Different Strengthening Techniques for RC Columns

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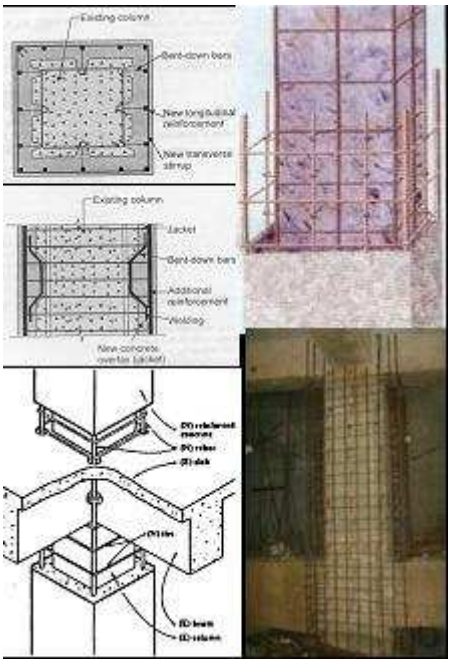
About FRP

Fiber Reinforced Polymers (FRP) composites comprise fibers of high tensile strength within a polymer matrix such as vinylester or epoxy. FRP composites have emerged from being exotic materials used only in niche applications following the Second World War, to common engineering materials used in a diverse range of applications such as aircraft, helicopters, space-craft, satellites, ships, submarines, automobiles, chemical processing equipment, sporting goods and civil infrastructure. The role of FRP for strengthening of existing or new reinforced concrete structures is growing at an extremely rapid pace owing mainly to the ease and speed of construction, and the possibility of application without disturbing the existing functionality of the structure.

Different Strengthening Techniques for RC Columns other than FRP Wrapping

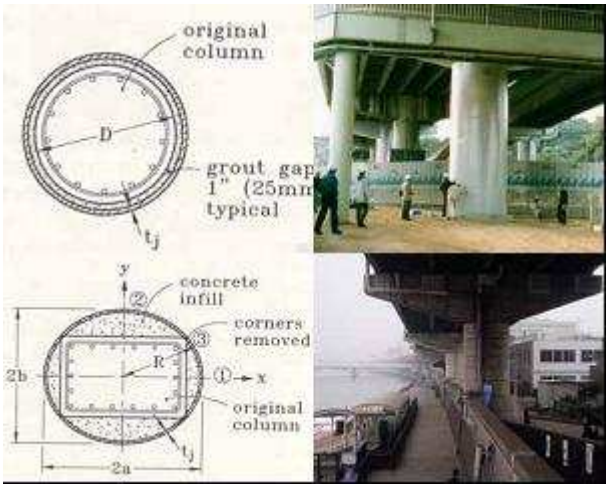
Concrete Jacketing

- **Involves addition of a thick layer of Reinforced Concrete (RC) in the form of a jacket, using longitudinal reinforcement and transverse ties.**
- **Additional concrete and reinforcement contribute to strength increase.**
- **Minimum allowable thickness of jacket = 100 mm.**
- **The sizes of the sections are increased and the free available usable space becomes less.**
- **Huge dead mass is added.**
- **The stiffness of the system is highly increased.**
- **Requires adequate dowelling to the existing column.**
- **Longitudinal bars need to be anchored to the foundation and should be continuous through the slab.**
- **Requires drilling of holes in existing column, slab, beams and footings.**
- **Increase in size, weight and stiffness of the column.**
- **Placement of ties in beam column joints is not practically feasible.**
- **The speed of implementation is slow.**



Steel Jacketing

- Encasing the column with steel plates and filling the gap with a non-shrink grout.
- Provides passive confinement to core concrete.
- Its resistance in axial and hoop direction can neither be uncoupled nor optimized.
- Its high young's modulus causes the steel to take a large portion of the axial load resulting sometimes in premature buckling of the steel.
- General thickness of grout = 25 mm.
- Rectangular steel jackets on rectangular columns are not generally recommended and a use of an elliptical jacket is solicited.
- Since steel jacket is vulnerable to corrosion and impact with floating materials, it is not used for columns in river, lake and seas.

