RETROFITTING OF COLUMNS OF AN EXISTING BUILDING BY RC, FRP, SFRC AND STEEL JACKETING TECHNIQUES

A PROJECT

Submitted in partial fulfilment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY

IN

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Under the supervision of

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By

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to

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

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CERTIFICATE

This is to certify that the work which is being presented in the project title "**Retrofitting of Columns of an Existing Building by RC, FRP, SFRC and Steel Jacketing Techniques**" in partial fulfilment of the requirements for the award of the degree of Bachelor of technology. This work is submitted to Civil Engineering Department, Jaypee University of Information Technology, Waknaghat. This is an authentic record of work carried out by **Pranay Ranjan ,**Roll No- **121625** during a period from July 2015 to June 2016 under the supervision of **Mrs. Poonam Dhiman** Assistant Professor, Civil Engineering Department, Jaypee University of Information Technology, Waknaghat, Solan, H.P.

The above statement made is correct to the best of my knowledge.

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ABSTRACT

Retrofitting is a technique to enhance the structural capacities including the strength, stiffness, ductility, stability, and integrity of a building that is found to be deficient or vulnerable. It can effectively raise the performance of a building against earthquake to a desired level, and to even satisfy the requirements of an upgraded design seismic code. The building need not be deteriorated or damaged. The retrofit is also intended to mitigate the effect of a future earthquake. In this project, an effort is made to elaborate the procedure of providing concrete jacketing to the column as per guidelines of IS 15988: 2013. It is seen that the overall performance of the column significantly improves after jacketing.

Seismic protection of buildings is a need-based concept aimed to improve the performance of any structure under future earthquakes. Earthquakes of varying magnitude have occurred in the recent past in India, causing extensive damage to life and property. Some recently developed materials and techniques can play vital role in structural repairs, seismic strengthening and retrofitting of existing buildings, whether damaged or undamaged. The primary concern of a structural engineer is to successfully restore the structures as quickly as possible. Selection of right materials, techniques and procedures to be employed for the repair of a given structures have been a major challenges.

An existing four storey RC framed residential building situated in Patna, Bihar is taken for this study. When this building was analysed for expected seismic loads i.e four storey, none of the columns failed, but it was proposed by owner to add two more storey to existing frame without any change in existing structure. When five storey building was modelled and analysed for same seismic performance ,6 columns failed & when one more storey was added, 19 columns failed . The failed columns were retrofitted using RC, FRP, SFRC, STEEL Jacketing.

All these jacketing techniques were also compared in terms of economic ease of application & change that was made in original space of building due to use of these jackets. After comparing it was found that STEEL Jacketing is best in terms of all of above set parameters.

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CHAPTER 1
INTRODUCTION

1.1 General

Jacketing is the most popularly used method for strengthening of building columns. Retrofitting can generally be classified in two categories: Global and the local. The Global retrofitting technique targets the seismic resistance of the building. It includes adding of infill wall, adding of shear wall, adding of steel bracings and base isolation. Adding of infill wall in the ground storey is a viable option to retrofit buildings with soft storey. Shear walls can be introduced in a building with flat slabs or flat plates. A new shear wall should be provided with an adequate foundation. Steel braces can be inserted in frames to provide lateral strength, stiffness, ductility, and to improve energy dissipation. These can be provided in the exterior frames with least disruption of the building use . Local retrofitting technique targets the seismic resistance of a member. The local retrofit technique includes the concrete, steel or Fibre reinforced polymer Jacketing to the structural members like beams, columns, beam column joint, foundation. Concrete jacketing involves adding a new layer of concrete with longitudinal reinforcement and closely spaced ties. The jacket increases both the flexural strength and the shear strength of the beam or the column. The following are the advantages of retrofitting. It increases the seismic resistance of the building without any demolition. It increases the ductile behaviour and lateral load capability of the building Strength and stiffness of the building is also improved.

1.2 Jacketing of Columns

Jacketing of columns consists of added concrete with longitudinal and transverse reinforcement around the existing columns. This type of strengthening improves the axial and shear strength of columns while the flexural strength of column and strength of the beam-column joints remain the same. It is also observed that the jacketing of columns is *not successful for improving the ductility*. A major advantage of column jacketing is that it improves the lateral load capacity of the building in a reasonably uniform and distributed way and hence avoiding the concentration of stiffness as in the case of shear walls. This is how major strengthening of foundations may be avoided. In addition the original function of the building can be maintained, as there are no major changes in the original geometry of the building with this technique.

1.3 Types of Jacketing

The most common types of jackets are steel jacket, reinforced concrete jacket, fibre reinforced polymer composite jacket, jacket with high tension materials like carbon fibre, glass fibre etc.

(i) Reinforced Concrete Jacketing
(ii) Steel Jacketing.
(iii) Fibre Reinforced Polymer Composite Jacket
(iv) Steel Fibre Reinforced Polymer Composite Jacketing

1.4 Reinforced Concrete Jacketing

Reinforced concrete jacketing can be employed as a repair or strengthening scheme. Damaged regions of the existing members should be repaired prior to their jacketing. There are two main purposes of jacketing of columns:

(i) Increase in the shear capacity of columns in order to accomplish a strong column-weak beam design

(ii) To improve the column's flexural strength by the longitudinal steel of the jacket made continuous through the slab system are anchored with the foundation. It is achieved by passing the new longitudinal reinforcement through holes drilled in the slab and by placing new concrete in the beam column joints as illustrated in Figure 1.1. Rehabilitated sections are designed in this way so that the flexural strength of columns should be greater than that of the beams. Transverse steel above and below the joint has been provided with details, which consists of two L-shaped ties that overlap diagonally in opposite corners. The longitudinal reinforcement usually is concentrated in the column corners because of the existence of the beams where bar bundles have been used as shown in Figure 1.1. It is recommended that not more than 3 bars be bundled together. Windows are usually bored through the slab to allow the steel to go through as well as to enable the concrete casting process.

