Glass Fibre Reinforced Polymer Jacketing over Concrete Column

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Abstract – **Macro-mechanics analysis that was once carried out for Fiber Reinforced Plastics (FRP) *laminate*d jacketing done over the concrete columns has been reported here in this paper. Numerical results for various stiffness coefficients, *specially* of non-circular column sections using the same have been computed and on comparison with that computed of un-jacketed, reinforced concrete columns, provided a reasonable understanding of beam-column behavior of such columns. This *study* was conducted to demonstrate suitable adoption of GFRP corrugated sandwich laminate confinement to the concrete columns with various advantages and hence the same may be recommended for used in the modern buildings.**

Keywords: Beam-columns, Confined concrete, FRP macro-mechanics, Stiffness coefficients

I. INTRODUCTION

Corrosion led deterioration has been one of the most associated problems in any reinforced concrete structures which is being dealt with by the construction industry. Beams and Columns in any reinforced concrete structure being the main load bearing members in the structures and once any of these members found deteriorated, necessarily either be soon repaired, rehabilitated or even completely replaced. Complete replacements of any such main load bearing members at times put significant amount of additional financial burdens to the owner of these structures and hence, in situations when replacement turns out as not a cost-effective solution, suitable rehabilitation technique needs be adopted. Literature reveals that most widely adopted rehabilitation process in the construction industry, the world over, has been Jacketing over deteriorated concrete members of the structures. It comprises of laying a skin of suitable materials, such as either of (*i*) the reinforced concrete (*ii*) the steel sheets or (*iii*) the fibre reinforced polymer(FRP). Among all such materials used, FRP layered composites for jacketing, attracted most researcher that explore various advantages under retrofitting techniques for rehabilitation.

Because of noncorrosive, non-magnetic and having good resistance to chemicals, fibres other than steel, are now being internally mixed in the concrete during construction. FRP composites fibers however, are also externally laid with ease as compared to other repair materials and hence these are being adopted successfully to retrofit structures that were built earlier by construction industry. Study of structural behavior of concrete cylinders, for example, wrapped in different FRP materials has been reported in the literature by Lau and Zhou[1]. One of the techniques indicated in literature for seismic strengthening of any existing concrete structures, has also been the simple winding of high strength carbon fibres around the column surfaces in the form of spiral hoops and these are used to accomplish the most desired 'strong column and weak beam' design. Shamim *et al.* [2] showed the use of such layers of Carbon Fibre Reinforced Polymer (CFRP) in retrofitting the concrete columns whereas Richard D. Lacobucci *et al.* [3] reported the use of CFRP to develop the desired seismic resistance. Once used as the FRP retrofitted jackets over the reinforced concrete columns, it significantly led to increase in the ductility and hence it was found that this technique of jacketing enhances energy absorption capacity of the columns.

From reported literatures it was further found that the ultimate load carrying capacity of such strengthened structural members in CFRP got increased to 125% when compared to that of any un-strengthen members. The ultimate load carrying capacity on use of Glass, Silica, Coir, Polypropylene fibers in strengthening has also been found respectively as to have increased further by 89.6%, 45.02% and 37.9% & 37.03%. While it remains apparent that any members, retrofitted with Carbon FRP composites, offers maximum ultimate load carrying capacity, the cost of Carbon FRP composites being still remains very high, an alternate cost effective solution need therefore be recommended. Retrofitting using Glass FRP laminates in such situations, proved economical, presently, the same is available in Indian Market of nearly Rs. 300/m^2 and added to this as reported above, GFRP also provides a next noticeable highest increase to 89.6% in the ultimate load carrying capacity.

FRP Jacketing technique which is practiced so far in the field, primarily uses the unidirectional layers wrapped around the structures and also has been adopted only to reinstate the dimensional stability of the structural members so that the pre-deteriorated design strengths of such retrofitted concrete constructions could successfully be restored. GFRP Jacketing subsequently has also been realized to offer adequate increments in lateral load design capacity of any columns, thereby it was felt that concrete columns can ideally be constructed with jacketing itself to behave like beam-columns (BC). For this purpose, GFRP Jacketing skins need consist of both longitudinal and transverse reinforcements and need comprise of adequate numbers of layers.

