Analysis and design of retrofitting of an existing building for columns by SFRC, RC, FRP jacketing techniques

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Abstract ***: The objectives of this paper is to design SFRC, RC and FRP 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 Fiber Reinforced Polymer Jacketing and Steel Fiber Reinforced Polymer Jacketing for strengthening 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. Retrofitting is a technique to enhance the structural capacities including the strength, stiffness, ductility, stability, and integrity of a building that is found to be deficient or vulnerable. It can effectively raise the performance of a building against earthquake to a desired level, and to even satisfy the requirements of an upgraded design seismic code. The building need not be deteriorated or damaged. The retrofit is intended to mitigate the effect of a future earthquake. It is seen that the overall performance of the column significantly improves after jacketing.***

IndexTerms* - *SFRC, FRP, stiffness, column retrofitting, ductility, RC jacketing.

I. INTRODUCTION

Jacketing is the most popularly used method for strengthening of building columns. Retrofitting can generally be classified in two categories: Global and the local. The Global Retrofitting technique targets the seismic resistance of the building. It includes adding of infill wall, adding of shear wall, adding of steel bracings and base isolation. Adding of infill wall in the ground storey is a viable option to retrofit buildings with soft storey. Shear walls can be introduced in a building with flat slabs or flat plates. A new shear wall should be provided with an adequate foundation. Steel braces can be inserted in frames to provide lateral strength, stiffness, ductility, and to improve energy dissipation. These can be provided in the Exterior frames with least disruption of the building use. Local retrofitting technique targets the seismic resistance of a member. The local retrofit technique includes the concrete, steel or Fiber reinforced polymer jacketing to the structural members like beams, columns, beam column joint, foundation. Concrete jacketing involves adding a new layer of concrete with longitudinal reinforcement and closely spaced ties. The jacket increases both the flexural strength and the shear strength of the beam or the column. The following are the advantages Of retrofitting. It increases the seismic resistance of the building without any demolition. It Increases the ductile behavior and lateral load capability of the building Strength and Stiffness of the building is also improved. [1]

Mrs. Poonam Dhiman, Mr.Anil Dhiman , Mrs Nikita Gupta.(2015) .And it was concluded that RC Jacketing is suitable for the old and existing building that are constructed without considering IS 1893:2002, are very liable for damage during an earthquake & columns that are damaged in the past earthquake during an accident like fire, Explosions.

Sri. Pravin B. Waghmare (2011). This research article was published at International Journal of Advanced Engineering Research and Studies in the year 2011. In the article of Sri. Pravin B Waghmare has discussed about Reinforced concrete Jacketing, Steel Jacketing, Carbon fibre reinforced polymer composite jacketing, Beam Jacketing. He has also discussed details about all three types of jacketing. In reinforced concrete jacketing he has discussed about Properties of jackets, minimum width of jacket, minimum area of longitudinal reinforcement, minimum area of transverse reinforcement, Shear stress in the interface and about Connectors. In steel jacketing he has discussed about Steel plate thickness, Shape of jackets, Free ends of jackets bottom clearance, Gap between steel jacket and concrete column Size of anchor Number of anchor bolts. And in beam jacketing how to calculate Minimum width for jacket, longitudinal reinforcement, Shear reinforcement, Depth of jacketed beam was discussed.

Kritika Gupta (2017**).** This review focussed on shear wall, reinforced concrete, seismic retrofitting, retrofitting bonding and beam column. After various literature review paper concluded that following method are carried out by most of researcher which are concrete are concrete jacketing of column of ground floor, brick masonry fill in the ground floor and v bracing shear wall, FRP beam and column.

II. MATERIALS

a) Cement: Cement is binder, a substance used for construction that sets, hardens, and adheres to other materials to bind them together. Cement mixed with fine aggregate produces mortar for masonry, or sand and gravel produces concrete is the most widely use material.
Cement is used is OPC 53 grade. It is confirmed to IS: 12269 used in presented study.

