DYNAMIC ANALYSIS OF RCC SLABS STRENGTHENED USING CFRP

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Abstract: The use of carbon fibre reinforced polymers (CFRP) in strengthening structural members is rapidly gaining in the past two decades. When compared to conventional steel reinforcement, CFRP has lots of advantages. This paper presents the dynamic analysis of RC cantilever slabs strengthened with CFRP. Dynamic analysis is important to determine the dynamic response of the structure during dynamic loading. This analysis is performed on ANSYS APDL 16.0. The results obtained from the analysis shows that the behaviour of cantilever slabs with the provision of CFRP has improved when compared to conventional slabs.

***Index Terms* – ANSYS APDL, Dynamic Analysis, CFRP, Slabs.**

I.INTRODUCTION

Slabs are most repeatedly used for forming roof covering, floors and bridges. It usually carries uniformly distributed gravity load acting normal to its span and transfers same to the supports by flexure, shear and torsion. Repair and rehabilitation has become an important aspect for the reinforced cement concrete structures because of the damage in the RC structures.

Strengthening of structural members using Fibre Reinforced Polymer (FRP) is the method to enhance the capacity and improves the mechanical properties of an individual member. FRP composites consist of high strength fibres embedded in a matrix of polymer resin. Carbon fibres are the stiffest, most durable and are quite resistant to most environmental impacts. Therefore, the most commonly used FRP systems are Carbon Fibre Reinforced Polymer (CFRP). CFRP is an extremely strong, light and anisotropic in nature. CFRP can be expensive but are commonly used wherever high strength-to-weight ratio and rigidity are required.

II.LITERATUREREVIEW

Bassam Q. Abdulrahman et al. (2017) discussed the strengthening method of existing flat slabs by the usage of fibre reinforced polymers in order to enhance the structural performance of slab to column zones by providing post cracking tensile resistance and controlling the width of the cracks. The method relies on strengthening the slabs in flexure by adding prestressed or non-prestressed FRP sheets or plates to the exposed surface of the slab so that this will enhances the ability of the system to carry the tensile stresses, reducing the opening of cracks at comparative load levels thus delaying the onset of punching shear. Greater ultimate load enhancements were attained from the orthogonal arrangement with the addition of longitudinal CFRP along the slab edges. Also the strengthened slab column connections have a stiffer behaviour than the un-strengthened slabs because the CFRP delays the initiation of cracking.

Anju Mary Martin et al. (2016) conducted finite element analysis of beam retrofitted with different fibre reinforced polymer (FRP) composite sheets using ANSYS 15 software. Composites used were CFRP, GFRP and AFRP. The aim of the study was to find out the best wrapping technique and to study the effect of thickness of FRP sheet. The maximum thickness of FRP sheet considered in the study was 6 mm and orientation was varied as 0 degree and 90 degree. It was concluded from the study that when the RC beam was wrapped with CFRP, the load carrying capacity was increased by 10 %. It was also observed that the CFRP sheet of 6 mm thickness took maximum load and the FRP layer with 90 degree orientation was superior in load carrying capacity.

Mustafa Basheer Mahmood et al. (2013) studied the finite element modelling of control RC slabs and strengthened slabs with the help of ANSYS 13. A control slab was modelled and the results were analysed and then strengthened slabs were modelled and analysed. The results of the control and strengthened slabs were compared with the experimental results. The load deflection curve and ultimate load carrying capacity of control slab and strengthened slabs were analysed. The load-deflection curves of the slabs modelled in ANSYS had shown close agreement with the experimental data. It has been concluded that strengthening the slab with CFRP bears larger deflection and strengthening the slab with CFRP sheet also increases the ultimate load carrying capacity of the slab.