While behavior of square concrete column confined with Glass Fibre Reinforced Polymer (GFRP) composite has experimentally been studied and reported in the literature by Riad Benzaid *et al.* [4], structural behaviors of concrete column of rectangular section in various desired sizes, with/without wraps of any GFRP jacketing have been studied here analytically. In what follows is a brief on an analytical study that was once carried out in ramifying the application of that extensively used Advance Composite Technology (ACT) in aerospace applications [5-8] into the construction industry. Presented here in this article is a generated constitutive relation for subsequent ready use and also some numerical results computed of various design parameters using the same analysis. Numerical values of the sectional stiffness parameters have been plotted to evaluate the ultimate bending strength and shear strength of such retrofitted reinforced concrete columns. Having concrete inside, jacketed columns in laminated composites, found to possess the desired beam-columns (BC) behaviors and hence recommended for effective deployment in the modern structures [9].

II. ACT-BASED ANALYSIS

Stress $\{\sigma\}$ and strain $\{\text{Є}\}$ tensors are generally defined in material coordinates using material stiffness [C] of any composite materials, the coefficients of which are expressed in terms of E_1, E_2, E_3 being the elastic moduli respectively in 1,2 and 3 directions of the material, $G_{12,}$ the shear moduli in the 1-2 planes and ν_{ij} the Poisson's ratio for transverse strain in j direction when stressed in the *i* direction. Assuming conveniently the laminate assemblage to be in state of plane strain in xy or xz plane, stress-strain relations therefore remain

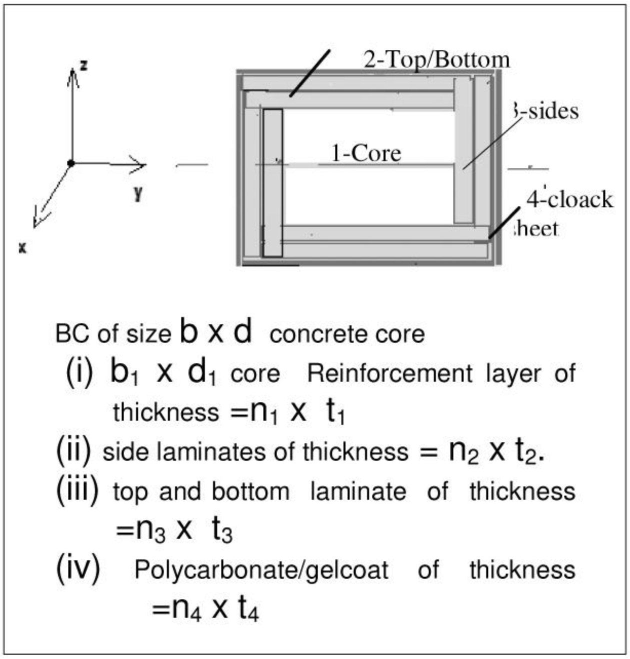
$$\{\text{Є}\} = [C].\,\{\sigma\} \;......... \qquad 1\,(a)$$

$$\text{where } \{\text{Є}\} = \begin{Bmatrix} \partial/\partial x & 0 & 0 \\ 0 & \partial/\partial y & 0 \\ 0 & 0 & \partial/\partial z \\ 0 & \partial/\partial z & \partial/\partial y \\ \partial/\partial z & 0 & \partial/\partial x \\ \partial/\partial y & \partial/\partial x & 0 \end{Bmatrix} \begin{Bmatrix} u \\ v \\ w \end{Bmatrix} + (1/2).\,Z \begin{Bmatrix} \partial/\partial x & 0 \\ 0 & \partial/\partial y \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ \partial/\partial y & \partial/\partial x \end{Bmatrix} \begin{Bmatrix} -\partial w/\partial x \\ -\partial w/\partial y \end{Bmatrix} \qquad 1(b)$$