53 grade cement property which attained from standard tests

S.NO.	Properties of Cement	Attained from standard tests
1.	Specific gravity of OPC Grade 53 cement	3.15
2.	Initial setting time	60 minutes
3.	Final setting time	600 minutes
4.	Standard consistency (%)	30
5.	Fineness (%)	4

Advantage of using 53 Grade Ordinary Portland Cement in column jacketing
It has great resistance to cracking and shrinkage.
Initial setting time is of OPC is faster than PPC so it is recommended in more projects.
Curing period of OPC is less than PPC and curing cost reduces.

b)Steel: Generally commercial high yield strength deformed bars having a yield strength of 415 N/mm^2 rod which is used in construction of jacketing of column is 20mm and 16mm used for main bar and 8 mm used for as lateral tie.

c) Coarse aggregate: 20 mm coarse aggregate is used in column jacketing IS: 2386-1963(2 & 3). Table show the coarse aggregate properties.

M-sand properties

S.NO.	Properties of Coarse aggregate	Attained from standard tests
1.	Specific gravity	2.72
2.	Water absorption (%)	0.5
3.	Fineness modulus	7.3
4.	Particle shape	Angular

d) Fine aggregate: River sand is completely replaced by M-sand.

M-sand properties

S.NO.	Properties of fine aggregate	Attained from standard tests
1.	Specific gravity	3.15
2.	Water absorption (%)	0.5
3.	Fineness modulus	.3

e) Water: Potable water is used and the water should be free from impurities. As per IS 456 water used for concrete mixing and curing should have pH value above 6. Water is one of the most important elements in construction and is required for the preparation of mortar, mixing of cement concrete and for curing work etc. The quality of water used has a direct impact on the strength of the motor and cement concrete in the construction work. The water used for curing and mixing must be free from high quantities of alkalis, acid, oils, salt, sugar, organic materials, vegetable growth, etc that might be deleterious to bricks, concrete or iron.

f) Steel fiber reinforced: Steel fibers are added to concrete to improve the structural properties, particularly tensile and flexural strength. The extent of improvement in the mechanical properties achieved with SFRC over those of plain concrete depends on several factors, such as shape, size, volume, percentage and distribution of fiber. Mixing steel fibers considerably improves the structural properties of concrete, particularly tensile and flexural strength. Ductility and post cracking strength, resistance to fatigue, spalling and wear and tear of SFRC are higher than in the case of conventional reinforced concrete.

g) Fiber reinforced polymer: A Fiber Reinforced Polymer (FRP) typically consist of high tensile continuous fibers oriented in desire direction in a specialty resin matrix. These continuous fibers are bonded to the external surface of the member to be retrofitted in the direction of tensile force or as confining reinforcement normal to its axis. FRP can enhance shear, flexural, compression capacity and ductility of the deficient member. Glass fiber is the most common type of fiber used in the majority of commercially available FRPs. FRP system, commonly used for structural applications.

h) Epoxy resin: It is used as a bonding agent between the fiber and concrete surface. Thermosetting resin is used in this work.

III. METHODOLOGY

Design of SFRC jacket

B=400 mm; d=360 mm; Effective cover of column(a) = 40 mm
Steel reinforcement(2,16Ø) in the compression zone of cross sectional area(As')=402.12 mm2
Steel reinforcement(2,16Ø) in the tensile zone of cross sectional area(As)=402.12 mm2
And, their yielding point, f_y=415MPa;
After rehabilitation, the column will have to undergo an axial force, F=1395.28kN and a bending moment, M=48.22 kN.m. The column cannot support these efforts without Strengthening.
The design column height(H_0) =3.60 m.
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 fiber reinforced concrete, γ_f = 0.85+0.03 (WL/D)/450 ≤ 0.88 ;Where WL/D is the percentage of steel fibers 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=700 mm; d'=d+2 t=660 mm