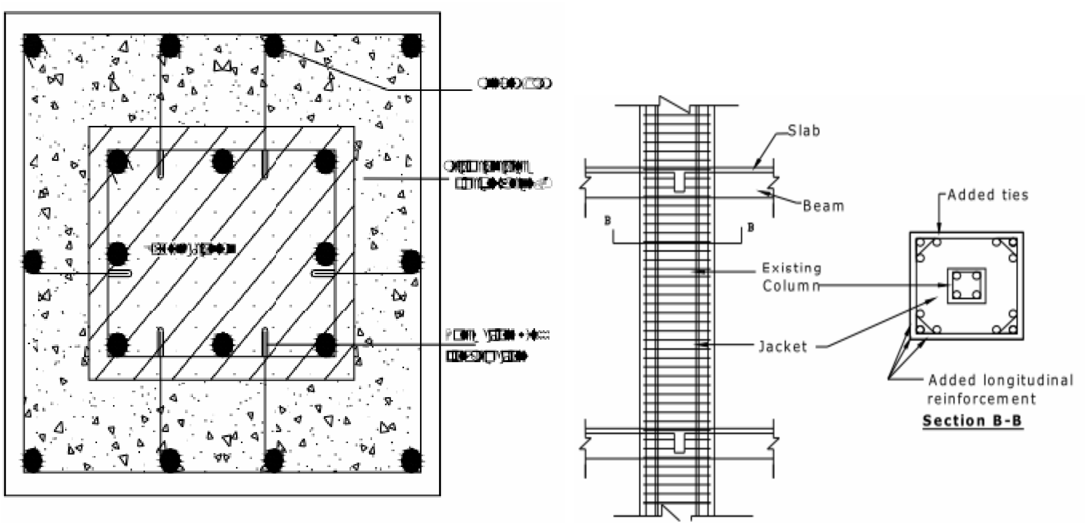

Fig-1.1 Cross-section of Concrete Jacketing Of column

1.5 Steel Jacketing

A large number of existing reinforced concrete (RC) buildings are not designed in accordance with advanced seismic codes and many have suffered severe damage or complete collapse during past earthquakes on account of inadequate shear strength, flexural strength and ductility of columns. The primary deficiencies of these columns included items, such as insufficient longitudinal and transverse reinforcement, and inadequate lap splices for longitudinal reinforcement. Such columns need to be strengthened in such a way that their failure mechanism changes from brittle to ductile mode. It is also desirable that strengthening technique is not only less interruptive, less time consuming and less expensive, but also should result in minimum loss of floor area One such technique is steel caging, which consists of steel angles at the corners of RC columns and steel straps at few places along the length. This technique is generally regarded as practical, fast and cost-effective, which helps to improve the global seismic behaviour of the structure by increasing lateral strength, ductility and shear capacity of structural members . This is widely used in construction, particularly in Japan, Taiwan and the United States and also has found application in retrofitting the damaged RC columns after earthquakes . Several researchers have investigated strengthening of RC columns using steel jackets. Dritsos and Pilakoutas developed a theoretical model to determine the effective confining stresses of column concrete due to steel cage assuming that the composite action at the interface of steel and concrete element is mobilized due to Poisson's expansion and interface friction. Experimental investigations on damaged RC columns showed that the axial compressive strength and ductility was greatly improved by strengthening using steel cage and steel encasement approach . However, considerable improvement in shear strength with stable hysteretic loops at higher ductility levels was only achieved when the columns were retrofitted over the entire length using steel jackets . Masri and Goel conducted an experimental research on a one-third scale, two-story, two-bay RC slab–column frame model strengthened by ductile steel bracing and external steel jacketing. Significant flexural contribution from jacketing elements (i.e. vertical angles at corners and horizontal battens) was noted. A method was developed to compute this flexural contribution of strengthened column appropriately accounting for the observed load-sharing mechanism between angles and battens. However, the model underestimated the observed values as it did not include the composite effect due to the confinement provided to concrete by steel jacketing elements. In the present study, rectangular RC columns, more typical of building columns, were externally strengthened by steel caging technique using four longitudinal steel angles and battens. The intermediate gap between steel cage and RC column was not filled with any kind of binder materials. An experimental investigation was carried out on both ordinary and strengthened columns under constant axial load and gradually increasing cyclic lateral load in order to verify the effectiveness of the proposed design method and the detailing of steel cage battens within the potential plastic hinge regions. In order to size various elements of steel cage for an effective and efficient design, a rational method is proposed that accounts for the confinement effect of steel cage on the existing column and prevents premature failure of steel cage.

Steel Jacketing is a method of retrofitting that uses a layer of steel plate placed over the reinforced concrete column or beam. In this research, steel jacketed columns were analyzed with steel thicknesses ranging from 1 mm to 6 mm with yielding strengths from as low as 185 MPa to as high as 360 MPa. Fig 1.2 shows steel jacketing of column.

As compared with conventional hoops or spirals, steel jacket has two more remarkable advantages:-

1) To easily provide a large amount of transverse steel, hence strong confinement to the compressed concrete, and

2) To prevent spalling off of the shell concrete. Spalling of the shell concrete may be considered as the main reason for deterioration of bond and buckling of longitudinal bars of columns and is hardly prevented by conventional hoops. Because of these advantages of the steel jacket, confining method utilizing steel jacket has been increasingly used to retrofit or strengthen the existing reinforced concrete columns without adequate detailing. This method is referred to as the steel jacket retrofit hereafter.

Fig 1.2: Steel Jacketing

1.6 Fibre Reinforced Polymer Composite Jackets

Traditional steel based reinforcement systems for concrete elements are facing with serious problems mainly caused by corrosion due to chemically aggressive environments and salts used in deicing procedures especially in case of bridge steel reinforced concrete girders. Also in some cases special applications require structural members with magnetic transparency. An alternative to this major problem has recently become the use of fibre reinforced polymer (FRP) composite bars as internal reinforcement. FRP composite materials have developed into economically and structurally viable construction materials for load bearing elements in buildings and bridges over the last two decades. FRP reinforcements for structural elements in construction have raised the interest of structural engineers since the beginning of the fibre reinforced plastics industry and the use of FRP composite materials with various fibre reinforcement types has become an interesting alternative as reinforcement for various concrete members. There is nowadays a wide range of available types of FRP composites (with polyester, epoxy or vinyl-ester matrices) reinforced with glass, carbon and aramid fibres with suitable properties for different applications in civil and structural engineering. However, the particularities of behaviour of FRP bars and the insufficient experimental data on structural and long time behaviour of concrete elements reinforced with internal FRP composite bars still requires extensive theoretical studies and experimental programs to be able to fully exploit the potential of these new materials. Over the latest decades structural strengthening of concrete structures has become an important issue due to ageing of infrastructure and the need for upgrading to fulfil more stringent design requirements. Also the seismic retrofit has become more important mainly in seismic active areas. The use of fibre reinforced polymer (FRP) composites in strengthening solutions has become an efficient alternative to some of the existing traditional methods due to some advantages such their features in terms of strength, lightness, corrosion resistance and ease of application. Such techniques are also most attractive for their fast execution and low labour costs

1.7 Steel Fibre Reinforced Polymer Composite Jacketing

During recent years, steel fibre reinforced concrete has gradually advanced from a new, rather unproven material to one which has now attained acknowledgement in numerous engineering applications. Lately it has become more frequent to substitute steel reinforcement with steel fibre reinforced concrete. Steel Fibres are generally distributed throughout a given cross section whereas reinforcing bars or wires are placed only where required. Steel fibres are relatively short and closely spaced as compared with continuous reinforcing bars of wires. It is generally not possible to achieve the same area of reinforcement to area of concrete using steel fibres as compared to using a network of reinforcing bars of wires. Steel Fibres are typically added to concrete in low volume dosages (often less than 1%), and have been shown to be effective in reducing plastic shrinkage cracking. It do not significantly alter free shrinkage of concrete, however at high enough dosages they can increase the resistance to cracking and decrease crack width. Steel Fibres in Concrete can improve Crack, Impact, Fatigue Resistance, Shrinkage Reduction, Toughness. Benefits of SFRC is that it distributed localized stresses, Reduces maintenance and repair cost and Resistance to freezing and thawing.

1.8 Additional Benefits of Retrofitting

Apart from increased strength and ductility, retrofitting has other benefits for engineers, contractors, and building owners. When a damaged member has been retrofitted, the strength is usually similar to the strength of a retrofit column with no original damage.

When a steel tube is used, the concrete is essentially sealed from migration of any moisture, therefore drying creep and shrinkage strains are considerably lower (Naguib and Mirmiran 2003). Therefore, retrofitting of existing structures is a very efficient method that strengthens damaged members as well as increases their future sustainability.

1.9 Purpose of Jacketing

1. To increase concrete confinement by transverse fibre reinforcement, especially for circular cross-sectional columns,
2. To increase shear strength by transverse fibre reinforcement,
3. To increase flexural strength by longitudinal fibre reinforcement provided. They were anchored at critical sections. Transverse fibre should be wrapped all around the entire circumference of the members possessing close loops sufficiently overlapped or welded in order to increase concrete confinement and shear strength. This is how members with

circular cross-section will get better confinement than member with rectangular cross-section. Where square or rectangular cross-sections are to be jacketed, circular/oval/ elliptical jackets are most oftenly used and the space between the jacket and column is filled with concrete. Such types of multi-shaped jackets provide a high degree of confinement by virtue of their shape to the splice region proving to be more effective. Rectangular jackets typically lack the flexural stiffness needed to fully confine the concrete. However, circular and oval jackets may be less desirable due to:

(i) Need of large space in the building potential difficulties of fitting in the jackets with existing partition walls, exterior cladding, and non-structural elements and

(ii) Where an oval or elliptical jacket has sufficient stiffness to confine the concrete along the long dimension of the cross-section is open to question. The longitudinal fibres similar to longitudinal reinforcement can be effective in increasing the flexural strength of member although they cannot effectively increase the flexural capacity of building frames because the critical moments are located at beam-column ends where most of the longitudinal fibres are difficult to pierce through to get sufficient anchorage.

1.10 When do we do Retrofitting?

1. Retrofitting is done to that buildings whose column or beam get damaged in an earthquake.
2. If we want to increase number of storeys of building, then we need to do jacketing of columns and beams.
3. We fall in love with old buildings because of their character and history , and due to parental property. That's why we want to live in same home for whole life. So, we retrofitted them to make them more energy efficient for living.

CHAPTER 2
LITERATURE REVIEW

2.1 General

Literature pertaining to studies on the behaviour of columns subjected to cyclic loading is presented. A detailed review of literature has been carried out to study the behaviour of RC columns retrofitted with various types of jacketing. Very scant literature is available on the retrofitting of RC columns using Reinforced concrete jacketing..

2.2 Overview Of Literature

1. *"Design and Detailing of RC Jacketing for Concrete Columns"* published at National Conference on Advances in Engineering, Technology & Management in the year 2015 given by Mrs. Poonam Dhiman, Mr.Anil Dhiman , Mrs Nikita Gupta. And it was concluded that RC Jacketing is suitable for the old and existing building that are constructed without considering IS 1893:2002, are very liable for damage during an earthquake & columns that are damaged in the past earthquake during an accident like fire, explosions.

2. *"Materials and Jacketing Techniques for Retrofitting of structures"* given by Sri. Pravin B. Waghmare. This research article was published at International Journal of Advanced Engineering Research and Studies in the year 2011 . In the article of Sri. Pravin B. Waghmare has discussed about Reinforced concrete Jacketing, Steel Jacketing, Carbon Fibre reinforced polymer composite jacketing, Beam Jacketing. He has also discussed details about all three types of jacketing. In reinforced concrete jacketing he has discussed about Properties of jackets, minimum width of jacket, minimum area of longitudinal reinforcement, minimum area of transverse reinforcement, Shear stress in the interface and about Connectors.

