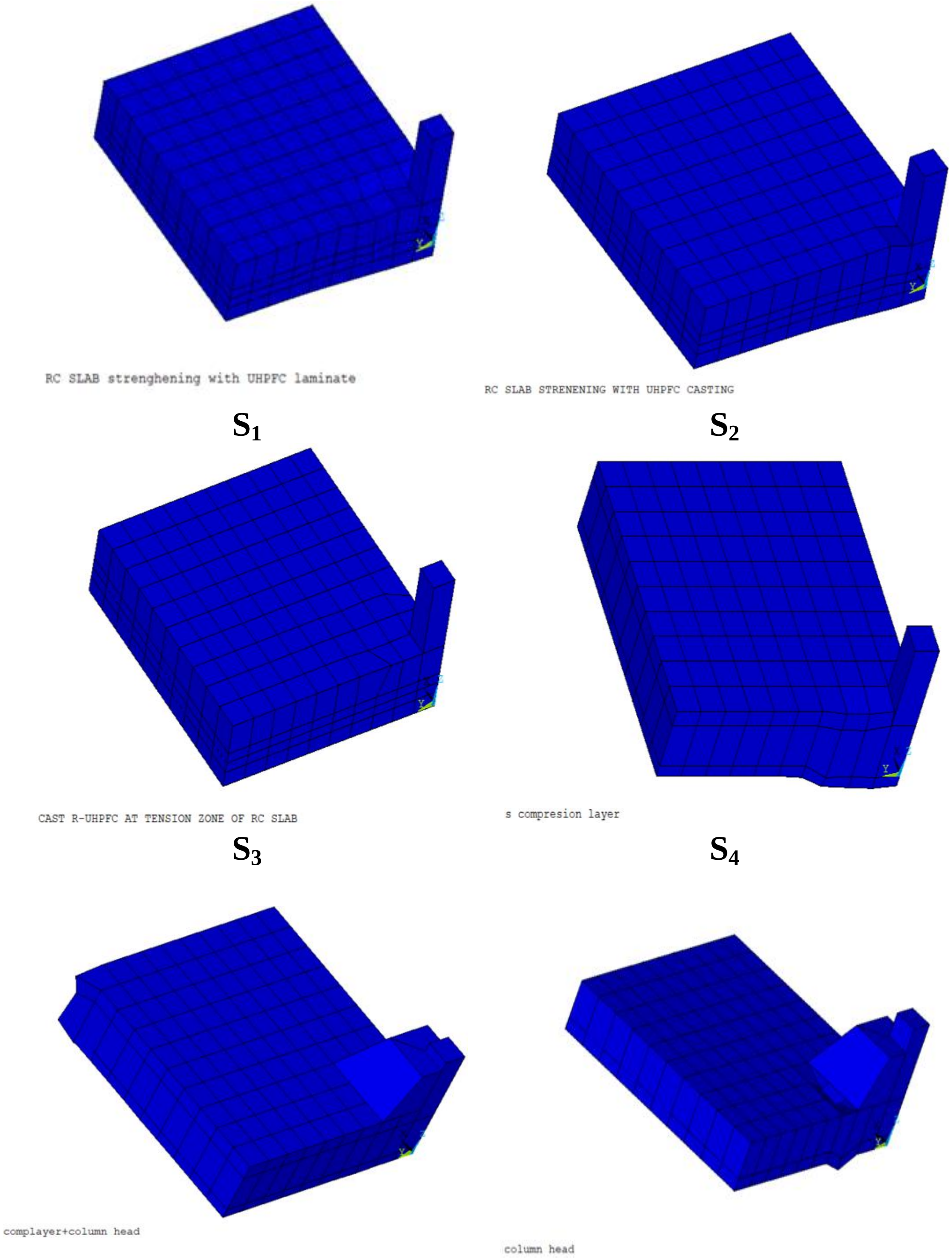


Fig.5 Load- deflection curve for models



Punching in R.C.flat Slab (kn-mm)

