EXPERIMENTAL INVESTIGATION ON EFFECT OF CFRP ON SHEAR STRENGTHENING OF RC BEAMS

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***Abstract*—The objective of the study is to know the structural behavior of reinforced concrete beams experimentally using externally bonded carbon fiber reinforced polymer strips which are deficient in shear .The test parameters includes changes in modes of failure, crack pattern ,load carrying capacity, increase in shear capacity with varying strengthening methods of carbon fiber reinforced polymer with unidirectional fabric . Five beams were casted and tested under two point loading with one control beam and two beams with strips of U-wrapping and two beams with side strips. Test results shows that U-wrap strengthening method is more efficient than side strips.**

***Index Terms*—shear strength, carbon fiber reinforced polymer, mode of failure.**

I. INTRODUCTION

Now a day's retrofitting or strengthening of structures are frequent due to the increase of service loads, design or construction faults, old design codes and change in use of structure. There are many methods to strengthen the structures RC jacketing, steel jacketing, FRP jacketing etc. in earlier days concrete jacketing and steel jacketing are used to increase the capacity of existing structure, but the dead weight of structure also increases to bare the new additional dead weight foundation also must be strengthened .For the past 30 years fiber reinforced polymers are becoming popular in strengthening of concrete structural components due to its corrosion resistance to environmental agents as well as the advantages of light weight, high tensile strength, high durability and ease of installation , high stiffness –to-weight and strength–to-weight ratios when compared to conventional construction materials. Faulty construction practices, insufficient design practice etc. leads to structural failure without any hazards and natural calamities also leads to structural failure. In a structure while designing in earth quake point of view beam is a weak member where it has to fail without disturbing the other structural components in which most of the beams failed under shear before flexure. The need for shear strengthening is required when the RC beams found to be deficient in shear or shear capacity of beams falls below its flexural capacity. Strengthening of shear deficient beams using CFRP laminate and strips under various strengthening methods depends on different parameters which affects the behavior strengthening and mode failure. In this study, the behavior and failure of beam strengthened with CFRP U wrap and side strip 90^0 orientation studied.

II. OBJECTIVES OF THE STUDY

To study and conclude best method of shear strengthening with CFRP

III. PARAMETERS SELECTED IN THIS STUDY

For the beams un strengthened and strengthened with carbon fiber reinforced polymer in form of side strips 90^0 and U-Wrapping and their variations in

1. Increase in shear strength.
2. Load carrying capacity
3. Failure mode and deflection.

IV. METHODOLOGY

Five beams of size 150 x 300 x3000mm size without shear reinforcement, are categorized as 1 control beam, 2 beams strengthened with CFRP side strips 90^0 orientation and 2 Beams strengthened with CFRP U-wrap. All beams tested under two point loading system.

V .MATERIALS SPECIFICATIONS

a) properties of concrete

M 25 grade concrete was used to the beam because it has better ductility properties when combine with FRP material which was indicated by literature compressive strength of concrete= 25Mpa

Density of concrete =25KN/m^3

Young's Modulus =E=5000√25=25000 N/mm^2

b) Properties of steel

Fe 415 grade steel is used for longitudinal and transverse steel. 32mm diameter bars were used as longitudinal reinforcement, 10mm diameter bars were used as stirrups.

c) Properties of CFRP material

Fiber orientation =Unidirectional
Fiber thickness = 0.3mm
Elastic modulus =180 KN/mm^2
Dry fiber Tensile strength =3500N/mm^2
Weight of fiber =300g/mm^2

Density of fiber =1.8g/cc
Elongation at rupture (%) =1.4

d) Properties of adhesives are shown in Table 1

Table 1 properties of adhesives

Property	Test Method	Value
Component	-	Part A Base 3.7 Kg
	-	Part-B Hardener 1.3kg
Mixed Form	-	paste
Appearance	-	Sky blue /light grey
Mixed density	ASTM D 1475	1.80kg/lit +/- 0.05
Pot life	-	70 +/- 10 min
Shelf life	-	12 months
Flexural strength	IS4456 (part-1)	25 Mpa and above
Bond strength	ASTM D 4541	>2.5 N/mm^2 at 7 days
Solid content	ASTM D 1475	100% solvent free
Application temperature	-	+5^{0}C to +45^{0}C
Coverage	-	1 KG/sq.m

VI. ANALYTICAL DESIGN

a. Flexural design:

All beams are designed as doubly reinforced and the tensile and compressive reinforcement as 3.57 % of gross cross- sectional .Because the beam does not fail under flexure while those are strengthened with CFRP in shear.