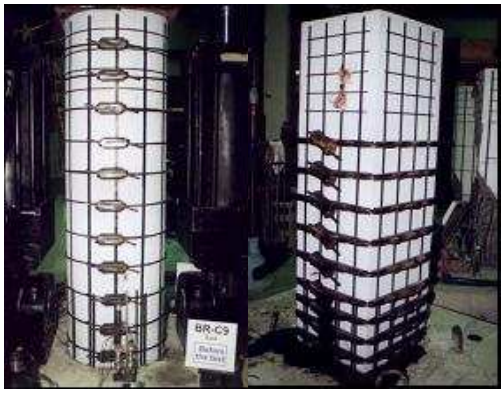


Precast Concrete Jacketing

- Helps in faster construction.
- New longitudinal reinforcement is set around the existing column, and precast concrete segments are set around the new reinforcement.
- All segments are tied together by strands.
- After injecting non-shrinkage mortar between the existing concrete and precast concrete segment, prestressed force is introduced in the strands to assure the contact of the segments.

External Prestressing

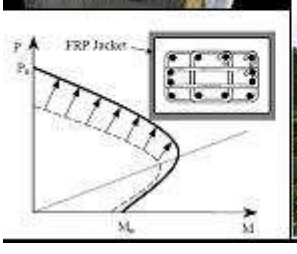
- Involves prestressing the columns by external strands to provide active confinement.
- It is efficient and can be more economical than steel jacketing.
- Installation of such a system can be less disturbing to the building occupants.
- The technique is very recently developed and on-site implementation is not known.
- Shear strength increase is only due to increase in concrete strength against the jacketing where the jacket contributes significantly towards shear strength.



Strengthening of RC Columns by FRP Composites

The concept

- Involves wrapping of RC columns by high strength-low weight fiber wraps to provide passive confinement, which increases both strength and ductility.
- FRP sheets are wrapped around the columns, with fibers oriented perpendicular to the



longitudinal axis of column, and are fixed to the column using epoxy resin.

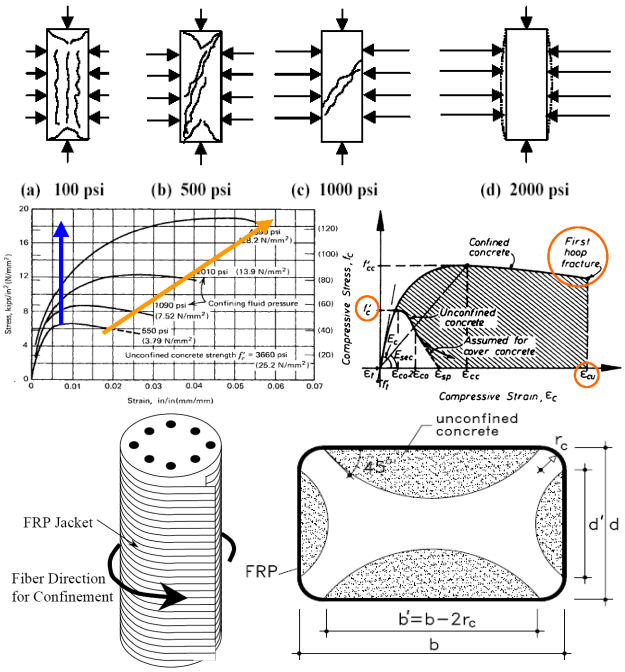
- **The wrap not only provides passive confinement and increases the concrete strength, but also provides significant strength against shear.**

Advantages of FRP for strengthening RC columns

- **It provides a highly effective confinement to columns.**
- **The original size, shape and weight of the members is unaltered (unlike any other jacketing), thus not attracting higher seismic forces.**
- **Due to the fact that the original shape and size of the members is practically unaltered, this method is particularly useful for strengthening historic and artistic masonry structures.**
- **Due to the orthotropy built in by fiber orientation, the wraps essentially provide only confinement without interfering with the axial load which is taken completely by concrete column as against steel jacketing, where the jacket takes most of the axial load and becomes susceptible to buckling.**
- **No drilling of holes is required as against concrete and steel jacketing.**
- **The FRPs have extremely good corrosion resistance, which makes them highly suitable for marine and coastal environments.**
- **FRP wraps prevent further deterioration of concrete and inside reinforcement.**
- **As the wraps are available in long rolls, construction joints can be easily avoided.**
- **Ease of installation, which is similar to putting up wall papers, makes the use of FRP sheets a very cost-effective and efficient alternative in the strengthening of existing buildings.**
- **Provides minimal disturbance to existing structure and generally the strengthening work can be performed with normal functioning of structure.**

The Concept of Confinement

- **As concrete is uni-axially compressed, Poisson's effect induces transverse strains that result in radial expansion of the concrete.**
- **This increase in transverse strain results in volumetric expansion.**
- **By confining the concrete using a continuous FRP jacket, the fibres resist the transverse expansion of the concrete.**
- **The effect of confining pressure provided by wrap is to induce a tri-axial state of stress in the concrete which thus exhibits superior**



behaviour in both strength and ductility than concrete under uniaxial compression.

