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Analysis & Design of FRP Jacketing for Buildings

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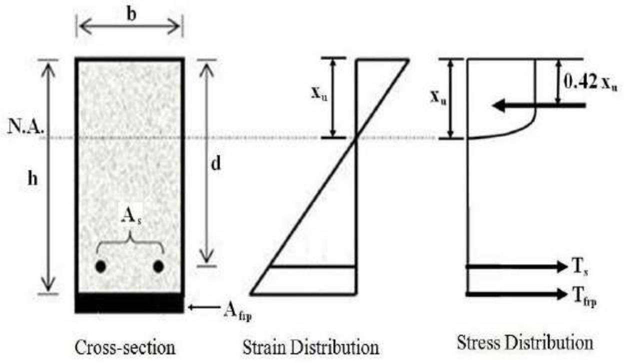
IV. DESIGN OF BEAM FRP JACKETING AS PER ACI 440-2R



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

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

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

Design ruptures strain of FRP reinforcement

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

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

Step 2:-Preliminary calculations:

Modulus of elasticity of concrete

i) Ec = 5000√fc′ = 5000√12 = 17320.50Mpa

ii) Properties of the externally bonded FRP reinforcement:

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

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

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

M_{DL} = 20kN.m , d_f = 400mm, k = 0.334 Assume, Icr = 7.266x10^8…from SP-16 table No.87

Strain level in concrete substrate at time of FRP installation

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

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

debonding strain of externally bonded FRP reinforcement,

$\varepsilon_{fd} = 0.41 \{ \sqrt{(fck /2Ef\ tf)} \} = 0.41\{ \sqrt{(12 /2x\ 37000x\ 1.02)} \}$

$\boldsymbol{\varepsilon_{fd} = 0.0073}$ $<= 0.9 \times (0.0142) = 0.0128$……..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 mm

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

effective strain level in FRP reinforcement attained at failure,

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

$\varepsilon_{fe} = 0.0152 > 0.0042478$….not ok

Revise effective strain

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

strain level in concrete,

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

$\boldsymbol{\varepsilon_c} = 0.0017$

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

Strain level in steel reinforcement,

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

$\boldsymbol{\varepsilon_s} = 0.0069$

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

Stress in Steel

$f_s = E_s \varepsilon_s <= fy$

$f_s = 1390.5 > 415$…..not ok

$\mathbf{f_s}$ = fy = **415.00** MPa

Stress in FRP

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

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

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

ε'c = 0.002

β1= (4ε'c- εc) / (6ε'c -2εc) = 0.734

α1= (3ε'c εc- εc2) / (3β1ε'c2) =0.840

C = (As fs+ Af ffe) / (α1 fc′ β1b) =16.19 <72.4mm

take

C= 72.4mm

Step 10:- Calculate flexural strength components:

Steel contribution to bending (Mns) = $A_s f_s (d - \frac{\beta 1 x C}{2})$

Mns = 55.95 kN-m

FRP contribution to bending

(Mnf) = $A_f f_{fe} (d_f - [df - \frac{\beta 1 x C}{2})$

Mnf = 10.30 kN-m

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

The design flexural strength is calculated as,

$\varphi Mn = \varphi [Mns + \psi_f Mnf]$ strength reduction factor of $\varphi = 0.90$

φMn = 0.9(55.95+0.85(10.30)) = 58.23

φMn = 58.23 kN-**m** > Mu 47.99 kN-m ...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

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

Design ruptures strain of FRP reinforcement

$\boldsymbol{\varepsilon_{fu}} = C_E \times \varepsilon_{fu*} = 0.95 \times 0.015 =$ **0.01425 mm/mm**

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

Active Bond Length

$$Le = \frac{23300}{(n \times tf \times Ef)^{0.58}} = \frac{23300}{(2x\ 0.165 \times 227530)^{0.58}}$$

