Performance Of RCC Walls Of High Aspect Ratio With Active Method Of CFRP Band Prestress

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Strengthening of existing concrete structure due to increment in designed load, deterioration in concrete structures, corrosion of rebars etc. are being carried out using traditional methods of RCC jacketing, steel plate jacketing, externally bonded steel plates and using composite laminates.

In composite laminate system, strengthening of axially loaded structural members is achieved by confinement with FRP materials. In this non-conventional method of strengthening, the Fibers are oriented in transverse direction to the longitudinal axis for confinement. This confinement significantly improves the performance under axial loads, shear and bending. However, the effect of FRP confinement is highly dependent on the shape of concrete member. The FRP confinement is most effective for a circular column, while in the rectangular column, the effectiveness of fiber confinement reduces because the stress induced in the fibers are concentrated at the corners and also the increment in the aspect ratio of column plays the vital role. This study discusses about the role of aspect ratio in the effectiveness of rehabilitation of axial loaded concrete structure using fiber laminates.

Limitations Of Existing Study Available

With the evolution of high-rise buildings in recent past, structural engineers have been relying on use of RCC walls which act as primary lateral load resisting system. These RCC walls considerably large aspect ratios i.e. more than 2. Although strengthening of structural members subjected to axial forces and bending are well covered in ACI 447-2R and other international codes, there are limitations in the code which prevent the use of FRP confinement for large aspect ratio RCC walls.

Below Table 1 summarizes the various codes which include the limitations on the aspect ratio for confinement of axial load carrying structural members.

Table 1: Comparison of Various Codes and its Limitations [2]

Standard/ Guideline	Loading Condition	Limitations
ACI 440.2R-17	Pure axial compression Combined axial compression and bending	Non Circular cross section: h/b ≤ 2.0 or b ≤ 900 mm
S806-12	Combined axial compression and bending	Non Circular cross section: h/b ≤ 1.5, corner radius, R ≥ 20 mm
CNR-DT 200 R1/2013	Pure axial compression Combined axial compression and bending	Non Circular cross section: h/b ≤ 2.0 or b ≤ 900 mm
GB 50608 - 2010	Combined axial compression and bending	Non Circular cross section: h/b ≤ 1.5; h or b ≤ 600 mm; corner radius, R ≥ 20 mm
DAfStb - Guideline	Combined axial compression and bending	Circular only: D ≥ 120 mm; column slenderness ≤ 40; maximum eccentricity ≤ 0.25 unconfined concrete strength ≤ 58 MPa

Active Method Of Band Prestressing Of RCC Walls

To cater to the requirement of industry designers and client for strengthening of shear walls with FRP confinement, this paper investigates the effectiveness of band prestressing of a 300mm thick RCC walls with higher aspect ratio. Band prestressing is an active method of prestressing where the shear walls are prestressed with carbon fiber reinforced polymer (CFRP) bands using aluminum anchor plates to restore the strength of the RCC wall to an acceptable level.

Typically, the CFRP bands have a tensile strength of 3800 MPa. In passive mode of confinement, the tensile strength of 600-900 MPa is used for design. In active mode of confinement, these CFRP bands are prestressed by min 25%[4] thereby increasing the tensile strength of the CFRP bands by 25-50%. Table 2 below summarizes typical properties of the CFRP band in non-prestressed state.

Table 2: Properties Of CFRP Band In Non-Prestressed State

CFRP Band Properties	
Composite Thickness (mm)	0.9-1.33
Elastic modulus (GPa)	60-95
Ultimate elongation	1.80%
Density (g/cm3)	1.8