- **Since, FRP jacket acts to contain damaged sections of concrete; the maximum usable strain level in the concrete is limited only by the ultimate strain obtainable in the FRP jacket and not by concrete crushing.**
- **To increase the effectiveness of wrap, the sharp edges of the rectangular sections must be rounded.**

Design of FRP Strengthening

The design of FRP strengthening is performed on the well established principles of mechanics. Most major codes like ACI, CEB-FIP, EuroCode, Japanese code, Swedish bridge code, Chinese Standard, Turkish code etc give guidelines for the design of FRP system for wrapping of concrete columns to increase their capacity. Various institutes like NCHRP, Caltrans, CPWD etc recommend the use of FRP Composites for strengthening of concrete structures.
For design of strengthening, a composite action is assumed between fiber and existing concrete. The design is based on following assumptions

- **No slip between FRP and Concrete.**
- **Shear deformation within adhesive layer is neglected.**
- **Tensile strength of concrete is neglected.**
- **FRP jacket has a linear elastic stress-strain relationship up to failure.**

Corrosion protection by FRP

- **Corrosion in reinforced concrete structures causes deterioration of infrastructure.**
- **Structures in or near marine environments are especially vulnerable.**
- **A widely promoted method for protecting structures in corrosive environments is the application of FRP composite wraps over the surface of the concrete elements.**
- **Corrosion due to chloride ingress is purportedly arrested by the prevention of further chloride contamination and penetration by the oxygen and water needed to continue a corrosion process that has begun or has caused damage.**

Onsite Application of FRP Wrapping

A proper application procedure involves following steps:

1. **Surface preparation: This includes**

a. **Grinding to he column surface to remove dust and cement loose layer.**

b. **Repair of hairline cracks, if any.**

c. **Rounding off of column corners to specified rounding radius**

d. Application of Primer

Application of Saturant **Wetting of Wrap with Saturant**

2. **Once the surface is prepared and primer dried, the next step is application of saturant.**
3. **The fiber wrap is then wetted with saturant.**
4. **Fiber is then wrapped on the column skilfully so that there are no undulations in the wrap.**

Wrapping with Carbon Fiber **Wrapping with Glass Fiber**

5. **After wrapping, the fiber is again wetted with one more layer of saturant to make sure that the fiber is soaked fully with saturant.**

Application of Saturant on FRP Wrapping


RC Columns after Completion of FRP Wrapping

Comparison of FRP system with Conventional Technique

Description	Concrete Jacketing	Steel Jacketing	FRP Wrapping	Remarks
Mode of strengthening	Increase in concrete and steel area	Confinement	Confinement	
Preparation of column for strengthening	Significant dismantling of cover concrete. At least 40 mm cover concrete to be removed. Epoxy primer to be applied on exposed surface.	Not major dismantling work involved. Mainly plaster to be removed and epoxy primer to be applied on exposed surface.	Only plaster to be removed and epoxy primer to be applied on exposed surface. For rectangular columns, corners to be rounded off.	FRP involves minimum surface preparation.
Drilling of holes	Large amount of drilling is required	Large amount of drilling is required	No drilling required	FRP involves minimum work since no drilling is required.
Additional weight	Extremely high (In example shown, the weight becomes 225% for just 50% increase in strength.	Very high (In example shown, the weight becomes 169% for 50% increase in strength.	Negligible. No increase in weight at all.	FRP does not increase the dead weight of the structure.
Size Increase	Very high (In example shown, the diameter of column increases from 400mm to 600mm for 50% increase in strength.	High (In example shown, the diameter of column increases from 400mm to 450mm for 50% increase in strength.	Negligible. The total increase in diameter is less than 5 mm.	The size remains unaltered thus retaining the free area.