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Retrofitting of Columns of an Existing Building by RC, FRP and SFRC Jacketing Techniques

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ABSTRACT: *The objectives of this paper is to design RC, FRP and SFRC Jacketing of failed columns of an existing building and to compare suitability of these three methods of retrofitting. The presented work also describes design procedure of Reinforced Concrete, Carbon Fibre Reinforced Polymer Jacketing and Steel Fibre Reinforced Polymer Jacketing for strengthening an existing columns. There is a large world-wide need for simple and reliable methods to repair and strengthen aging infrastructure and buildings. The use of FRP Jacketing offers several advantages over the RC and SFRC Jacketing but it is slightly expensive.*

Keywords *- Concrete Jacketing, FRP Jacketing, SFRC Jacketing, Retrofitting.*

1. INTRODUCTION

Jacketing of columns consists of added concrete with longitudinal and transverse reinforcement around the existing columns. This type of strengthening improves the axial and shear strength of columns while the flexural strength of column and strength of the beam-column joints remain the same. It is also observed that the jacketing of columns is not successful for improving the ductility. A major advantage of column jacketing is that it improves the lateral load capacity of the building in a reasonably uniform and distributed way and hence avoiding the concentration of stiffness as in the case of shear walls. This is how major strengthening of foundations may be avoided. In addition, the original function of the building can be maintained, as there are no major changes in the original geometry of the building with this technique. Jacketing of columns is needed when the load carried by the column is increased due to either increasing the number of floors or due to mistakes in the design. Jacketing is practiced when the compressive strength of the concrete or the percent and type of reinforcement are not according to the codes' requirements and also when columns is exposed to an earthquake, an accident such as collisions, fire, explosions.

The most common types of jackets are steel jacket, reinforced concrete jacket, fibre reinforced polymer composite jacket, jacket with high tension materials like carbon fibre, glass fibre etc.

1.1 Problem Statement

The building that is considered for this work has been modelled in STADD PRO software. This residential building is situated in Patna, Bihar. This building is initially designed to be built upto 4 storey in approx 2000 sq. feet . For its foundation there are 22 Live piles which are 9 meter deep in the soil and 9 Dead piles which are 7 meter deep in the soil. It has 31 tie beams of dimension 0.300 m × 0.300 m. It has 5 rooms , 4 bathrooms, a store room ,a dining hall, a drawing hall ,a kitchen, and with 4 balconies for each room. Room sizes are 3.66 m by 3.35 m, size of dining hall is 3.20 m by 6.55 m and that of drawing hall is 6.55 m by 3.35 m, bathroom size are 2.44 m by 1.52 m & 1.52 m by 1.52 m . Kitchen has a dimensions of 3.2 m by 2.13 m. Its columns sizes are of 0.3m×0.3m, 0.36m×0.3m, and 0.4m×0.3m & beams are of 0.3m×0.25m , 0.3m×0.3m, 0.25m×0.25m,0.36m×0.3m. slab has a thickness of 5 inch i.e 0.125 m. For the present work, (G+3) storey building with storey height 3 meter for all, with plan 18mx9m is taken. Buildings has bays in irregular form in both X & Y axis. For this 4 storey building, load was applied as per IS code 1875:1987 (Part 2), to show that no column failed for 4 storey. And as we increase the storey of building by 1 storey, then it's 6 columns failed due to increase in load. And as we modelled this building to 6 storey , it's 19 columns failed, only at ground and first floor level.

- As existing building was modelled as per cross-section of columns provided and load applied & analyse in Stadd Pro V8i and found that till 4 storey there is no any deficient (failed) columns (as shown in fig1) because initially building was designed as per 4 storey.
- As we model 5 storey ,some of columns (six columns) of building failed. Columns(highlighted) that fails are 63 , 64 , 74 , 79 , 80 are of cross-section 300mm×300mm as shown in fig 2.
- As we model 6th storey, many columns failed. Columns(highlighted) which fail are 62,63,64,65,66,67,69,70,72,73,74,77,78,79,80,179,180,189,190 are of cross-section 300mm×300mm & 400mm×300mm as shown in fig 3.

