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Seismic Strengthening of Existing RCC Structure by FRP Jacketing

Karan Singhai, A.K. Jain

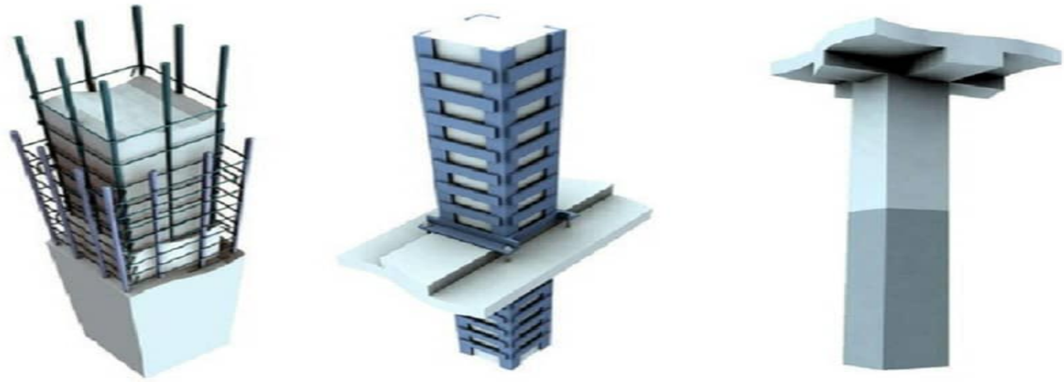
Abstract: ***India has been facing many disasters since long. Among the entire disasters earthquake is of serious concern to Civil Engineers. Because of collapse of structures subjected to seismic loads many lives were lost because these buildings were not designed for seismic loads. The problem becomes more serious when additional storeys are constructed. In these buildings many of the columns are not safe if the building is analyzed for seismic load. To make the building safe we need to adopt the technique of FRP (Fiber Reinforced Polymer) jacketing. The FRP Jacketing is comparatively better than other retrofitting because no major strengthening of foundation is required in this technique, also original function of the building can be maintained without any major change in the original geometry of the building. The present study is on a four storey building that has been planned in STAAD.ProV8i, considering M30 cement and Fe415 steel bars.***

Keywords: Equivalent Static Method, Jacketing, Flexural Capacity, Shear Limit, Retrofitting, Reinforced Concrete Structure, FRP Strengthening.

I. INTRODUCTION

When additional storeys are placed on the existing building it is observed that many deficiencies like irregular load path, lower stiffness of primary individual members, many a times poor quality of workmanship is observed. Seismic retrofitting is the modification of existing structures to make them higher resistance to seismic movement, ground motion, or soil failure. Rehabilitation or Strengthening is suggested as sustainable solution compared to simply demolition and reconstructing the entire structure. This can be accomplished by either deducting the seismic load on each members and the structure as a whole or by increasing strength of the member. Stiffness, strength and ductility are the key parameters taken in account while retrofitting the structure. The decision of selecting a particular retrofitting method depends upon locally available materials and construction advancements, cost effectiveness, duration of work and engineering. Methods like RC Shear Wall, steel bracings, seismic base isolation dampers and jacketing are few of the popular methods adopted for retrofitting. Out of all these methods, FRP

jacketing is widely adopted because of high strength-weight proportion, erosion resistant, easy application involved, relatively smaller thickness, having no practical impact on the outer aesthetics of the structure, greater tensile strength etc. The only limitation of FRPs is that they are fire and temperature sensitive. The fiber fortified polymers used for structural reinforcement of structures are made of carbon, glass or aramid.



Concrete Jacket **Steel Jacket** **FRP Jacket**

Figure 1.1 Types of Jacketing

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II. OBJECTIVES

i. Study the seismic behavior of the structure with the help of Staad. Pro for G+3 G+4 and G+5 storey building.

ii. Find out the number of members failing when subjected to seismic loading.

iii. Calculate and suggest number of FRP wraps to be provided for jacketing the failing member along with the cost per column required in retrofitting the structure.

