COMPARISON OF PRE-STRESSED CFRP with conventional RCC AND STEEL JACKETING

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There has been an increased demand for the strengthening of reinforced concrete (RCC) columns and shear walls in modern as well as old structures. These are mainly due to an increase in load of the building or deterioration of concrete due to old age. There are various techniques (traditional and new) that are available to cater to this requirement. Traditional techniques like reinforced concrete (RCC) jacketing, steel plate jacketing, externally bonded steel plates have been used for quite some time to strengthen columns and shear walls.

New technology like carbon fibre reinforced polymer (CFRP), glass fibre reinforced polymer (GFRP), and aramid fibre-reinforced polymer (AFRP) have been making their presence in the retrofitting industry for the past decade. However, the advanced method of using pre-stressed CFRP is not much explored in the Indian market. This paper presents the comparison of the traditional strengthening technique of RCC and steel plate jacketing with pre-stressed CFRP for RCC columns and shear walls.

1.1 RCC Jacketing

RCC jacketing is a method that involves the addition of a thick layer of reinforced concrete in the form of a jacket using longitudinal reinforcement and transverse ties. This is an effective way to increase both strength and stiffness of columns. As per IS 15988:2013, min jacket thickness shall be 100mm. Due to RCC jacketing, the size of the sections is increased, thereby reducing the usable carpet area. Further, dead mass is added to the building. Fig 1 shows an RCC jacketed column.

1.2 Steel plate jacketing

Steel jacketing is a technique of encasing the columns with steel plates or steel angles and filling the gap with non-shrink grout. This provides passive confinement to core concrete. High young's modulus of steel causes the steel to take a large portion of axial load resulting sometimes in premature buckling of the steel. As steel is vulnerable to corrosion, it is not recommended to use for column strengthening in rivers, lakes, or seas.

1.3 Jacketing with Pre-stressed CFRP

Jacketing of columns with Prestressed CFRP involves wrapping of RCC column by high strength-low weight carbon fibre wraps and then providing with prestressed CFRP bands, which increases both strength and ductility. CFRP sheets are wrapped around the columns with fibres oriented perpendicular to the longitudinal axis of the column and fixed to the column using epoxy resin. CFRP bands are then prestressed to min of 25 to 50% of the ultimate strength and then wrapped around and anchored to the column with an anchor plate. The original size and shape of the column are unaltered, thus not attracting higher seismic forces. Further CFRP has good corrosion resistance, which makes them suitable for the coastal environment. Another advantage is that this technique provides minimum disturbance to the existing structure.

2. Example Of Column Strengthening With Rcc Jacketing, Steel Jacketing, And Prestressed Cfrp Jacketing

2.1 Problem statement

A deficient column is assumed to be located in the moderate seismic zone of India is taken as a reference for this work. Depending on the expected performance level, 3 possible retrofitting schemes are designed for a column and then compared in terms of cost of construction. The prime objective of this research is to identify cost-effective retrofitting options based on the level of performance.

2.2 Description of column

A typical rectangular shape column of 300 mm x 600 mm is considered for the study and the floor to floor height of the column is measured as 3000 mm. The column is reinforced with 16-T16 rebars with the grade of steel Fe 500. The column is projected to axial loading and the load-carrying capacity is calculated for all retrofitting methods before and after deterioration.

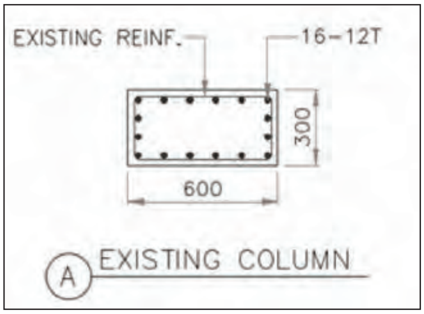

Fig 3.1.1: Geometry and reinforcement details of the unstrengthene column

2.3 Required capacity enhancement of column

It is assumed the that column required an enhancement of 15% in axial load carrying capacity due to an increase in loads on the column.

3. Retrofitting Options

Based on the level of performance for axial Strengthening, the following 3 retrofitting options are designed.

RCC Jacketing:

The axial load carrying capacity (Pu) of a short column is calculated using IS 456: 2000 section 39.3

$Pu = 0.4\, f_{ck}\ Ac + 0.67\, f_y A_{st}$

Hence, the load-carrying capacity of the unstrengthened column, Pu = 3198 kN

Required load capacity after strengthening with RCC jacketing = 3678 kN

Let the jacket thickness be 't' mm.

