Increasing the Strength of Existing Building using FRP Materials in Seismic Zone

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Abstract:-The most of the structure throughout the world have seismic effect and are not capable of withstanding earthquake action according to the current code provisions. In addition to that the seismic behavior of the existing buildings is affected due to design deficiency, construction deficiency, additional loads, additional performance demand, etc. Recent earthquakes have clearly shown an urgent need to upgrade and strengthen these seismically deficient structures. The retrofitting is only the options to make an existing building safe against future probable earthquake or other environmental forces. Retrofitting reduces the vulnerability of damage of an existing structure during a near future seismic activity. It aims to strengthen a structure to satisfy the requirements of the current codes for seismic design. The Significant amount of research work has been carried out in recent years to develop various strengthening and rehabilitation techniques to improve the seismic performance of structures. This paper aims to present an overview on Fibre reinforced polymer technique of retrofitting for strengthening the damaged structures.

Keywords: carbon fiber, concrete columns, epoxy, glass fiber, strengthening, sprayed FRP, vinyl’s.

Introduction:- Fibre reinforced polymer (FRP) composites consist of high strength fibres embedded in a matrix of polymer resin. Fibres typically used in FRP are glass, carbon and aramid. These fibres are all linear elastic up to failure, with no significant yielding compared to steel. The primary functions of the matrix in a composite are to transfer stress between the fibres, to provide a barrier against the environment and to protect the surface of the fibres from mechanical abrasion. The mechanical properties of composites are dependent on the fibre properties, matrix properties, fibre-matrix bond properties, and fibre amount and fibre orientation. A composite with all fibres in one direction is designated as unidirectional. If the fibres are woven, or oriented in many directions, the composite is bidirectional or multidirectional. Since it is mainly the fibres that provide stiffness and strength composites are often anisotropic with high stiffness in the fibre direction. In strengthening applications, unidirectional composites are predominantly used, the approximate stiffness and strength of a unidirectional CFRP with a 65% volume fraction of carbon fibre is given. As a comparison the corresponding properties for steel are also given.

Adhesives are used to attach the composites to other surfaces such as concrete. The most common adhesives are acrylics, epoxies and urethanes. Epoxies provide high bond strength with high temperature resistance, whereas acrylics provide moderate temperature resistance with good strength and rapid curing. Several considerations are involved in applying adhesives effectively. Careful surface preparation such as removing the cement paste, grinding the surface by using a disc sander, removing the dust generated by surface grinding using an air blower and careful curing are critical to bond performance.

Application in Retrofitting

For structural applications, FRP is mainly used in two areas. The first area involves the use of FRP bars instead of steel reinforcing bars or pre-stressing strands in concrete structures. The other application, which is the focus of this thesis, is to strengthen structurally deficient structural members with external application of FRP. Retrofitting with adhesive bonded FRP has been established around the world as an effective method applicable to many types of concrete structural elements such as columns, beams, slabs and walls. FRP plates can be bonded to reinforced concrete structural elements using various techniques such as external bonding, wrapping and near surface mounting. Retrofitting
with externally bonded FRP has been shown to be applicable to many types of RC structural elements. FRP plates or sheets may be glued to the tension side of a structural member to provide flexural strength or glued to the web side of a beam to provide shear strength. FRP sheets can also be wrapped around a beam to provide shear strength and be wrapped around a column to provide confinement and thus increase the strength and ductility. Near surface mounting consists of sawing a longitudinal groove in a concrete member, applying a bonding material in the groove and inserting an FRP bar or strip.