In such multi laminated column sections shown in figure -1, *stresses may vary from its layer to layer* (laminae) as well as in its core material, the stress and moment resultants of column section in xy plane for example, is then defined as

$$(N_x, N_y, N_{xy}) = \int_{-to}^{to} (\sigma_x, \sigma_y, \sigma_{xy})\,dz$$

$$(\dot{M}_x, \dot{M}_y, M_{xy}) = \int_{-to}^{to} z\,(\sigma_x, \sigma_y, \sigma_{xy})\,dz \qquad ...(1c)$$



BC of size $b \times d$ concrete core
(i) $b_1 \times d_1$ core Reinforcement layer of thickness $= n_1 \times t_1$
(ii) side laminates of thickness $= n_2 \times t_2$.
(iii) top and bottom laminate of thickness $= n_3 \times t_3$
(iv) Polycarbonate/gelcoat of thickness $= n_4 \times t_4$

Figure 1. Geometric parameters of BC.

III. CONSTITUTIVE RELATION

For the required assemblage of laminates, the constitutive relation is expressed using reduced stiffness coefficients of kth lamina in terms of in-plane stiffness coefficients 'A_{ij}', in-plane / flexural stiffness coupling coefficients 'B_{ij}'and the flexural stiffness coefficients 'D_{ij}'of laminates as

$$\begin{Bmatrix} N_i \\ M_i \end{Bmatrix} = \begin{bmatrix} A_{ij} & B_{ij} \\ B_{ij} & D_{ij} \end{bmatrix} \begin{Bmatrix} \text{Є}_j \\ X_j \end{Bmatrix} \qquad ...(1d)$$

wherein, the laminae material axes and laminate geometry need primarily be mapped appropriately into an equivalent section for example, that of top and bottom laminates, and on superposition, the respective stiffness coefficients are then defined as

$$(A_{11}, B_{11}, D_{11}) = [\{b_1/(b_1+n_{2*}t_2)\} \sum_{k=1}^{n} \mathbf{C}_{11}(k).\{\int_{z_{k-1}}^{z_k} (1,z,z^2)dz\}_{\text{Core}} + \sum_{k=1}^{n} \mathbf{C}_{11}(k).\{\int_{z_{k-1}}^{z_k} (1,z,z^2)dz\}_{\text{top \& bottm}}$$

$$+ [\{(d_1+n_{3*}t_3)/(b_1+n_{2*}t_2)\} \sum_{k=1}^{n} \mathbf{C}_{11}(k).\{\int_{y_{k-1}}^{y_k} (1,y,y^2).dy\}_{\text{for sides}}] \qquad ....(1e)$$

The in-plane and out-of-plane transverse displacement *u, v, w* in *x,y* and *z* directions respectively of the considered laminated glass beam-column subject to an axial force '*R*'(force per unit column width) and/or distributed transverse load '*q*'(force per unit column height), is thus computed using Eqs.(1) and employing Rayleigh Ritz's method that lead to the governing equations as

$$\begin{bmatrix} S_{11} & s_{12} & s_{13} \\ s_{12} & S_{22} & s_{23} \\ s_{13} & s_{23} & S_{33} \end{bmatrix} . \begin{Bmatrix} u \\ v \\ w \end{Bmatrix} = [R.\{H\} + q.\{F\}] \begin{Bmatrix} u \\ v \\ w \end{Bmatrix} \qquad \text{... (2)}$$

Solution of differential equation (2) is obtained by choosing some suitable beam-characteristic functions [10] for *u*, *v* and *w* respectively, satisfying the edge conditions, and these are

$$\begin{Bmatrix} u \\ v \\ w \end{Bmatrix} = d.\sum_{m=1}\sum_{n=1} \begin{Bmatrix} U(x)*\Phi_m(\xi)*\Psi_n(\eta) \\ V(y)*\Phi_m(\xi)*\Psi_n(\eta) \\ W(xy)*\Phi_m(\xi)*\Psi_n(\eta) \end{Bmatrix} \qquad \text{... (3a)}$$

and $q = d.\sum_{m=1}\sum_{n=1} Q(xy)*\Phi_m(\xi)*\Psi_n(\eta)$ ... (3*b*)

