Numerical Investigation on Two Way RCC Slabs Strengthened Using FRP Fabrics

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***Abstract*—Finite element analysis (FEA) has become the favourite method of analysis for complex engineering structures. The application of computer software's to model and analyse the structure is faster, and predominantly cost-effective compared to experimental versions. This paper describes the finite element simulation of the two way RCC slabs with different composite layered retrofitted RCC slabs strengthened with two wrapping techniques (plus and square type of configurations) using Fibre Reinforced Polymer (FRP) fabrics. The FRP used in the workare Carbon, Glass, Basalt and Polypropylene fabrics.The ultimate loads, deflection at ultimate load, deflection contours and the crack patterns of all the slabs are discussed.**

***Index Terms*— *C*omposite, Cost-effective, Fibre Reinforced Polymer (FRP), Retrofitted, Simulation.**

I. INTRODUCTION

The application of FE analysis has increasedsince the enormous scientific advancement in current years. This has eased the researchers to improve the skillsof computer tasks by combining the sophisticated software's and hardware's. Finite element analysis (FEA) has become the favourite method of analysis for complex engineering structures. The application of computer software's to model and analyze the structure is faster, and predominantly cost-effective compared to experimental versions. By considering the application of Finite Element (FE) packages, more capable and advanced analyses can be done. This paper describes the finite element simulation of the two way RC slabs and also different composite layered retrofitted RCC slabs strengthened with different wrapping techniques using Fibre Reinforced Polymer (FRP) fabrics. The FRP used in the work are Carbon (CFRP), Glass (GFRP), Basalt (BFRP) and Polypropylene (PPFRP) fabrics.Here a non-linear finite element analyses for all slab specimens is carried out.

II. LITERATURE REVIEW

A research work desires to be assessed with a numerical analysis using either software or a mathematical model. The elements of a structure such as slab, beams were modeled by describing the elements in software which exhibits the same material properties of the members in practice, followed by load application, support conditions and attaining the outputs.

In the research works taken up bySingh et al. 2016 [1], Subramani & Balamurugan 2016 [2], Demakos et al. 2013 [4], Mahmood & Agarwal 2013 [6], Jayajothi et al. 2013 [7], Banu et al. 2012 [9], Rousan et al. 2012 [11], Patil et al. 2012 [13], Saifullah et al. 2011 [15] and Kim et al. 2010 [16] utilized a finite element software ANSYS to model and analyze the members. The results achieved were in good agreement with the experimental investigations.

Other Finite element softwares such as 3D CAMUI, Cervenka, ATENA and LS-DYNA were utilised by Larrinaga et al. 2014 [3], Elsanadedy et al. 2013 [5], Almusallam et al. 2013 [8], Schladitz et al. 2012 [10], Hashemi & Mahaidi 2012 [12] and Farghaly& Ueda 2011 [14]

III. MATERIALS

The RCC structure is classified into one, two or three dimensional finite elements depending on the requirement and this categorization of the structure was of fictitious lines or surfaces or volumes.

Concrete was modeled usingSOLID65, which was a solid with or without reinforcing rebars. The solid was capable of cracking in compression and crushing in tension. SOLID65 element was with 8 nodes and three degrees of freedom at each node, translations in the nodal was in x, y, and z directions.

LINK180 element was used to model the reinforcing rebars, distinct modeling was carried out by the assumption that bonding between steel and concrete was 100%. LINK180 was a uniaxial tension-compression member with the nonlinear material properties. The element comprises of 2 nodes with three degree of freedom at each node, translations in the nodal x, y, and z directions.

The steel supports at both the ends and also the steel plates through which the uniformly distributed load was applied on all the slabs, was modeled by using SOLID 45. The element comprises of 8 nodes with three degrees of freedom at each node: translations in the nodal X, Y, and Z directions. This element represents the properties such as plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities.

