

Analysis & Design of FRP Jacketing for Buildings

Vedprakash C. Marlapalle, P. J. Salunke, N. G. Gore

Abstract: The objective this paper is to discuss effectiveness of FRP jacketing method used to improve the performance of deteriorated structure, this technique successfully applied on the structure. Also Design method, field application techniques, Advantages, Disadvantages and suitability have been discussed.

Keywords: FRP, Jacketing, Retrofitting, Concrete, Strengthening, Repair

I. INTRODUCTION

Fibre Reinforced Polymer (FRP) materials have been widely applied in construction and structural rehabilitation due to their high strength, stiffness-to-weight ratio, high corrosion resistance, the ability to form and to shape to the existing structure, and the application process which is relatively fast and easy. Many models and standards are suggested for estimating strength enhancement from FRP jacket but, there is still lacking to identify adequately accurate model to use in design purpose. Most of these models were calibrated by limited data. This paper provides an evaluation and numerical analysis of the previously published models that predict the axial strength and strain of circular reinforced concrete column confined with FRP. The goal of this research is to find a new approach, which will be based on analytical, numerical simulation and experimental study, for the formulation of strength enhancement of FRP confined concrete columns.

II. ADVANTAGES OF FRP MATERIAL

1. Corrosion Resistance
2. Light Weight
3. Ease of Installation
4. Less Finishing
5. Less Maintenance
6. High tensile strength
7. Storage & Transportation is easy

III. DISADVANTAGES OF FRP MATERIAL

1. Temperature & moisture effect
2. Lack of Design Code
3. Lack of Awareness
4. Skill supervision is required

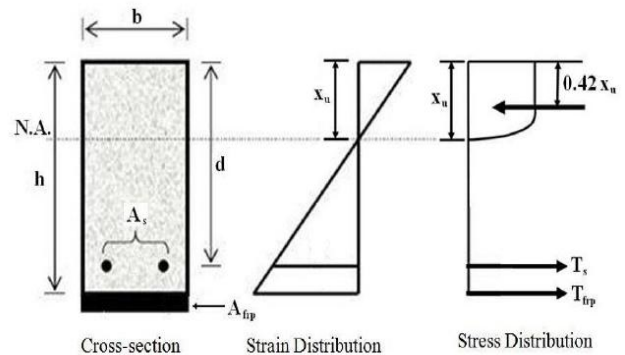
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IV. DESIGN OF BEAM FRP JACKETING AS PER ACI 440-2R



C/S of Beam	230x400
Top Steel	2-8T
Bottom steel	2-16T
Stirrups	8T@150C/C
d (Effective Depth)	360mm
Moment	47.99 kN.m
Vu (Shear force)	85 kN
Grade of concrete (f _{ck})	12 N/mm ²
Grade of Steel reinforcement (f _y)	415 N/mm ²

CFRP System Properties

Thickness Per Ply (t _f)	1.02 mm.
Ultimate Tensile Strength (f _{fu*})	621 N/ mm ² .
Rupture Strain (ε _{fu*})	0.015 mm/mm.
Modulus Of Elasticity Of CFRP Laminate (E _f)	37,000N/mm ² .
Width of FRP sheet (w _f)	100 mm

Step 1:- Calculate the FRP system design material properties:

Design ultimate tensile strength of FRP

$$f_{fu} = C_E \times f_{fu*}$$

$$f_{fu} = 0.95 \times 621 = 589.95 \text{ MPa}$$

Design ruptures strain of FRP reinforcement

$$\epsilon_{fu} = C_E \times \epsilon_{fu*}$$

$$\epsilon_{fu} = 0.95 \times 0.015 = 0.01425 \text{ mm/mm}$$

Step 2:-Preliminary calculations:

Modulus of elasticity of concrete

$$i) E_c = 5000\sqrt{f_c'} = 5000\sqrt{12} = 17320.50 \text{ Mpa}$$

ii) Properties of the externally bonded FRP reinforcement:

Thickness of FRP = 1.02 mm, No. of FRP = 1 No, Width of FRP = 100 mm

$$A_f = n \times t_f \times w_f = 1 \times 1.02 \times 100 = 102 \text{ mm}^2$$

Step 3:-Determine the existing state of strain on the soffit:

M_{DL} = 20kN.m, d_f = 400mm, k = 0.334 Assume, I_{cr} = 7.266x10⁸...from SP-16 table
No.87



Strain level in concrete substrate at time of FRP installation

$$\epsilon_{bi} = \{M_{DL} (d_f - kd)\} / I_{cr} E_c = 0.000554$$

Step 4:-Determine the design strain of the FRP system:

debonding strain of externally bonded FRP reinforcement,
 $\epsilon_{fd} = 0.41 \sqrt{\{f_{ck} / 2E_f t_f\}} = 0.41 \sqrt{\{12 / 2 \times 37000 \times 1.02\}}$

$$\epsilon_{fd} = 0.0073 < 0.9 \times (0.0142) = 0.0128 \dots \dots \dots \text{ok}$$

Step 5:-Estimate c, the depth to the neutral axis:

The value of the c is adjusted after checking equilibrium.

$$C = 0.2 \times d$$

$$C = 72.4 \text{ mm}$$

Step 6:- Determine the effective level of strain in the FRP reinforcement:

effective strain level in FRP reinforcement attained at failure,

$$\epsilon_{fe} = (0.0035 \{ (d_f - c) / c \}) - \epsilon_{bi} < \epsilon_{fd}$$

$$\epsilon_{fe} = 0.0152 > 0.0042478 \dots \dots \text{not ok}$$

Revise effective strain

$$\epsilon_{fe} = \epsilon_{fd} = 0.0073$$

strain level in concrete,

$$\epsilon_c = (\epsilon_{fe} + \epsilon_{bi}) [C / (d_f - C)]$$

$$\epsilon_c = 0.0017$$

Step 7:-Calculate the strain in the existing reinforcing steel:

Strain level in steel reinforcement,

$$\epsilon_s = (\epsilon_{fe} + \epsilon_{bi}) [(d - C) / (d_f - C)]$$

$$\epsilon_s = 0.0069$$

Step 8:-Calculate the stress level in the reinforcing steel and FRP:

Stress in Steel

$$f_s = E_s \epsilon_s < f_y$$

$$f_s = 1390.5 > 415 \dots \dots \text{not ok}$$

$$f_s = f_y = 415.00 \text{ MPa}$$

Stress in FRP

$$f_{fe} = E_f \epsilon_{fe}$$

$$f_{fe} = 270.50 \text{ MPa}$$

Step 9:- calculate internal forces resultant and check equilibrium:

$$\epsilon'c = 0.002$$

$$\beta_1 = (4\epsilon'c - \epsilon_c) / (6\epsilon'c - 2\epsilon_c) = 0.734$$

$$\alpha_1 = (3\epsilon'c - \epsilon_c) / (3\beta_1 \epsilon'c) = 0.840$$

$$C = (A_s f_s + A_f f_{fe}) / (\alpha_1 f_c' \beta_1) = 16.19 < 72.4 \text{ mm}$$

take

$$C = 72.4 \text{ mm}$$

Step 10:- Calculate flexural strength components:

$$\text{Steel contribution to bending (Mns)} = A_s f_s (d - \frac{\beta_1 x C}{2})$$

$$Mns = 55.95 \text{ kN-m}$$

FRP contribution to bending

$$(Mnf) = A_f f_{fe} (d_f - [df - \frac{\beta_1 x C}{2}])$$

$$Mnf = 10.30 \text{ kN-m}$$

Step 11:- Calculate design flexural strength of the section:

The design flexural strength is calculated as,

$$\phi Mn = \phi [Mns + \psi_f Mnf] \text{ strength reduction factor of } \phi = 0.90$$

$$\phi Mn = 0.9(55.95 + 0.85(10.30)) = 58.23$$

$$\phi Mn = 58.23 \text{ kN-m} > Mu \ 47.99 \text{ kN-m} \dots \dots \text{safe}$$

"Hence provide 1 layer of CFRP jacket."

