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FLEXURAL BEHAVIOUR OF PROFILED COMPOSITE SLAB STRENGTHENED WITH CARBON FIBER REINFORCED POLYMER

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ABSTRACT:

The profiled composite slab (PCS) is a composite structure element consisting of profiled steel sheet (PSS) in filled with concrete in the troughs and connected using studs. The PCS like any other structural members, may need upgrading or strengthening for various reasons such as to carry extra loads and there is very limited studies examine strengthen the PCS. So, due to the limited studies on the strengthening technique of the PCS, this study investigate the positive effect of strengthened the PCS with CFRP as an upgrading, strengthening or repairing to carry extra load. Then, a parametric study was generated to cover the effect of the CFRP length on the flexural load behaviour of the PCS.

The ultimate flexural load for the FE models was equal to 130, 137 and 149 kN, respectively, for PCS-CFRP-L(50), PCS-CFRP-L(75) and PCS-CFRP-L(100). The FE results, proved that using CFRP as a strengthen technique for the PCS system has positive effect with different lengths.

الخلاصة:

profiled composite slab (PCS) هو عنصر هيكلي مركب يتكون من صفائح فولاذية (PSS) مملوءة بالخرسانة في الأحواض ومتصلة باستخدام مسامير. مثل أي أعضاء هيكلية أخرى ، فتحتاج إلى التطوير أو التعزيز لأسباب مختلفة مثل الحاجة إلى التطوير لتحمل أحمال إضافية وهناك دراسات محدودة للغاية تدرس تقوية PCS. لذلك ، نظرًا للدراسات المحدودة حول تقنية تقوية PCS ، تقترح هذه الدراسة التحقيق في التأثير الإيجابي لتقوية PCS باستخدام (البوليمر المقوى بألياف الكربون CFRP) كاسناد أو تقوية أو إصلاح لتحمل حمل إضافي. قدمت هذه الدراسة التحقق من سلوك الحمل لل PCS مع دراسة موجودة قام بها د.عباس وآخرون (2015). بعد ذلك ، كان الحمل النهائي للثني لنماذج FE يساوي 130 و 137 و 149 كيلو نيوتن ، على التوالي ، لـ PCS-CFRP-L (50) و PCS-CFRP-L (75) و PCS-CFRP-L (100). أثبتت نتائج FE أن استخدام CFRP كتقنية تقوية لنظام PCS له تأثير إيجابي بأطوال مختلفة.

LIST OF ABREVIATIONS

PCS	Profiled composite slab
PSS	Profiled steel sheets.
CFRP	Carbon fibre reinforced polymer
FE	Finite element.
PSS DB	PSS dry board.
DB	Dry board.
FSS	Flat steel sheet.

1. INTRODUCTION:-

Several full-size experimental tests have been proposed by past researchers to account for complex phenomenon of shear bond behaviour between the steel deck-concrete interactions in composite slabs. Wright et al. (1987) have carried out more than 200 tests on composite slab specimens including embossment, shear stud, and intermediate stiffeners with trapezoidal deck and compared the same with BS 5950: Part 4 design methods by considering two aspects, i.e., composite slab and beam actions.

PCS is a composite structure element consisting of profiled steel sheet (PSS) in filled with concrete in the troughs and connected using studs as presented in Figure 1.

