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Effect of Thickness of FRP Layer on Debonding in CFRP Strengthened Beams

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ABSTRACT: The use of externally bonded fibre-reinforced polymer (FRP) composite strips/sheets for the strengthening of reinforced concrete (RC) structures has become very popular in recent years. The sheets act compositely with the concrete and help to carry the loads. But the major disadvantage associated with FRP strengthened RC structure is debonding at the interface of FRP sheet and concrete layer. Debonding is such an important phenomenon when retrofitting with CFRP is concerned. The success of most of strengthening or retrofitting technologies for concrete structures by using external bonded FRP sheets highly depends on the interface bond between FRP sheets and concrete substrates, thickness of FRP sheet and its orientation. This paper aims to study the debonding characteristics on the basis of contact friction stresses by varying thickness of CFRP sheets using finite element analysis method.

KEYWORDS: CFRP, ANSYS, contact friction stress

I. INTRODUCTION

Reinforced concrete structures often have to face modification and improvement of their performance during their service life. The main contributing factors are change in their use, new design standards, deterioration due to corrosion in the steel caused by exposure to an aggressive environment and accident events such as earthquakes. In such circumstances there are two possible solutions: replacement or retrofitting. Full structure replacement might have determinate disadvantages such as high costs for material and labour, a stronger environmental impact and inconvenience due to interruption of the function of the structure e.g. traffic problems. When possible, it is often better to repair or upgrade the structure by retrofitting.

In the last decade, the development of strong epoxy glue has led to a technique which has great potential in the field of upgrading structures. Basically the technique involves gluing steel plates or fibre reinforced polymer (FRP) plates to the surface of the concrete. The plates then act compositely with the concrete and help to carry the loads. The popularity of this method has been due to the advantages of FRP composites, including their high strength-to-weight ratio, corrosion resistance, environmental and chemical resistivity, Impact resistance, limit thickness and easy application, clean and smooth finished surface. It has been shown through experimental and theoretical studies that externally bonded FRP composites can be used to improve the desired performance of a structural member such as its load carrying capacity and stiffness, ductility, performance under cyclic and fatigue loading and environmental durability.

Fibre reinforced polymer (FRP) composites consist of high strength fibres embedded in a matrix of polymer resin. Fibres typically used in FRP are glass, carbon, basalt and aramid. 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 based

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(CFRP). Adhesives are used to attach the composites to other surfaces such as concrete. The most common adhesives are epoxies.

Debonding is such an important phenomenon when retrofitting with CFRP is concerned. Debonding occurs if the physical, chemical or mechanical forces that hold the bond together are broken. This implies complete loss of composite action between concrete and laminate. This type of failure appears in the region of the bond as one of several types of cracking or separation patterns. The major reason for debonding is the high shear and normal stresses developed at the laminate ends and at crack locations of concrete, which lead to interfacial debonding failures. So study of debonding and crack propagation due to debonding is of great importance from the structural point of view.

II. RELATED WORK

The layup technique, where FRP sheets are placed on e.g. concrete element and fixed externally usually with epoxy resin, is gaining wide acceptance in structural engineering because of its advantages. FRP materials are non-metallic and are more likely to be resistant to aggressive chemicals; therefore they are good option for reinforcement of concrete structures. By means of structural strengthening the bearing capacity can be increased. If the service life of a structure is shorter than anticipated, investments related to maintaining the structure can be justified. The maintenance can be categorized into two types, repair (retrofit) and strengthening (upgrading) of a certain structure. Strengthening with FRP sheets has shown to be a beneficial alternative to structural elements that have had a change in function. It has been shown from past studies that FRP sheets can be used to enhance the capacity of both flexural and shear. Due to the flexible nature of FRP sheets they are found to be a good retrofitting alternative for concrete structures in earthquake areas. By means of repairing (retrofitting), durability is the most urgent need in the repair of concrete structures. Concrete structure can deteriorate due to environmental actions like steel corrosion, freeze thaw, alkali-silica reaction, fire etc.

Contact stresses causes deformation, plastic or elastic. The contact area will change depending upon the magnitude of contact stress. Therefore, it is very important to calculate the actual stresses at the point of contact, the so-called contact stress.

Parandaman P. and Jayaram M. studied the Finite element analysis of reinforced concrete beam retrofitted with different fibre composites. They have used ANSYS for analysing the modelled geometry. They used carbon fibre reinforced polymer (CFRP) sheet for first layer of RC beam, glass fibre reinforced polymer (GFRP) sheet for second layer and Kevlar fibre reinforced polymer (KFRP) sheet for third layer. SOLID65 element for concrete beam and SOLID45 element for FRP has been used by them. They found that deflection has been minimized around 75% compared to the conventional RC beam when CFRP used.