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III. THEORY AND FORMULATION

3.1.1 FRP Strengthening of Concrete Members: In this study factor of safety against the event of both serviceability limit states (cracking, deflection) and the ultimate limit states (stress rupture, failure, fatigue) have been considered. While calculating the flexural strength of structure equipped with FRP framework, the following assumptions have been made:-

- Design calculation depends on the original measurements, internal fortifying steel
- arrangement and material properties of the existing member being retrofitted.
- There is no relative slipping between concrete and external FRP fortification.
- The strength of cement concrete in tension is ignored.
- The maximum allowable compressive strain in cement concrete is 0.003.
- The FRP fortification has a direct elastic stress- strain relationship to failure. An extra strength reduction factor is used to take care for suspicious assumptions made. As per norms of the code FBI (2001), the accompanying flexure failure modes are to be checked in a FRP-fortified section.

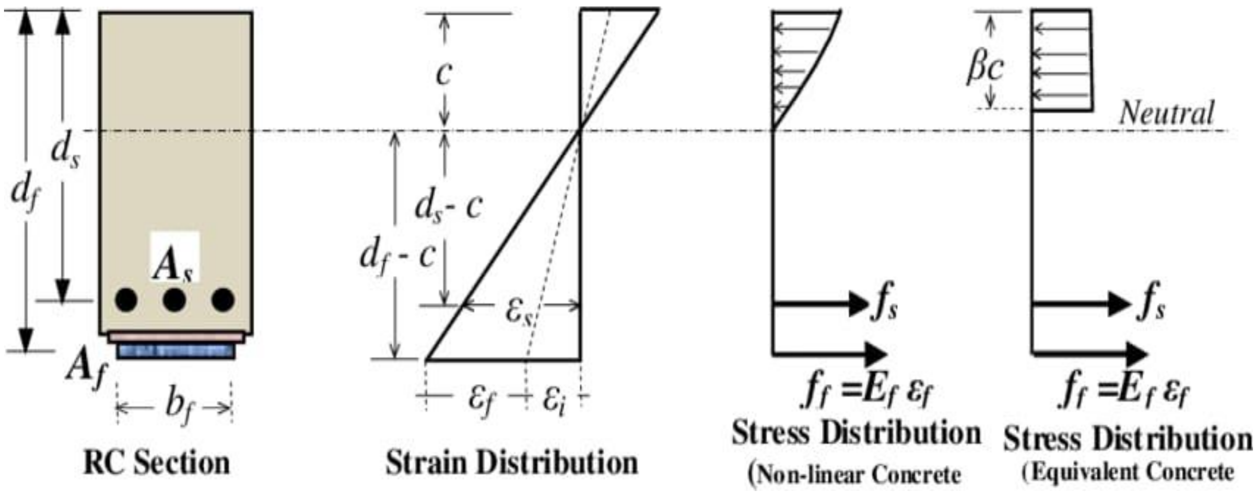

Fig 3.1 Internal stress strain distribution for a rectangular concrete section (FRP strengthened) under flexure at ultimate stage

3.2. Methodology

3.2.1 Description of Multistorey structure: The G+3 residential building considered for study have following details:

1. **Beams**: 300mm × 250mm and 300mm × 300mm.
2. **Columns:** 300mm ×300mm and 300mm × 400mm.
3. **Slab thickness:** is taken as 125mm.
4. **Storey height:** 3m for G+3, G+4 and G+5 building.
5. **Plan area:** 18m× 9m is taken.
6. **Geometry:** Having bays irregular in pattern in both X & Y axis.

3.2.1 Finding the failing members with the aid of software:

1. Loading applied to structure is dead, live and seismic loads as per IS Code 875:1987 (Part I, Part II, Part III).

2. Seismic loading as per norms stated in IS CODE 1893:2013 are applied.

3. OMRF (ordinary moment resisting frame) is assumed taking zone factor (Z =0.24) in accordance with seismic zone IV.

4. All end supports are considered fixed and Fck as 30 and Fy as 415 N/mm2 respectively.

5. Loads are applied in following orders:-

a) Seismic loads in + & - X and Z axis.

b) D.L = 4 kN/m2 in downward direction (D.L. is assigned to entire structure). L.L. =3 kN/m2 in downward directions and is assigned by software itself. Automatic load combinations generated by software in accordance with IS code are also considered.