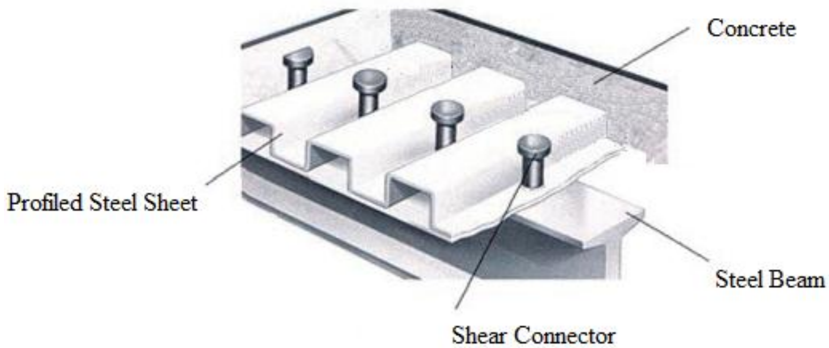
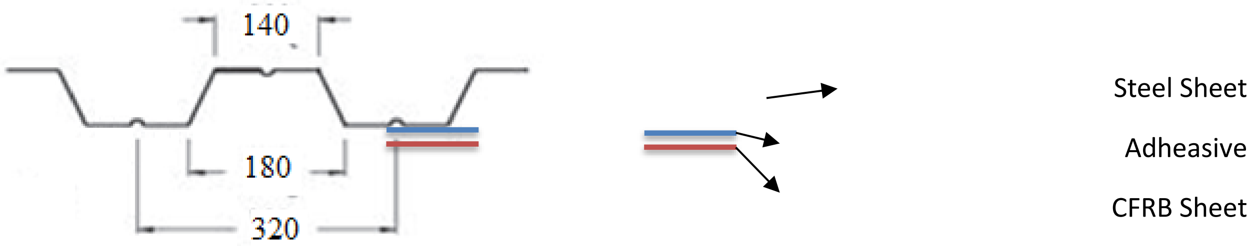


Figure 1 Details of profiled composite slab

As known, the PCS considered as a light weight structural element due to its small thickness. In the PCS, the concrete above the neutral axis resist the compressive stress and the PSS with the infill concrete which in filled in the troughs resist the tensile stress. Nevertheless, the compressive stress of the PCS makes the PSS vulnerable to local buckling which make the failure of the system. Due to this facts, this study suggest to strengthened the PCS with CFRP plate in the bottom side of the system to increase the tensile strength and decrease the local buckling in the PSS. The main objectives of this study is to find the positive effect of the CFRP plate and light weight concrete on the flexural behaviour of the PCS, effect of the CFRP plate versus different length on the flexural behaviour of the PCS, and select the optimum percentage of the increasing in the Pu of the PCS strengthened with CFRP.

2. Geometry

The composite slab was cast with the profiled corrugated steel sheet as the base and in filled with concrete. The slab was 2000 mm in length, 1000 mm in width, and 140 mm in total thickness, meanwhile the PSS thickness was 1 mm only. The detailing of the steel corrugated deck, and the view of the embossed steel sheet, are shown in Figure 2. All specifications of the experimental model are tabulated in Table 1.



Cross-section of VL deck

Figure 2 VL deck cross section and embossment details.

Table 1 Deck section dimensions and properties

W_t mm	W_b mm	W_c mm	T mm	Weight kN/m2	F_y MPa	F_u MPa	A_s mm^1
140	180	320	1	1	460	500	1056

3. Finite Element Models

The main parts of the FE models were light weight concrete, profiled steel sheet (PSS) and CFRP. The (ABAQUS/CAE Version 6.9) software were used in finite element modelling.

For the concrete infill, where the automated meshing was not capable of covering the linear hexahedral element (C3D8R) at the profiled corners, linear triangular prism (C3D6) was used. The linear quadrilateral shell element (S4R) was assigned for the PSS. The shell element type S4R is used for the CFRP patch. The element library likewise has a 'cohesive element' type, COH3D8, which is typically used in modelling the adhesive material. This element is applicable for conditions characterized by damage/deform, particularly in the analysis of shear and tensile stresses. The 'cohesive element' technique, which has been used by some previous studies, exhibits excellent results in

3.1 MATERIAL PROPERTIES

The materials used in the numerical analysis of this study were steel for the PSS and the embedded tubes, and normal concrete for the concrete infill. The properties of these materials are presented below.

3.1.1 Concrete

Three different models to simulate the behaviour of the concrete are available in ABAQUS/CAE Version 6.9 namely; concrete damaged plasticity, concrete smeared cracking and brittle cracking. Each type of these models has its limitations to simulate the concrete material depending on the loading type, concrete with or without reinforcement and low or high confining of concrete (Hibbitt & Sorensen 2002).