Tensile reinforcement = 2 no. of 32mmdiameter
Compressive reinforcement =2 no of 32 mm diameter

b. Shear strength by concrete:

From IS-456code
$V_c = \tau_c bd = 0.96*150*280 = 40.320$ KN

c. Shear strength improved by CFRP as per ACI 440 2R08:

U-wrap or Side strips:

Bond reduction coefficient $K_v = K_1 K_2 L_e / (1900\varepsilon_{fu}) \leq 0.75$
Where $L_e = 23300/(n_f t_f E_f)^{0.58}$
$K_1 = (f_c / 27)^{2/3}$
For U –wrap $K_2 = (d_{fv} - L_e) / d_{fv}$
For side strips $K_2 = (d_{fv} - L_e) / d_{fv}$
Strain in FRP $\varepsilon_{fe} = K_v \varepsilon_{fu}$
Area of reinforcement $A_{fv} = 2n\, t_f W_f$
Tensile stress in FRP $f_{fe} = \varepsilon_{fe} E_f$
The shear contribution of FRP shear reinforcement
$V_f = (A_{fv} f_{fe} (\sin \alpha + \cos \alpha) d_{fv} / S_f$
ψ_f = FRP reduction factor =0.85 for two / three sided wrapping
Calculations are shown in table 2

Table2 calculations in tabular form

specification of method	Effective length L_e (mm)	K_1	K_2	K_V	A_{fv} (mm^2)	S_f (mm)	V_f (KN)	shear strength due to CFRP only $=\psi_f * V_f$	shear strength due to concrete and CFRP(KN)
U wrap strips	41.93	0.949	0.850	0.1994	60	100	42.97	36.52	76.84
U wrap continuous	41.93	0.949	0.850	0.1944	1500	100	138.60	117.8	158.12
Side strips 90^o	41.93	0.949	0.700	0.1643	60	100	35.41	30.09	70.41
Side strips 45^o	41.93	0.949	0.700	0.1643	60	100	50.07	42.56	82.88

Out of the above the above specification methods U wrap strips and side strips 90^o were chosen,to study and conclude best method of shear strengthening with CFRP for a shear span to depth ratio of 4.