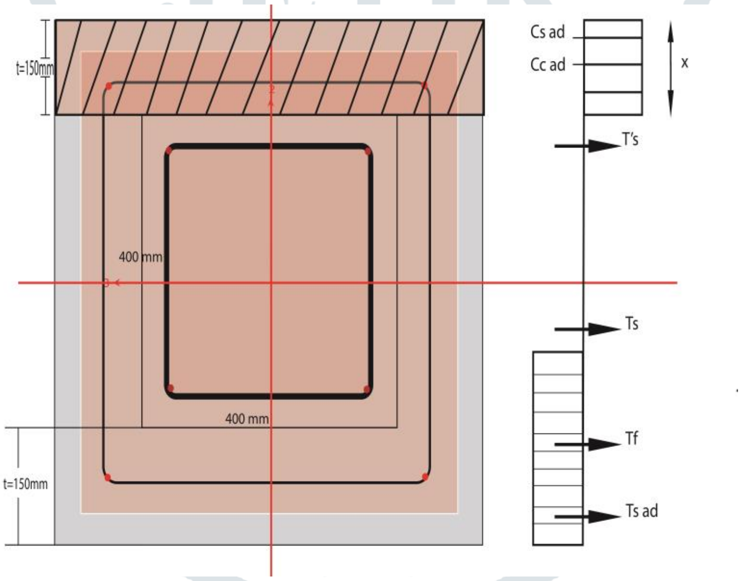
Loading eccentricity about centroid of the cross section(e_o) = M/F=28.93 mm
Loading eccentricity about centroid of the additional steel reinforcement in the tension zone of the cross section, e= e_o +0.5 d' -a=318.93 mm
Projection of all forces on the longitudinal axis of the column ΣX=0 gives:
$F - C_{s\,ad} - C_{c\,ad} + T_{s'} + T_s + T_f + T_{scad}=0$ (1)
Where the resultant force in the additional compression and in the tension reinforcing steel bars, $C_{s\,ad}$ =28 A_s' =28 As = $T_{s\,ad}$ =11259.36 mm2
The resultant force in the compression fiber concrete, $C_{cad} = \gamma_f\, fc'_{ad}\, b'(x)$ = 10679.84x.
The resultant force in the existing tension reinforcing steel, initially working in the compression zone, $T_{s'} = f_y A_{s'}$ = 415×402.12= 166.87 kN
The resultant force in the existing tension steel,
$T_s = f_y A_s$=210×402.12= 166.87 kN
The resultant force in the tension fiber 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=173.44 mm.
Taking moments of all forces and equating to zero gives:
$F_e - C_{sad}$ (d'-2 a) - C_{cad} (d' -0.5x-a) + T_s' (d+t-2 a) + T_s t + T_f (0.5 t-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= (*√3/6)* d' =190.29mm H_o/H =18.91
Consequently, the reinforcement cross sectional area required by the code
A s min=0.1% b' (d'-a)=434 mm2 We take 4,12 Ø
Let us check the resistance condition:
$F_e \leq C_{sad}$ (d'-2 a) + C_{cad} (d' -0.5x-a)- $T_{s'}$ (d+t-2 a)- T_s t -T_f(0.5 t-a)
444.99kN.m<6423.18 kN.m (Since, $C_{Cad} = \gamma_f\, f_{cad'}\, b'x$ = 10679.84x=1852.311 KN)

Obviously, the flexural strength of the column is sufficient after the strengthening by the S.F.R.C.

Cost of SFRC jackets of column

Vol. of concrete used in Jacketing
= (150mm×400mm×3600)×4=0.561m3
Vol. of reinforcement used in jacketing
=7850 kg/m3×0.000452×3.6=12.77kg
Cost of reinforcement used in jacketing=Rs50×12.77=Rs 638
Cost of concrete used in jacketing
Dry volume of concrete
0.564×1.54=0.864
Cement=226kg
=4.52×300=1000
Sand=0.236cum
=0.236×1250=300
Aggregate=0.471cum
0.471×2000=950
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/m3×Rs20 = Rs1000

So, Total Cost of SFRC=Rs 3888



Column Jacketing By Steel Fiber Reinforced Concrete

Design of RC jacket

Height of column= 3600mm ;Width (B) =400mm ; Depth (D)=400mm; d= 360mm;
Reinforcement provided= 4,16Ø=804.25 mm2 ; f_y = 415MPa; f_{ck}=15MPa.
So, P_u = 1395.28 kN,