In steel jacketing he has discussed about Steel plate thickness , Shape of jackets, Free ends of jackets bottom clearance, Gap between steel jacket and concrete column Size of anchor Number of anchor bolts. And in beam jacketing how to calculate Minimum width for jacket , Longitudinal reinforcement, Shear reinforcement, Depth of jacketed beam were discussed.

3. *''Columns under Seismic Loading''* Abram (1987) studied the effect of axial load on the reversed lateral cyclic loading of columns and found that the additional axial load increasers the stiffness, flexural strength and shear capacity. They found that the shape of the hysteretic loop was influenced by the range of axial force variation and the rate of change of axial force with lateral deflection.

4. *''Repair and Strengthening Techniques for Non-seismically Designed Reinforced Concrete Column, Beam, Beam Column Joints''*, reported between 1975 and 2003 given by Abdul-Hamid Zureick and Lawrence F. Kahn. It was concluded that Epoxy repair techniques have exhibited limited success in restoring the bond of reinforcement, in filling the cracks, and restoring shear strength in one-way joints. Concrete jacketing of columns and encasing the joint region in a reinforced fillet is an effective but the most labour-intensive strengthening method due to difficulties in placing additional joint transverse reinforcement.

5. Azizinamini et al (1992) conducted *''Full Scale Testing of Columns with Different Transverse Reinforcement''* details and found that the flexural capacity of columns increased with axial load but ductility reduced substantially. Test results indicate that increase in the amount of transverse reinforcement improves the ductility.

6. Aycardi et al (1994) tested the *''Columns Designed for Gravity Load under Simulated Seismic Loading''*, with low and high axial forces and with and without lap splices, representing interior and exterior columns at floor slab and beam soffit level. The failures of the columns were flexurally dominated resulting in buckling of column reinforcement in the case of high axial loads and low cycle fatigue of the longitudinal bars in the case of low axial loads. The maximum strength was observed when inter storey drift was between 2% and 3% and subsequently strength decreased with additional drifts. Mo and Wang (2000) conducted experiments on RC columns with various tie configurations by reversed

cyclic loading. They proposed transverse reinforcement configurations with alternate ties to improve seismic performance.

7. Elwood and Moehle (2003) observed that the *" Lateral Displacement or Drift of a Reinforced Concrete Column"* at axial failure was dependent upon and directly proportional to the spacing of transverse reinforcement and the axial stress developed within the column. It was noted that the lateral drift experienced by the columns at axial failure was dependent upon and inversely proportional to the amount of axial load exerted on the column. The performance of columns under seismic loading is also influenced by the secondary moment due to drift.

8. Montes et al (2004) studied the *"Impact of Optimal Longitudinal Reinforcement on the Curvature Ductility Capacity of Column Sections"*. An approach for determining an acceptable reinforcement by means of reinforcement sizing diagram has been described. The authors concluded that the curvature ductility capacity enhanced for the case of optimal longitudinal reinforcement relative to the values computed for conventionally reinforced columns.

9. Mark et al (2008) developed a non linear conjugate gradient search method for finding the *"Optimal Reinforcement of a Rectangular Reinforced Concrete Column Cross Section"*. The authors suggested the use of the model for sections subjected to uniaxial or bi axial bending. As per the literature reviewed on behaviour of columns under cyclic loading, it was concluded that transverse reinforcement and longitudinal reinforcement will provide better ductility, stiffness and strength to column elements of the buildings. The research by Montes et al (2004) indicated that the use of optimal reinforcement improves the curvature ductility of columns than that of higher percentage of reinforcement. Hence the effect of longitudinal reinforcement on behaviour of columns under cyclic loading are experimentally studied as a preliminary part in this project work.

10. *"Strengthening of Concrete Beams Using Cementitious Carbon Fibre Composites"*-2013 given by Anders Wiberg It was concluded that the use of cementitious fibre composites offers several advantages over the existing methods. Due to the novelty of this technique no specially adapted materials are available and ready for use in cementitious composites.

11. Durgesh C. Rai gave the guidelines for "*Seismic Evaluation and Strengthening of Buildings"*. This document is developed as part of project entitled ―Review of Building Codes and Preparation of Commentary and Handbooks‖ awarded to Indian Institute of Technology Kanpur by the Gujarat State Disaster Management Authority (GSDMA), Gandhinagar through World Bank finances. This document is particularly concerned with the seismic evaluation and strengthening of existing buildings and it is intended to be used as a guide.

CHAPTER 3

SEISMIC ANALYSIS OF BUILDING FRAMES

3.1 Introduction

In actual practice, the structures will usually be built in having one of the irregularities i.e. stiffness, diaphragm, mass, re-entrant corner, and torsion irregularity. In the multi storey buildings damages due to earthquake are usually at the weak points. This weakness is due to strength, variation in stiffness etc. So if a structure can perform well in earthquake means it should possess adequate strength, stiffness, ductility and simple configuration. Therefore these types of structures should be well designed under earthquake loading accounting the specified seismic design philosophies so that they can sustain moderate to strong earthquakes. The structures are analyzed by using methods Equivalent static method of analysis and Dynamic method of analysis. The dynamic analysis method can be performed by Time history method and Response spectrum method. And also nonlinear static analysis i.e. pushover analysis is also carried out.

There is growing responsiveness of multi-storey reinforced concrete structures, to accommodate growing population. Generally such structures have prismatic sections which are common in developing countries, which resist applied loads without any appreciable deformation of one part relative to another. It is the need to accomplish some function, one of them is to receive loads (usually known as service loads) at certain points & transmit them safely to other points, that prompts the designer to give life to a structure furthermore since it is the need for a safe, serviceable, feasible and aesthetically pleasing fulfilment of a structure. The ultimate aim of structural analysis is to design all the structural elements of a structural system in such a way that they perform their functions satisfactorily and at the same time assist design to become efficient, elegant and economical which helps to choose the right type of sections consistent with economy along with safety of the structure.

3.2 Description of Study Building Structure

The building that are considered for the analysis has been modelled in STADD PRO software. This building is situated in Patna Bihar which is my Residential building. This building is designed to built up to 4 storey in approx 2000 sq feet . This building has 22 Live piles and 9 dead piles. Live piles are 9 meter deep in the soil and Dead piles are 7 meter deep in the soil. It has 31 tie beams of dimension 300 mm ×300 mm. It has 5 rooms , 1 kitchen, 4 bathrooms, 1 store room ,1 dinning hall and 1 drawing hall, with 4 balconies for each room. Room sizes are 12 ft × 11 ft, dinning hall has a size of 10.5 ft × 21.5 ft and drawing hall has size of 21.5 ft × 11 ft, bathroom size are 8 ft × 5 ft & 5 ft × 5 ft . Kitchen has a dimensions of 10.5 ft × 7 ft.

Its columns sizes are of 0.3m × 0.3m, 0.36m × 0.3m, and 0.4m × 0.3m & Beams are of 0.3m × 0.25m , 0.3m × 0.3m, 0.25m × 0.25m,0.36m × 0.3m. slab has a thickness of 5 inch i.e 0.125 m.

For the present work, (G+3) storey building with storey height 3 meter for all, with plan 18m × 9m is taken. Buildings has bays in irregular form in both X & Y axis. For this building the modelling has been made according to IS code first for (G+3) storey to show that no column fails upto 4 storey. And as we increase the storey of building by 1 storey even it's 6 column fails due to increase in load. And as we modelled this building to 6 storey , it's 19 columns fail at ground and first floor level.

3.3 Loads Applied on the Building

1. Loads are applied on the building are dead load, live load, seismic loads according to IS CODE 875:1987 (Part I, Part II, Part III).
2. In this buildings dead loads on outer walls are applied of 12 kN in downward direction for 9 inch walls and on inner wall dead loads are applied of 6 kN in downward direction for 4.5 inch walls.
3. Live loads are applied of 2 kN/m^2 on rooms, kitchen, toilets, bathroom, and 3 kN/m^2 on balconies, corridors, passages, staircases.
4. Seismic loads are applied on the basis of IS CODE 1893:2013 .

5. Loads are in following sequential orders :-

a) Seismic loads(E.L) in positive & negative X axis and positive and negative Z axis with a factor of 0.24.

b) Dead load are applied of 4 kN/m^2 in downward directions a/c to IS code for different height of building for different storey.

c) Live load are applied of 2 kN/m^2 & 3 kN/m^2 in downward directions a/c to IS code for different height of building for different storey.