6. In analysis & print command 'Design beam', 'Design column', and 'Take off' command are used for calculation of reinforcing steel required for each beam and column, load taken by each beam and column are also calculated as well as moments in 'Z' direction is noted . Analysis command with full data option is used to print data. The data of failing columns is taken and FRP jacketing is provided to failing members.

3.2.2 Design of FRP jacketing using norms of FBI (2001):

1. Confinement of failed columns using FRP jacketing and design: Confinement of RC columns notably enhances their performance against axial load, bending and shear loading due to increase in concrete compressive strength.

The confinement of columns is provided by FRP wraps. The steps given below are followed for designing FRP jacketing for the failed column member:

(a)Total Plan Area of Unconfined concrete as per eqn. 6.28 FIB (2001) is

b’ = b - 2 × rc and d’ = d- 2 × rc.

Where rc=Radius of rounded corners of column.

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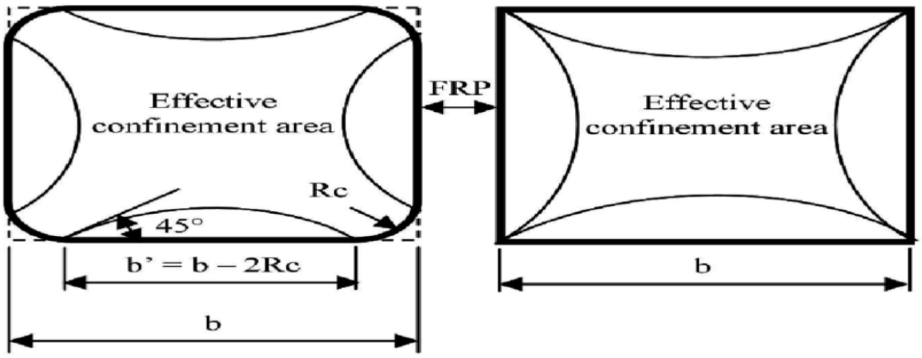

Figure 3.2: Effectively confined core for non-circular sections.

(b) Taking the summation of the different parabolas, the total plan area of unconfined concrete is:
Au = (b^2+ d^2)/3.

(c) The confinement effectiveness coefficient Ke according to Fib 14 eqn 6.29 is given:
Ke = 1-[(b^2+d^2)/{3Ag(1-ρsg)}]
Where Ac is confined area =Ag(1-ρsg), ρsg is steel volumetric ratio= As/Ag
As= Area of steel, Ag = gross area of concrete.

(d) The Lateral confining pressures due to FRP wrapping according to FIB (2001) equation 6.30 is given as
Along direction b: Kconfb = ρb ke Ef , Along direction d: Kconfd = ρd keEf.
Where, ρb =2ntf/b (steel volumetric ratio for b)
and ρd =2ntf/d (steel volumetric ratio for d)
Ef= Elastic modulus of carbon fiber, tf =Effective fiber thickness.
εf= Ultimate strain in carbon fiber. n=No of FRP Wrap.

(e) Effective confining pressure,
along direction b: flb = (Kconfb×εf)/2Ke.
Along direction d : fld =(Kconfd×εf)/2Ke.
This minimum value (f1) should be smaller than maximum confining pressure according
to equation 6.5 of FIB [2001],Which is given as,
fcc = fco [2.254 (square root (1+7.94fl / fco) - 2fl/fco - 1.254]

where fco=unconfined concrete strength fco (in MPa).
Which is given by equation (6.8 of FIB 2001) as
Beta=5700/(square root fco) -500
The constant beta is a property of concrete provided under manufacture details.
If f1<fcc then provided no of wraps make structure safe, otherwise redesign.