$$P_u = 0.4 \times f_{ck} \times A_c + 0.67 \times f_y \times A_{sc}$$

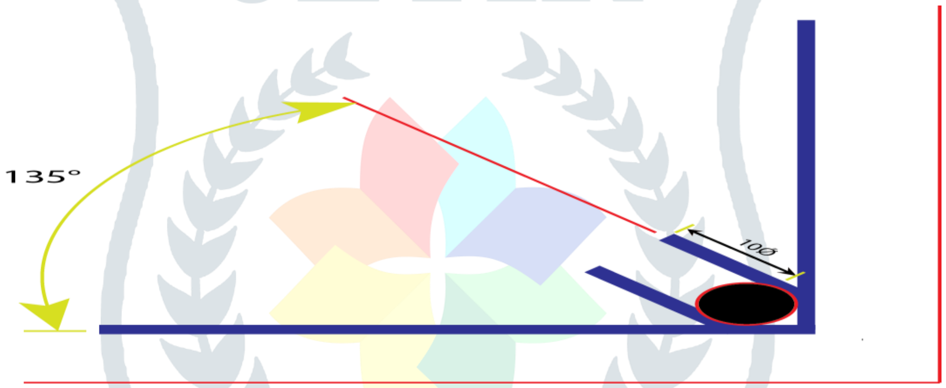
According to the provisions provided in to 8.5.1.2 (a) of IS 15988: 2013 , Concrete strength shall be at least 5 MPa greater than the strength of the existing concrete. Thus, taking value of f_{ck} = 20 N/mm2 and assuming A_{sc} = 1% Ac

1395.28 x 103 = 0.4 × 20 × Ac + 0.67 × 415 × (1 %A_c)
1395.28 x 103= 8 × A_c + 2.78× A_c
1395.28 x 103= 10.78 × A_c
A_c = 129432.282 mm^2
According to 8.5.1.1 (e) of IS 15988:2013, A'_c =1.5A_c
Thus, A'_c =194148.423mm2
Assuming the cross sectional details as:
B=500mm, D=194148.423/500=388.29 mm

Jacketing details of cross section:
B = (500-400)/2=50 mm, D = (388.29-400)/2=11.70 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 [1].
Thus, New size of the column: B = 400+100 +100=600mm, D =400 +100 +100=600mm
New concrete area=600 × 600=360000mm2 > Ac= 160000 mm2
Area of steel, A_s =1% × 600 × 600=3600 mm
But according to 8.5.1.1 (e) IS 15988:2013, A'_s = (4/3) A_s= (4/3) × 3600 = 4800 mm2
Assuming 20mm Ø bars,
Thus, number of bars, N =4800 × 4/ ($\pi \times 20^2$) = 15.28bars
Provide 10 NO. -20mm Ø bars for jacketed section. Therefore, revised jacketed section will be 600mm x 600 mm.

design of lateral tie

As per 8.5.1.2 (e) of IS15988: 2013, Minimum diameter of ties shall be 8 mm and not less than one-third of the longitudinal bar diameter.
Diameter of bar =1/3 of Ø of largest longitudinal bar = 1/3x 16 = 6mm ….take 8mm
Spacing of ties as per 8.5.1.1 (f) of IS 15988:2013- The code suggests that the spacing of ties to be provided in the jacket in order to avoid flexural shear failure of column and provide adequate confinement to the longitudinal steel along the jacket is given as:
s = (f_y x d_h2)/(□f_{ck} x t_j) = (415 x 20^2)/(□20 x 200) = 110mm
Provide 8mm Ø @110mm c/c.