Loads Combination that are applied are as follows :

a) 1.5 × (DL+LL)

b) 1.2 × (DL+LL+E.L in +ve X direction)

c) 1.2 × (DL+LL+E.L in +ve Z direction)

d) 1.2 × (DL+LL-E.L in -ve X direction)

e) 1.2 × (DL+LL-E.L in -ve Z direction)

f) 1.2 × (DL+E.L in +ve X direction)

g) 1.2 × (DL+E.L in +ve Z direction)

h) 1.2 × (DL-E.L in -ve Z direction)

g) 1.2 × (DL+E.L in -ve X direction)

i) DL+E.L in +ve X direction

j) DL+E.L in +ve Z direction

h) DL+E.L in -ve X direction

k) 0.9DL-1.5E.L in -ve Z direction

3.4 Analysis

Analysis is done for 3 model - 4 storey building , 5storey building & 6 storey building.

Its columns sizes are of 0.3m × 0.3m, 0.36m × 0.3m, and 0.4m × 0.3m & Beams are of 0.3m × 0.25m , 0.3m × 0.3m, 0.25m × 0.25m, 0.36m × 0.3m. slab has a thickness of 5 inch i.e 0.125 m.

In analysis & print command 'Design beam', 'Design column', and 'Take off' command is applied for calculation of reinforcement required for each beams and columns, load taken by each beams and columns were also specified and moments in 'Z' direction was also specified.

Building is been analyse to print load data only from analyse and print command.

3.5 Deficient Columns

Till four storey there is no any deficient columns as per cross-section of columns provided and load applied because initially building was designed as per four storeys.

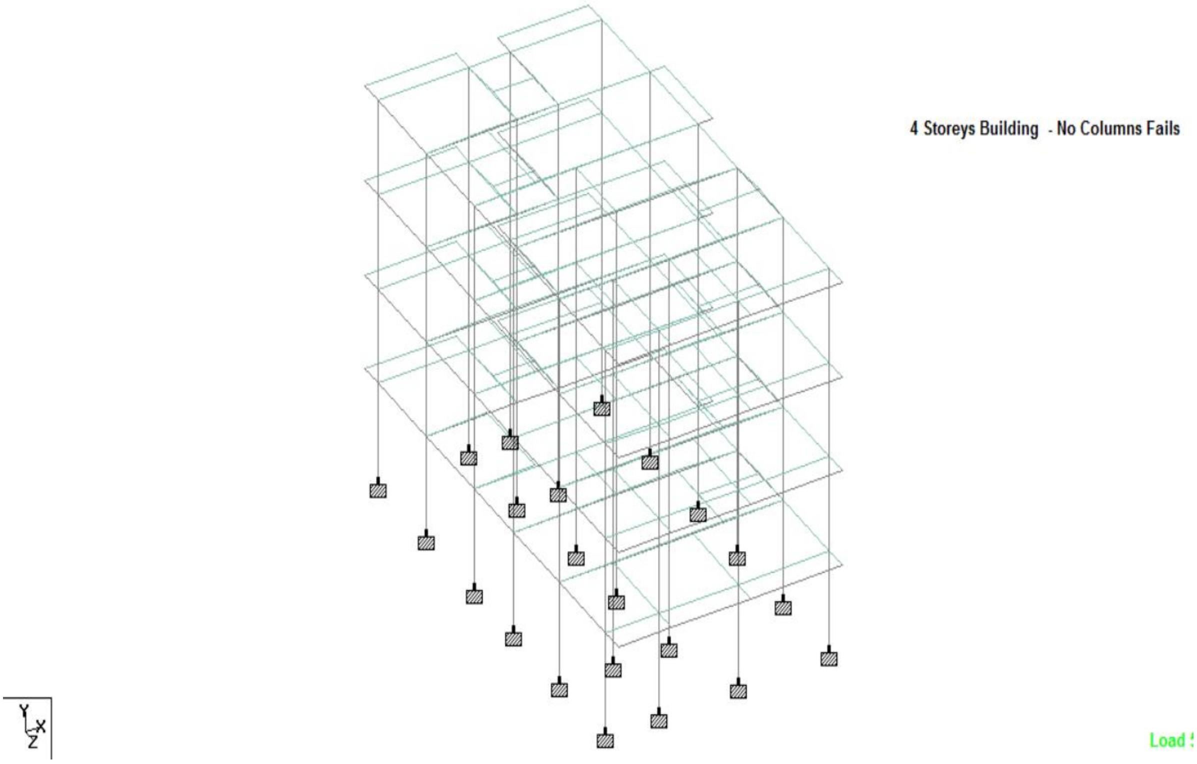

Fig-3.1 - 4 Storey Building -- No Columns Fail

3.5.1 Analysis Results of the Columns of 5 Storey Building

As we model 5^{th} storey ,some of columns (six columns) of building fails. Columns that fails are 63^{th}, 64^{th} , 74^{th}, 79^{th}, 80^{th} column .

All above columns are of cross-section 300mm × 300mm.

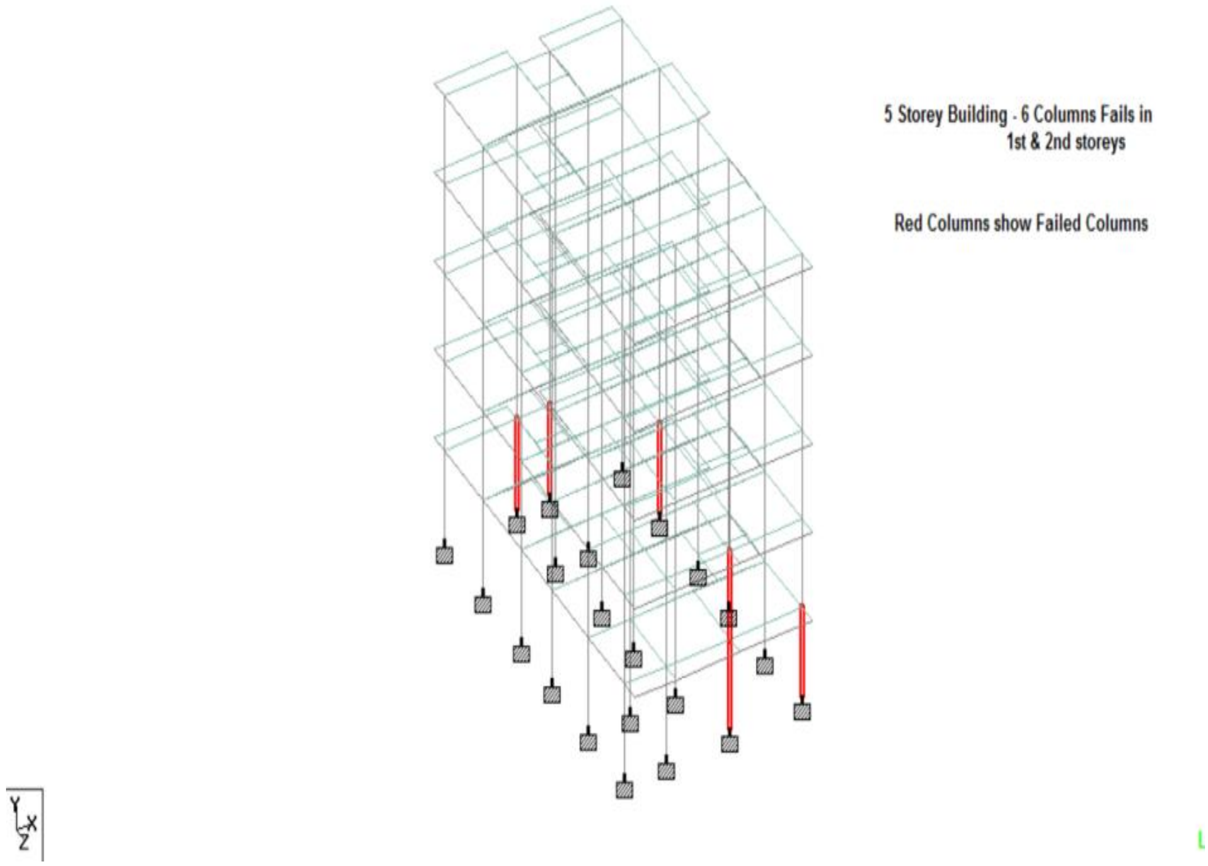

Fig 3.2: 5 Storey Building -- 6 Columns Fail (Red Columns show Failed Columns)

Given below are the analysis results of the columns of 5 storey building :-

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         C O L U M N   N O.     74  D E S I G N   R E S U L T S

      M30                    Fe415  (Main)                Fe415  (Sec.)