Referring Fig-1, here $d=(d_1+2t_3n_3)$, $b=(b_1+2t_2n_2)$, and $\lambda = b/d$ ... (3*c*)

Various sub-elements of [S],{H} and{F}are defined on substituting (3) into (2) respectively as

$$S_{11}= [A_{11}*X_{10}+2.*A_{13}*\lambda*X_8+A_{33}*\lambda^2*X_1]*d^2$$
$$S_{12}= S_{21}=[A_{12}*\lambda*X_8+A_{13}*X_{10}+A_{23}*\lambda^2*X_1+A_{33}*\lambda*X_4]*2.*d^2$$
$$S_{13}= S_{31}=[-B_{11}*X_{13}-B_{12}*\lambda^2*X_9-2.*B_{13}*\lambda(2.*X_{11}+X_7)-B_{23}*\lambda^3*X_2-2.*B_{33}*\lambda^2*X_5]*d^3$$
$$S_{22}= [A_{22}*\lambda^2*X_1+2.*A_{23}*\lambda*X_4+A_{33}*X_{10}]*d^2$$
$$S_{23}= S_{32}=[-B_{12}*\lambda*X_7-2.*B_{23}*\lambda^2*(X_9+2.*X_5)-B_{13}*X_{13}-2.*B_{33}*\lambda*X_{11}]*d^3 \qquad \text{... (4a)}$$

$$S_{33}= [D_{11}*X_{16}+2.*D_{12}*\lambda^2*X_{14}+4.*D_{13}*\lambda*X_{15}+D_{22}*\lambda^4*X_3+4.*D_{23}*\lambda^3*X_6+4.*D_{33}*\lambda^2*X_{17}]*d^4$$
$$H_{11}=H_{22}=0;\ H_{33} = d^2*RX*X_{10}+d^2*\lambda^2*RY*X_1+2.*d^2*\lambda*RXY*X_8 \qquad \text{…(4b)}$$

and $F_{11}=F_{22}= 0;\ F_{33} =X_0$ …(4*c*)

Numerical values of design parameters therefore obtained by solving eq(4) wherein $\mathbf{X_i= \sum\sum I^{pq}_{mr}J^{pq}_{ns}}$ with values to '*pq*' assigned as obtained from table-1, and

$$I^{pq}_{mr}=\int_0^1[\phi^p_m(\xi).\phi^q_r(\xi)]d\xi$$

$$J^{pq}_{ns}=\int_0^1[\Psi^p_n(\eta).\Psi^q_n(\eta)]d\eta \qquad \text{…(4d)}$$

TABLE 1–DIFFERENTIAL OPERATORS ON BEAM CHARACTERISTICS FUNCTIONS [10]

pq forJ / forI	00	01	02	10	11	12	0	21	22
00	X_0				X_1	X_2			X_3
0				X_4	X_5			X_6	
02				X_7					
10		X_8	X_9						
11	X_{10}	X_{11}			X_{12}				
12	X_{13}								
20							X_{14}		
21		X_{15}							
22	X_{16}								X_{17}

Figure 2. Beam-column with end moments.

An increment in column end bending moment ,'ΔM_y' owing to beam-column behavior, acting in *x-z* plane for example, causes the increments in its rotation angle $\Delta\theta_y$ at ends *i* and *j*, which is computed as

$$\Delta\theta_y(i) = (2L/6E_yI_y + 1/G_{xy}AL)\ \Delta M_y(i) + (-L/6E_yI_y+1/G_{xy}AL)\ \Delta M_y(j)$$
$$\Delta\theta_y(j) = (-L/6E_yI_y + 1/G_{xy}AL)\ \Delta M_y(i) + (2L/6E_yI_y+1/G_{xy}AL)\ \Delta M_y(j) \qquad \text{…(5a)}$$

An increase in axial force 'ΔN_x', causes an increment in axial deformation and is also computed as

$$\Delta\delta u = \Delta N_x/E_xA \qquad \text{…(5b)}$$

here '*L*' is the column height and 'E_yI_y', '$G_{xy}A$', 'E_xA' are respective flexural, shear and axial stiffness values of equivalent configuration of beam-column, computed through this ACT -based analysis.