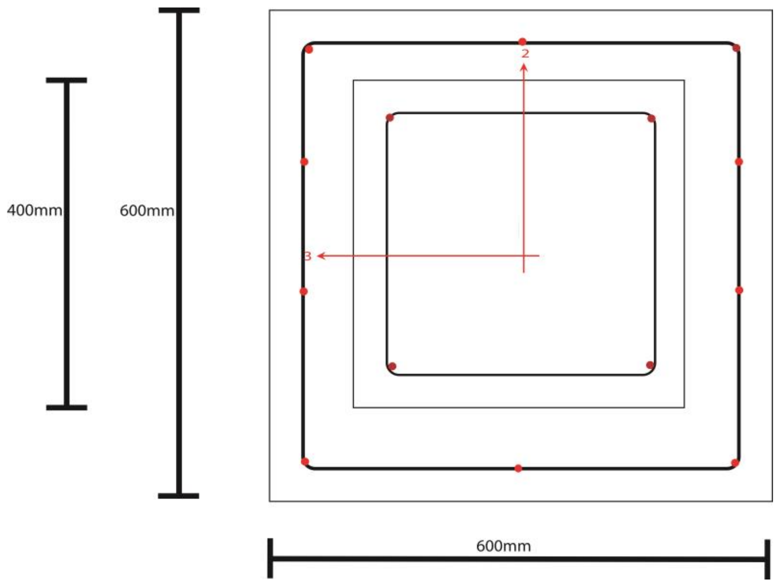


Reinforcement Jacket detailing for minimum level of retrofit

Cost of RC jacket on column

Vol of concrete in jacketed section - Vol of reinforcement
=[(600^2- 400^2)-(10×π×20^2÷4)] = 0.197 m3
Dry volume of concrete
0.197×1.54=0.303m3
Cement=80kg
=1.6×350=560
Sand=0.085cum
0.085×1250=110
Aggregate=0.167cum
0.167×2000=340
Vol of lateral & transverses reinforcement
= $7.23\times10^{-3}+1.82\times10^{-3} = 9.05\times10^{-3}$
MR= Mass of reinf.= 7850 kg/m3 ×9.05×10-3 = 71.05 kg
Cost of reinforcement
71.05×50=3553
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.

Therefore, Total cost of material= INR 4560



Design of C/S of Jacketed Column

Design of FRP jacketing

The given dimensions are, B =400mm, D =400mm;
F_{ck} provided = 15 Mpa; f_{ck} required = 20 Mpa,
Pt % provided = 1 % of A_c = 1600mm^2,
Area of concrete = 158400 mm^2
P_u = 1395.28 kN,
Data provided from manufacturer for jacket is as follows :
Ultimate strain in carbon fiber (ε_f) = 1.5% ; Effective fibre thickness(t_f) =0.33mm
Elastic modulus of carbon fiber (E_f) = 137000 N/mm2; No of Wrap (n) =2 No.
Effectively Confined Core for Non Circular Section
Total Plan Area of Unconfined concrete is obtained as per FIB
b' = b - 2 × rc = 400- 2 ×25 =350 mm ; r_c=Radius of rounded corners of column
d' = d- 2 × rc = 400- 2 ×25 = 350 mm
A_u = (b'2+d'2)÷3 =81666.66 mm2
The confinement effectiveness coefficient ke considering ratio (A_c-A_u)/A_c as per Fib 14 eqn 6.29 is given as,
K_e = 1-[(b'2+d'2)/{3A_g(1-ρ_{sg})}]= 0.467 ;
P_{sg} =A_s/A_g = (π×16^2/400^2) = 0.0050
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} = ρb k_e E_f K_{confd} = ρd k_e E_f
Where, ρb =2nt_f/b = 0.0033; and ρd =2nt_f/d= 0.0033
K_{confb} = 220.172; K_{confd} = 220.172

Effective confining pressure, along direction b; Along direction d
f_{lb} = (K_{confb}×ε_f)/2K_e= 3.39 N/mm2 f_{ld} =(K_{confd}×ε_f)/2K_e =3.39 N/mm2

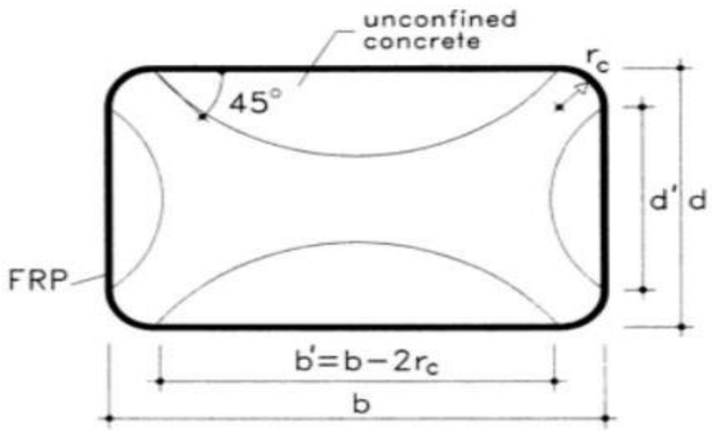
Taking min value: f_l = 3.39 N/mm2

Maximum confining pressure as per equation 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/mm2

"Hence provide 2 layer of FRP jacket.