The Concrete Damage Plasticity (CDP) was chosen to simulate the behaviour of the concrete in this study because it is a comprehensive model that was used in many previous studies, and it is the most useful type for the applied loading and the concrete that are used in this work. The CDP model is designed for applications in which the concrete is subjected to flexural, axial, monotonic, cyclic loading conditions and it is based on the assumption of scalar (isotropic) damage. The elastic stiffness and plastic straining in tension and compression behaviour takes into consideration the degradation in the CDP model. To choose the CDP in ABAQUS/CAE from the menu bar in the edit material dialog box, select mechanical, plasticity and then the CDP will be visible in the dialog box(Hibbitt & Sorensen 2002). The concrete material propertie was 25.0 MPa for the concrete compressive strength and 3.3 MPa for the concrete tensile strength.

*3.1.2 **Steel***

The steel properties for the PSS and embedded cold-formed steel tubes that were obtained from the existing study Abbas et. al. (2015). As shown if figure [2]

*3.1.3 **CFRP sheet***

Unidirectional carbon fibre reinforced polymer (CFRP) sheet is used to strengthen the CFST columns; the type of CFRP sheet is MBrace 240, with modulus of elasticity, ultimate tensile strength, sheet thickness and Poisson's ratio of 240 GPa, 3800 MPa, 0.24 mm and 0.4, respectively. However, the CFRP material is an elastic-brittle material; thus, the mechanical material is modelled as damage for fibre reinforced polymer-Hashin Damage. Moreover, the CFRP material is treated as an orthotropic material, and the elastic-engineering constants are selected to identify its elasticity properties (i.e., modulus of elasticity, Poisson's ratio and shear modulus).

*3.1.4 **Adhesive***

The adhesive material is principally applied along the surface interaction between the CFRP patch and the steel sheet surface as well as to bond the multiple layers of CFRP sheets together. However, in this study, the adhesive layer along the surface interaction. As shown in figure [2].