VII .EXPERIMENTAL ANALYSIS

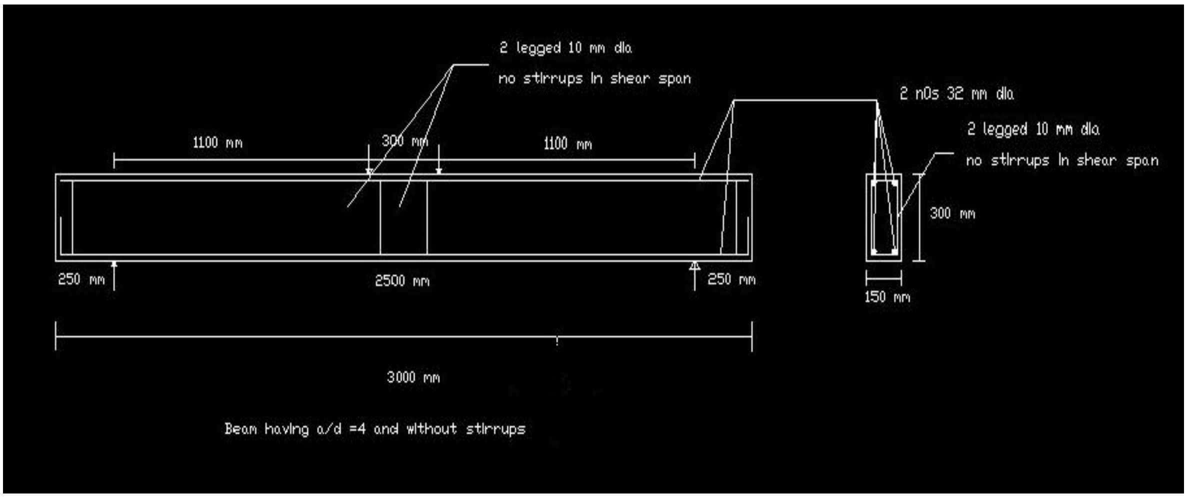


Fig.1 Beam Reinforcement Details

VII .A. CFRP WRAPPING

Surface preparation

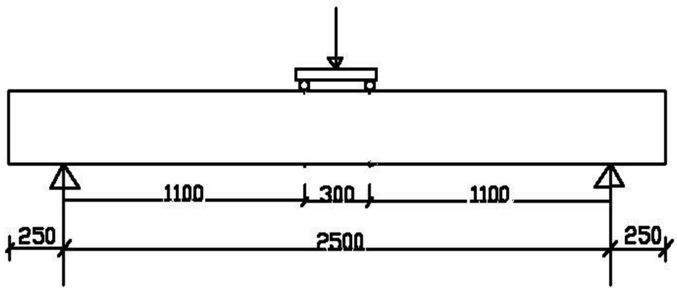
1. To make the surface clean , dry and free from dirt , oil , grease ,cavities
2. To remove cementitious material underlying over the surface of concrete
3. To chip off and remove loose / damaged concrete
4. To make sure that, there should not be any sharpness throughout the periphery of surface, at corners and junctions of members.

Application of Adhesives

1. The bonding saturate of the fiber cannot be applied directly on the rough surface.
2. To make surface smooth and for stopping the absorption power of concrete apply a thin layer of first coat of epoxy called Resin primer i.e., a well-mixed solution of base and hardener in the ratio of (1:0.5).
3. Allow it to cure for at least 24 hours.
4. Then to fill up the undulations and unevenness on the surface prepare and apply leveling mortar with hardener , base and aggregate powder in the ratio of (1:2.85:10).
5. Cut the CFRP material as per the design ,
6. For side strip 90^0 orientation, each strip of width 100mm and 300mm length.
7. For U-wrap, strip method, each strip of width 100mm and 750mm length.
8. In a container, add base and hardener in the ratio of (1:1/3) and gently Mix them well using a stirrer.
9. Apply first coat of the mixture using a brush or roller. Carry out wrapping of fabric around the surface as per designed requirement, working wet on wet and gently roll the fabric surface using fiber roller in the longitudinal direction of fabric so that fiber should get properly embedded in epoxy for superior bonding with concrete which results in developing better strength.
10. Apply multiple of coats this mixture on the wrapped surface.
11. Allow the fiber wrapping to cure in dry (protect it from rain for at least 24hrs after application) and ambient temperature for 48 hours then member can be tested at any time.

VII .B. EXPERIMENTAL SET UP:

All the five beams were tested as simply supported beams under two point loading over an effective span of 2500mm .The two point loads with the distance between them as 300mm and each were applied at a distance of 1100mm from their near end of support i.e., for a shear span to depth ratio of 4.The loading frame capacity is 50 tones. The loads were monitored through load cell 50T. Mid span deflections were measured using LVDT 50



Load (all dimensions are in mm)

Fig. 2. Beam setup

VII .B. I. CONTROL BEAM

To know the effect of the beam without internal transverse reinforcement this condition is taken as one of the parameter.

Fig.3. Failure mode of control beam

Control beam has a crack pattern of predicted shape and diagonal shear crack produced and it was propagated from load point and support which is shear span of the beam of 1100mm.As the beam has no shear reinforcement i.e. the beam is weak in shear.

So the failure of the beam is shear failure which occurred at 132 KN with a mid-span deflection of 14 mm.

Shear capacity of the beam (V) = 66 KN

Shear stress produced in the beam (τ_c) = V/bd = ($66*10^3$) /(150*280)=1.57N/mm^2

Maximum shear stress for M25 grade concrete ($\tau_{c\,max}$) =3.1 N/mm^2

shear Stress induced in the beam is less than the maximum shear stress.