S_0



S_1 S_2

S_3 S_4

S_5 S_6

Fig.6 Deformed shape for models

3.2 Comparison between analytically and experimental approach results

The results of an experimental study published previously [1] to investigate the enhancement of punching shear strength of RC slabs strengthened with the UHPFC layer are mentioned in **Table 3. Fig 7 and Fig 8**showed the comparison of punching shear capacity between experimental and analytical results for specimens. Results showed that reinforcing RC slabs with casting UHPFC at tension or compression zone increased the punching shear capacity up to 147.97%, the ductility up to 44%, and the toughness up to 101.4% compared with the un-reinforced slab. The mean value of the ratio between experimental and analytical results was 1.01 with a standard deviation of 0.06. The deflection and versus load graphs showed a very close behavior. The ultimate load for control slab S_0 in the experimental test is higher than the numerical analysis by 2.5%. From the comparison, it can be observed that; the ultimate load for S_1 in the numerical analysis is higher than the experimental test by 0.46%. From the comparison, it can be observed that; the ultimate load for S_2 in the experimental test is higher than the numerical analysis by 2.45 %. The ultimate load for S_3 in the experimental test is higher than the numerical analysis by 12.75 %. The ultimate load for S_4 in the experimental test is higher than the numerical analysis by 4.10 %. The ultimate load for S_5 in the numerical analysis is higher than the experimental test by 5.78 %. The ultimate load for S_6 in the numerical analysis is higher than the experimental test by 2.08 %.

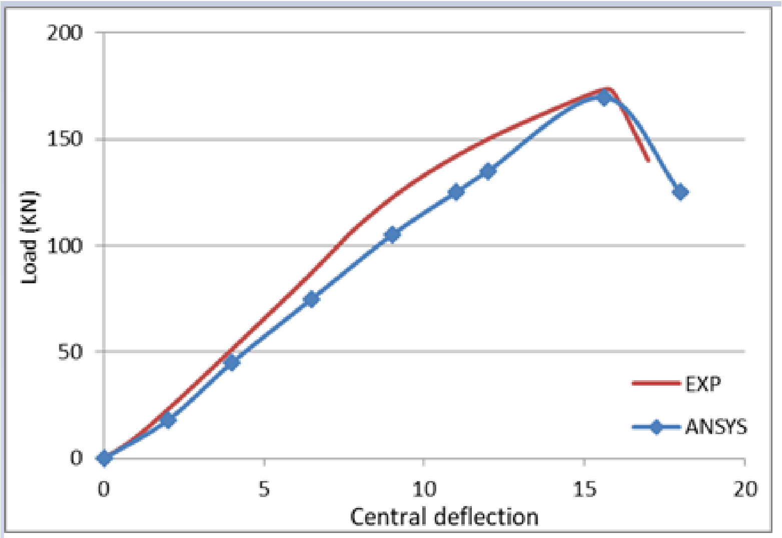
Table 3:

Comparison of punching shear capacity of experimental and analytically results.

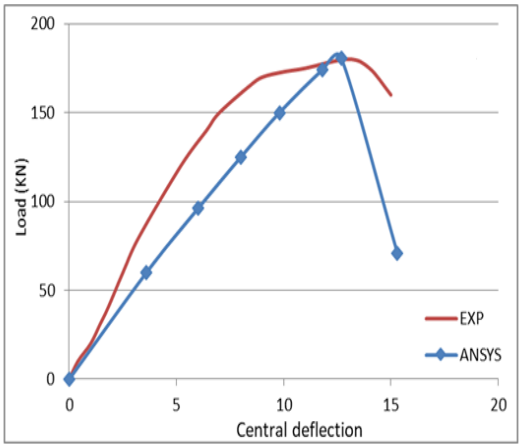
Specimens	**Punching Shear Capacity Vu (KN)**				**ANSYS**		$V_{Exp.}/V_{ANSYS}$
	EXP		**ANSYS**		**Ductility** (δ_u/δ_y)	**Toughness** (kN/mm)	
	Load (KN)	**Def (mm)**	**Load (KN)**	**Def (mm)**			
So	174.00	15.75	169.70	15.62	1.07	1754.28	1.02
S1	180.10	13.00	180.84	12.68	1.12	1881.15	1.00
S2	201.50	15.00	206.47	14.57	1.09	2666.78	0.98
S3	474.50	15.00	420.8	16.50	1.54	5852.02	1.13
S4	268.00	10.75	257.37	9.88	1.19	2372.11	1.04
S5	336.20	9.50	356.81	8.68	1.16	2591.09	0.94
S6	218.40	15.50	222.90	15.02	1.25	3124.67	0.98
Average							1.01
Coefficient of variation							0.06