J.G. Teng et al. (2001) studied the behaviour of GFRP strengthened RC cantilever slabs from experimental studies. For the experiment, samples with fibre anchors inserted through horizontal slots in order to hold the FRP sheets were made so that this will arrest the propagation of debonding. Other than debonding, other type of failure observed in the member was FRP rupture. In the case of debonding failure, ultimate load was reached before the complete debonding, where as in FRP rupture, peak load was reached at first rupture.

III.DATA COLLECTION

In order to perform the dynamic analysis of the slabs in ANSYS APDL, the properties of concrete, steel, CFRP and the adhesive were collected. Table 3.1 shows the properties of the above mentioned materials.

Table 3.1 Material Properties

Material	Element Type	Material Properties		
Concrete	Solid 65	**Linear Isotropic**		
		EX		28125e6 N/m^2
		PRXY		0.2
		Multi-linear Isotropic		
			Strain (m/m)	Stress (N/m^2)
		1	0.00032	9e6
		2	0.0006	15.28e6
		3	0.0009	21.08e6
		4	0.0012	25.27e6
		5	0.0015	27.96e6
		6	0.0018	29.42e6
		7	0.0021	29.96e6
		8	0.00219	30e6
		Concrete		
		Open shear transfer coefficient		0.3
		Closed shear transfer coefficient		0.9
		Uniaxial Cracking Stress		3.13e6 N/m^2
		Uniaxial Crushing Stress		-1 e6 N/m^2
		Tensile Crack Factor		0.45
		Density		2500 kg/m^3
Steel	Beam 188	**Linear Isotropic**		
		EX		2e11 N/m^2
				0.3
		Bilinear Isotropic		
		Yield stress		415e6 N/m^2
		Tangent Modulus		20e6 N/m^2
		Density		7850 kg/m^3
CFRP Laminates	Solid 185	**Linear Orthotropic**		
		EX		165000e6 N/m^2
		EY		9650e6 N/m^2
		EZ		9650e6 N/m^2
		PRXY		0.3
		PRYZ		0.3
		PRXZ		0.45
		GXY		5200e6 N/m^2
		GYZ		5200e6 N/m^2
		GXZ		3400e6 N/m^2
		Density		1800 kg/m^3
Adhesives	Solid 185	**Linear Isotropic**		
		EX		3000e6 N/m^2
		PRXY		0.35
		Density		1200 kg/m^3

IV.METHODOLOGY

It is essential to determine the behaviour of RCC structures under different frequency domain. The behaviour of elements under dynamic loading is determined by conducting modal and dynamic analysis in ANSYS software.

4.1. Modal Analysis

Modal analysis is the study of the dynamic properties of systems in the frequency domain. A typical example would be testing structures under vibration excitation. Modal analysis is the field of measuring or calculating and analysing the dynamic response of structures or fluids or other systems during excitation. The goal of modal analysis in structural mechanics is to determine the natural mode shapes and frequencies of an object or structure during free vibration. Finite Element Method (FEM) is commonly used to perform this analysis because, here the object being analysed can have arbitrary shape and the results of the calculations are acceptable.

A mode shape is a specific pattern of vibration executed by a mechanical system at a specific frequency. Different mode shapes will be associated with different frequencies. The technique of modal analysis discovers these mode shapes and the frequencies corresponding to it.

4.2.Dynamic Analysis

Dynamic Analysis is a type of structural analysis which covers the behaviour of structures subjected to dynamic (actions having high acceleration) loading. Dynamic loads include people, wind, waves, traffic, earthquakes, and blasts. Any structure can be subjected to dynamic loading. Dynamic analysis can be used to find dynamic displacements, time history, and modal analysis. A dynamic analysis is also related to the inertia forces developed by a structure when it is excited by means of dynamic loads applied suddenly (e.g., wind blasts, explosion, and earthquake).

4.3. ANSYS Software

ANSYS is general purpose software used for different types of analysis in the areas including structural, acoustics, cyclic symmetry, fluid, roto dynamics etc. ANSYS Mechanical APDL is a finite element analysis tool for structural analysis, including linear, non-linear and dynamic studies. This computer simulation product provides finite elements to model behaviour, and supports material models and equation solvers for a wide range of mechanical design problems.