According to the experimental study of Pan and Leung (2007), the mean thickness of the adhesive is an important factor affecting the debonding behaviour. In this study, different thicknesses of the adhesive layer are selected to examine the effect of the thickness of adhesive layer on performance of the FRP-concrete interface, e.g. In the case of the adhesive layer with the smallest thickness (i.e., $h_0 = 1.0$ mm), a full softening zone was created, and debonding initiated at the right end. When $h_0 = 2.5$ mm, the shear stress at the right end was greater than zero, and it showed that only a partial softening zone (69.02 mm) appeared along the FRP-concrete interface near the right end. When the thickness of adhesive layer further increased to $h_0 = 4.0$ mm, a smaller softening zone (59.86 mm) was observed.

Sharif et al. (1994) argued that thin FRP plates bonded to relatively lightly reinforced sections would fail as a result of laminate rupture. Increasing the plate thickness would drive the failure mechanism toward ripping or plate end interfacial debonding. Similar results were presented by **Rahimi and Hutchinson (2001)** who indicated that thickening of the laminate plate moved the failure toward the beam ends, indicating an increase in normal and shear stress with increasing plate thickness.

P.Parandaman et al(2014) worked on RC structure which is damaged during earthquake and they tried to retrofitting of that reinforced structure with fibre reinforced composite. They Investigation on the behaviour of FRP retrofitted reinforced concrete structures has in the last decade become a very important research field. In terms of experimental application several studies were performed to study the behaviour of retrofitted beams and analyzed the various parameters influencing their behaviour

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Thomsen et al. (2004) analyzed the failure modes of reinforced concrete beams strengthened in flexure with externally bonded FRP sheets and concluded that FRP sheet width plays a role in the failure modes reported such that wider sheets with equal cross sections will give better strengthening results by reducing the bond stress between the concrete surface and the FRP sheets leading to higher flexural beam strength.

III. METHODOLOGY

The methodology worked out to achieve the above-mentioned objectives is as follows:

- Review the existing literature for modelling the CFRP strengthened RCC Beams and decide the range of thickness of FRP layer to be varied.
- Adopt the beam size and reinforcement to be provided.
- Analyse an RCC beam for validation of the results.
- CFRP strengthened RCC beams are modelled in ANSYS by varying the thickness of CFRP layers.
- Results and Discussions

IV. ANALYTICAL RESULTS

A quarter of the beam having overall length 1960 mm, breadth of 150 mm and depth of 300 mm is modelled in ANSYS and considered for analysis for the advantage of the symmetry of the beam and loadings. Two bottom bars of 16 mm diameter and two top bars of 10 mm diameter are provided as the main reinforcement and shear reinforcement of 6 mm diameter is provided. A load of 2500 kN is applied at the loading plate at the nodes and the supports are considered as fixed.

Three models of CFRP strengthened RCC beam was modelled with thickness of CFRP as 1.5 mm, 5 mm and 10 mm. The contact stress for 1.5 mm thick CFRP laminates was observed to be less than that for 5mm and 10 mm thick laminates.

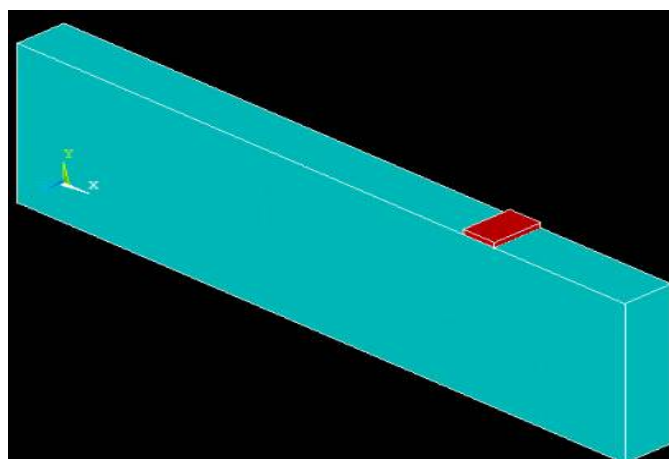


Fig 1. Quarter of the RCC beam modelled in AnSys

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The properties of concrete and steel used are:

Material Model No.	Element Type	Material properties		
1	Solid 65	Linear Isotropic		
		EX	28125 N/mm ²	
		PRXY	0.2	
		Multilinear Isotropic		
			Strain (mm/mm)	Stress (N/mm ²)
		1	0.00032	9
		2	0.0006	15.28
		3	0.0009	21.08
		4	0.0012	25.27
		5	0.0015	27.96
		6	0.0018	29.42
		7	0.0021	29.96
		8	0.00219	30
		Concrete		
			Open shear transfer coefficient	0.3
			Closed shear transfer coefficient	0.9
	Uniaxial Cracking Stress	3.13		
	Uniaxial Crushing Stress	-1		
	Tensile Crack Factor	0.45		
2	Beam 188	Linear Isotropic		
		EX	200000 N/mm ²	
		PRXY	0.3	
		Bilinear Isotropic		
		Yield stress	415 N/mm ²	
	Tangent Modulus	1480 N/mm ²		
3	Solid 185	Linear Isotropic		
		EX	200000	
		PRXY	0.3	

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The properties of CFRP is provided as:

Material	Element Type	Properties	
CFRP Laminates	Solid 185	Linear Orthotropic	
		EX	165000
		EY	9650
		EY	9650
		PRXY	0.3
		PRYZ	0.3
		PRXZ	0.45
		GXY	5200
		GYZ	5200
Adhesive	Solid 185	Linear Isotropic	
		EX	3000
		PRXY	0.35

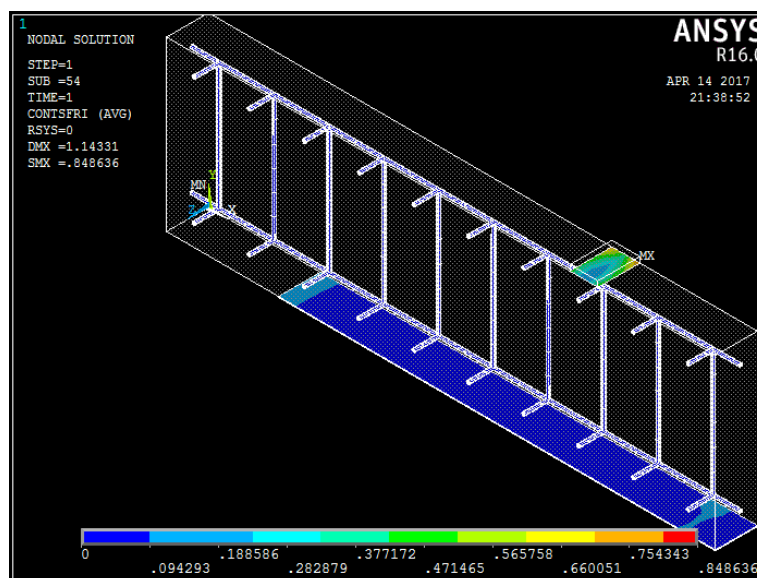


Fig 2. Contact friction stress for 1.5 mm thick CFRP laminate

The contact stress for 1.5 mm thick CFRP laminates was found to be 0.188586 N/mm² and the maximum deflection is 1.14331 mm.

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Fig 3. Contact friction stress for 5 mm thick CFRP

The contact stress for 5 mm thick CFRP laminates was found to be 0.715851 N/mm^2 which is more than that for 1.5 mm thick CFRP.

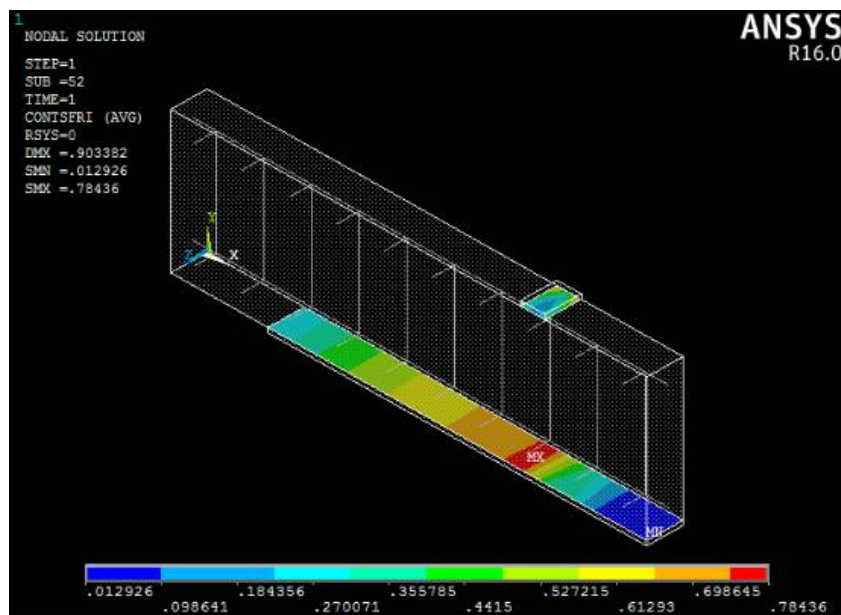


Fig. 4. Contact stress for 10 mm thick CFRP

The contact stress for 10 mm thick CFRP laminates was found to be 0.78436 N/mm^2 which is more than that for 1.5 mm and 5 mm thick CFRP. Hence, from the results it is clear that the contact stress for 1.5 mm thick CFRP is less and debonding will be minimum for 1.5 mm thick CFRP.

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The results obtained have been tabulated as follows.

Table 1: Results of analysis

BEAM SIZE	THICKNESS	CONTACT FRICTION STRESS
1960*150*300	1.5 mm	0.188586 N/mm ²
1960*150*300	5 mm	0.715851 N/mm ²
1960*150*300	10 mm	0.78436 N/mm ²

V. CONCLUSION

From the analysis of RCC strengthened CFRP beams, it was obtained that a thickness of 1.5 mm gives the minimum contact stress and hence debonding will be less for thickness of 1.5 mm. Also, it was observed that the value of contact friction stress increases with increase in thickness of the FRP layer. Hence, it is advisable to use a lower value of thickness to prevent debonding.

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