LENGTH:  3000.0 mm   CROSS SECTION:  300.0 mm X  300.0 mm  COVER: 40.0 mm

** SECTION IS NOT ADEQUATE
   Reinforcement % exceeds maximum limit
============================================================================


============================================================================
```

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=============================================================================

        C O L U M N   N O.    63  D E S I G N   R E S U L T S

     M30                  Fe415 (Main)              Fe415 (Sec.)

LENGTH:  3000.0 mm   CROSS SECTION:  300.0 mm X  300.0 mm  COVER: 40.0 mm

** SECTION IS NOT ADEQUATE
   Reinforcement % exceeds maximum limit
=============================================================================


=============================================================================

        C O L U M N   N O.    64  D E S I G N   R E S U L T S

     M30                  Fe415 (Main)              Fe415 (Sec.)

LENGTH:  3000.0 mm   CROSS SECTION:  300.0 mm X  300.0 mm  COVER: 40.0 mm

** SECTION IS NOT ADEQUATE
   Reinforcement % exceeds maximum limit
=============================================================================
-------------------------------< PAGE 10 Ends Here >---------------------------
 STAAD SPACE                                              -- PAGE NO.   11


=============================================================================

        C O L U M N   N O.    79  D E S I G N   R E S U L T S

     M30                  Fe415 (Main)              Fe415 (Sec.)

LENGTH:  3000.0 mm   CROSS SECTION:  300.0 mm X  300.0 mm  COVER: 40.0 mm

** SECTION IS NOT ADEQUATE
   Reinforcement % exceeds maximum limit
=============================================================================


=============================================================================

        C O L U M N   N O.    80  D E S I G N   R E S U L T S

     M30                  Fe415 (Main)              Fe415 (Sec.)

LENGTH:  3000.0 mm   CROSS SECTION:  300.0 mm X  300.0 mm  COVER: 40.0 mm

** SECTION IS NOT ADEQUATE
   Reinforcement % exceeds maximum limit
=============================================================================
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============================================================================

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         C O L U M N   N O.   179  D E S I G N   R E S U L T S

      M30                  Fe415 (Main)              Fe415 (Sec.)

 LENGTH:  3000.0 mm   CROSS SECTION:  300.0 mm X  300.0 mm  COVER: 40.0 mm

 ** SECTION IS NOT ADEQUATE
    Reinforcement % exceeds maximum limit
============================================================================

============================================================================
```

Fig 3.3 : Analysis Results Of Failed Column No- 63,64,74,79,80&179

3.5.2 Analysis Results of Columns of 6 Storey of Column

As we model 6th storey, many columns fails. Columns which fail are 62th,63th,64th,65th,66th,67th,69th,70th,72th,73th,74th,77th,78th,79th,80th,179th,180th,189th,190th column. In above failed columns cross-section of 300mm × 300mm & 400mm × 300mm are present.

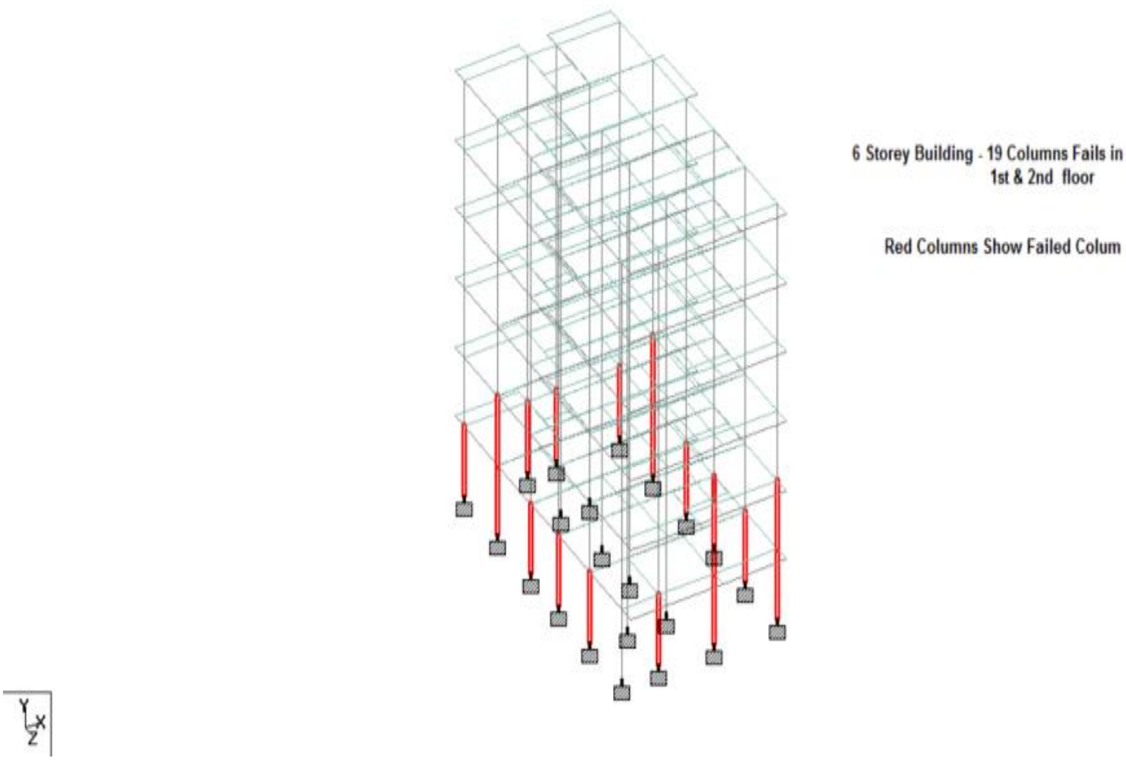


Fig 3.4 : 6 Storey Building -- 19 Columns Fail (Red Columns show Failed Column)

Given below are the analysis results of columns of 6 storey of column :--

```
===========================================================================

         C O L U M N   N O.    62  D E S I G N   R E S U L T S

      M30                  Fe415 (Main)              Fe415 (Sec.)

  LENGTH:  3000.0 mm   CROSS SECTION:  300.0 mm X  300.0 mm  COVER: 40.0 mm

  ** SECTION IS NOT ADEQUATE
     Reinforcement % exceeds maximum limit
===========================================================================

--------------------------------< PAGE 460 Ends Here >---------------------------
   STAAD SPACE                                           -- PAGE NO.  461


===========================================================================

         C O L U M N   N O.    63  D E S I G N   R E S U L T S

      M30                  Fe415 (Main)              Fe415 (Sec.)

  LENGTH:  3000.0 mm   CROSS SECTION:  300.0 mm X  300.0 mm  COVER: 40.0 mm

  ** SECTION IS NOT ADEQUATE
     Reinforcement % exceeds maximum limit
===========================================================================
```

```
===========================================================================

         C O L U M N   N O.    64  D E S I G N   R E S U L T S

      M30                  Fe415 (Main)              Fe415 (Sec.)

  LENGTH:  3000.0 mm   CROSS SECTION:  300.0 mm X  300.0 mm  COVER: 40.0 mm

  ** SECTION IS NOT ADEQUATE
     Reinforcement % exceeds maximum limit
===========================================================================


===========================================================================

         C O L U M N   N O.    65  D E S I G N   R E S U L T S

      M30                  Fe415 (Main)              Fe415 (Sec.)

  LENGTH:  3000.0 mm   CROSS SECTION:  400.0 mm X  300.0 mm  COVER: 40.0 mm

  ** SECTION IS NOT ADEQUATE
     Reinforcement % exceeds maximum limit
===========================================================================
```

```
=============================================================================

        C O L U M N   N O.    66  D E S I G N   R E S U L T S

     M30                    Fe415 (Main)              Fe415 (Sec.)

LENGTH:  3000.0 mm   CROSS SECTION:  300.0 mm X  300.0 mm  COVER: 40.0 mm

** SECTION IS NOT ADEQUATE
   Reinforcement % exceeds maximum limit
=============================================================================

------------------------------< PAGE 461 Ends Here >---------------------------
 STAAD SPACE                                                 -- PAGE NO.  462


=============================================================================

        C O L U M N   N O.    67  D E S I G N   R E S U L T S

     M30                    Fe415 (Main)              Fe415 (Sec.)

LENGTH:  3000.0 mm   CROSS SECTION:  300.0 mm X  300.0 mm  COVER: 40.0 mm

** SECTION IS NOT ADEQUATE
   Reinforcement % exceeds maximum limit
=============================================================================
```

```
=============================================================================

        C O L U M N   N O.    69  D E S I G N   R E S U L T S

     M30                    Fe415 (Main)              Fe415 (Sec.)

LENGTH:  3000.0 mm   CROSS SECTION:  400.0 mm X  300.0 mm  COVER: 40.0 mm

** SECTION IS NOT ADEQUATE
   Reinforcement % exceeds maximum limit
=============================================================================


=============================================================================

        C O L U M N   N O.    70  D E S I G N   R E S U L T S

     M30                    Fe415 (Main)              Fe415 (Sec.)

LENGTH:  3000.0 mm   CROSS SECTION:  300.0 mm X  300.0 mm  COVER: 40.0 mm

** SECTION IS NOT ADEQUATE
   Reinforcement % exceeds maximum limit
=============================================================================
```

```
        C O L U M N   N O.    72  D E S I G N   R E S U L T S

     M30                 Fe415 (Main)              Fe415 (Sec.)

LENGTH:  3000.0 mm   CROSS SECTION:  400.0 mm X  300.0 mm  COVER: 40.0 mm

** SECTION IS NOT ADEQUATE
   Reinforcement % exceeds maximum limit
============================================================================


============================================================================

        C O L U M N   N O.    73  D E S I G N   R E S U L T S

     M30                 Fe415 (Main)              Fe415 (Sec.)

LENGTH:  3000.0 mm   CROSS SECTION:  300.0 mm X  300.0 mm  COVER: 40.0 mm

** SECTION IS NOT ADEQUATE
   Reinforcement % exceeds maximum limit
============================================================================


============================================================================

        C O L U M N   N O.    74  D E S I G N   R E S U L T S

     M30                 Fe415 (Main)              Fe415 (Sec.)

LENGTH:  3000.0 mm   CROSS SECTION:  300.0 mm X  300.0 mm  COVER: 40.0 mm

** SECTION IS NOT ADEQUATE
   Reinforcement % exceeds maximum limit
============================================================================
```

```
============================================================================

        C O L U M N   N O.    80  D E S I G N   R E S U L T S

     M30                 Fe415 (Main)              Fe415 (Sec.)

LENGTH:  3000.0 mm   CROSS SECTION:  300.0 mm X  300.0 mm  COVER: 40.0 mm

** SECTION IS NOT ADEQUATE
   Reinforcement % exceeds maximum limit
============================================================================
```

```
===========================================================================

         C O L U M N   N O.   179  D E S I G N   R E S U L T S

      M30                   Fe415 (Main)              Fe415 (Sec.)

LENGTH:  3000.0 mm   CROSS SECTION:  300.0 mm X  300.0 mm  COVER: 40.0 mm

** SECTION IS NOT ADEQUATE
   Reinforcement % exceeds maximum limit
===========================================================================


===========================================================================

         C O L U M N   N O.   180  D E S I G N   R E S U L T S

      M30                   Fe415 (Main)              Fe415 (Sec.)

LENGTH:  3000.0 mm   CROSS SECTION:  300.0 mm X  300.0 mm  COVER: 40.0 mm

** SECTION IS NOT ADEQUATE
   Reinforcement % exceeds maximum limit
===========================================================================
```

```
===========================================================================

         C O L U M N   N O.   189  D E S I G N   R E S U L T S

      M30                   Fe415 (Main)              Fe415 (Sec.)

LENGTH:  3000.0 mm   CROSS SECTION:  300.0 mm X  300.0 mm  COVER: 40.0 mm

** SECTION IS NOT ADEQUATE
   Reinforcement % exceeds maximum limit
===========================================================================


===========================================================================

         C O L U M N   N O.   190  D E S I G N   R E S U L T S

      M30                   Fe415 (Main)              Fe415 (Sec.)

LENGTH:  3000.0 mm   CROSS SECTION:  300.0 mm X  300.0 mm  COVER: 40.0 mm

** SECTION IS NOT ADEQUATE
   Reinforcement % exceeds maximum limit
===========================================================================
```