δu…………. deflection at maximum load

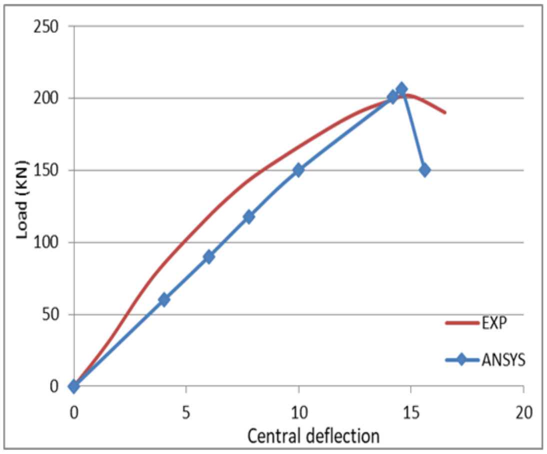
δy…………. deflection at yield load


200
150
100
50
0
Load (KN)
0
5
10
15
20
Central deflection
EXP
ANSYS

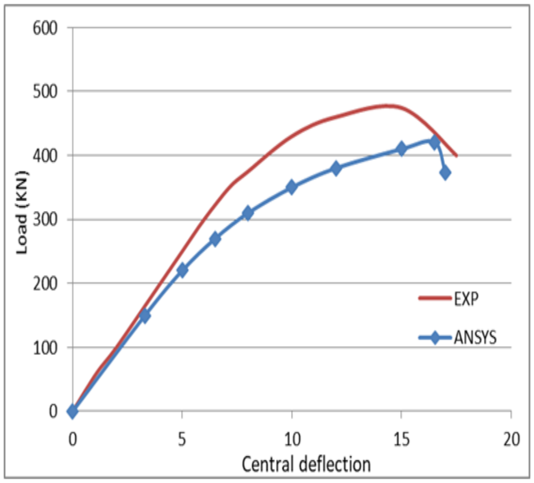
S$_0$


200
150
100
50
0
Load (KN)
0
5
10
15
20
Central deflection
EXP
ANSYS

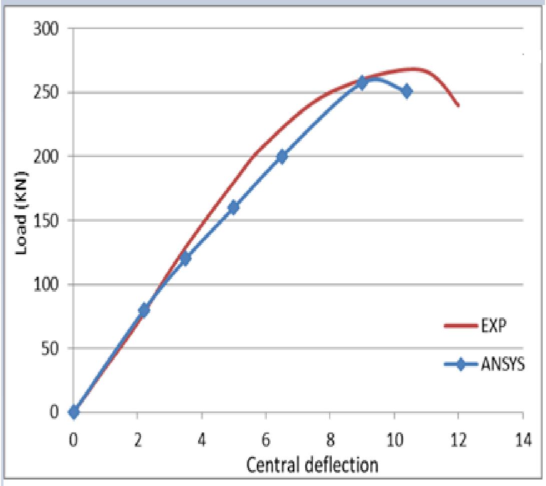
S$_1$


250
200
150
100
50
0
Load (KN)
0
5
10
15
20
Central deflection
EXP
ANSYS

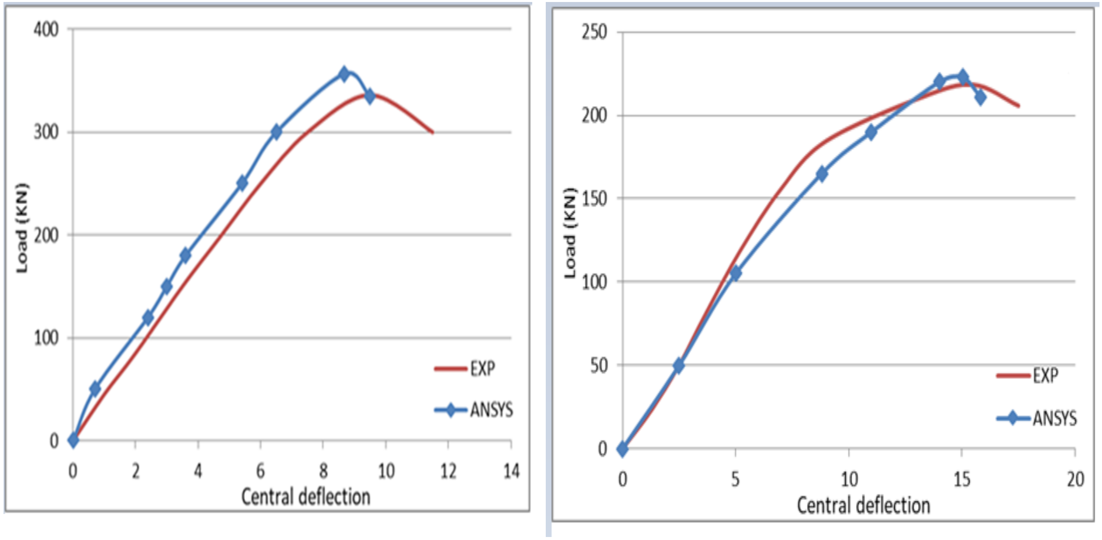
S$_2$


600
500
400
300
200
100
0
Load (KN)
0
5
10
15
20
Central deflection
EXP
ANSYS

S$_3$


300
250
200
150
100
50
0
Load (KN)
0
2
4
6
8
10
12
14
Central deflection
EXP
ANSYS

S$_4$



S_5 S_6

Fig 7: Compression between experimental and analytically load- deflection curves for group 1.

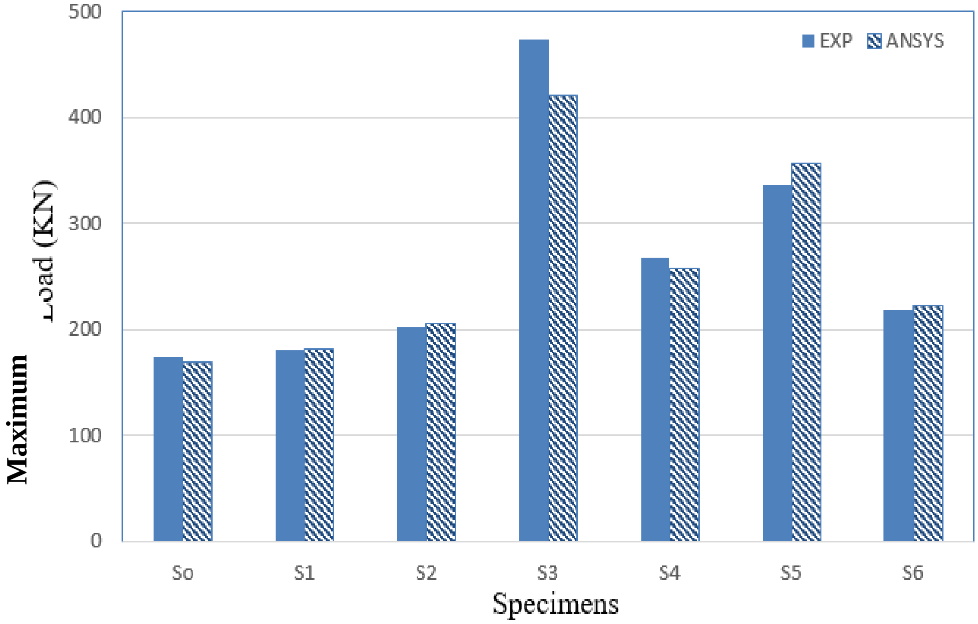


Fig8: Compression between experimental and analytically results for group 1.

4. Parametric study

4.1 Effect of increasing steel fiber content of UHPFC

- For group 2

A parametric study is carried out in this section by developing five additional models to investigate the effect of increasing the steel fiber content of UHPFC on the punching shear capacity of strengthened RC slabs. **Table 4** and **Fig 9** show increasing in load in group 2 due to increase the steel fiber content of UHPFC to 3%. Results showed that increasing punching shear capacity up to 27.14% for strengthened slabs with UHPFC due to an increase in the steel fiber content from 3% compared with group 1 which UHPFC mix contains 1.5% steel fiber. Ductility increased also up to 20.18% and toughness increased up to 86.45% compared with group 1.

Table 4:

Increasing punching shear strength for the additional models due to increasing in steel fiber content of UHPFC to 3%.