4.4. Finite Element Modelling

ANSYS needs the finite element model for analysis and final solution as it does not use solid model. A finite element model consists of nodes, key points, elements, real constants, material properties, loading and boundary conditions. The following steps are involved in the finite element modelling:

1. Creating the solid model
2. Defining the element attributes (element types, real constants, and material properties).
3. Define meshing attributes and meshing the solid model.
4. Applying the loads and boundary conditions.
5. Solution.
6. Post processing the Result.

V.WORK DONE

It involves the validation of our method, modal and dynamic analysis performed in ANSYS to obtain the dynamic response.

5.1. Validation

A cantilever slab having plan dimensions 700 x 500 mm and depth 100 mm was modelled in ANSYS APDL 16.0 and a static load of 1 kN was applied at the free end of the slab. The same model has been modelled in STAAD Pro. The deflection values obtained by conducting static analysis in both softwares have been analysed. The maximum deflection obtained in ANSYS is .097 mm and .13 mm in STAAD Pro. Thus the method was validated.

5.2. Modelling

A cantilever slab having plan dimensions 700 x 500 mm and depth 100 mm was modelled in ANSYS APDL 16.0. The main reinforcement bars of 8 mm diameter were provided at 200 mm c/c spacing and distribution bars of 8 mm diameter were provided at 300 mm c/c spacing. A time dependent load of 1 kN was applied at the free end of the slab within a duration of 1 second. The slab modelled in ANSYS and the reinforcement details are shown in figure 5.1.

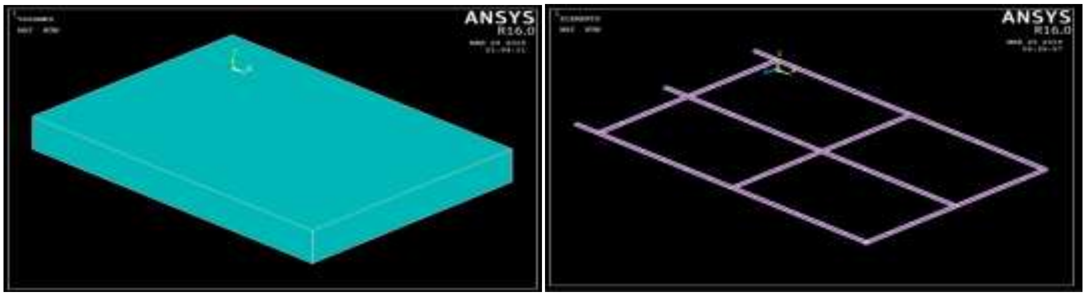

Figure 5.1. Model and reinforcement details of RCC Beam in ANSYS APDL

The RCC slab strengthened with CFRP have been modelled in ANSYS for varying thicknesses of CFRP laminate ranging from 1, 2, 5 and 10 mm. Also, the slabs were modelled by varying the spacing of the laminates from 0 mm, 100 mm and 300 mm respectively. The modal analysis and the dynamic analysis of the slabs were performed on these models and the results were compared.

VI. RESULTS AND DISCUSSION

6.1. Thickness of CFRP

The results of the RCC slab reinforced without and with CFRP of thicknesses 1, 2, 5 and 10 mm were obtained as shown in table 6.1. By comparing the results of slab with CFRP and without CFRP, it is concluded that provision of CFRP laminates imparts phenomenal decrease in deflection during dynamic loading thereby it offers increased strength to the structure. Figure 6.1 show that the increase in the thickness of the CFRP laminates decreases the deflection of the slab. The minimum value of deflection is obtained with slab provided with 10 mm CFRP laminate.