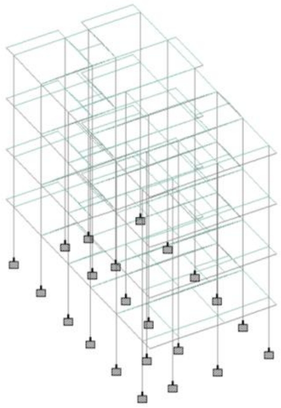


Fig 1: 4 Storey building - No column failed

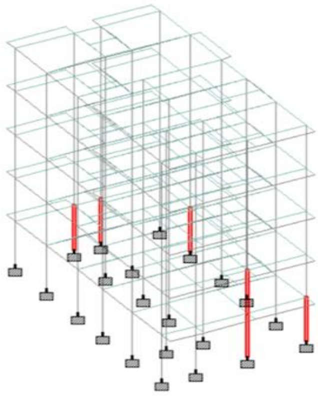


Fig 2: 5 Storey Building -6 columns failed

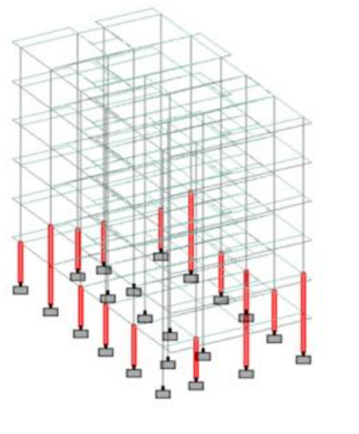


Fig 3: 6 Storey Building -19 columns fail

2. DESIGN OF RC JACKETING OF FAILED COLUMNS FOR 5 STOREY BUILDING

For 5 storey building, A total of six columns failed as shown in fig 2. RC Jacketing to these columns are designed as per IS code 15988:2013.
One design example for column no 63 is given here:

Column No- 63

Height of column= 3000mm ; Width (b) =300mm ; Depth (D)=300mm; d= 260mm;
Reinforcement provided= 4,16Ø=804.25 mm^2 ; f_y = 415 MPa; f_{ck}=30 MPa.
P = 965.156 kN ; M = 15.307 kNm; P_u = 1447.734 kN ; M_u = 22.961 kNm
Since, $Pu = 0.4 \times f_{ck} \times A_c + 0.67 \times f_y \times A_{sc}$
According to the provisions provided in to §8.5.1.2 (a) of IS 15988: 2013, Concrete strength shall be at least 5 MPa greater than the strength of the existing concrete. Thus, taking value of f_{ck} = 35 N/mm^2 and assuming A_{sc} = 0.8% A_c
$1447.734 \times 10^3 = 0.4 \times 35 \times A_c + 0.67 \times 415 \times (0.8\,\% A_c)$; Therefore, A_c = 89234.10 mm^2
According to §8.5.1.1 (e) of IS 15988:2013, $A'_c = 1.5A_c$; Thus, A'_c =133851.15 mm^2
Assuming the cross sectional details as:
B = 400mm ; D = 133851.15/400 = 334.63 mm
Jacketing details of cross section: B = (400-300)/2 = 50 mm; D = (334.63-300)/2 = 17.315 mm
However, According to the code specified above, Minimum jacket thickness shall be 100 mm as per §8.5.1.2 (c) of IS 15988:2013
Thus, New size of the column: B = 300+100 +100 = 500mm, D =300 +100 +100 = 500mm
New concrete area=500 × 500 = 250000 mm^2 > A_c = 89234.10 mm^2
Area of steel, A_s = 0.8% × 500 × 500 = 2000 mm^2
But according to §8.5.1.1 (e) IS 15988:2013, $A'_s = (4/3)\, A_s = (4/3) \times 2000$ = 2666.67 mm^2
Assuming 16mm Ø bars, Thus, number of bars, N = 2666.67 × 4/ (π x 162) = 13.263 bars
Therefore, 14 no. -16mm Ø bars is for whole sections. So, providing 10 NO. -16mm Ø bars for jacketed section. And jacketed section will be 500mm x 500 mm. Details of all jackets with their reinforcement details are given below in Table 1.