Fig 3.5 : Analysis results of failed column no-62,63,64,65,66,67,69,70,72,73,74,80,179,180,189,190

CHAPTER 4
DESIGN OF RC JACKETS

4.1 Jacketing of Failed Columns for 5 Storey Building

After modelling of 5 storey building, analysis is done and no of failed columns is been noted down. Failed columns are 63,64,74,79,80 & 179. And Jacketing of all these columns are designed as per IS CODE 15988:2013 [1].

4.1.1 Column No- 63

Height of column= 3000mm ;Width (b) =300mm ; Depth (D)=300mm; d= 260mm;
Reinforcement provided= 4,16Ø=804.25 mm^2 ; f_y = 415MPa; f_{ck}=30MPa.
P = 965.156 kN ; M = 15.307 kNm
So, P_u = 1447.734 kN ;M_u = 22.961 kNm

$$Pu = 0.4 \times f_{ck} \times A_c + 0.67 \times f_y \times A_{sc}$$

According to the provisions provided in to 8.5.1.2 (a) of IS 15988: 2013 [1], Concrete strength shall be at least 5 MPa greater than the strength of the existing concrete. Thus, taking value of f_{ck} = 35 N/mm^2 and assuming A_{sc} = 0.8% Ac

$$1447.734 \times 10^3 = 0.4 \times 35 \times A_c + 0.67 \times 415 \times (0.8 \% A_c)$$
$$1447.734 \times 10^3 = 14 \times A_c + 2.224 \times A_c$$
$$1447.734 \times 10^3 = 16.224 \times A_c$$
$$A_c = 89234.10 \text{ mm}^2$$

According to 8.5.1.1 (e) of IS 15988:2013, A'_c =1.5A_c
Thus, A'_c =133851.15 mm^2

Assuming the cross sectional details as:
B=400mm, D=133851.15/400=334.63 mm

Jacketing details of cross section:
B = (400-300)/2=50 mm, D = (334.63-300)/2=17.315 mm

However, According to the code specified above, Minimum jacket thickness shall be 100 mm as per 8.5.1.2 (c) of IS 15988:2013 [1].
Thus, New size of the column: B = 300+100 +100=500mm, D =300 +100 +100=500mm

New concrete area=500 × 500=250000mm^2 > A_c= 89234.10 mm^2
Area of steel, A_s =0.8% × 500 × 500=2000 mm^2

But according to 8.5.1.1 (e) IS 15988:2013, A'_s = (4/3) A_s= (4/3) × 2000 = 2666.67 mm^2
Assuming 16mm Ø bars,
Thus, number of bars, N =2666.67 × 4/ (π × 16^2) = 13.263 bars

Provide 10 NO. -16mm Ø bars for jacketed section. Therefore, revised jacketed section will be 500mm x 500 mm.

Design of Lateral Ties:

As per 8.5.1.2 (e) of IS15988: 2013, Minimum diameter of ties shall be 8 mm and not less than one-third of the longitudinal bar diameter.

Diameter of bar =1/3 of Ø of largest longitudinal bar = 1/3x 16 = 6mm ….take 8mm

Spacing of ties as per 8.5.1.1 (f) of IS 15988:2013- The code suggests that the spacing of ties to be provided in the jacket in order to avoid flexural shear failure of column and provide adequate confinement to the longitudinal steel along the jacket is given as:

$s = (f_y \times d_h^2)/(\sqrt{f_{ck}} \times t_j) = (415 \times 16^2)/(\sqrt{35} \times 200) = 89.8$ mm

Provide 8mm Ø @90mm c/c.

4.1.2 Column No- 64

Height of column= 3000mm ;Width (b) =300mm ; Depth (D)=300mm; d= 260mm;

Reinforcement provided= 4,16Ø=804.25 mm^2 ; f_y = 415MPa; f_{ck}=30MPa.

P = 762.207 kN ;M = 22.198 kNm

So, P_u = 114331 kN ;M_u = 33.297 kNm

$$P_u = 0.4 \times f_{ck} \times A_c + 0.67 \times f_y \times A_{sc}$$

According to the provisions provided in to 8.5.1.2 (a) of IS 15988: 2013 [1], Concrete strength shall be at least 5 MPa greater than the strength of the existing concrete. Thus, taking value of f_{ck} = 35 N/mm^2 and assuming A_{sc} = 0.8% Ac

$$1143.31 \times 10^3 = 0.4 \times 35 \times A_c + 0.67 \times 415 \times (0.8\,\%A_c)$$

$$1143.31 \times 10^3 = 14 \times A_c + 2.224 \times A_c$$

$$1143.31 \times 10^3 = 16.224 \times A_c$$

$$A_c = 70470.29\ mm^2$$

According to 8.5.1.1 (e) of IS 15988:2013, A'_c =1.5A_c

Thus, A'_c =105705.44 mm^2

Assuming the cross sectional details as:

B=325mm, D=133851.15/325=325.25 mm

Jacketing details of cross section:

B = (325-300)/2=12.5 mm, D = (325.25-300)/2=12.625 mm

However, According to the code specified above, Minimum jacket thickness shall be 100 mm as per 8.5.1.2 (c) of IS 15988:2013 [1].

Thus, New size of the column: B = 300+100 +100=500mm, D =300 +100 +100=500mm

New concrete area=500×500=250000mm^2 > A_c= 70470.29 mm^2

Area of steel, A_s =0.8% × 500 × 500=2000 mm^2

But according to 8.5.1.1 (e) IS 15988:2013, A'_s = (4/3) A_s= (4/3) × 2000 = 2666.67 mm^2
Assuming 16mm Ø bars,
Thus, number of bars, N = 2666.67 × 4/ (π × 16^2) = 13.263 bars

Provide 10 NO. -16mm Ø bars for jacketed section. Therefore, revised jacketed section will be 500mm × 500 mm

Design of Lateral Ties:

As per 8.5.1.2 (e) of IS15988: 2013, Minimum diameter of ties shall be 8 mm and not less than one-third of the longitudinal bar diameter.