V. DESIGN OF SHEAR REINFORCEMENT AS PER ACI 440

CFRP properties:

Thickness Per Ply (t_f)	1.02mm.
Ultimate Tensile Strength (f_{fu}^*)	621 N/mm ² .
Rupture Strain (ϵ_{fu}^*)	0.015mm/mm.
Modulus Of Elasticity Of CFRP Laminate (E_f)	37,000N/mm ² .
Width of FRP sheet (w_f)	100mm

Step 1—calculate the FRP system design material properties:

Design ultimate tensile strength of FRP

$$f_{fu} = C_E \times f_{fu}^* = 0.95 \times 621 = 589.95 \text{ MPa}$$

Design ruptures strain of FRP reinforcement

$$\epsilon_{fu} = C_E \times \epsilon_{fu}^* = 0.95 \times 0.015 = 0.01425 \text{ mm/mm}$$

Step 2—calculate the effective strain level in the FRP shear reinforcement:

Active Bond Length

$$Le = \frac{23300}{(n \times t_f \times E_f)^{0.58}} = \frac{23300}{(2 \times 0.165 \times 227530)^{0.58}}$$

$$Le = 34.63 \text{ mm}$$

Modification Factor for concrete strength

$$K1 = (\frac{f_c'}{27})^{2/3} = (25/27)^{2/3} = 0.94$$

Modification Factor for wrapping scheme

$$K2 = ((dfv - Le) / dfv) = ((237 - 34.63) / 237) = 0.853$$

Bond-dependent coefficient for shear

$$kv = \frac{K1 \times K2 \times Le}{11900 \times \epsilon_{fu}} = \frac{0.94 \times 0.853 \times 34.63}{11900 \times 0.014} = 0.166 < 0.75$$

Effective strain level in FRP reinforcement attained at failure

$$\epsilon_{fe} = K_v \times \epsilon_{fu} = 0.166 \times 0.0142 = 0.0023 < 0.004$$

Step 3 Cal. Contribution of the FRP r/f to the shear strength:

Area of FRP shear reinforcement with spacing s,

$$A_{fv} = 2n t_f w_f = 2 \times 2 \times 0.165 \times 254 = 167.64 \text{ mm}^2$$

Effective Stress In FRP Shear Reinforcement

$$f_{fe} = \epsilon_{fe} \times E_f = 0.0023 \times 227.6 = 0.523 \text{ kN/ mm}^2$$

Nominal shear strength provided by FRP stirrups

$$V_f = \frac{A_{fv} \times f_{fe} (\sin \alpha + \cos \alpha) dfv}{s f} = \frac{167.64 \times 0.523 \times 1 \times 237}{304.8} = 68.17 \text{ kN}$$

Step 4 Total Shear Strength of Section:

$$\Phi V_n = \Phi (V_c + V_s + \Psi_f V_f) = 0.75 \times (66.65 + 0 + 0.85 \times 68.17) = 93.44 \text{ kN} > 85 \text{ kN} \dots \dots \text{safe}$$

"Hence provide 2 layer of CFRP jacket."

VI. DESIGN OF COLUMN FRP JACKETING AS PER FIB CODE

Data:-

b = 230 mm, d = 450mm, f_{ck} provided = 12mpa,

f_{ck} required = 25mpa, P_t % provided = assume 0% due to corrosion of bar,

Area of concrete = 103500mm², P_u = 675 kN, M_x = 25kN.m

Manufacture Data –

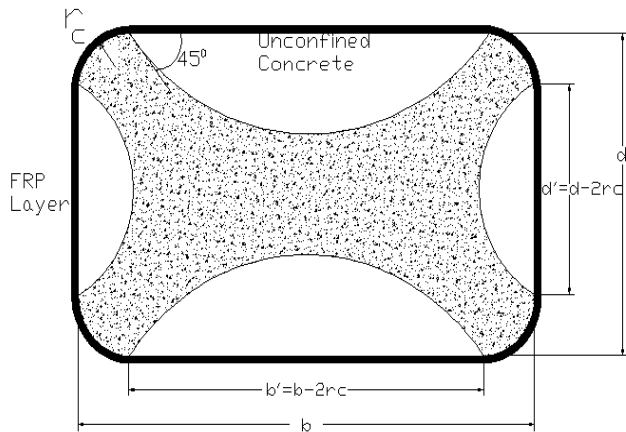
Ultimate strain in carbon fiber

$$(\epsilon_f) = 1.5\%$$



Elastic modulus of carbon fiber (E_f) = 137000 N/mm²
Effective fiber thickness (t_f) = 0.33 mm
No of Wrap (n) = 2 No.