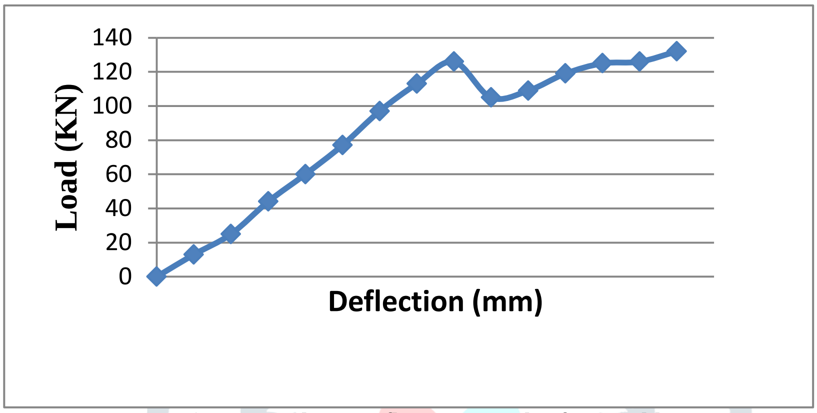


Fig. 4. Load v/s Deflection Graph of control beam

VII. B .II. BEAM STRENGTHENED WITH CFRP SIDE STRIP 90^{0}ORIENTATION :

(a) side strip beam-1

Fig.5. Failure mode of side strip beam-1

As crack is propagating, with approximately 45^0 inclination from support to load point, the CFRP strips in shear span particularly strips nearer to support deboned from concrete surface with a sudden sound at failure and then the strip width ruptured intoparts. Due to local debonding in one FRP strip does not affect the performance of adjacent strip. The ultimate load capacity of the beam is 159.6 KN with deflection of 14.9mm.

Shear capacity of the beam (V) = 79.8 KN

Shear stress produced in the beam (τ_c) = V/bd= ($79.8*10^3$) /(150*280) =1.9 N/mm^2

Maximum shear stress for M25 grade concrete ($\tau_{c\,max}$) =3.1 N/mm^2

Shear Stress induced in the beam is less than the maximum shear stress.

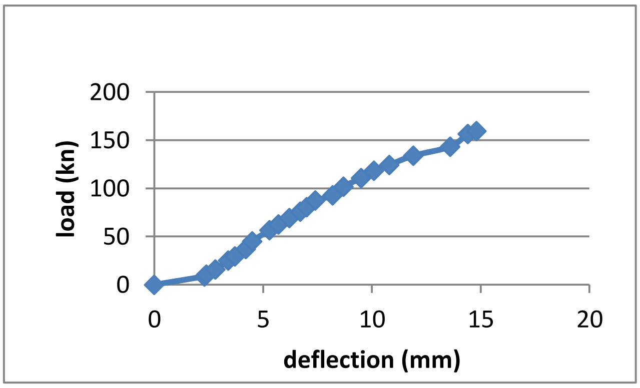


Fig.6. Load v/s deflecti on of side strip beam -1

(b) Side strip beam -2

Fig.7 Failure Mode Of Side Strip Beam-2

Failure occurred by crushing of concrete beyond support .This is because the beam is not strengthened with CFRP beyond the support. The ultimate load capacity of the beam is 210 KN with deflection of 16.9 mm.
Shear capacity of the beam (V)= 105 KN
Shear stress produced in the beam (τ_c) = V/bd = ($105*10^3$) / (150*280) = 2.5 N/mm^2
Maximum shear stress for M25 grade concrete ($\tau_{c\,max}$) =3.1 N/mm^2
Shear Stress induced in the beam is less than the maximum shear stress

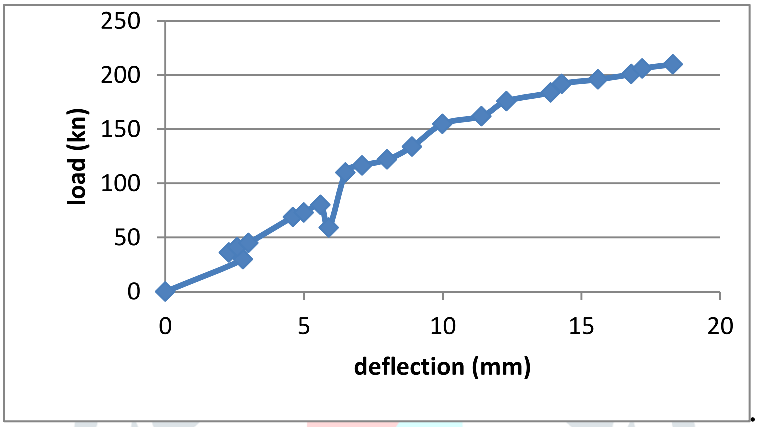


Fig.8. Load v/s deflection of side strip beam -2

VII. B .III. BEAM STRENGTHENED WITH U- WRAP STRIP:

(a) U wrap strip beam 1

Fig. 9. Failure mode of U -wrap strip beam -1

As the stress concentration, more at the load applied crack propagated from load point to towards the support and the CFRP ruptured and peeled off along with concrete. The ultimate load capacity of the beam is 244.6KN with deflection of 20.5 mm.
Shear capacity of the beam (V) = 122.3 KN
Shear stress produced in the beam (τ_c) = V/bd = ($122.3*10^3$) /(150*280) = 2.9 N/mm^2
Maximum shear stress for M25 grade concrete ($\tau_{c\,max}$) =3.1 N/mm^2
shear Stress induced in the beam is less than the maximum shear stress