Proposed Analytical Approach For Walls With CFRP Band Prestress

Consideration for Material Parameters

Concrete: Concrete is modeled using built in concrete-damage plasticity model provided by ABAQUS. The stress-strain relationship under uniaxial compression is plotted using the design stress strain curve of IS 456:2000 which is based on model from Hognestad et al. The equation is presented below:

$$fc = \left\{0.447\, f_{ck} \left[2\left(\frac{\varepsilon}{0.002}\right) - \left(\frac{\varepsilon}{0.002}\right)^2\right]\right\} for\ \varepsilon < 0.002$$

$$fc = \{0.447\, f_{ck}\}\ for\ 0.002 \leq\ \varepsilon \leq 0.0035$$

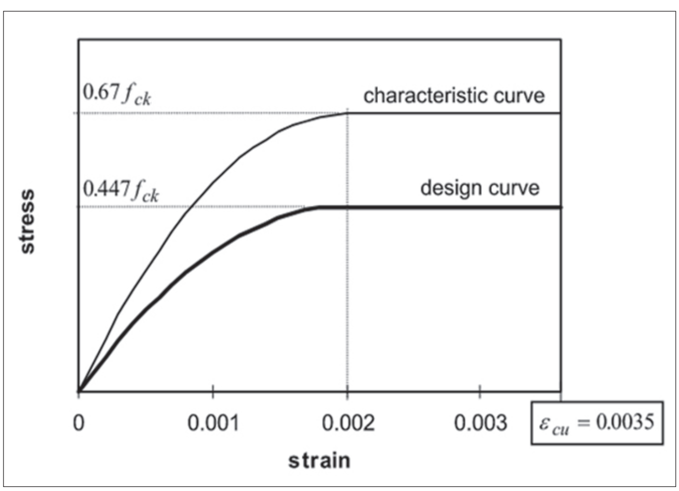

Fig. 1: Design Stress Strain Curve for Concrete

The tensile behavior of concrete is modelled in a tri-linear manner. Tensile stress-strain curve starts as a linear elastic upto tensile rupture (f_t). Upon reaching tensile strength, stress is reduced to 40% of f_t and then followed by linear descending curve up to 0.01 MPa. The tensile strength f_t is taken as per equation below:

$$f_t \ = \ 0.7\sqrt{f_{ck}}\ MPa$$

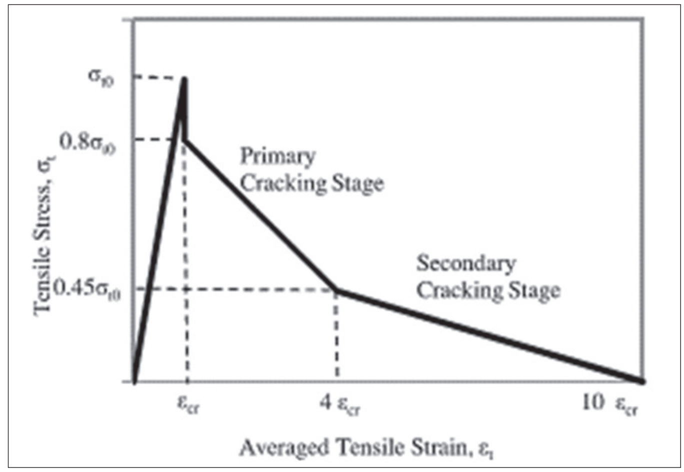

Fig. 2: Design Stress Strain Curve for Concrete in Tension

Steel Reinforcement: The stress-strain behavior of steel reinforcement is taken as design stress strain curve as per IS 456:2000. Steel reinforcement grade of Fe500 is used in the numerical analysis.