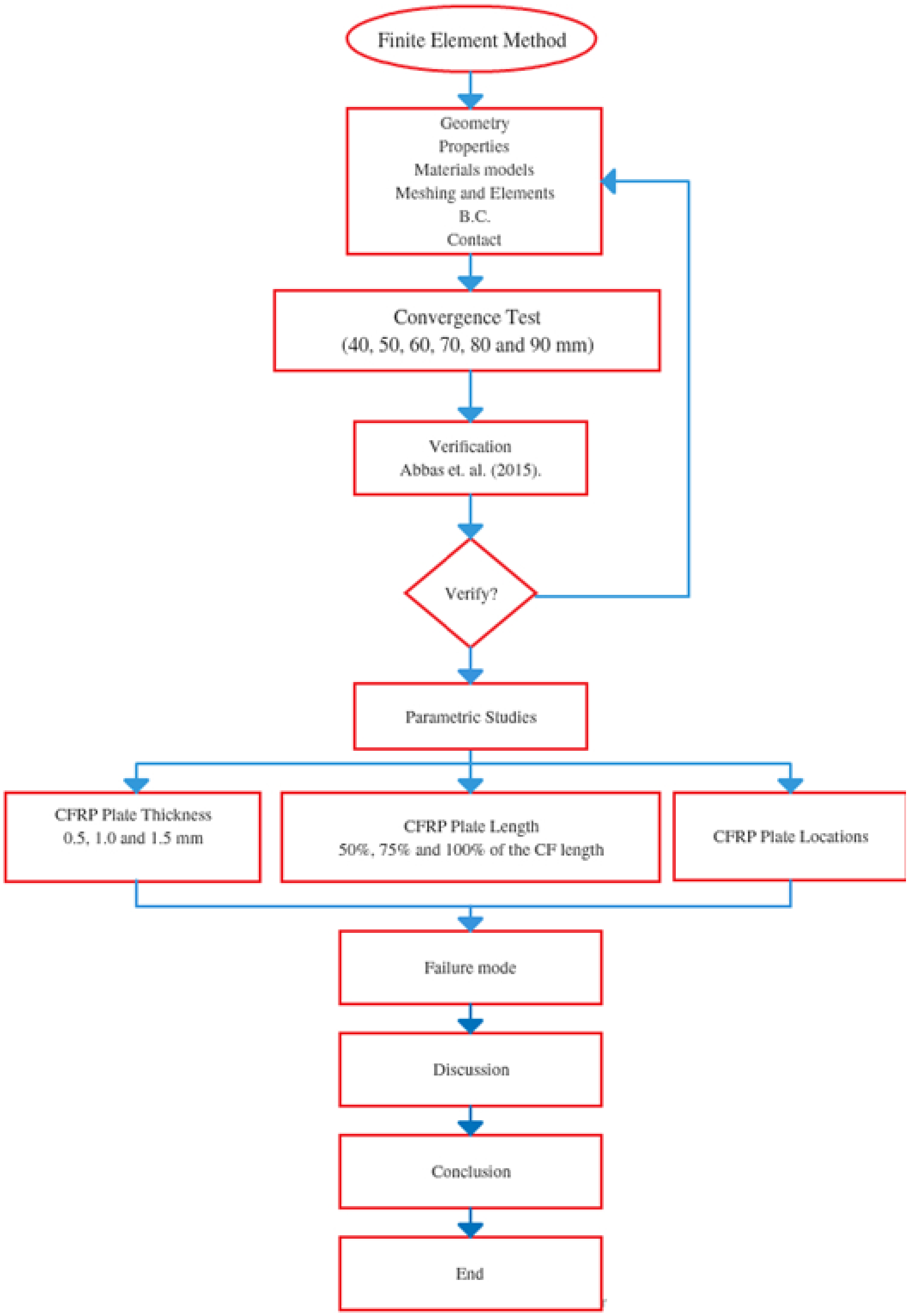

Finite Element Method
Geometry
Properties
Materials models
Meshing and Elements
B.C.
Contact
Convergence Test
(40, 50, 60, 70, 80 and 90 mm)
Verification
Abbas et. al. (2015).
Verify?
Parametric Studies
CFRP Plate Thickness
0.5, 1.0 and 1.5 mm
CFRP Plate Length
50%, 75% and 100% of the CF length
CFRP Plate Locations
Failure mode
Discussion
Conclusion
End

Figure 3. Flow chart for the current methodology.

To achieve that objective, a FE model was designed and analysed using ABAQUS/CAE (DassaultSystèmesSimulia Corp. 2008). The results of the FE model will be compared with the results of an existing experimental tests done by Abbas et. al. (2015).

Based on the results of the validated FE model, four comprehensive parametric studies will be generated to investigate the effect of the light weight concrete, CFRP plate length. Presented a flow chart for the current methodology.

3.2 Boundary Conditions and Displacement Control Analysis

Two lines load were applied to the top surface of the infill light weight concrete to represent displacement flexural loading. The displacements in all three degree of freedoms (DOFs) were restrained meanwhile the displacements in the vertical degree of freedoms (DOFs) was valued as -45 mm to act as displacement flexural loading for the FE models. The displacements in all three degree of freedoms (DOFs) were restrained at the bottom two side ends of the PSS vertically to represent the supports, meanwhile The displacements in all three degree of freedoms (DOFs) were released for X axis and Z axis.

Figure 4 presented the boundary condition with more details.

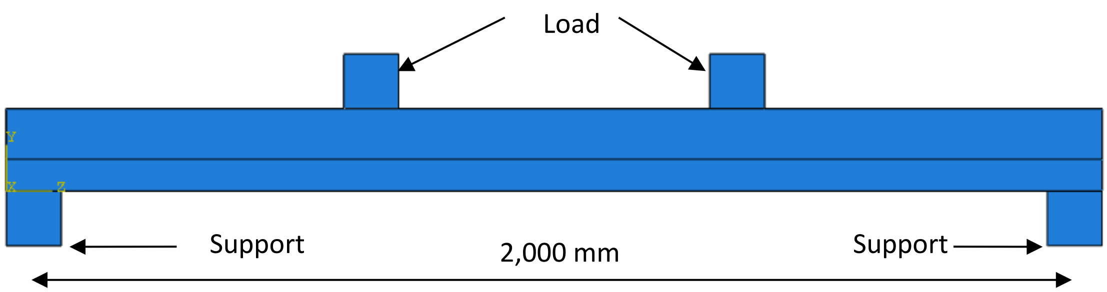


Figure 4 Boundary condition for the composite flooring

It was suggested to conduct a convergence study on the FE model to find the optimum meshing size for the parametric study which will be presented later in the chapter. Then, six different sizes of meshing have been used in analysis by using ABAQUS software (40, 50, 60, 70, 80, 90 mm) The convergence study was conducted for the control model which will be used for the verification study. The results showed that by using meshing with size60mm was gave a flexural loading very close to that meshing size 50 mm So, it was suggested to use meshing size 60 as a meshing size for the FE models of the verification study and the FE models for the parametric study as well.