The composite FRP materials used in the work are Carbon (CFRP), Glass (GFRP), Basalt (BFRP) and Polypropylene (PPFRP) fabrics were modeled using layered SOLID46 structural solid element. This element comprises of 8 nodes with three degree of freedom at each node. The element material was assumed to be orthotropic and perfect interlaminate bonding. It was also assumed that the stress-strain relationships for all the FRP materials were linearly elastic.

IV. METHODOLOGY

A numerical investigation with the provision of finite element software ANSYS 19.0 workbench was utilized to carry out non-linear Finite Element Analysis of all the RCC slabs.

The modeling for the analysis was done as volumes. Only half of all the slabs were modeled, since it was symmetric. The composites were modeled by using separate volumes for plus and square wrapping schemes respectively as shown in Fig 1.

A rectangular or square mesh was suggested (Wolanski 2004 [17], Kachlakev et al 2001 [18]) to obtain an excellent result from the SOLID65 element. Hence, the mesh was setup so that square elements were formed. It was attained by mapped meshing which is available in ANSYS 19.0 workbench. Mapped meshing was known to deliver the best results with higher accuracy as compared to free or sweep meshing represented in Fig 2.

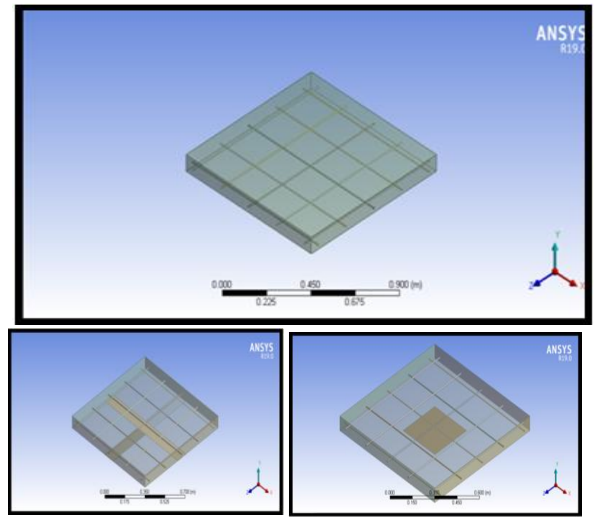

Fig 1: Representation of modeled RC slab a) control slab, b) slab with plus wrapping configuration and c) slab with square wrapping configuration.

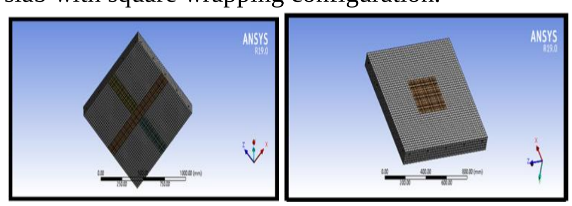

Fig 2: Represents the meshing for the strengthened slab models a) plus wrapping configuration & b)square wrapping configuration

For slabs, the load was transferred through steel plates and the steel supports at the end of the RCC slabs as shown in Fig 3.

The analysis was associated to study three different behaviors of the model under initial cracking of the slab, deflection and the ultimate strength of the slab. The nonlinear response was computed using Newton-Raphson method of analysis.

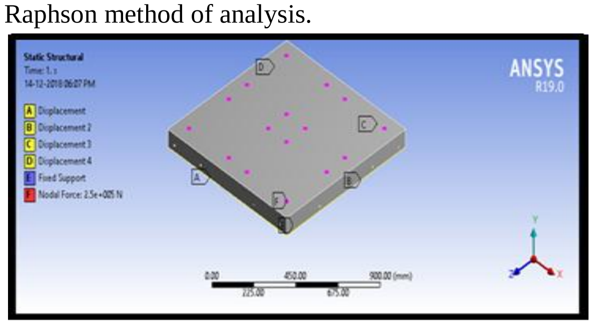

Fig 3: Represents the applied load and the support constraints applied to the model

Incremental loads are applied up to the failure as required by the Newton-Raphson procedure. The output controls assist in achieving every step print out and for data storage. The L2 convergence norm was employed where the convergence was stood on the structural force F, with a tolerance value of 0.1. All the limits were set to zero, such as nodal DOF solution, cumulative iterations, elapsed time and CPU time.