Group 2	**Punching shear capacity (kN)**	**deflection (mm)**	**Increase in punching shear strength (%)**	**Ductility (δu/ δy)**	**Toughness (kN/mm)**
S_1’	191.21	8.85	5.73	1.13	2017.05
S_2’	262.50	14.37	27.14	1.31	3813.59
S_3’	501.00	14.60	19.06	1.62	10910.63
S_4’	309.06	10.36	20.08	1.13	3485.69
S_5’	398.50	9.10	11.68	1.10	2947.50

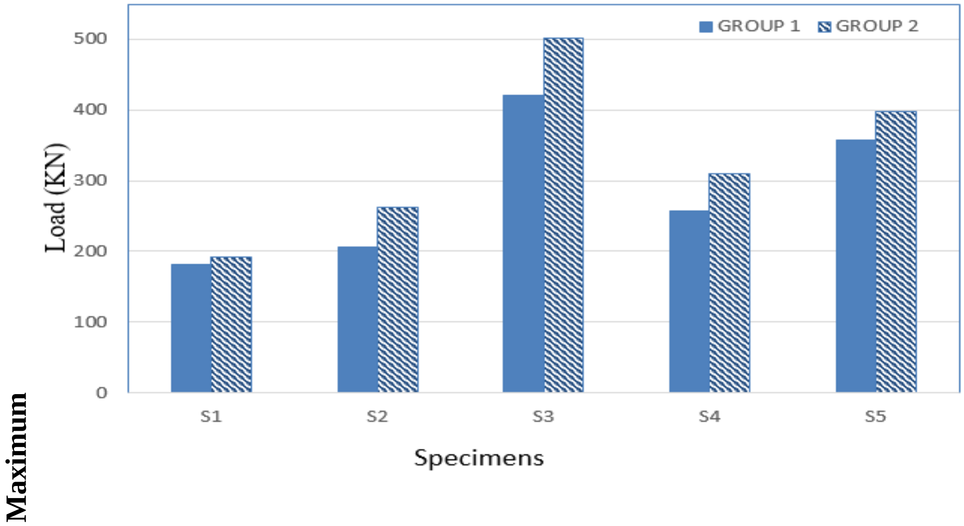


Fig 9: Compression between analytical results for group 1 and group 2.

4.2 Effect of increasing thickness of UHPFC layer (results of group 3)

- For group 3

A parametric study is carried out in this section by developing five additional models to investigate the effect of increasing the thickness of the UHPFC layer from 30mm to 50mm on the punching shear capacity of strengthened RC slabs. **Table 5** and **Fig 10** show increasing in load in group 3 due to the increasing thickness of the UHPFC layer. Results showed that increasing the punching shear capacity up to 37.81% for strengthened slabs with UHPFC due to increase the thickness of the UHPFC layer to 50mm compared with group 1 which the thickness of UHPFC was 30mm. Ductility increased also up to 10.79 % and toughness increased up to 92.76 % compared with group 1.

Table 5:

Increasing in punching shear strength for the additional models due to increasing in thickness of UHPFC layer to 50mm.

Group 3	Punching shear capacity (kN)	deflection (mm)	% Increase in punching shear strength (%)	Ductility (δu/ δy)	Toughness (kN/mm)
S_1’’	212.45	8.88	17.48	1.11	1804.77
S_2’’	271.00	14.78	31.25	1.07	3505.42
S_3’’	579.92	13.91	37.81	1.39	11280.64
S_4’’	333.48	9.90	29.57	1.15	3424.63
S_5’’	435.90	8.30	22.17	1.06	2888.48

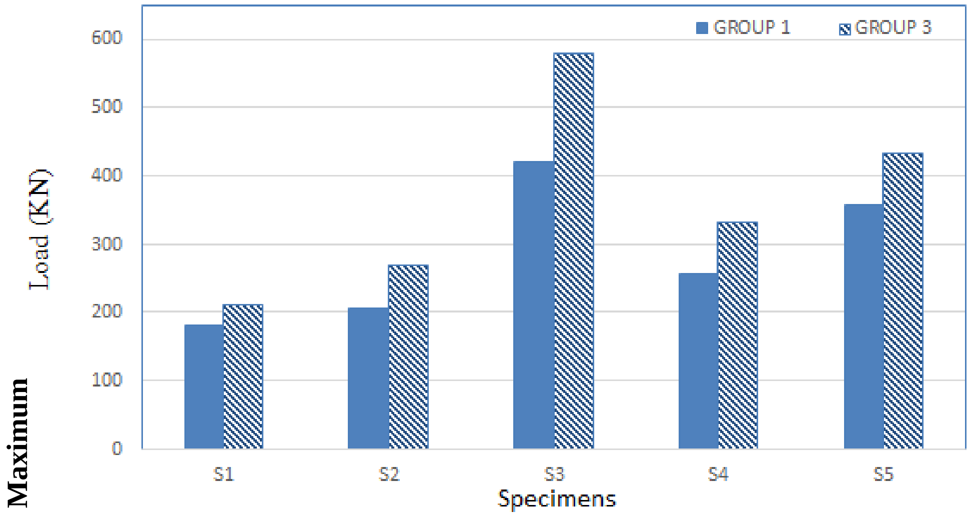


Fig 10: Compression between analytically results for group 1 and group 3

5. Conclusion

1. Analytical solution with the finite element for RC slabs strengthened with UHPFC showed good agreement with experimental results.