Le = 34.63mm

Modification Factor for concrete strength

K1 = $(\frac{fc'}{27})$^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

$$kv = \frac{K1 \times K2 \times Le}{11900 \times \varepsilon fu} = \frac{0.94 \times 0.853x\ 34.63}{11900 \times 0.014} =$$

0.166 < 0.75

Effective strain level in FRP reinforcement attained at failure

εfe = Kv x εfu = 0.166 x 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*,

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

Effective Stress In FRP Shear Reinforcement

ffe = $\varepsilon_{fe} \times \varepsilon f$ = 0.0023 x 227.6 = 0.523 kN/ mm^2

Nominal shear strength provided by FRP stirrups

$$\mathbf{V_f} = \frac{Afv \times ffe(\sin \alpha + \cos\alpha)dfv}{sf} = \frac{167.64 \times 0.523x1x237}{304.8} = 68.17kN$$

Step 4 Total Shear Strength of Section:

$\Phi V_n = \phi (V_c+V_s+ \Psi_f V_f) = 0.75x (66.65 + 0 + 0.85x\ 52.78)$

=**93.44 kN** > 85kN….safe

"Hence provide 2 layer of CFRP jacket."

VI. DESIGN OF COLUMN FRP JACKETING AS PER FIB CODE

Data:-

b =230 mm, d = 450mm, fck provided = 12mpa,

fck required = 25mpa, Pt % provided = assume 0% due to corrosion of bar,

Area of concrete = 103500mm^2, Pu = 675 kN, Mx =25kN.m

Manufacture Data –

Ultimate strain in carbon fiber (ε_f) = 1.5%

Elastic modulus of carbon fiber (E_f) = 137000 N/mm^2

Effective fiber thickness (t_f) =0.33 mm

No of Wrap (n) =2 No.

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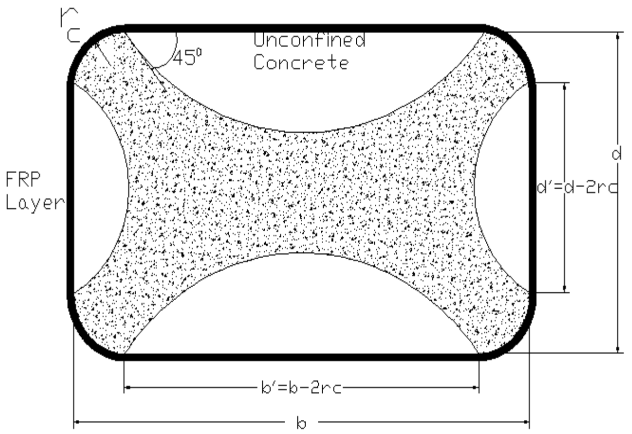
Solution:-



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 x rc = 230- 2x 25 =180 mm

d' = d- 2 x rc = 450- 2x25 = 400 mm

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

The confinement effectiveness coefficient ke considering ratio (Ac-Au)/Ac as per Fib 14 eqn 6.29 is given as,

$Ke = 1- \frac{b'^2 + d'^2}{3Ag(1-\rho sg)} = 1- \frac{Au}{Ag(1-\rho sg)} = 0.367$

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

Along direction b,

$Kconf_b = \rho_b k_e E_f$

Along direction d,

$Kconf_d = \rho_d k_e E_f$

Wher, $\rho_b = \frac{2 \times nt \times f}{b}$ and $\rho_d = \frac{2 \times nt \times f}{d}$

ρ_b = 0.0057 and ρ_b = 0.0029

K_{confb} = **288.09** K_{confd} = 147.31

Effective confining pressure, along direction b

$flb = \frac{Kconfb\ \varepsilon f}{2Ke} = 5.89 N/mm^2$

Along direction d

$fld = \frac{Kconfb\ \varepsilon f}{2Ke} = 3.01 N/mm^2$

Taking min value,

fl = 3.014 N/mm^2

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

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

f_{cc} = **25.73** 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

Ec = 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

φMn = Calculate design flexural strength of the section

Le = 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*,

ffe = 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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[6] ACI 440-2R

[7] Fib

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