IV. NUMERICAL RESULTS AND DISCUSSIONS

Reinforced concrete columns Jacketed with GFRP (E_G=70Gpa) using Epoxy(E_e=5Gpa) in laminates with desired numbers of layers and sizes are considered. Numerical results are obtained of column sections (size 100 x 100 x 1000mm^3) with six different configurations namely (*i*) Reinforced concrete core of b_1 x d_1 with steel reinforcement of n_1 and t_1 as layers in the concrete itself (*ii*) section as in i, but sandwiched between top and bottom GFRP laminates (*iii*) section as in ii, sandwiched between side GFRP laminates (*iv*) section as in *ii* & *iii*, but with hollow core (*v*) section as in *ii* & *iii*, fully cloaked in GFRP laminates (*vi*) section as in *iv*, with further cloaked in a Polycarbonate sheet (E_{pc}= 10Gpa) /re-presenting a required gel coats.

The effect of variation in design parameters ‘λ’(=1-4), and ‘L’(=500-4000mm), onto the respective stiffness values as of Beam-Column sections, their maximum bending and buckling stresses, central deflections so computed are all plotted as for example shown in the Figure 3(*a-c*).

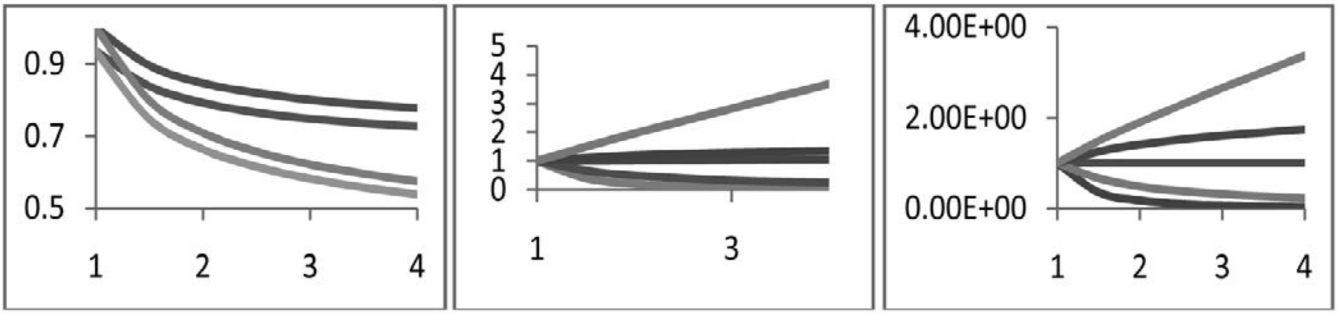
Plots of variation in axial deformation and rotation angles at ends of column caused respectively by the increase in axial force and end moments also are obtained as shown for example in Figure 4(*a,b*). As may also be seen from these plots, bending stresses, deflection & critical buckling follows same patterns in these cases and tend to remain unchanged for cases with ‘λ’ > 2 . As an important observation made here is that its value increases - (*i*) in-plane axial displacement under axial loads show a decreasing trend , as in Fig. 4(*a*) whereas (*ii*) rotation angle caused by moments at other end is observed with increasing trend as in Fig.4(*b*). As it should be, RC Columns when jacketed in GFRP laminates observed here as offering the required advantages of Beam-Columns.