Table 1 Detailing of RC Jacket for 5 storey building

Column	Pu (kN)	Mu (kNm)	Jacketed	Jacketed C\S (mm^2)	Lateral Ties
63	1447.73	22.96	10-16 ø	500 x 500	8mm ø @90mm c/c
64	1143.31	33.29	10-16 ø	500 x 500	8mm ø @90mm c/c
74	1213.04	27.63	10-16 ø	500 x 500	8mm ø @90mm c/c
79	1114.12	36.23	10-16 ø	500 x 500	8mm ø @90mm c/c
80	1113.09	18.01	10-16 ø	500 x 500	8mm ø @90mm c/c

179	1147.68	22.13	10-16 ø	500 x 500	8mm ø @90mm c/c

Similarly for six storey building, size of jacket is calculated as per design steps given above and given in Table 2 for all Failed columns.

Table 2 Detailing of RC Jacket for 6 storey building

Column No	Pu (kN)	Mu (kNm)	Jacketed section	Jacketed C\S	Lateral Ties
62	1281.79	19.23	10- 16 ø	500 x 500	8mm ø @90mm c/c
63	1701.29	19.75	10- 16 ø	500 x 500	8mm ø @90mm c/c
64	1379.89	31.79	10- 16 ø	500 x 500	8mm ø @90mm c/c
65	1489.16	44.46	10- 16 ø	500 x 600	8mm ø @90mm c/c
66	1155.17	28.48	10- 16 ø	500 x 500	8mm ø @90mm c/c
67	1176.81	18.02	10- 16 ø	500 x 500	8mm ø @90mm c/c
69	1529.95	45.01	10- 16 ø	500 x 600	8mm ø @90mm c/c
70	1249.54	27.32	10- 16 ø	500 x 500	8mm ø @90mm c/c
72	1746.78	31.65	25- 12 ø	500 x 600	8mm ø @55mm c/c
73	1278.43	24.31	10- 16 ø	500 x 500	8mm ø @90mm c/c
74	1443.32	24.92	10- 16 ø	500 x 500	8mm ø @90mm c/c
77	1030.51	24.42	10- 16 ø	500 x 500	8mm ø @90mm c/c
78	1099.29	33.30	10- 16 ø	500 x 500	8mm ø @90mm c/c
79	1327.93	33.68	10- 16 ø	500 x 500	8mm ø @90mm c/c
80	1328.14	17.30	10- 16 ø	500 x 500	8mm ø @90mm c/c
179	1402.36	18.49	10- 16 ø	500 x 500	8mm ø @90mm c/c
180	1154.20	44.04	10- 16 ø	500 x 500	8mm ø @90mm c/c
189	1063.84	32.99	10- 16 ø	500 x 500	8mm ø @90mm c/c
190	1196.94	29.49	10- 16 ø	500 x 500	8mm ø @90mm c/c

2.1 Cost of RC Jackets of column no 63

The formula for calculation of materials for required volume of concrete is given by equation given as follows.

$$V_C = \frac{W}{1000} + \frac{C}{1000S_C} + \frac{F_a}{1000S_{fa}} + \frac{C_a}{1000S_{ca}} \qquad \text{-------(1)}$$

Where, V_c = Absolute volume of fully compacted fresh concrete ;W =Mass of water; C = Mass of cement ; Fa = Mass of fine aggregates ; Ca = Mass of coarse aggregates; S_c, S_{fa} and S_{ca} are the specific gravities of cement, fine aggregates and coarse aggregates respectively.

Let, Vcj = Vol of concrete in jacketed section ; V_R= Vol of lateral & tranverse reinf.
- Vol of reinforcement = $6.13\times10^{-3} + 3.52\times10^{-3} = 9.65\times10^{-3}$ m^3
$=[(500^2-300^2)-(10\times\pi\times16^2\div4)] = 0.482$ m^3

Let, M_R= Mass of reinf.= 7850 kg/m^3 $\times9.65\times10^{-3}$ = 75.75 kg

Consider concrete with mix proportion of 1:1.5:3 where, 1 is part of cement, 1.5 is part of fine aggregates and 3 is part of coarse aggregates of maximum size of 20mm. The water cement ratio required for mixing of concrete is taken as 0.45.

Assuming bulk densities of materials
- Cement = 1500 kg/m^3
- Sand = 1700 kg/m^3
- Coarse aggregates = 1650 kg/m^3

Specific gravities of concrete materials
- Cement = 3.15
- Sand = 2.6
- Coarse aggregates = 2.6.