Types of FRP Material
- Carbon
- Aramid
- Glass

Advantages of FRP material
- Corrosion Resistance
- Light Weight
- Ease of Installation
- Less Finishing
- Less Maintenance
- High tensile strength
- Storage & Transportation is easy

Disadvantages of FRP material
- Temperature & moisture effect
- Lack of Design Code
- Lack of Awareness
- Skill supervision is required

Beam Strengthening In Flexure
In flexural strengthening applications FRP plates or sheets are bonded to the tensile surfaces of reinforced concrete beams. It is assumed that FRPs are perfectly linear-elastic materials. Thus, failure of an FRP-strengthened section in flexure can be due to FRP rupture or to concrete crushing. The ultimate flexural strength for both of these failure modes can be calculated using a similar methodology as that used for steel-reinforced sections. The design Values for the FRP material safety factor $\varphi_f$ are suggested in Table 1.1

<table>
<thead>
<tr>
<th>FRP type</th>
<th>Application type A(1) Application type</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFRP</td>
<td>1.20</td>
</tr>
<tr>
<td>AFRP</td>
<td>1.25</td>
</tr>
<tr>
<td>Aramid</td>
<td>1.30</td>
</tr>
</tbody>
</table>

Table 1.1 Material Safety Factors (ACI: 440-2R)

Failure Modes
There are four potential flexural failure modes for externally-strengthened reinforced concrete flexural members:
- Concrete crushing before yielding of the reinforcing steel
- Steel yielding followed by concrete crushing
- Steel yielding followed by FRP rupture
- De-bonding of the FRP reinforcement at the FRP/concrete interface.

Beam with FRP jacketing
Due to corrosion of reinforcement moment carrying capacity and share strength of beam is reduces. To increase the flexural strength of beam FRP wrap is required. Following is the data given. Calculate layer of wrap for required moment. (Assume existing Reinforcements is zero due corrosion for analysis purpose).

Beam details:-

| C/S of Beam | 230x400 |
| Top steel   | 2-8T    |
| Bottom Steel| 2-16T   |
| Stirrups    | 8T@150/C/C |
| D (Effective Depth) | 360 mm |
| Moments     | 47 KN/M |
| $V_u$ (Shear Force) | 85 KN |
| Grade of concrete ($f_{ck}$) | 25 N/mm2 |
| Grade of steel Reinforcement ($f_y$) | 415 N/mm2 |
CFRP System Properties:

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness Per Ply (tf)</td>
<td>1.02 mm</td>
</tr>
<tr>
<td>Ultimate Tensile Strength (ffu*)</td>
<td>621 N/mm²</td>
</tr>
<tr>
<td>Rupture Strain ( f_u*)</td>
<td>0.015 mm/mm</td>
</tr>
<tr>
<td>Modulus Of Elasticity Of CFRP Laminate (Ef )</td>
<td>37000 N/mm²</td>
</tr>
<tr>
<td>Width of FRP sheet (wf)</td>
<td>100 mm</td>
</tr>
</tbody>
</table>

**Design Steps**

**Step 1:** Calculate the FRP system design material properties:

Design ultimate tensile strength of FRP

\[ ffu = CE \times f_u * \]

\[ ffu = 0.95 \times 621 = 589.95 \text{ MPa} \]

Design ruptures strain of FRP reinforcement

\[ f_u = CE \times \varepsilon_u * \]

\[ f_u = 0.95 \times 0.015 = 0.01425 \text{ mm/mm} \]

**Step 2:** Preliminary calculations:

Modulus of elasticity of concrete

\[ i) E_c = 5000 \sqrt{fc'} = 5000 \sqrt{12} = 17320.50\text{ MPa} \]

\[ ii) \text{Properties of the externally bonded FRP reinforcement:} \]

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

\[ A_f = n t_f w_f = 1 \times 1.02 \times 100 = 102 mm^2 \]

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

\[ M_{DL} = 47kN.m, d_f = 400mm, \ k = 0.334 \text{ Assume, I}_{cf} = 7.266x10^8 \text{ from SP-16 Table No.87} \]

\[ \text{Strain level in concrete substrate at time of FRP installation} \ varepsilon_{bi} = \left( \frac{M_{DL}}{d_f - C} \right) / I_{cf}, \ E_c = 0.000554 \]

**Step 4:** Determine the design strain of the FRP system debonding strain of externally bonded FRP reinforcement

\[ \varepsilon_{td} = 0.41 \left( \frac{f_c}{2Ef_t} \right) = 0.41 \left( \frac{12/2x37000x1.02}{1.02} \right) \]

\[ \varepsilon_{td} = 0.0073 \]

\[ \varepsilon = 0.9 \times (0.0142) = 0.0128 \text{……..ok} \]