Jacket thickness required for enhanced load:

$Pu_{new} = 0.4\, f_{ck}\ A_c + 0.67\, f_y\ A_{st}$

3678 x 1000 = 0.4 * 30 * [(300+2t)*(600+2t)-3216] + 0.67 * 500 * 3216

Hence, RCC jacket thickness required, t = 21.3mm

According to IS 15988:2013, 8.5.1.2 C, the minimum jacket thickness = 100mm

Hence column strengthened RCC jacketing = 500 x 800 mm

% Increase in weight of column for 15% enhancement of load = 122 %

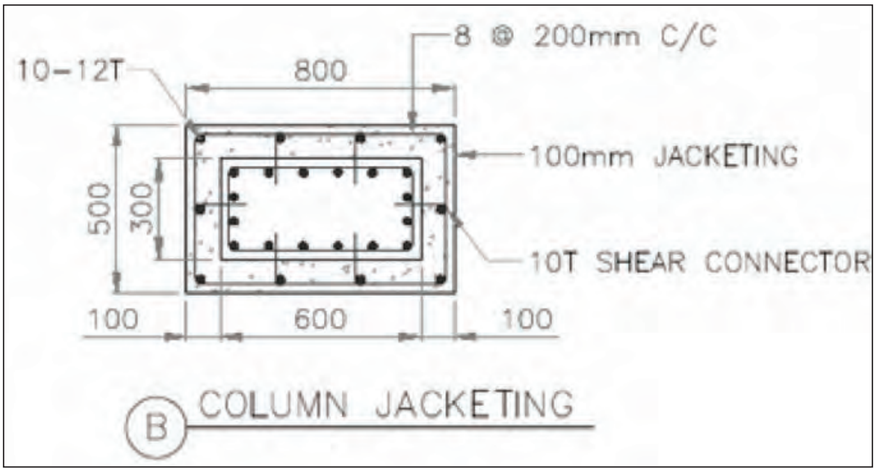

Fig 3.1.2: Geometry and reinforcement details of RC-jacketed column

Steel Jacketing:

For strengthening rectangular columns, the retrofit option is to use a rectangular jacket. In that case, the procedure is, two L-shaped panels are field welded together. And the gaps created should be filled with concrete instead of grout.

The load-carrying capacity of unstrengthen column = 3198 kN

Required load capacity after strengthening with Steel jacketing = 3678 kN

Additional required to be taken by column= 3198-3678 = 480 kN

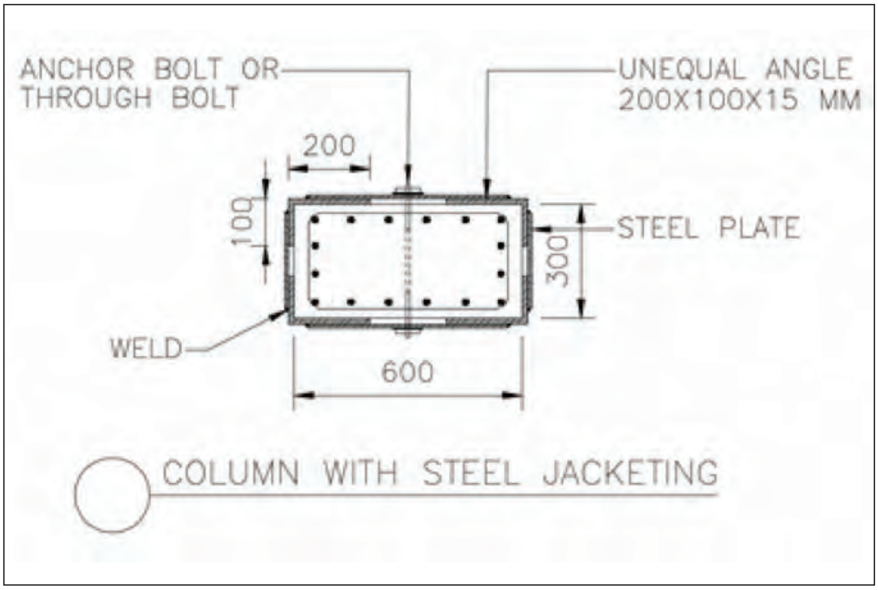

Fig 3.1.2: Geometry and reinforcement details of Steel-jacketed column

Fig: Column jacketed with prestressed CFRP system

Fig: Column with steel jacketing

Providing four angle section ISA 200x100x15 mm thick,

Provided Area of angle section = 1710 mm2

Grade of Steel = Fe345

Slenderness ratio = 11

from IS 800 Table 9(c) for Column Buckling Class c (Clause 7.1 .2.1)

Design compressive strength = 309 MPa

Load caring capacity of steel jacket = Area of steel x design compressive strength /1000 = 528 > 480 kN

% Increase in weight of column for 15% enhancement of load = 30 %

Column strengthening with Pre-stressed CFRP

The load-carrying capacity of unstrengthen column, Pu = 3198 kN

Required load capacity after strengthening with Prestressed CFRP = 3678 kN

Grade of concrete required to achieve the desired strength

$f_{ck}=(Pu -0.67\ f_y A_{st})/(0.4\ A_c)$

= 36.8 MPa

Properties of CFRP system:

Thickness	0.33 mm
Elastic modulus	240 GPa
Effective strain	0.8%

Let us strengthen the column with 1 layer of CFRP wrap and 100 mm pre-stressed CFRP bands at 300 mm c/c vertical spacing.