2. The increase in load when using UHPFC laminates for strengthening achieved 6.56% unlike using UHPFC casting which achieved 21.67 %, compared with the control RC slab.

3 .Strengthened tension zone with R-UHPFC casting achieve high strength than strengthened with UHPFC casting by 126.3%.

4.An increase in steel fiber content of UHPFC mixture, the thickness of the UHPFC layer, and using RFT enhancement the punching shear capacity and increasing the ductility and stiffness of RC slabs.

6. Reference

1. Elsayed, M., et al., Strengthening of slab-column connections using ultra high-performance fiber concrete. Case Studies in Construction Materials, 2022. **17**: p. e01710.
2. Ebead, U., H. Marzouk, and L.M. Lye. Strengthening of two-way slabs using FRP materials: A simplified analysis based on response surface methodology. in 2nd World engineering congress, Sarawak, Malaysia. 2002.
3. Martin, T., et al., Finite element modelling of FRP strengthened restrained concrete slabs. Engineering Structures, 2019. **187**: p. 101-119.
4. Teng, X. and Y. Zhang, Nonlinear finite element analyses of FRP-strengthened reinforced concrete slabs using a new layered composite plate element. Composite Structures, 2014. **114**: p. 20-29.
5. Taresh, H.R., M.Y. Md Yatim, and M.R. Azmi, Finite element analysis of interior slab-column connections strengthened by steel angle plates. Structural Concrete, 2021. **22**(2): p. 676-690.
6. Abdulrazzaq, M.M., et al., Numerical investigation for the flexural load behaviour of profiled composite slab strengthened with CFRP. Materials Today: Proceedings, 2022. **61**: p. 1115-1125.
7. Mahmood, M.B. and V. Agarwal, Non-Linear Finite Element Analysis of RC Slabs Strengthened with CFRP Laminates. vol, 2013. **5**: p. 140-143.
8. Anas, S., M. Alam, and R. Tahzeeb, Impact response prediction of square RC slab of normal strength concrete strengthened with (1) laminates of (i) mild-steel and (ii) C-FRP, and (2) strips of C-FRP under falling-weight load. Materials Today: Proceedings, 2022.

9. Alkhalil, J. and T. El-Maaddawy, Finite element modelling and testing of two-span concrete slab strips strengthened by externally-bonded composites and mechanical anchors. Engineering Structures, 2017. **147**: p. 45-61.

10. Kadhim, M.M., et al., Analysis and design of two-way slabs strengthened in flexure with FRCM. Engineering Structures, 2022. **256**: p. 113983.

11. Baniya, W.J., et al., Behavior of composite pre-flat slabs in resisting punching shear forces. Alexandria Engineering Journal, 2020. **59**(1): p. 333-347.

12. Sliseris, J., Numerical analysis of reinforced concrete structures with oriented steel fibers and re-bars. Engineering Fracture Mechanics, 2018. **194**: p. 337-349.

13. Safdar, M., T. Matsumoto, and K. Kakuma, Flexural behavior of reinforced concrete beams repaired with ultra-high performance fiber reinforced concrete (UHPFRC). Composite structures, 2016. **157**: p. 448-460.

14. Huang, Y., et al., Strengthening of concrete structures with ultra high performance fiber reinforced concrete (UHPFRC): A critical review. Construction and Building Materials, 2022. **336**: p. 127398.

15. Menna, D.W. and A.S. Genikomsou, Punching shear response of concrete slabs strengthened with ultrahigh-performance fiber-reinforced concrete using finite-element methods. Practice Periodical on Structural Design and Construction, 2021. **26**(1): p. 04020057.

16. Menna, D.W. and A.S. Genikomsou. Punching Shear Response of RC Slab-Column Connections Strengthened with UHPFRC-Finite Element Investigation. in RILEM-fib International Symposium on Fibre Reinforced Concrete. 2020. Springer.

17. ANSYS, "ANSYS User‟s Manual and Help Revision 19," ANSYS Inc., PA, USA, 2018.