Diameter of bar =1/3 of Ø of largest longitudinal bar = 1/3 × 16 = 6mm ….take 8mm

Spacing of ties as per 8.5.1.1 (f) of IS 15988:2013- The code suggests that the spacing of ties to be provided in the jacket in order to avoid flexural shear failure of column and provide adequate confinement to the longitudinal steel along the jacket is given as:

$s = (f_y \times d_h^2)/(\sqrt{f_{ck}} \times t_j) = (415 \times 16^2)/(\sqrt{35} \times 200) = 89.8$ mm

Provide 8mm Ø @90mm c/c.

4.1.3 Column No- 74

Height of column= 3000mm ;Width (b) =300mm ; Depth (D)=300mm; d= 260mm;
Reinforcement provided= 4,16Ø=804.25 mm^2 ; f_y = 415MPa; f_{ck}=30MPa.

P = 808.693 kN ;M = 18.422 kN

So, P_u = 1213.04 kN ;M_u =27.633 kNm

$P_u = 0.4 \times f_{ck} \times A_c + 0.67 \times f_y \times A_{sc}$

According to the provisions provided in to 8.5.1.2 (a) of IS 15988: 2013, Concrete strength shall be at least 5 MPa greater than the strength of the existing concrete. Thus, taking value of f_{ck} = 35 N/mm^2 and assuming A_{sc} = 0.8% Ac

$$1213.04 \times 10^3 = 0.4 \times 35 \times A_c + 0.67 \times 415 \times (0.8\ \%\ A_c)$$

$$1213.04 \text{ x } 10^3 = 14 \times A_c + 2.224 \times A_c$$

$$1213.04 \times 10^3 = 16.224 \times A_c$$

$$A_c = 74768.245 \text{ mm}^2$$

According to 8.5.1.1 (e) of IS 15988:2013, $A'_c = 1.5A_c$

Thus, A'_c =112152.37 mm^2

Assuming the cross sectional details as:

B=350mm, D=112152.37/350=320.44 mm

Jacketing details of cross section:

B = (350-300)/2=25 mm, D = (320.44-300)/2=10.22 mm

However, According to the code specified above, Minimum jacket thickness shall be 100 mm as per 8.5.1.2 (c) of IS 15988:2013

Thus, New size of the column: B = 300+100 +100=500mm, D =300 +100 +100=500mm

New concrete area=500x500=250000mm^2 > A_c= 89234.10 mm^2

Area of steel, A_s =0.8% x 500 x 500=2000 mm^2

But according to 8.5.1.1 (e) IS 15988:2013, $A'_s = (4/3)\ A_s = (4/3) \times 2000 = 2666.67$ mm^2

Assuming 16mm Ø bars,

Thus, number of bars, $N = 2666.67 \times 4/ (\pi \times 16^2) = 13.263$ bars

Provide 10 NO. -16mm Ø bars for jacketed section. Therefore, revised jacketed section will be 500mm × 500 mm

Design of Lateral Ties:

As per 8.5.1.2 (e) of IS15988: 2013, Minimum diameter of ties shall be 8 mm and not less than one-third of the longitudinal bar diameter.

Diameter of bar =1/3 of Ø of largest longitudinal bar = 1/3 × 16 = 6mm ….take 8mm

Spacing of ties as per 8.5.1.1 (f) of IS 15988:2013- The code suggests that the spacing of ties to be provided in the jacket in order to avoid flexural shear failure of column and provide adequate confinement to the longitudinal steel along the jacket is given as:

$s = (f_y \times d_h^2)/(\sqrt{f_{ck}} \times t_j) = (415 \times 16^2)/(\sqrt{35} \times 200) = 89.8$ mm

Provide 8mm Ø @90mm c/c.

4.1.4 Column No- 79

Height of column= 3000mm ;Width (b) =300mm ; Depth (D)=300mm; d= 260mm; Reinforcement provided= 4,16Ø=804.25 mm2 ; f_y = 415MPa; f_{ck}=30MPa.

P = 742.748 kN ;M = 24.152 kNm

So, P_u = 1114.122 kN ;M_u = 36.228 kNm

$P_u = 0.4 \times f_{ck} \times A_c + 0.67 \times f_y \times A_{sc}$

According to the provisions provided in to 8.5.1.2 (a) of IS 15988: 2013, Concrete strength shall be at least 5 MPa greater than the strength of the existing concrete. Thus, taking value of f_{ck} = 35 N/mm^2 and assuming A_{sc} = 0.8% Ac

$1114.122 \times 10^3 = 0.4 \times 35 \times A_c + 0.67 \times 415 \times (0.8\,\%A_c)$

$1114.122 \times 10^3 = 14 \times A_c + 2.224 \times A_c$

$1114.122 \times 10^3 = 16.224 \times A_c$

$A_c = 68671.23$ mm^2

According to 8.5.1.1 (e) of IS 15988:2013, $A'_c = 1.5A_c$

Thus, $A'_c = 103006.84\ mm^2$

Assuming the cross sectional details as:
B=325mm, D=103006.84/325=316.95 mm

Jacketing details of cross section:
B = (325-300)/2=12.5 mm, D = (316.95-300)/2=8.475 mm

However, According to the code specified above, Minimum jacket thickness shall be 100 mm as per 8.5.1.2 (c) of IS 15988:2013
Thus, New size of the column: B = 300+100 +100=500mm, D =300 +100 +100=500mm

New concrete area=500 ×500=250000mm^2 > A_c= 68671.23 mm^2

Area of steel, A_s =0.8% x 500 x 500=2000 mm^2

But according to 8.5.1.1 (e) IS 15988:2013, $A'_s = (4/3)\ A_s = (4/3) \times 2000 = 2666.67\ mm^2$
Assuming 16mm Ø bars,
Thus, number of bars, N =2666.67 x 4/ (π x 16^2) = 13.263 bars

Provide 10 NO. -16mm Ø bars for jacketed section. Therefore, revised jacketed section will be 500mm × 500 mm.

Design of Lateral Ties:

As per 8.5.1.2 (e) of IS15988: 2013, Minimum diameter of ties shall be 8 mm and not less than one-third of the longitudinal bar diameter.

Diameter of bar =1/3 of Ø of largest longitudinal bar = 1/3× 16 = 6mm ….take 8mm

Spacing of ties as per 8.5.1.1 (f) of IS 15988:2013- The code suggests that the spacing of ties to be provided in the jacket in order to avoid flexural shear failure of column and provide adequate confinement to the longitudinal steel along the jacket is given as:

$s = (f_y \times d_h^2)/(\sqrt{f_{ck}} \times t_j) = (415 \times 16^2)/(\sqrt{35} \times 200) = 89.8$ mm

Provide 8mm Ø @90mm c/c.

4.1.5 Column No- 80

Height of column= 3000mm ;Width (b) =300mm ; Depth (D)=300mm; d= 260mm;
Reinforcement provided= 4,16Ø=804.25 mm^2 ; f_y = 415MPa; f_{ck}=30MPa.
P = 742.06 kN ;M = 12.007 kNm
P_u = 1113.09 kN ;M_u = 18.0105 kNm

$$P_u = 0.4 \times f_{ck} \times A_c + 0.67 \times f_y \times A_{sc}$$

According to the provisions provided in to 8.5.1.2 (a) of IS 15988: 2013, Concrete strength shall be at least 5 MPa greater than the strength of the existing concrete. Thus, taking value of f_{ck} = 35 N/mm^2 and assuming A_{sc} = 0.8% Ac

$$1113.09 \times 10^3 = 0.4 \times 35 \times A_c + 0.67 \times 415 \times (0.8\,\%A_c)$$
$$1113.09 \times 10^3 = 14 \times A_c + 2.224 \times A_c$$
$$1113.09 \times 10^3 = 16.224 \times A_c$$

$$A_c = 68607.62 \text{ mm}^2$$

According to 8.5.1.1 (e) of IS 15988:2013, $A'_c = 1.5A_c$
Thus, A'_c =102911.43 mm^2

Assuming the cross sectional details as:
B=325mm, D=133851.15/325=316.65 mm

Jacketing details of cross section:
B = (325-300)/2=12.5 mm, D = (316.65-300)/2=8.325 mm

However, According to the code specified above, Minimum jacket thickness shall be 100 mm as per 8.5.1.2 (c) of IS 15988:2013
Thus, New size of the column: B = 300+100 +100=500mm, D =300 +100 +100=500mm

New concrete area=500 × 500=250000mm^2 > A_c= 68607.62 mm^2
Area of steel, A_s =0.8% x 500 x 500=2000 mm^2

But according to 8.5.1.1 (e) IS 15988:2013, A'_s = (4/3) A_s= (4/3) × 2000 = 2666.67 mm^2
Assuming 16mm Ø bars,
Thus, number of bars, N =2666.67 × 4/ (π × 16^2) = 14 bars

Provide 10 NO. -16mm Ø bars for jacketed section. Therefore, revised jacketed section will be 500mm x 500 mm

Design of Lateral Ties:

As per 8.5.1.2 (e) of IS 15988: 2013, Minimum diameter of ties shall be 8 mm and not less than one-third of the longitudinal bar diameter.