Solution:-



Effectively Confined Core for Non Circular Section

Total Plan Area of Unconfined concrete is obtained as per Fib 14 eqn 6.28 is given as,

$$b' = b - 2 \times rc = 230 - 2 \times 25 = 180 \text{ mm}$$

$$d' = d - 2 \times rc = 450 - 2 \times 25 = 400 \text{ mm}$$

$$A_u = \frac{b'^2 + d'^2}{3} = 64133.33 \text{ mm}^2$$

The confinement effectiveness coefficient k_e considering ratio $(A_c - A_u)/A_c$ as per Fib 14 eqn 6.29 is given as,

$$K_e = 1 - \frac{b'^2 + d'^2}{3Ag(1 - \rho_{sg})} = 1 - \frac{A_u}{Ag(1 - \rho_{sg})} = 0.367$$

The Lateral confining pressures induced by the FRP wrapping as per Fib eqn 6.30 is given as

Along direction b ,

$$K_{conf_b} = \rho_b k_e E_f$$

Along direction d ,

$$K_{conf_d} = \rho_d k_e E_f$$

$$\text{Where, } \rho_b = \frac{2 \times n t_f \times f}{b} \quad \text{and} \quad \rho_d = \frac{2 \times n t_f \times f}{d}$$

$$\rho_b = 0.0057 \quad \text{and} \quad \rho_d = 0.0029$$

$$K_{conf_b} = 288.09 \quad K_{conf_d} = 147.31$$

Effective confining pressure, along direction b

$$f_{lb} = \frac{K_{conf_b} \times f}{2K_e} = 5.89 \text{ N/mm}^2$$

Along direction d

$$f_{ld} = \frac{K_{conf_d} \times f}{2K_e} = 3.01 \text{ N/mm}^2$$

Taking min value,

$$f_l = 3.014 \text{ N/mm}^2$$

Maximum confining pressure as per Fib eqn 6.5 is given as,

$$f_{cc} = f'_c \left(2.254 \sqrt{1 + 7.94 \frac{f_l}{f'_c}} - 2 \frac{f_l}{f'_c} - 1.254 \right)$$

$$f_{cc} = 25.73 \text{ N/mm}^2$$

"Hence provide 2 layer of CFRP jacket."

VII. RESULTS

FRC can be used to upgrade the beam or column elements and the joints of RC frames. While FRC wraps improve the deformability of the sections FRC longitudinal improve their

stiffness. Depending on the required capacities in bending moments and rotations the required FRC can be found out using the method presented here.

VIII. APPENDIX-1 NOTATIONS

- f_{fu} = Design ultimate tensile strength of FRP
- ϵ_{fu} = Design ruptures strain of FRP reinforcement
- E_c = Modulus of elasticity of concrete
- ϵ_{fd} = debonding strain of externally bonded FRP reinforcement,
- ϵ_{fe} = effective strain level in FRP reinforcement attained at failure,
- ϵ_s = Strain level in steel reinforcement,
- f_s = Stress in Steel
- f_{fe} = Stress in FRP
- Mns = Calculate flexural strength components
- ϕM_n = Calculate design flexural strength of the section
- L_e = Active Bond Length
- K1 = Modification Factor for concrete strength
- K2 = Modification Factor for wrapping scheme
- KV = Bond-dependent coefficient for shear
- A_{fv} = Area of FRP shear reinforcement with spacing s ,
- f_{fe} = Effective Stress In FRP Shear Reinforcement
- V_f = Nominal shear strength provided by FRP stirrups
- ΦV_n = Total Shear Strength of Section
- f_{cc} = Maximum confining pressure

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