4 VERIFICATION STUDY

To verify the adequate of FE modelling to predict the flexural load behaviour of the PCS this study suggest comparing the flexural load of an existing study done by Abbas et. al. (2015) with the flexural load of the FE analysis.

4.1 Model Geometry

The slab was 2000 mm in length, 1000 mm in width, and 140 mm in total thickness. The bolt was 19 mm in diameter and 100 mm in height before welding, and 95 mm in height after the welding to reduce the horizontal movement of the steel corrugated plate. The number of studs at every line (along the beam) was four (the distance between each was 320 mm, as it should be less than 600 mm), and the distance between the two lines was 80 mm (the standard distance must be at least four times the stud diameter) according to EC4. Figure 6 presented the PCS dimensions and distances.

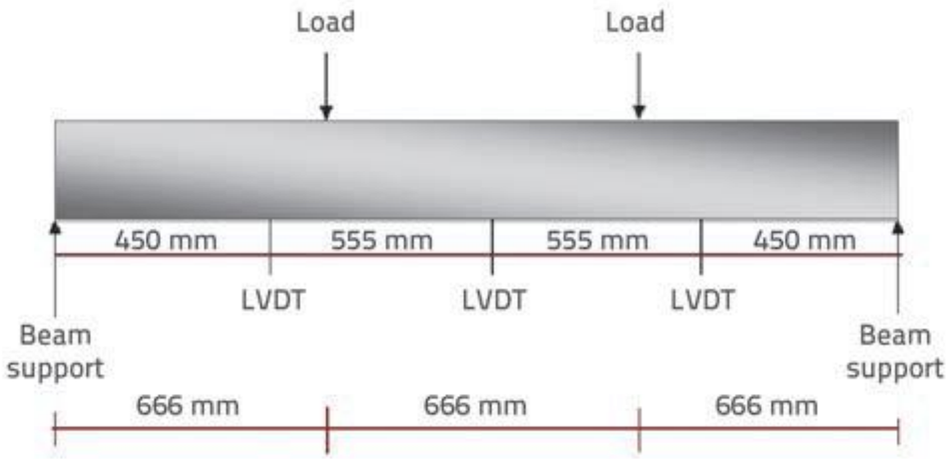


Figure 6 Composite slab dimensions and distances

4.2 Results

A FE model was designed with the given parameters and details from the existing study, and the result of the FE analysis showed that the ultimate flexural load resisting was 125kN and the displacement was equal to 31 mm. The ultimate flexural load resisting and displacement for the experimental test was equal to 120kN and 31 mm, respectively as presented in Table 3. After comparing these results (FE and experimental) the deviation percentage was equal to 4.2 % only as presented in Figure 7, which it is considered very small percentage to prove that the FE model was verified with the experimental test which conducted by Abbas et al. (2015).

Table 3 Load and displacement for the experimental test and FE model.

Label	Load (kN)	Displacement (mm)	Division percentage (%)
FE model	125	31	+ 4.2
Exp. test	120	31	-