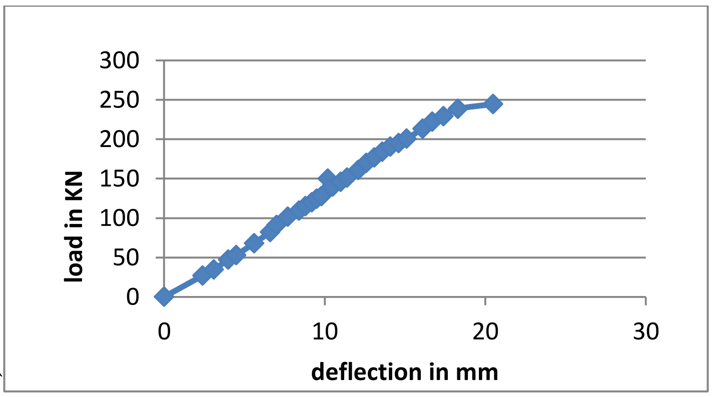


Fig.10. Load v/s deflection of U wrap strip beam -1

(b) U –wrap strip beam-2

Fig.11. Failure mode of U-wrap strip beam-2

Initially cracks propagated in between strips along shear span with approximately 45^0 inclination and then one of the sides of CFRP wrapped side the concrete spalled of f along with strip up to its depth. The ultimate load capacity of the beam is 256.7KN with deflection of 23.60 mm.

Shear capacity of the beam (V) = 128.35 KN

Shear stress produced in the beam (τ_c)= V/bd =($128.35*10^3$) /(150*280)= 3.0 N/mm^2

Maximum shear stress for M25 grade concrete ($\tau_{c\ max}$) =3.1 N/mm^2

Shear Stress induced in the beam is nearly reached its maximum shear stress

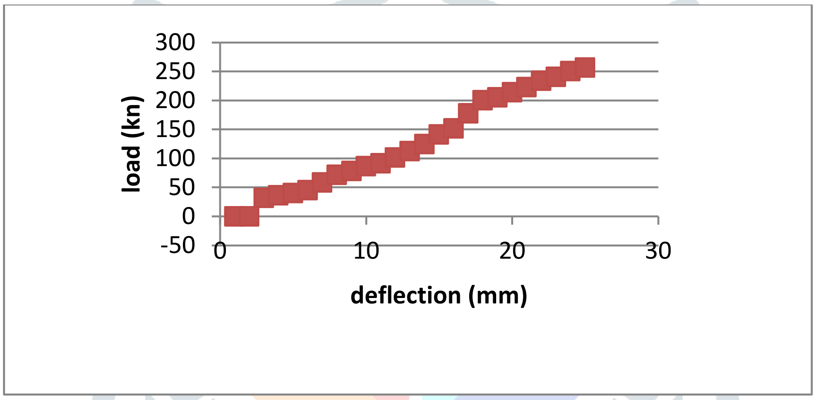
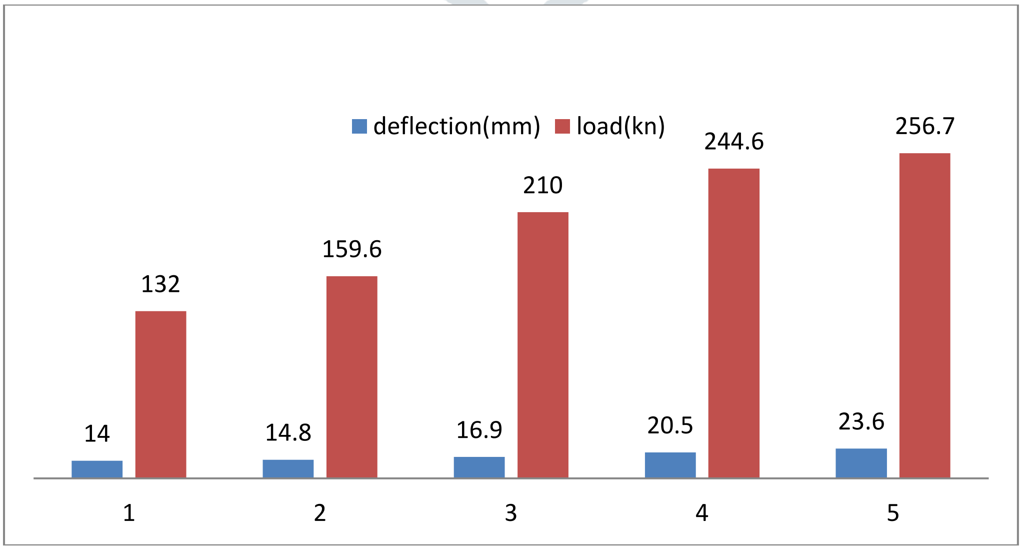