The mix proportion of 1:1.5:3 by dry volume of materials can be expressed in terms of masses as:
Cement = 1 × 1500 = 1500 kg ; Sand = 1.5 × 1700 = 2550 kg
Coarse aggregate = 3 × 1650 = 4950 kg
Therefore, the ratio of masses of these materials w.r.t. cement will as follows =1:(2550/1500):(4950:1500)
= 1 : 1.7 : 3.3
So, from above data, C= 179.15 kg ; F_a= 304.55 kg ; C_a = 591.18 kg
Therefore, cost of concrete = Cost of (Cement + FA + CA + Reinf.)
=(179.15÷50×Rs350)+(304.55÷1700×Rs882)+(591÷1650×Rs2258) =Rs 2220

Cost of Reinf. = Rs 50/kg× 75.75 kg= Rs 3788.
Therefore total cost of material= **INR** 6008.

3. DESIGN OF FIBRE REINFORCED POLYMER JACKETING

FRP Jacketing is used because Carbon fibre is flexible and can be made to contact the surface tightly for a high degree of confinement due to its high strength and high modules of elasticity. The use of FRP in strengthening solutions has become an efficient alternative to some of the existing traditional methods due to some advantages such their features in terms of strength, lightness, corrosion resistance and ease of application. Such techniques are also most attractive for their fast execution and low labour costs. FIB Model Code for concrete Structures 2010 is the code which is used in the design of FRP Jacketing.

3.1 Design of FRP Jacketing of Failed column no-63

The given dimensions are, b =300 mm, d =260mm;
f_{ck} provided = 30Mpa; f_{ck} required = 35Mpa,
Pt % provided = 0.8% of A_c = 720mm^2,
Area of concrete = 89280 mm^2, Pu = 1447.734 kN, Mu = 22.961 kNm
Data provided from manufacturer for jacket is as follows :
Ultimate strain in carbon fibre (ε_f) = 1.5% ; Effective fibre thickness(t_f) =0.33mm
Elastic modulus of carbon fibre (E_f) = 137000 N/mm^2; No of Wrap (n) =2 No.

Effectively Confined Core for Non Circular Section

Total Plan Area of Unconfined concrete is obtained as per FIB (2010).
$b' = b - 2 \times r_c$ = 300- 2 ×25 =250 mm ; r_c=Radius of rounded corners of column
$d' = d- 2 \times r_c$ = 260- 2 ×25 = 210 mm
$Au = (b'^2+d'^2)\div 3$ =35533.33 mm^2
The confinement effectiveness coefficient k_e considering ratio $(A_c-A_u)/A_c$ as per Fib 14 eq^n 6.29 is given as,
$K_e = 1-[(b'^2+d'^2)/\{3A_g(1-\rho_{sg})\}]$= 0.602 ; $\rho_{sg} = A_s/A_g$
The Lateral confining pressures induced by the FRP wrapping as per Fib eqn 6.30 is given as
Along direction b, Along direction d,
$K_{confb} = \rho_b k_e E_f$ $K_{confd} = \rho_d k_e E_f$
Where, ρ_b =2ntf/b = 0.0044; and ρ_d =2ntf/d= 0.0051
K_{confb} = 362.89 ; K_{confd} = 420.62
Effective confining pressure, along direction b; Along direction d
$f_{lb} = (K_{confb} \times \varepsilon_f)/2K_e$= 4.52 N/mm^2 $f_{ld} = (K_{confd} \times \varepsilon_f)/2K_e$ = 5.24 N/mm^2
Taking min value: f_l = 4.52 N/mm^2

Maximum confining pressure as per equation 6.5 of FIB, which is given as,
$f_{cc} = f'_c\,[2.254\sqrt{(1+7.94f_l / f'_c)} - 2f_l/f'c - 1.254]$
f_{cc} = 53.552 N/mm^2
"Hence provide 2 layer of CFRP jacket."
Cost of FRP Jackets is around Rs2600 - Rs4600 per m^2
And area to be jacketed = 3.65 m^2
So, total cost of FRP Jacket per column(2 layer)= **INR** 18980
All columns for 5&6 storey posses same cost per column.