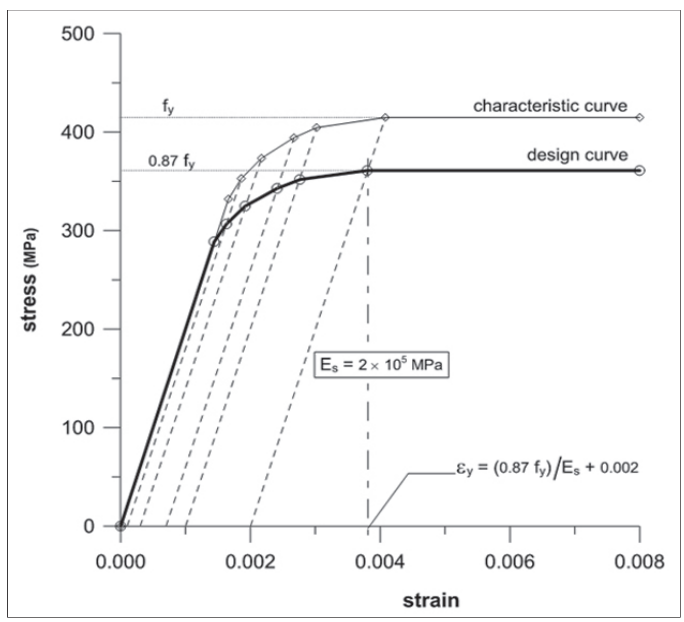

Fig. 3: Design Stress Strain Curve for Steel Reinforcement

Specimen and Strengthening Procedure

In this study, numerical investigation is done on the effect of band prestressing on the load carrying capacity of RCC walls with high aspect ratio. Commercially available and widely accepted FE software ABAQUS is used to study RCC wall subjected to axial loading.

3 RCC wall specimens are analyzed with band prestress. Initially 3 layers of vertical bands are provided in each specimen followed by horizontal prestressed bands at 300mm spacing. The remaining portion is provided with 1 layer of non-prestressed CFRP sheets.

Configuration of strengthening scheme of RCC wall is depicted in Fig 4 below:

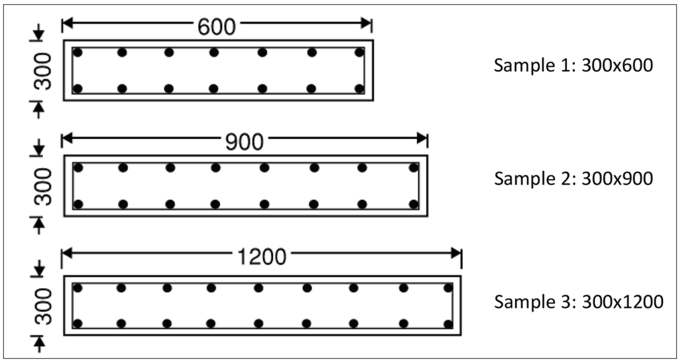

Fig. 4: Diagram Showing Column Sizes used in the Analytical Study

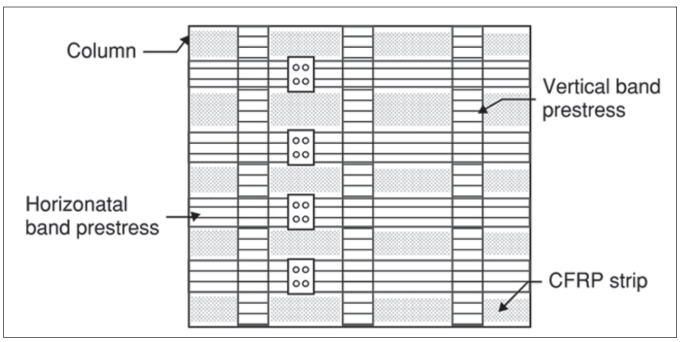

Fig. 5: Typical Elevation of Column with Band Prestress

Table 2: Geometrical Properties Of RCC Column Specimen Analysed After Band Prestressing

Specimen	Grade	Size (mm)	Rebar
Sample 1	M30	300 x 600	8-T16
Sample 2	M30	300 x 900	8-T20
Sample 3	M30	300 x 1200	10-T32

Analytical Modelling In FEM

Three-dimensional analysis of axially loaded RCC wall with high aspect ratio confined with band prestressing is conducted using CDP model available in ABAQUS software. A 3D hexahedral element of eight nodes (C3D8) is used for modelling concrete wall. 3D tie element with 2 nodes (T3D2) element is utilized to model vertical reinforcement and stirrups. Interaction between concrete and steel reinforcement is modelled to represent full bond action. Full bond is also assumed between CFRP bands and concrete surface. A rigid plate the top is used for uniform distribution of axially applied load. The model is analyzed using a displacement control option and axial displacement is applied at center of rigid plate.