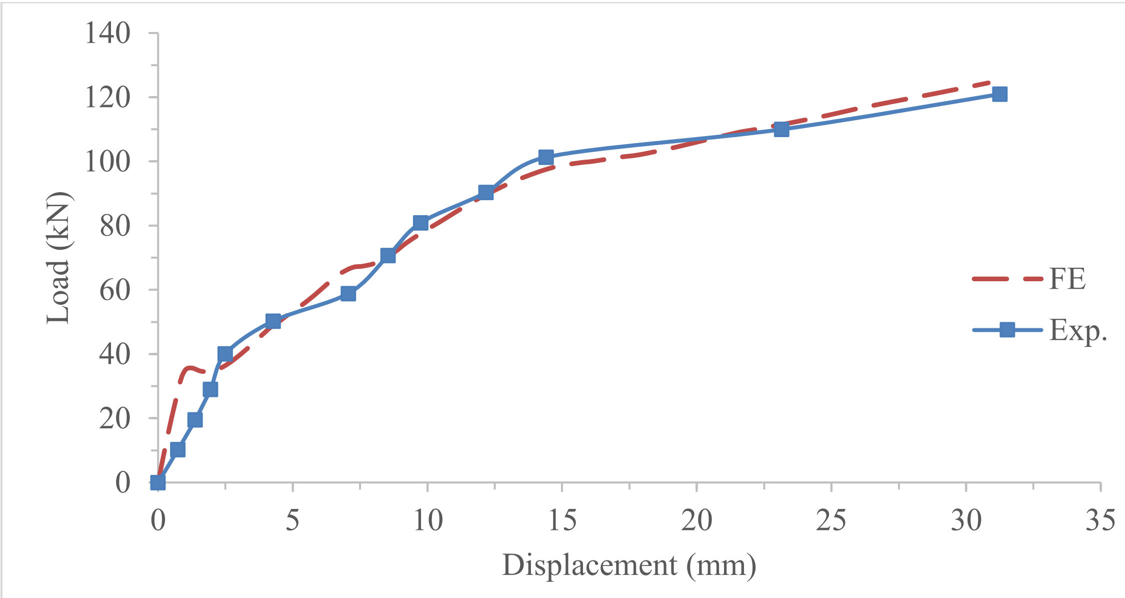


Figure 7 Load – displacement curve for the FE model and the existing experimental test.

5.0 PARAMETRIC STUDIES

The study suggest to investigate the effect of the CFRP plate length on the flexural behaviour of the PCS to present deep information to the structural designers and to improve the PCS to be used widely.

5.1 Effect of CFRP Plate Length

This study suggest to find the effect of the CFRP plate length on the flexural behaviour of the PCS to find the optimum strengthening technique by saving the cost and to present deep information about strengthening the PCS with CFRP plate.

Three different FE models will be generating to simulate PCS with different CFRP plate lengths and with 1.5 mm CFRP thickness. The first FE will be with 100% length of the PCS, the second FE model will be with 75% length of the PCS and the third FE model will be with 50% length of the PCS. As presented in Figure 8 and Table 4.