Fig.11. Load v/s deflection of U wrap strip beam -2

VIII. RESULTS AND DISCUSSIONS

Table 3. Load and deflection values of all beams

Type of beam	Load (KN)	Deflection
CONTROL BEAM	132	14
SIDE STRIP-1	159.6	14.8
SIDE STRIP-2	210	16.9
U-WRAP-1	244.6	20.5
U-WRAP-2	256.7	23.60



1-Control beam 2-sidestrip1 3-side strip2 4-Uwrap1 5-Uwrap2

Fig.13. Comparisonof load and deflection values of beams

Table.4. Numerical and experimental shear capacity values

Type of beam	shear capacity (KN) as per ACI 440 2R08	Experimental shear capacity (KN)
Control beam	40.320	66
Side strip-1	70.41	79.8
Side strip-2	70.41	110.5
U-wrap 1	76.84	122.3
U-wrap 2	76.84	128.35

Table.5. Load and Shear Capacity of All Beams

Type of beam	Load (KN)	Shear capacity(KN)
Control beam	132	66
Side strip -1	159.6	79.8
Side strip-2	210	110.5
U- wrap1	244.6	122.3
U –wrap-2	256.7	128.35

The load carrying capacity i.e., shear capacity of the beam wrapped with CFRP by side strip 90^0 orientation increases by 40% compared with the control beam. The load carrying capacity i.e., shear capacity of the beam wrapped with CFRP by U wrap strip increases by 89.8% compared with the control beam.

IX.CONCLUSIONS

1. As per ACI 440 2 R08 code and experimental analysis, the U-wrap strip strengthening method is concluded as the best strengthening method compared to side strip 90^0 orientation strengthening method.
2. The amount CFRP used in U-wrap strip method is 25% more than the side strip 90^0orientation method. The increase in load carrying capacity with U- wrap strips is 31% more when compared with side strip 90^0 orientation.
3. The ultimate load capacity with U-wrap strip is 22% more when compared with side strip.
4. Maximum deflection with U-wrap strips is 23.60mm and with side strips is 16.9 mm.

REFERENCES

[1] Ahmed khalifa, Antonio Nanni. “Improving shear capacity of existing RC T beams using CFRP composites”. cement and concrete composites Elsevier science 2000

[2] Bjorn Taljsten “strengthening concrete beams for shear with CFRP sheets”.Construction and building materials Elsevier 2003

[3] J.F. chena, j.g.Tengb. “shear capacity of FRP strengthened RC Beams :FRP DEBONDING ”. construction and building materials Elsevier science 2003

[4] Ghani Razaqpur, Marwan shedid and BurkanIsgor “Shear strength of fiber –Reinforced p[polymer reinforced concrete beams subject to Unsymmetric loading”, journal of composites for construction ASCE / October 2011

[5] Amirmofidi and Omar challal, M. ASCE “shear strengtheningof RC beams with externally bonded FRP composites effect of strip –width-strip spacing ratio”journal of composites for construction ASCE / October 2011

[6] Ahmed Godat, Zhequ, Xnzheng Lu “Size effects for RC beams strengthened in sheae with CFRP strips” journal of composites for construction ASCE 2011

[7] O.challal,M.J.Nollet D. Perraton ., “shear strengthening of RC beams by externally bonded side CFRP strips” journal of composites for construction 1998

[8] Ahmed Khalifa ,AbdeldjelilBelarbi and NtonnioNanni “shear performance of RC members strengthened with externally bonded frp wraps” 12WCEE 2000.

[9] Amer M. Ibrahim ,Mohemmood “investigations to the parameters effecting shear strength of RC beams strengthened with CFRP Laminations”Diayala journal of engineering Dec 2009