**Step 5:** Estimate c, the depth to the neutral axis, the value of c is adjusted after checking equilibrium.

\[ C = 0.2 \times d \]

\[ C = 72.4 \text{ mm} \]

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

\[ \text{effective strain level in FRP reinforcement attained at failure, } \ varepsilon_{fe} = (0.0035 \left( \frac{d_f - c}{C} \right) - \varepsilon_{bi} < \frac{\varepsilon_{td}}{C} \] \]

\[ \varepsilon_{fe} = 0.0152 > 0.0042478 \text{……not ok} \]

Revise effective strain

\[ \varepsilon_{fe} = 0.0073 \]

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

\[ s = \left( \frac{f_{ce} + \varepsilon_{bi}}{C} \right) \left( \frac{C}{d_f - C} \right) s = 0.0069 \]

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

\[ f_s = Es \ s = fy \]

\[ f_s = 1390.5 > 415 \text{…….not ok} \]

\[ f_s = fy = 415.00 \text{ MPa} \]

**Step 9:** Calculate internal forces resultant and check equilibrium

\[ \varepsilon_{c} = 0.002 \beta_1 = (4\varepsilon_{c} - \varepsilon_{c}) / (6\varepsilon_{c} - 2\varepsilon_{c}) = 0.734 \alpha_1 = (3\varepsilon_{c} - 2\varepsilon_{c}) / (3\beta_1\varepsilon_{c}) \]

\[ C = (As f_s + A f_{fe}) / (\alpha_1 f_{c} \beta_1 b) = 16.19 < 72.4 \text{mm} \]

**Step 10:** Calculate flexural strength components

Steel contribution to bending (Mns) = As (d - C)

\[ M_{ns} = 55.95 \text{ kN-m, Mnf} = 10.30 \text{ kN-m} \]

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

The design flexural strength is calculated as,

\[ \phi M_n = \phi [Mns + \psi f Mnf] \]

a strength reduction factor of \( \varphi = 0.90 \)

\[ \phi M_n = 0.9(55.95+0.85(10.30)) = 58.23 \]

\[ \phi M_n = 58.23 \text{ kN-m} > Mu 47 \text{ kN-m} \]

**Step 12:** Hence the proposed FRP strengthening scheme satisfies the design requirements with suitable safety margin.
**Beam Strengthening In Shear**

FRP materials can be applied to the side faces (webs) of reinforced concrete beams to provide external shear reinforcement, in this technique, fibres can be aligned at any angle to the longitudinal axis of the beam. The FRPs can be applied to the side faces only or in the form of U-wraps which are continuous underneath the beam. U wraps have the added advantage of improving the anchorage of flexural external FRP reinforcements when placed over the flexural sheets or strips. Furthermore, FRP shear reinforcement can be applied as continuous sheets or in strips of finite width externally bonded FRP shear reinforcement acts in a manner similar to internal steel stirrups, by bridging shear cracks to increase the shear capacity of the concrete. Since the length over which FRP stirrups can be anchored is limited by the height of the beam, the quality of the existing concrete is of utmost importance. To avoid possible failure of the FRP sheets due to stress concentrations at the corners of the beam, corners should be rounded to a minimum radius of 15 mm.

CFRP properties are same as beam with FRP jacketing.

**Design Steps:**

1. Calculate the FRP system design material properties:
   - Design ultimate tensile strength of FRP $f_{fu} = CE \times f_{fu} = 0.95 \times 621 = 589.95$ MPa
   - Design ruptures strain of FRP reinforcement $f_u = CE \times f_u = 0.95 \times 0.015 = 0.01425$ mm/mm