Design stress of CFRP wrap = 240 GPa* 0.008 = 1920 MPa

Assuming 25% prestress applied to CFRP band. Prestress applied to CFRP band = 0.25*1920 = 480 MPa

Effective stress of pre-stressed system, ff = 2064 MPa CEB-FIP Bulletin 14 is used to determine the capacity of the strengthened column. Fibre reinforcement ratio, f = 0.0033 Effectiveness coefficient a. = 1-[((D-2*rc) ²+ (na+1) (B-2*rc) ²) / 3 (na + Ag)] = 0.296

Where,

b' = B-rc and d' = D – rc

rc is rounding off radius = 25mm,

Ag is Gross area of concrete

Hence, Confining pressure, fl = a.f.ff/2 = 1.009 MPa

Effective cylindrical confined concrete strength is given by:

$f_{cc}= f_c\ (2.254\ \sqrt{(1+7.94\ f_l/f_c)} - 2\ f_l/f_c -1.254)$

= 30.32 MPa

Effective cube compressive strength after strengthening = 37.9 MPa > 36.8 MPa

Hence, the capacity of strengthened column = 3757 kN % Increase in weight of column for 15% enhancement of load = 1.0 %

Fig. 3.3.1: Band stressing of the column with CFRP

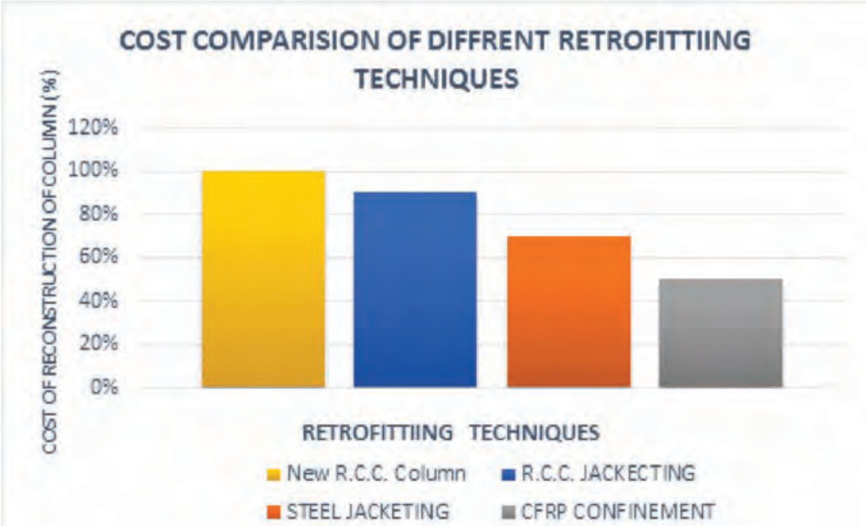

Fig. 4.1: Cost Comparison of different strengthening techniques

4. Cost Analysis

The bar chart **(see Fig. 4.1: Cost Comparison of different strengthening technique)** represents the cost of different retrofitting options in comparison with new construction.

Use of pre-stressed CFRP, which is an active mode of confinement is an attractive proposition for strengthening of columns. It is cost effective and provides a minimum modification to the geometry and aesthetics of the structure.

REFERENCES

1. CEB-FIP, Bulletin (2001), Task group 9.3 FRP reinforcement for concrete structures, "Externally bonded FRP reinforcement for RC structures", fib CEB-FIP, Technical report bulletin 14.

2. IS 15988.2013 Seismic evaluation and strengthening.

3. IS 800-2007 (steel code of practice)

5. COMPARISON OF PRESTRESSED CFRP WITH RCC AND STEEL JACKETING

Following comparison is obtained between 3 retrofitting options:

Description	R.C.C. Jacketing	Steel Jacketing	Pre-stressed CFRP Jacketing
Mode of strengthening	increase in concrete and steel area	Confinement	Confinement
Preparation of column for strength-ening	Significant dismantling of 40 mm covers concrete. Epoxy primer to be applied on the exposed surface.	No major dismantling work is involved. Mainly plaster to be removed and Epoxy primer to be applied on the exposed surface.	Only plaster to be removed and Epoxy primer to be applied on the exposed surface. For rectangular columns, corners to be rounded off.
cost in comparison with Recon-struction of column	90% of the new build column.	70% of the new build column.	50% of the new build column.
Additional weight	The weight of the column is increased by 122%.	The weight of the column is increased by 30%.	The weight of the column is increased by 1.0%.
size increase	The cross-section of the column increased from 300x600 mm to 500x800 mm for a 15% increase in strength.	The cross-section of the column increased from 300x600 mm to 350x650 mm for a 15% increase in strength.	The total increase in the cross-section of the column is negligible, it is less than 5 mm.
Drilling of holes	A large amount of drilling is required.	A large amount of drilling is required.	No drilling is required.