V. RESULTS& DISCUSSIONS

The ultimate load and deflection at ultimate load for the FE model was considered based on the variations in the cracks and the deflectionsshown in Table 1.

Table 1: Ultimate load and deflection at ultimate load of all the slabs obtained from ANSYS

Sl No.	FEM model	Ultimate load (kN)	Deflection at ultimate load (mm)
1	Plain	130	16.09
2	CFRP with Plus configuration	247	13.19
3	GFRP with Plus configuration	215	13.23
4	BFRP with Plus configuration	184	13.34
5	PPFRP with Plus configuration	184	13.47
6	CFRP with Square configuration	239	13.54
7	GFRP with Square configuration	202	13.29
8	BFRP with Square configuration	176	13.36
9	PPFRP with Square configuration	194	13.47

From the Table 1, it was observed that the ultimate load was least for the control slab whereas and deflection was higher compared over the other slab models. All the slab models performed well in terms of ultimate load carrying capacity however the deflections for all the strengthened slab models were nearly same.

Table 2: Percentage increase in Ultimate load of slabs strengthened using different fabrics

Sl No.	FEM model	Percentage increase in Ultimate load (%)
1	Plain	-
2	CFRP fabric	46.5
3	GFRP fabric	37.6
4	BFRP fabric	27.8
5	PPFRP fabric	31.2

From Table 2,it was observed that Carbon fabric performed well with the highest load carrying capacity of 46.5% and Basalt fabric with the least load carrying capacity of 27.8% in comparison with the unstrengthened slab model.

The deflection contours for few slab models obtained from the analysis are represented in Fig 4.

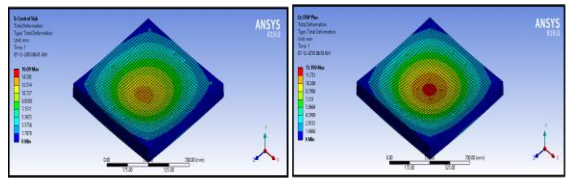

Fig 4: Deflection contour obtained for slabs

The bottom view of the crack patterns of few slabs as acquired using ANSYS 19.0 workbench are represented in Fig 5.

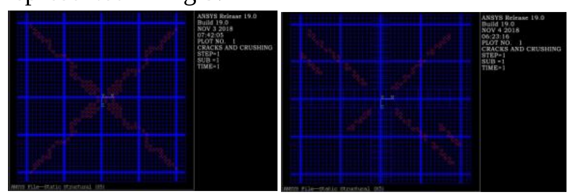

Fig 5: Crack pattern obtained for slabs

VI. CONCLUSIONS

The research work conducted can be concluded with the following remarks.

- The strengthening technique adopted in the work was effective.
- The two types of wrapping techniques plus and square configurations enhanced the load carrying capacity of the strengthened slabs than the plain slab model.
- There was a decrease in deflection of the strengthened slabs in comparison with the unstrengthened slab model.
- Slabs strengthened using Carbon FRP fabric and Glass FRP fabric achieved the maximum ultimate load compared to all the slab models, however the performance of BasaltFRP fabric and Polypropylene FRP fabric was also higher than the plain slab model.

REFERENCES

[1] Pradeepsingh, Abhishek Mishra, ArpitKulshreshtha, Finite Element Analysis Of Reinforced Concrete Beam Using Ansys, *International Journal Of Current Engineering*

And Scientific Research (IJCESR), Vol 3, No 1, 122-126, 2016

[2] T.Subramani, K.Balamurugan, Finite Element Analysis Of Composite Element For FRP Reinforced Concrete Slab By Using ANSYS, *International Journal of Application or Innovation in Engineering & Management (IJAIEM)*,Vol 5, No. 5, 76-84, 2016

[3] Pello Larrinaga, Carlos Chastre, Hugo C. Biscaia, José T. San-Jose, Experimental and numerical modeling of basalt textile reinforced mortar behavior under uniaxial tensile stress, *Materials and Design*, 55, 66-74, 2014