2. Calculate the effective strain level in the FRP shear reinforcement
   - Active Bond Length $L_e = (23300/nxt_f)^{0.58} = (23300/2x0.165x227530)^{0.58}$
   - $L_e = 34.63$ mm
   - Modification Factor for concrete strength $K_1 = (f_e/27)^{2/3} = (25/27)^{2/3} = 0.94$ Modification Factor for wrapping scheme
   - $K_2 = ((df_v- Le)/df_v) = ((237 - 34.63)/237) = 0.853$
   - Bond-dependent coefficient for shear
   - $k_v = K_1 x K_2 x n x L_e/11900 x f_{fu}$
   - $\epsilon = 0.94 x 0.853 x 34.63/11900 x 0.014v = 0.166 < 0.75$ Effective strain level in FRP reinforcement attained at failure $\epsilon_{fe} = K_v x \epsilon_{fu} = 0.166 x 0.0142 = 0.0023 < 0.004$

3. Step 3. Contribution of the FRP r/f to the shear strength
   - Area of FRP shear reinforcement with spacing $s$, $A_f = 2n t f_w = 2 x 2 x 0.165 x 254 = 167.64$ mm$^2$
   - Effective Stress In FRP Shear Reinforcement $f_{re} = f_{ef} = 0.0023 x 227.6 = 0.523$ kN/mm$^2$
   - Nominal shear strength provided by FRP stirrups $V_f = A_f x f_{re} (\sin\alpha + \cos\alpha)df_v/df_{ef} = 167.64 x 0.523 x 1 x 237/304.8 = 68.17$ kN

4. Step 4 Total Shear Strength of Section $V_n = \phi (V_c + V_s + \Psi_f V_f) = 0.75 x (66.65 + 0 + 0.85 x 52.78) = 93.44$ kN > 82 kN $\ldots$ safe

   "Hence provide 2 layer of CFRP jacket."

**Column with FRP jacketing**

Due to corrosion of reinforcement Axial Force carrying capacity of column is reduces. To increase the axial strength of column extra confinement is required. Following is the data given.

**Data:**
- $b = 230$ mm, $d = 450$ mm, $f_{ck}$ provided = 12 mpa, $f_{ck}$ required = 25 mpa, $P_t$ % provided = 0.02% ,
- Area of concrete = 103500 mm$^2$, $P_u = 1037$ kN, $M_y = 25kN.m$
- Manufacture Data – Ultimate strain in carbon fiber ($\epsilon_f$) = 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.

**Solution:**

- $P_u = 0.4 \times f_{ck} \times A_c + 0.67 \times f_y \times A_{st}$
  - $= 0.4 \times 12 \times ((230x450)-(1608)) + 0.67 \times 250 \times 0$
  - $P_u = 489.06$ kN < 1037 kN $\ldots$ not safe
- Load deficiency = 1037 – 489.06 = 547.94 kN

**Design steps**

Step No.-1
- Total Plan Area of Unconfined concrete is $b' = b - 2 \times r_c = 230 - 2 \times 25 = 180$ mm
- $d' = d - 2 \times r_c = 450 - 2 \times 25 = 400$ mm
Au = b'^2 + d'^2 /3 = 64133.33 mm^2

Step No. -2

The confinement effectiveness coefficient ke considering ratio (Ac-Au)/Ac,

Ke = 1 - b'^2 + d'^2 /3Ag(1-psy ) = 1 - Au / 3Ag(1-psy ) = 0.367

Step No. -3

The lateral confining pressures induced by the FRP wrapping along direction b,

Kconfb = ρb ke Ef

Along direction d.

Kconfd = ρd ke Ef

Where, ρb = 2 x nt x f /b and ρd = 2 x nt x f /d

Kconfb = 288.09 Kconfd = 147.31

Step No.-4

Effective confining pressure, along direction b fb = kconfb f/2ke = 5.89 N/mm^2 Along direction d fd = kconfb f/2ke = 3.01 N/mm^2 Taking min value,

fl = 3.014 N/mm^2

Step No.-5

Maximum confining pressure

fcc = 25.73 N/mm^2

"Hence provide 2 layer of CFRP jacket."