Table 6.1 Results obtained by varying thickness of CFRP

Description	RCC	RCC with CFRP			
Thickness of CFRP (mm)	-	1	2	5	10
Deflection obtained from Dynamic Analysis (mm)	211.39	210.31	209.25	206.16	201.28
Frequencies obtained from the Modal Analysis (Hz)	110.58	111.67	112.75	115.99	121.36
	333.57	336.62	339.00	347.06	360.24
	428.11	428.11	428.10	428.08	428.06
	644.51	649.78	655.03	670.62	696.06
	1071.8	1079.5	1087.2	1109.9	1146.8
	1208.3	1208.3	1208.3	1208.1	1208.0

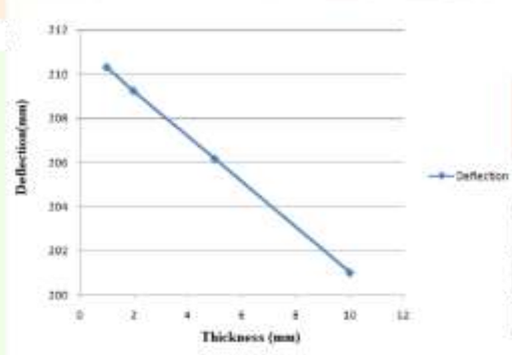

Figure 6.1 Variation of deflection with increase in thickness of CFRP

6.2. Spacing of CFRP

The results obtained by providing CFRP of thickness 2 mm at 0 mm, 100 mm and 300 mm spacing at the soffit of slab is shown in Table 6.2. With the increase in spacing between the CFRP strips, the deflection decreases. The variation of the deflection with increase in spacing is shown in figure 6.2.

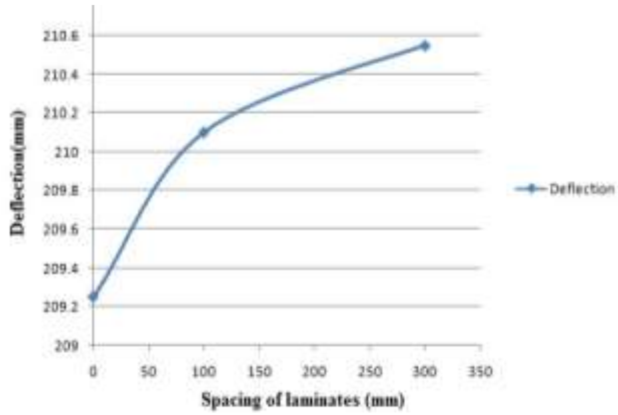

Figure 6.2. Variation of deflection with increase in spacing of CFRP

Table 6.2 Results obtained by varying spacing of CFRP

Description	**RCC with CFRP of thickness 2 mm**		
Spacing of CFRP (mm)	0	100	300
Deflection obtained from Dynamic Analysis (mm)	209.2	210.1	210.5
Frequencies obtained from Modal Analysis (Hz)	112.7	111.9	111.5
	339.0	335.9	334.3
	428.1	428.4	428.8
	655.0	651.0	648.9
	1087.2	1079.1	1074.5
	1208.3	1208.3	1208.3

6.3. Mode Shapes

The different mode shapes of the cantilever RCC slab strengthened with CFRP from modal analysis are shown in the figure 6.3.