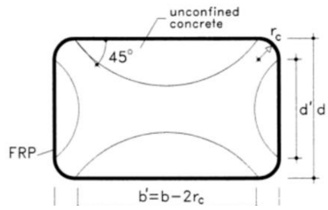


Fig4: Effective confined core for non circular

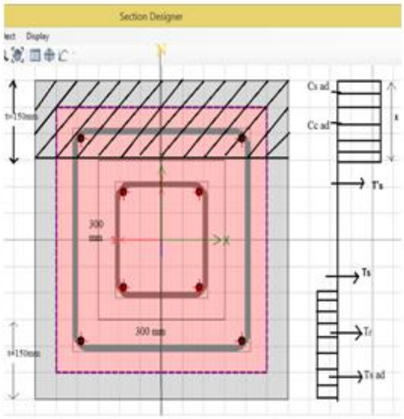
4. DESIGN OF STEEL FIBRES REINFORCED CONCRETE JACKETS

During recent years, steel fibre reinforced concrete has gradually advanced from a new, rather unproven material to one which has now attained acknowledgement in numerous engineering applications. Lately it has become more frequent to substitute steel reinforcement with steel fibre reinforced concrete. Steel Fibres are generally distributed throughout a given cross section whereas reinforcing bars or wires are placed only where required. Steel fibres are relatively short and closely spaced as compared with continuous reinforcing bars of wires. It is generally not possible to achieve the same area of reinforcement to area of concrete using steel fibres as compared to using a network of reinforcing bars of wires. Steel Fibres are typically added to concrete in low volume dosages (often less than 1%), and have been shown to be effective in reducing plastic shrinkage cracking. It do not significantly alter free shrinkage of concrete, however at high enough dosages they can increase the resistance to cracking and decrease crack width. Steel Fibres in Concrete can improve Crack, Impact, Fatigue Resistance, Shrinkage Reduction, Toughness. Benefits of SFRC is that it distributed localized stresses, Reduces maintenance and repair cost and Resistance to freezing and thawing.

4.1 Design of SFRP Jacketing of Failed column no-63
b=300 mm; d=300 mm; Effective cover of column a=40 mm
Steel reinforcement(2,16Ø) in the compression zone of cross sectional area(As')=402.12 mm^2
Steel reinforcement(2,16Ø) in the tensile zone of cross sectional area(As)=402.12 mm^2
And, their yielding point, f_y=210 MPa;
After rehabilitation, the column will have to undergo an axial force, F=1447.73kN and a bending moment, M=22.96 kN.m. The column cannot support these efforts without strengthening.
The design column height(H_0) =3.05 m.
Solution.
Let us choose the strengthening materials: Steel fibre
Compressive strength($f_{c' ad}$) =17.72MPa ; Tensile strength(f_t)=1.37 MPa;
Ultimate compressive strain(ε_u)=0.00337
The factor defining the intensity of compressive stress on the equivalent rectangular stress block for fibre reinforced concrete, γ_f=0.85+0.03 (WL/D)/450 ≤ 0.88 ;Where WL/D is the percentage of steel fibres by weight. In this case, γ_f =0.861 is taken.