Table 1.2 No of Wraps Required For Beam Strengthening

<table>
<thead>
<tr>
<th>Sr. no.</th>
<th>Floor</th>
<th>Beam no.</th>
<th>M.R. Req. in KN.m</th>
<th>No. of wrap req.</th>
<th>M.R. Pro. in KN.m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Plinth Beam</td>
<td>B10,B8,B12</td>
<td>47</td>
<td>1</td>
<td>58.23</td>
</tr>
<tr>
<td></td>
<td>Plinth Beam</td>
<td>B1 to B7,B9,B11,B13,B14,B15,B16,B17,B18,B19,B20,B21,B22,B23,B24</td>
<td>33</td>
<td>1</td>
<td>58.23</td>
</tr>
<tr>
<td>2</td>
<td>First Floor</td>
<td>B1 to B45</td>
<td>40</td>
<td>1</td>
<td>58.23</td>
</tr>
<tr>
<td>3</td>
<td>Second Floor</td>
<td>B1 to B26,B29,B30,B31,B32,B33,B34,B36,B37,B38,B41,B42,B43,B44,B45</td>
<td>27</td>
<td>1</td>
<td>58.23</td>
</tr>
<tr>
<td></td>
<td>Second Floor</td>
<td>B27,B28,B35,B36,B37,B38,B39,B40</td>
<td>24</td>
<td>1</td>
<td>58.23</td>
</tr>
<tr>
<td>4</td>
<td>Third Floor</td>
<td>B1 to B31</td>
<td>33</td>
<td>1</td>
<td>58.23</td>
</tr>
<tr>
<td>5</td>
<td>Roof Beam</td>
<td>B1 to B45B43</td>
<td>22</td>
<td>1</td>
<td>58.23</td>
</tr>
</tbody>
</table>

Table 1.2 No of Wraps Required For Beam Strengthening

<table>
<thead>
<tr>
<th>Sr. no.</th>
<th>Floor level</th>
<th>Column No.</th>
<th>fck by NDT (N/mm2)</th>
<th>fck Req. (N/mm2)</th>
<th>No. Of Wraps Req.</th>
<th>Confining Pressure (N/mm2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ground floor</td>
<td>C1,C2,C3,C5,C6,C7,C8,C9,C10,C11,C12,C13,C14,C15,C16,C17,C19,C20,C21,C22,C23,C24</td>
<td>12</td>
<td>25</td>
<td>2</td>
<td>25.73</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C4,C16,C18, C25</td>
<td>14</td>
<td>25</td>
<td>2</td>
<td>28.76</td>
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<tr>
<td>2</td>
<td>1st</td>
<td>C1,C2,C3,C4,C5,C6,C7,C8,C9,C10,C11,C12,C13,C14,C15,C16,C17,C19,C20,C21,C22,C23,C24</td>
<td>12</td>
<td>25</td>
<td>2</td>
<td>25.73</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C16,C17, C25</td>
<td>15</td>
<td>25</td>
<td>2</td>
<td>29.63</td>
</tr>
<tr>
<td>3</td>
<td>2nd</td>
<td>C1 to C25</td>
<td>17</td>
<td>25</td>
<td>1</td>
<td>25.69</td>
</tr>
<tr>
<td>4</td>
<td>3rd</td>
<td>C1 to C25</td>
<td>18</td>
<td>25</td>
<td>1</td>
<td>26.76</td>
</tr>
</tbody>
</table>
Discussion

The purpose of this paper was to assess the analysis of an existing RC structure and to provide for retrofit in case the members fail. Consider building is 60 years old, G+3 R.C.C. Structure. Structural Audit is done on the building. In audit Slabs and footings are Safe, but beams and columns are unsafe. The plan and reinforcement details of the building were provided. Analyzed the building in STAAD.Pro V8i software, Present Building Strength is calculated, it is found that building is unsafe, for that Extra moment jacketing is design by FRP method.

Conclusion

- It is advisable to monitor the building health periodically by taking a professional opinion. Non-destructive testing should be carried out if buildings found deteriorated and damaged over time.
- FRP jacketing gives better advantages than RCC jacket and steel jacketing. Easy to implement, dead load is negligible, higher confinement, faster construction.

References

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