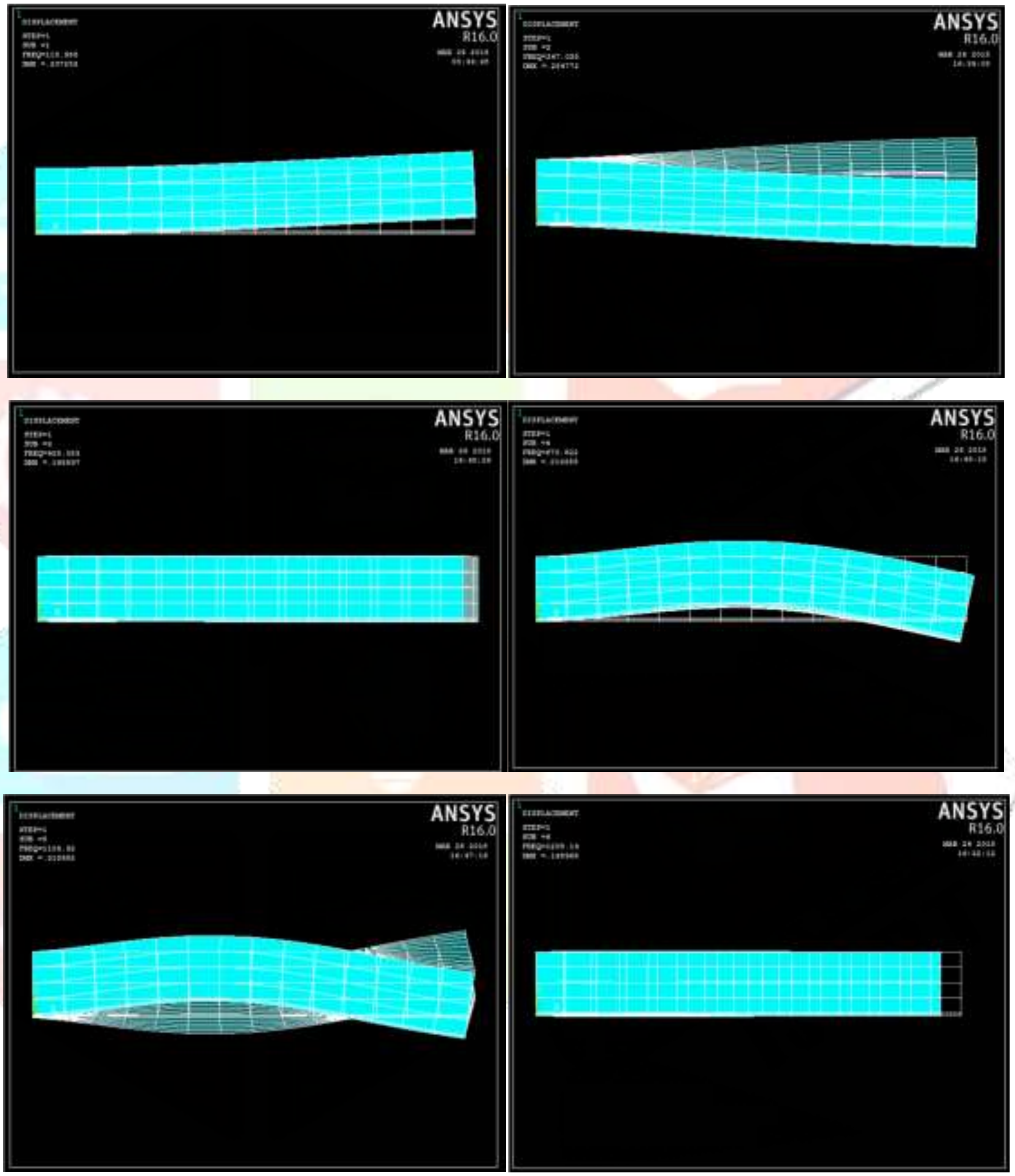

Figure 6.3. Mode Shapes

VII. CONCLUSION

Parametric studies conducted on RCC cantilever slab models strengthened with CFRP laminates using Finite Element Analysis have led to the following conclusions.

1. The behaviour of RCC slabs under dynamic loading have improved by the incorporation of Carbon Fibre Reinforced Polymers at the soffit of the slab.
2. Increase in the thickness of CFRP decreases their amount of deflection during dynamic loading.
3. Spacing of the CFRP laminates plays an important role in their behaviour during dynamic loading. Laminates provided along the full length of the slab showed better results when compared to that with laminates provided at different spacing.

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