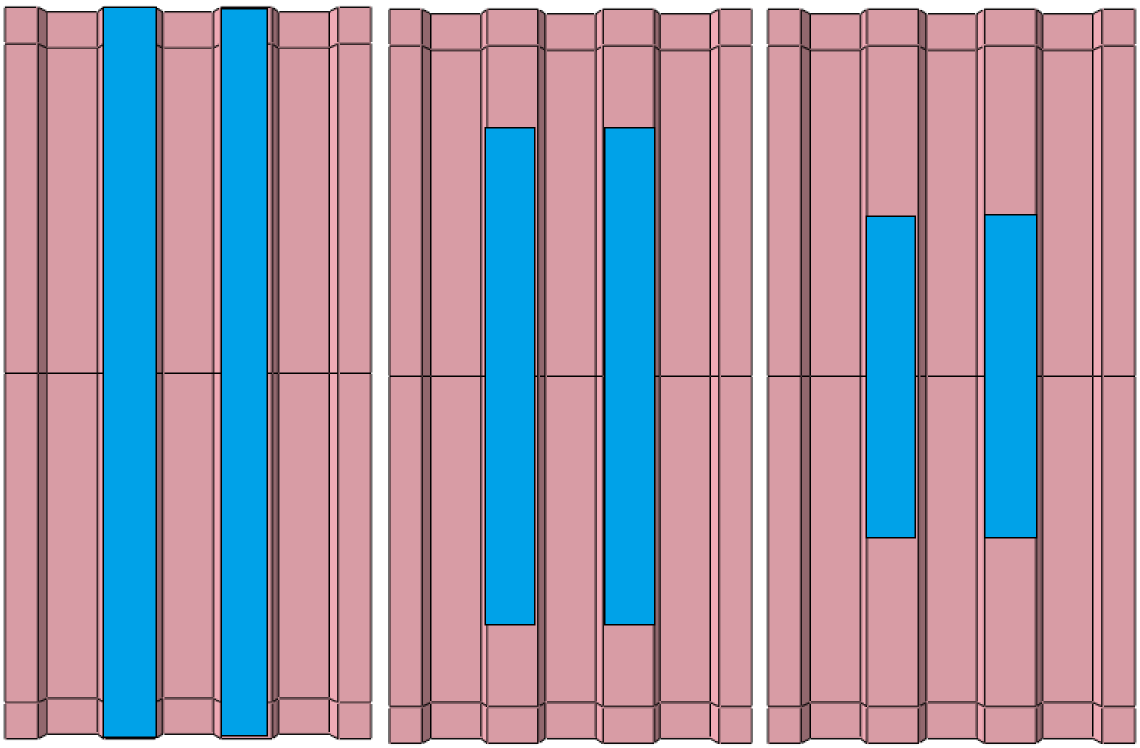


Figure 8 Details of the FE models with different length of CFRP plate

Table 4 Details of the FE models with deferent length of the CFRP plate

Label	CFRP plate length (%)
PCS	0
PCS-CFRP-L(50)	50
PCS-CFRP-L(75)	75
PCS-CFRP-L(100)	100

5.2 Effect of CFRP Plate Length

The ultimate flexural load for the FE models was equal to 130, 137 and 149 kN, respectively, for PCS-CFRP-L(50), PCS-CFRP-L(75) and PCS-CFRP-L(100), and the displacement was around 3.1 mm for the FE models as presented in Table 5. The results of these FE models were compared with the result of the control model (PCS) and recorded deviation percentage +4.5, +10.0 and +16.0, respectively, as presented in Figure 9. The FE results, proved that using CFRP as a strengthen technique for the PCS system has positive effect with different lengths.

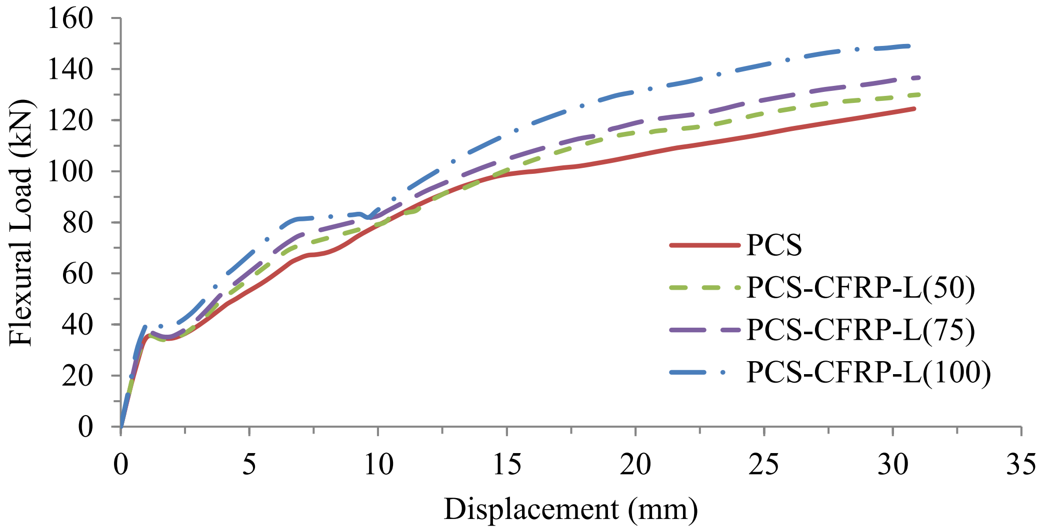


Figure 9 Flexural Load – Displacement for PCS FE models with different CFRP lengths.

It was suggested in this study to present the failure mode for the PCS as well to present more information about strengthening the PCS with CFRP sheets with different lengths. The results proved that the ultimate failure mode was separation between the PSS and concrete in the left and right side of the whole system as presented in Figure 10.