Additional steel reinforcing bars in the jacket: $A_{s\ ad}' = A_{s\ ad}$; $f_{y\ ad}$=280 MPa.
For this design, rectangular stress block is to be used.
Let us assume the thickness of the SFRC(t)=150 mm.
The sizes of the strengthened element are, b'=b+2 t=600 mm; d'=d+2 t=600 mm
Loading eccentricity about centroid of the cross section(e) = M/F=15.85 mm
Loading eccentricity about centroid of the additional steel reinforcement in the tension zone of the cross section, e= e_o +0.5 d' -a=275.85 mm
Projection of all forces on the longitudinal axis of the column ∑X=0 gives:
$F - C_{s\ ad} - C_{c\ ad} + T_s' + T_s + T_f + T_{s\ cad} = 0$ ———— (1)
Where the resultant force in the additional compression and in the tension reinforcing steel bars,
$C_{s\ ad}$ =28 A_s' =28 A_s = $T_{s\ ad}$ =11259.36 mm^2
The resultant force in the compression fibre concrete, $C_{c\ ad} = \gamma_f f_{c\ ad}' b'(x)$ = 9154.15x.
The resultant force in the existing tension reinforcing steel, initially working in the compression zone,
$T_s' = f_y A_s'$ = 210×402.12= 84.45 kN
The resultant force in the existing tension steel, $T_s = f_y A_s$=210×402.12= 84.45 kN
The resultant force in the tension fibre concrete, $T_f = f_t$ b'd =1.37×600×150 =123.3 kN
By replacing the forces by their respective values in the equation (1), the depth of the equivalent rectangular stress block is calculated as, x=190.07 mm.
Taking moments of all forces and equating to zero gives:
$Fe - C_{sad}(d'-2a) - C_{cad}(d'-0.5x-a) + T_s'(d+t-2a) + T_s t + T_f(0.5t-a) = 0$ ———— (2)
The following calculations indicate that the additional steel reinforcing bars are not needed. However the design code requires in this case a minimum reinforcement, the amount of which depends on the ratio H_o/H .
Since, H= $(\sqrt{3}/6)$ d' =173.21mm ⇒ H_o/H =17.6
Consequently, the reinforcement cross sectional area required by the code
$A_{s\ min}$=0.1% b' (d'-a)=336 mm^2 ⇒ We take 3,12 Ø
Let us check the resistance condition:
$Fe \le C_{sad}(d'-2a) + C_{cad}(d'-0.5x-a) - T_s'(d+t-2a) - T_s t - T_f(0.5t-a)$
399.35kN.m<741.29 kN.m (Since, $C_{Cad} = \gamma_f f_{cad}' b'x$ = 9154.15x=1739.93 kN)
Obviously, the flexural strength of the column is sufficient after the strengthening by the S.F.R.C.
Hence, Jacket of thickness(t)=150 mm.

4.2 Cost of SFRC Jackets of column no 63
Vol. of concrete used in Jacketing
= (150mm×300mm×3050mm)×4=0.549m^3
Vol. of reinforcement used in jacketing
=7850 kg/m^3×0.000336×3.05=8.04 kg
Cost of reinforcement used in jacketing=Rs50×8.04=Rs 402
Cost of concrete used in jacketing derived similar as done
in section 2.1=Rs 2530



Since, Cost of SFRC in the market is Rs 20000-Rs 60000/ton
Cost of SFRC used in jacketing=
(1% of concrete used in jackets)×7900kg/m^3×Rs20 = Rs867.42
So, total cost of SFRC=Rs 3800

5. CONCLUSION

The following table shows a detailed comparison of RC, FRP and SFRC Jacketing.

Table 3: Comparison of RC,FRP and SFRC Jacketing

	RC Jacketing	FRP Jacketing	SFRC Jacketing
Minimum width of Jacket	• Width of jackets used is 100 mm which will reduce carpet area of building.	• Width of jackets used is 0.66mm which is very less and will not pose any changes in carpet area of building.	• Width of jackets used is 150 mm which is even more than RC Jacketing.
Properties of Jacket	• Match with the concrete of the existing structure. • Compressive strength greater than that of the existing structures by 5 N/mm^2 or at least equal to that of the existing structure.	• Completely different with that of existing structure. • Compressive strength is greater than that of existing structures by 5 N/mm^2 or equal to that of the existing structure.	Match with that of RC as well as FRP Jacketing because concrete, reinforcement, and steel fibre are used.
Cost of Jacket	• **INR** 6000 per column	• **INR** 18900 per column	• **INR** 3800 per column
Factored Load and Moment	• Factored load is only used for the design of RC Jacketing.	• Neither Factored load nor moment is used for the design of RC Jacketing.	• Factored load as well as moment is only used for design of RC Jacketing.

In addition to above, the following can also be concluded:

1. In RC Jacketing , sizes of the sections are increased and the free available usable space becomes less and also huge dead mass is added.
2. In RC Jacketing , drilling of holes in existing column, slab, beams and footings are required which cause further damage to the columns.
4. RC retrofitting technique are significant improvement in Moment resisting capacity, shear strength capacity in Beam and Axial load carrying capacity in column.
5. FRP Jacketing is costlier as compared to RC & SFRC Jacketing but better than RC and SFRC jacketing.
7. Confinement by FRP Jackets enhanced the performance of concrete columns.

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