(f) Manufacture details taken from Technical Design Guide for FRP Composite Products and Parts as below:
1.Ultimate strain in carbon fiber (εf) = 1.5% ,
2.Effective fiber thickness(tf) =0.35mm,
3.Elastic modulus of carbon fiber (Ef) = 138000 N/mm2,
4.No of Wrap (n) =2 No.
5.beta=628.
6.rc=25mm.

Figure 3.3: (a) Hand lay-up of CFRP sheets or fabrics.

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Figure 3.3: (b) Application of prefabricated strips.

IV. RESULT

1. For the initial structure, no columns fail in accordance to cross-section of columns initially provided, reason behind it may be higher FOS (factor of safety) provided during initial construction and hence no FRP jacketing is required.

2. After extending the structure by one storey i.e. for G+ 4 structures, columns having cross section 300mmx300mm 06 column fail. Using FBI 2001 norms, 02 wraps of FRP jackets provided and cost per column comes out to be INR 21600.

TABLE 4.1 Analysis Result for G+4 storey building.

Column No.	Length H(mm)	Cross Section(mm2)	RESULT	Layers of FRP jacketing
57	3000	300x300	**SECTION IS NOT ADEQUATE.**	2
58	3000	300x300	**SECTION IS NOT ADEQUATE**	2
68	3000	300x300	**SECTION IS NOT ADEQUATE**	2
73	3000	300x300	**SECTION IS NOT ADEQUATE**	2
74	3000	300x300	**SECTION IS NOT ADEQUATE**	2
173	3000	300x300	**SECTION IS NOT ADEQUATE**	2

The reason behind “**SECTION IS NOT ADEQUATE**” remark given by software is that reinforcement exceeds maximum limit.

3. On further extending the structure by on more storey i.e. G+5 structures, 19 columns fail having cross section 300mmx300mm and 300mmx400mm. Using FBI 2001 norms 02 wraps of FRP jackets provided and cost per column comes out to be INR 21600 for 300mmx300mm columns and INR 25,200 for 300mmx 400mm columns.

TABLE 4.2: Analysis result of G+5 storey building.

Column No.	Length H (mm)	Cross Section(mm2)	RESULT	Layer of FRP jacketing
60	3000	300x300	**SECTION IS NOT ADEQUATE**	2
61	3000	300x300	**SECTION IS NOT ADEQUATE**	2
62	3000	300x300	**SECTION IS NOT ADEQUATE**	2
63	3000	300x400	**SECTION IS NOT ADEQUATE**	2
64	3000	300x300	**SECTION IS NOT ADEQUATE**	2
65	3000	300x300	**SECTION IS NOT ADEQUATE**	2
67	3000	300x400	**SECTION IS NOT ADEQUATE**	2
68	3000	300x300	**SECTION IS NOT ADEQUATE**	2
70	3000	300x400	**SECTION IS NOT ADEQUATE**	2
71	3000	300x300	**SECTION IS NOT ADEQUATE**	2
72	3000	300x300	**SECTION IS NOT ADEQUATE**	2

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75	3000	300x300	**SECTION IS NOT ADEQUATE**	2
76	3000	300x300	**SECTION IS NOT ADEQUATE**	2
77	3000	300x300	**SECTION IS NOT ADEQUATE**	2
78	3000	300x300	**SECTION IS NOT ADEQUATE**	2
177	3000	300x300	**SECTION IS NOT ADEQUATE**	2
178	3000	300x300	**SECTION IS NOT ADEQUATE**	2
187	3000	300x300	**SECTION IS NOT ADEQUATE**	2
188	3000	300x300	**SECTION IS NOT ADEQUATE**	2

V. CONCLUSIONS

1. There is no use of data of Factored load and Factored moment provided by software for the design of FRP Jacketing as per FIB (2001).
2. FRP jacketing enhances Moment resistance, axial load carrying capacity of column.
3. Confinement using FRP wraps enhances performance of concrete columns.
4. Due to non availability of universal standard for FRP jacketing, the norms stated in FIB (2001) are strictly followed.

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