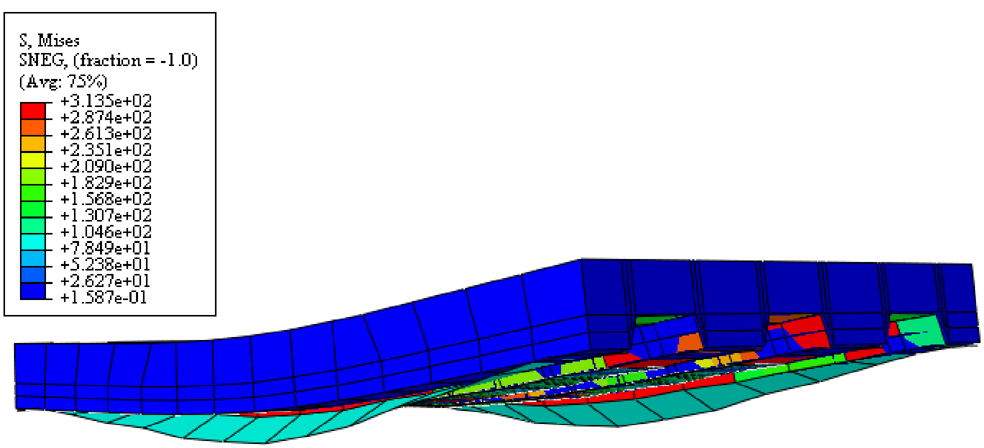


Figure 10 Ultimate failure mode for the PCS strengthened with 1000 mm CFRP sheets

Table 5 Details of the FE models with deferent CFRP plate length

Label	CFRP plate length (%)	Flexural Load (kN)	Displacement (mm)	Deviation (%)
PCS	0	125	3.2	-
PCS-CFRP-L(50)	50	130	3.0	+04.5

PCS-CFRP-L(75)	75	137	3.2	+10.0
PCS-CFRPL(100)	100	149	3.1	+16.0

6 CONCLUSIONS

The main conclusion is using CFRP as a strengthen technique for the PCS system with different CFRP plates length (1000, 1500, 2000 mm, respectively)

This study hardly recommend to use CFRP sheets as a strengthen technique for the PCS system. Moreover, FE model to prove that 100% length was more optimum to resist the flexural loading.

7 REFERENCES

Abbas H. S., Bakar S. A., Ahmadi M., Haron Z. (2015). Experimental studies on corrugated steel-concrete composite slab. GRAĐEVINAR 67. 3, pp. 225-233

Abdullahi (2011). Finite-element analysis of steel_concrete composite plate girder. ASCE, Journal of Structural Engi- neering.128(9):pp.1158_68.

Ahmed, R., Easterling, W. S. (2002). New evaluation and modeling procedure for horizontal shear bond in composite slabs, *Journal of constructional steel research*, 65, pp. 891-899.

Ahmed, R., Easterling, W. S. (2000). shear connectors in composite profiled slabs. Journal of Constructional Steel Research. 57:pp. 1267_87.

Akhand, M., (2001). Rib shear connectors in composite profiled slabs, *Journal of Constructional Steel Research*, 59, pp. 385-403.

Awang H. and W. H. Wan Badaruzzaman, "Structural performance and applications of a reversed profiled steel sheeting dry board roof panel system," Asian Journal of Civil Engineering (Building and Housing), vol. 11, pp. 371-384, 2009.

E. Ahmed and W.H. Wan Badaruzzaman, "Vibration Performance of Profiled Steel Sheet Dry Board Composite Floor Panel," KSCE Journal of Civil Engineering. Vol. 17, No. 1, pp. 133-138, 2013.

Khalil CR. (2010) Two-way flexure of steel-deck reinforced slabs. ASCE, Journal of the Structural Division;105(ST6):pp. 1039_54.

Marimuthu, V., Seetharaman, S., Arul, S., Chellappan, A., Bandyopadhyay, T., Dutta, D.: Experimental studies on composite deck slabs to determine the shear-bond characteristic (m-k) values of the embossed profiled sheet, *Journal of construction steel research*, 63 (2006), pp. 791-803.

Mohammed, B., Al-Ganad, M., Abdullahi, M.: Analytical and experimental studies on composite slabs utilising palm oil clinker concrete, *Construct build mater*, 25 (2011) 8, pp. 3550-3560.