Effective confined core for non circular sections

Cost of FRP jackets of column

Since, Cost of FRP Jackets is around Rs 2600 - Rs4600 per m^2

And area to be jacketed = 3.76 m^2

So, total cost of FRP Jacket per column (2 layer)= INR 19552

IV. RESULTS REPORT AND DISCUSSION

a) Visual inspection of building SATI vidisha

1	Type of building	Brick masonry
2	Use of building	College(SATI Vidisha)
3	Plan size(approximate)	11967 m^2
4	Building height	3.6 m
5	No. of storey above ground level	2
6	No. of basement below ground level	N.A
7	Type of foundation	footing
8	Roof-top water tank or any other type of large mass	yes
9	Expansion /separation joints	yes
10	environment	temperate
11	Deterioration located	yes

b) Structural analysis of SATI vidisha

1.	Load path	uniform
2.	Adjacent building	Yes
3.	mezzanines	No
4.	Deterioration of concrete	No
5.	Lintel band condition	Somewhere damaged
6.	Masonry units	cracked
7.	Span of beam	Medium(2-3)m
8.	Cracks at beam, slab joints	Yes
9.	Cracks in infill walls	Yes
10.	Cracks in boundary column	Yes
11.	Post-tensioning anchors	No
12.	Concrete wall cracks	Yes
13.	Deterioration of steel reinforcement	No

14.	Plaster condition	Somewhere damaged
15.	Water seepage condition	Detected

c) Analysis of geotechnical and geological of SATI vidisha

1.	Type of soil	Soft
2.	Type of foundation	footing
3.	Seismic zone	**III**
4.	Presence of liquefaction-susceptible saturated , loose granular soil at foundation level	No
5.	Building situated close to slope susceptible to fail under earthquake	No

d) Load analysis applied on the Building of SATI vidisha

1. Loads are applied on the building are dead load, live load, seismic loads according to IS CODE 875:1987 (Part I, Part II, Part III).
2. In this buildings dead loads are applied of 12 kN in downward direction for outer walls and dead loads are applied of 6 kN in downward direction for inner walls.
3. Live loads are applied of 2 kN/m^2 on class rooms, cabins bathroom, and 3 kN/m^2 on Smart class room, corridors, passages, labs, staircases.
4. Seismic loads are applied on the basis of IS CODE 1893:2013.
5. Loads are in following sequential orders :-

a) Seismic loads(E.L) in positive & negative X axis and positive and negative Z axis with a factor of 0.24.
b) Dead load are applied of 4 kN/m^2 in downward directions a/c to IS code for different height of building for different storey.
c) Live load are applied of 2 kN/m^2 & 3 kN/m^2 in downward directions a/c to IS code for different height of building for different storey.

e) Damage analysis of building of SATI vidisha

Cracks on the column of SATI building

V. CONCLUSION

This study is carried out by design of column by RC, FRP, AND SFRC some point as conclusion which are given below:

1. In RC and SFRC 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 and SFRC Jacketing, drilling of holes in existing column, slab, beams and footings are required which cause further damage to the columns.
3. FRP Jacketing is costlier as compared to RC, SFRC and but better than all of two.
4. Confinement by FRP Jackets enhanced the performance of concrete columns.
5. RC jacketing Match with the concrete of the existing structure, FRP jacketing completely different with that of existing structure and SFRC match with that of RC as well as FRP Jacketing because concrete, reinforcement, and steel fiber.

.6. Factored load is only used for the design of RC Jacketing Neither Factored load nor is moment used for the design of FRP Jacketing. Factored load as well as moment is used for design of SFRP Jacketing.

REFERENCE

1. Seismic analysis and retrofit of existing multistoreyed building in India, Alman K. Sengupta, Chemeru srinivansulu reddy, bandari narayanan V T, asokan A
2. IS 12269: 2013 Indian Standard ordinary Portland cement, 53 grade specification (First Revision)
3. Strengthening of a reinforced concrete column by SFRC, by P Nibasumba, Tsinghua University, China, 2001.
4. Handbook on Externally Bonded FRP Reinforced for RC Structures by FIB Federation.
5. IS 15988:2013, Seismic Evaluation and Strengthening Of Existing Reinforced Concrete? Buildings –Guidelines, Bureau of Indian Standards, New Delhi, 2013.
6. IS 456:2000, Plain and Reinforced Concrete, Bureau of Indian Standards, New Delhi,
7. IS 875:1987(Part1& 2), Design Loads For Buildings and Structures- BIS, New Delhi, 1987
8. IS 1893(Part 1) 2002 Indian Standard, Criteria for Earthquake Resistant Design of Structures, Part 1: General Provisions and Buildings (Fifth Revision).