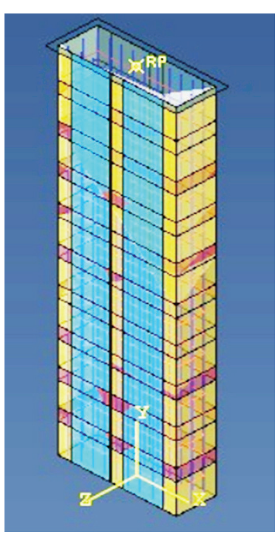

Fig. 6: Typical Model of RCC Wall with Band Prestressing

Results And Discussion

The 3 specimens were analyzed. As a result of confinement with band prestressing, the load carrying capacity of column increases. Table 2 below summarizes the improvement in load carrying capacity of the column when band prestressed.

Table 3: Peak Load Carrying Capacity of RCC Specimen after Band Prestressing

Column Sample	Size (mm)	Load carrying capacity (kN)	Load carrying capacity after band prestressing (kN)	Percentage increase
Sample 1	300 x 600	2620	4341	65.6%
Sample 2	300 x 900	4540	7077	55.8%
Sample 3	300 x 1200	6650	9313	40.0%

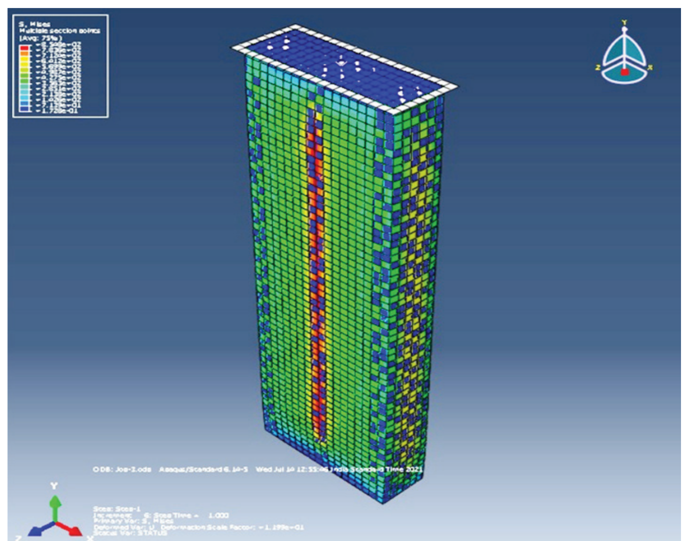

Fig. 7: Figure Showing Von Mises Stress in RCC Specimen with Band Prestress

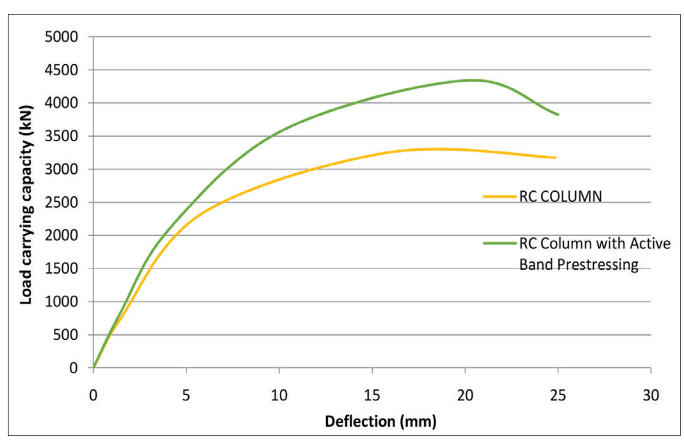

Fig. 8: Load Deflection Plot of RCC Wall vs RCC Wall with Active Band Prestressing (Sample 1)