V. CONCLUSION

Analytical study of macro mechanics has successfully been made for Reinforced concrete structures through generating a constitutive relation which could now readily be used specially for the non-circular section essentially by obtaining the required numerical values for further study of their Beam-Column behavior using various stiffness coefficients of any FRP Laminated (Jacketed) concrete columns with/without additional thermoplastic/ gelcoat wrapping. From the several interesting numerical results so obtained from this analysis, a reasonable comparison of the results of such FRP jacketed reinforced concrete columns with that of unjacketed cement concrete columns could be made. Although some representative cases only are reported here, the study has however facilitated in clear understanding on the behavior of any cloaked concrete columns providing all the beam-column advantages. This study is believe to also pave a clear way further for GFRP Laminates to get adopted as a suitable construction material even for direct application in major structural members in the modern buildings with desired advantages.

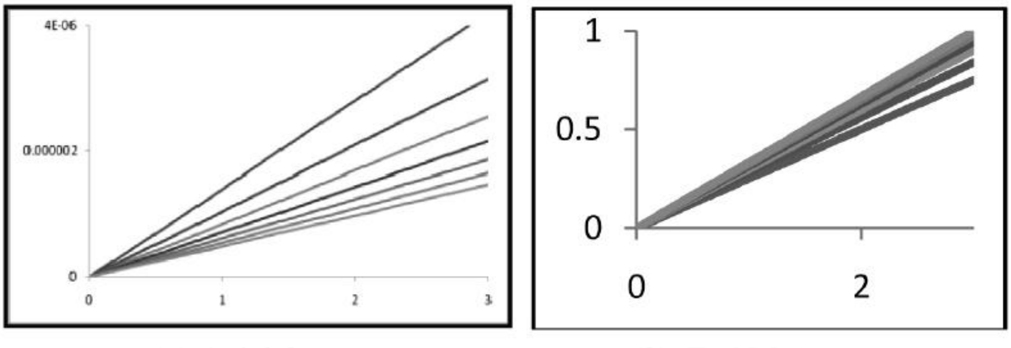
VI. REFERENCES

[1] K. T. Lau and L. M. Zhou, “The mechanical behavior of composite-wrapped concrete cylinders subjected to uniaxial compression load”, *Composite Structures* .vol. 52, no.2, pp.189–198, May 2001.



(*a*) Section Stiffness (*b*) Beam-column with core (*c*) Beam-column without core

Figure 3. Some normalized parameter values.



(*a*) Axial force (*b*) End Moments

Figure 4. Beam Column behavior with axial force and end moments.

[2] Shamim, A. Sheikh and Grace Yau, "Seismic behaviour of concrete columns confined with steel and fibre reinforced polymers", *ACI Structural Journal*, vol. 99, no. 1, pp.72-80, Jan 2002.

[3] Richard D. Lacobucci, Shamim A. Sheikh and Oguzhan Bayrak, "Retrofit of square concrete columns with carbon fibre reinforced polymer for seismic resistance", *ACI Structural Journal,* vol. 100, no.6, pp. 785-794, Nov-Dec 2003.

[4] Riad Benzaid and H.A. Meshbah, (2008). "Behaviour of square concrete column confined with GFRP composite wrap", *Journal of Civil Engineering and Management,* vol. 14, no.2**,** pp-115–120, Jun 2008.

[5] K. Kamal and S. Durvasula, "Macro mechanical behavior of composite laminates", *International Journal of Composite Structures*, vol. 5, no. 4, pp-309-318, 1986.

[6] K. Kamal, "On the use of glass matrix composites (GMC) to knack the dwelling units in sandy deserts', *Proc. Structural Engineers World Congress*, Bangalore, India, V.12-24, 2007.

[7] K. Kamal, "On the use of advanced composite corrugated core sandwich laminates as structural panels-*Proc. INCCOM-10, RDE(E)*, Pune, India, pp-18-19, Nov 2011.

[8] K. Kamal, "Structural units developed for field applications using ACT in civil engineering", *Journal of IBC*, pp. 31-35, Oct. 2011.

[9] K. Kamal and Anubha Gupta, "Pragmatic strengths Advantage on use of GFRP Composite Jacketed Concrete Columns", included in ICCE-26, held at Paris, France, July 2018.

[10] K. Kamal, "Numerical values of integrals of Trigono-Beam-Characteristics function", *Tech Report No.371S*, DAE, IISc, Bangalore , Dec. 1982.

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