[4] Constantinos B. Demakos, Constantinos C. Repapis, DimitriosDrivas, Investigation of Structural Response of Reinforced Concrete Beams Strengthened with Anchored FRPs, *The Open Construction and Building Technology Journal*, 7,146-157, 2013

[5] Hussein M. Elsanadedy, Tarek H. Almusallam, Saleh H. Alsayed, Yousef A. Al-Salloum, Flexural strengthening of RC beams using textile reinforced mortar – Experimental and numerical study, *Composite Structures*, 97, 40-55, 2013

[6] Mustafa BasheerMahmood, V. C. Agarwal, Non-Linear Finite Element Analysis of RC Slabs Strengthened with CFRP Laminates, *International Journal of Engineering Trends and Technology (IJETT*), vol 5 No. 3, 140-143, 2013

[7] P. Jayajothi, R. Kumutha, K. Vijai, Finite Element Analysis Of Frp Strengthened Rc Beams Using Ansys, *Asian Journal Of Civil Engineering (BHRC)*, Vol. 14, No. 4, 631-642, 2013

[8] Tarek H. Almusallam, Hussein M. Elsanadedy, Yousef A. Al-Salloum, Saleh H. Alsayed, Experimental and numerical investigation for the flexural strengthening of RC beams using near-surface mounted steel or GFRP bars, *Construction and Building Materials*, 40, 145-161, 2013

[9] DragosBanu, RuiCarneiro de Barros, NicolaeTaranu, Numerical Modelling Of Two Way Reinforced Concrete Slabs Strengthened With Carbon Fiber Reinforced Polymers Strips, *15th International Conference on Experimental Mechanics*, Portugal, 2012

[10] Frank Schladitz, Michael Frenzel, Daniel Ehlig, Manfred Curbach, Bending load capacity of reinforced concrete slabs strengthened with textile reinforced concrete, *Engineering Structures*, 40, 317-326, 2012

[11] R. Al-Rousan, M. Issa, H. Shabila, Performance of reinforced concrete slabs strengthened with different types and configurations of CFRP, *Composites: Part B*, 43, 510-521, 2012

[12] S. Hashemi, R. Al-Mahaidi, Experimental and finite element analysis of flexural behavior of FRP-strengthened RC beams using cement-based adhesives, *Construction and Building Materials*, 26, 268-273, 2012

[13] S. S. Patil, A. N. Shaikh, B.R.Niranjan, Non Linear Finite Element Method of Analysis of Reinforced Concrete Deep Beam, *International Journal of Modern Engineering Research (IJMER)*, Vol.2, No.6, 4622-4628, 2012

[14] Ahmed SabryFarghaly, Tamon Ueda, Prediction of punching shear strength of two-way slabs strengthened externally with FRP sheets, *Journal of Composites for Construction*, Vol.11, 181-193, 2011

[15] I. Saifullah, M.A. Hossain, S.M.K.Uddin, M.R.A. Khan, M.A. Amin, Nonlinear Analysis of RC Beam for Different Shear Reinforcement Patterns by Finite Element Analysis, *International Journal of Civil & Environmental Engineering*, Vol 11, No. 1, 63-74, 2011

[16] Yail.J.Kim, Jesse M.Longworth, R.Gordon Wight, Mark F.Green, Punching shear of two-way slabs retrofitted with Prestressed or Non-prestressed CFRP sheets, *Journal of Reinforced Plastics and Composites*, vol. 29, No.8, 1206-1223, 2010

[17] Anthony J. Wolanski, B.S., Flexural behavior of reinforced and prestressed concrete beams using finite element analysis, Master of Science thesis, *Faculty of the Graduate School*, *Marquette University*, Milwaukee, Wisconsin, 2004.

[18] Damian Kachlakev and Thomas Miller, Finite element modeling of reinforced concrete structures strengthened with FRP laminates: Final Report SPR 316, *Oregon department of transportation, For Oregon Department of Transportation Research Group and Federal Highway Administration*, 2001.