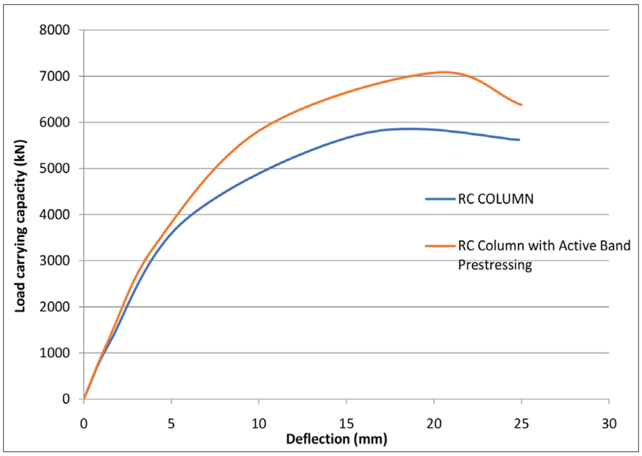

Fig. 9: Load Deflection Plot of RCC Wall vs RCC Wall with Active Band Prestressing (Sample 2)

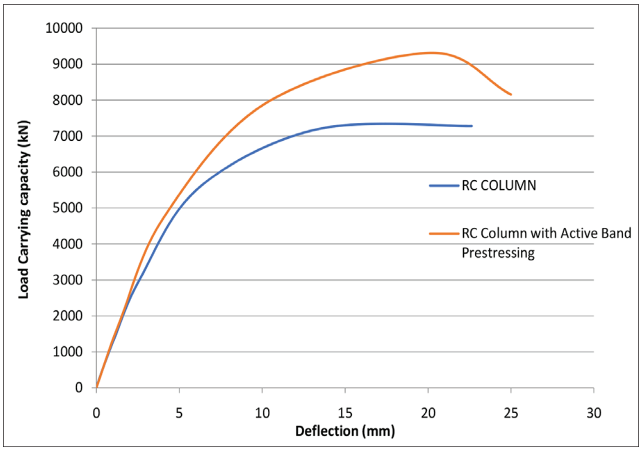

Fig. 10: Load Deflection Plot of RCC Wall vs RCC Wall with Active Band Prestressing (Sample 3)

Conclusion

1. There was a significant increase of 40-65% in the peak load carrying capacity of the RCC walls after active band prestressing.
2. The peak load carrying capacity is found to be in decreasing as the aspect ratio of RCC wall increases.
3. Using active method of band prestressing is an optimized way to achieve peak load carrying capacity as it utilizes ultimate strength of CFRP.
4. With the advanced method of active band prestressing, the passive method of confinement is transformed to active method of confinement thereby achieving higher confining pressure and increase in peak load carry capacity.

Future Scope

This paper provides details on effective use of active method of CFRP band prestress for strengthening of RCC walls. It offers the advantage of utilizing the benefits of light weight non prestressed CFRP system with high efficiency offered by external prestressing. This method of prestressing can be used for strengthening of RCC walls of very high aspect ratio. This is an area of further research which can be further worked on.

Reference

1. *ACI 440.2R-17: Guide for the Design and construction of Externally Bonded FRP systems for Strengthening concrete structures.*
2. *Stefan Kaeseberg, Dennis Messerer, Klaus Holschemacher. Assessment of Standards and Codes dedicated to CFRP confinement of RC Columns.*
3. *Task Group 9.3 FRP reinforcement for concrete structures, Externally bonded FRP reinforcement for RC structures, CEB-FIB, Technical Report Bulletin 14 (2001).*
4. *R. El-Hacha, R. G. Wright and M. F. Green, Prestressed fiber-reinforced polymer laminates for strengthening structures, Prog. Struct. Engng Mater .2001., vol. 3, pp. 111-121, (2001).*
5. *IS 456:2000: Plain and Reinforced concrete – Code of Practice*