Diameter of bar =1/3 of Ø of largest longitudinal bar = 1/3 × 16 = 6mm ….take 8mm

Spacing of ties as per 8.5.1.1 (f) of IS 15988:2013- The code suggests that the spacing of ties to be provided in the jacket in order to avoid flexural shear failure of column and provide adequate confinement to the longitudinal steel along the jacket is given as:

$s = (f_y \times d_h^2)/(\sqrt{f_{ck}} \times t_j) = (415 \times 16^2)/(\sqrt{35} \times 200) = 89.8$ mm
Provide 8mm Ø @90mm c/c.

4.1.6 Column No- 179

Height of column= 3000mm ;Width (b) =300mm ; Depth (D)=300mm; d= 260mm;
Reinforcement provided= 4,16Ø=804.25 mm^2 ; f_y = 415MPa; f_{ck}=30MPa.

P = 765.117 kN ;P_u = 1147.68 kN

M = 14.751 kNm ;M_u = 22.127 kNm

$$P_u = 0.4 \times f_{ck} \times A_c + 0.67 \times f_y \times A_{sc}$$

According to the provisions provided in to 8.5.1.2 (a) of IS 15988: 2013, Concrete strength shall be at least 5 MPa greater than the strength of the existing concrete. Thus, taking value of f_{ck} = 35 N/mm^2 and assuming A_{sc} = 0.8% Ac

$$1147.68 \text{ x } 10^3 = 0.4 \times 35 \times A_c + 0.67 \times 415 \times (0.8\,\%A_c)$$

$$1147.68 \text{ x } 10^3 = 14 \times A_c + 2.224 \times A_c$$

$$1147.68 \text{ x } 10^3 = 16.224 \times A_c$$

$$A_c = 70739.65 \text{ mm}^2$$

According to 8.5.1.1 (e) of IS 15988:2013, $A'_c = 1.5A_c$

Thus, A'_c =106109.47 mm^2

Assuming the cross sectional details as:

B=325 mm, D=133851.15/325=326.49 mm

Jacketing details of cross section:

B = (325-300)/2=12.5 mm, D = (326.49-300)/2=13.245 mm

However, According to the code specified above, Minimum jacket thickness shall be 100 mm as per 8.5.1.2 (c) of IS 15988:2013

Thus, New size of the column: B = 300+100 +100=500mm, D =300 +100 +100=500mm

New concrete area=500 × 500=250000mm^2 > A_c= 70739.65 mm^2

Area of steel, A_s =0.8% × 500 × 500=2000 mm^2

But according to 8.5.1.1 (e) IS 15988:2013, A'_s = (4/3) A_s= (4/3) × 2000 = 2666.67 mm^2
Assuming 16mm Ø bars,
Thus, number of bars, N =2666.67 × 4/ ($\pi \times 16^2$) = 13.236 bars

Provide 10 NO. -16mm Ø bars for jacketed section. Therefore, revised jacketed section will be 500mm × 500 mm

Design of Lateral Ties:

As per 8.5.1.2 (e) of IS 15988: 2013, Minimum diameter of ties shall be 8 mm and not less than one-third of the longitudinal bar diameter.

Diameter of bar =1/3 of Ø of largest longitudinal bar = 1/3 × 16 = 6mm ….take 8mm

Spacing of ties as per 8.5.1.1 (f) of IS 15988:2013- The code suggests that the spacing of ties to be provided in the jacket in order to avoid flexural shear failure of column and provide adequate confinement to the longitudinal steel along the jacket is given as:

$s = (f_y \times d_h^2)/(\sqrt{f_{ck}} \times t_j) = (415 \times 16^2)/(\sqrt{35} \times 200) = 89.8$ mm

Provide 8mm Ø @90mm c/c.

4.2 Jacketing Of Failed Columns For 6 Storey Building

After modelling of 6 storeys building, analysis is done and no of failed columns is been noted down. Failed columns are 62, 63, 64, 65, 66, 67, 69, 70,72,73,74,77,78,79,80,179,180,189,190. And Jacketing of all these columns are designed as per IS CODE 15988:2013 [1].

4.2.1 Column No- 62

Height of column= 3000mm ;Width (b) =300mm ; Depth (D)=300mm; d= 260mm;
Reinforcement provided= 4,16Ø=804.25 mm^2 ; f_y = 415MPa; f_{ck}=30MPa.
P = 854.53 kN ;P_u = 1281.795 kN
M = 12.819 kNm ;M_u = 19.23 Nm

$$P_u = 0.4 \times f_{ck} \times A_c + 0.67 \times f_y \times A_{sc}$$

According to the provisions provided in to 8.5.1.2 (a) of IS 15988: 2013 [1], Concrete strength shall be at least 5 MPa greater than the strength of the existing concrete. Thus, taking value of f_{ck} = 35 N/mm^2 and assuming A_{sc} = 0.8% Ac

$$1281.795 \times 10^3 = 0.4 \times 351 \times A_c \text{ x} + 0.67 \times 415 \times (0.8\,\%A_c)$$
$$1281.795 \times 10^3 = 14 \times A_c + 2.224 \times A_c$$
$$1281.795 \times 10^3 = 16.224 \times A_c$$

$$A_c = 79006.102 \text{ mm}^2$$

According to 8.5.1.1 (e) of IS 15988:2013, A'_c =1.5A_c
Thus, A'_c =118509.15 mm2

Assuming the cross sectional details as:
B=325 mm, D=118509.15/325=364.64 mm

Jacketing details of cross section:
B = (325-300)/2=12.5 mm, D = (364.64-300)/2=32.32 mm

However, According to the code specified above, Minimum jacket thickness shall be 100 mm as per 8.5.1.2 (c) of IS 15988:2013
Thus, New size of the column: B = 300+100 +100=500mm, D =300 +100 +100=500mm

New concrete area=500 × 500=250000mm^2 > A_c= 79006.102 mm^2

Area of steel, A_s =0.8% x 500 x 500=2000 mm^2

But according to 8.5.1.1 (e) IS 15988:2013, $A'_s = (4/3) A_s = (4/3) \times 2000 = 2666.67\ mm^2$
Assuming 16mm Ø bars,
Thus, number of bars, N =2666.67 x 4/ (π x 16^2) = 13.236 bars

Provide 10 NO. -16mm Ø bars for jacketed section. Therefore, revised jacketed section will be 500mm × 500 mm

Design of Lateral Ties:

As per 8.5.1.2 (e) of IS15988: 2013, Minimum diameter of ties shall be 8 mm and not less than one-third of the longitudinal bar diameter.

Diameter of bar =1/3 of Ø of largest longitudinal bar = 1/3 × 16 = 6mm ….take 8mm

Spacing of ties as per 8.5.1.1 (f) of IS 15988:2013- The code suggests that the spacing of ties to be provided in the jacket in order to avoid flexural shear failure of column and provide adequate confinement to the longitudinal steel along the jacket is given as:

$s = (f_y \times d_h^2)/(\sqrt{f_{ck}} \times t_j) = (415 \times 16^2)/(\sqrt{35} \times 200) = 89.8$ mm

Provide 8mm Ø @90mm c/c.

4.2.2 Column No- 63

Height of column= 3000mm ;Width (b) =300mm ; Depth (D)=300mm; d= 260mm;
Reinforcement provided= 4,16Ø=804.25 mm^2 ; f_y = 415MPa; f_{ck}=30MPa.
P = 1134.19 kN ;P_u = 1701.29 kN
M = 13.163 kNm ;M_u = 19.75 kNm

$$P_u = 0.4 \times f_{ck} \times A_c + 0.67 \times f_y \times A_{sc}$$

According to the provisions provided in to 8.5.1.2 (a) of IS 15988: 2013, Concrete strength shall be at least 5 MPa greater than the strength of the existing concrete. Thus, taking value of f_{ck} = 35 N/mm^2 and assuming A_{sc} = 0.8% Ac

$$1701.29 \times 10^3 = 0.4 \times 35 \times A_c + 0.67 \times 415 \times (0.8\,\%A_c)$$

$$1701.29 \times 10^3 = 14 \times A_c + 2.224 \times A_c$$

$$1701.29 \times 10^3 = 16.224 \times A_c$$

$$A_c = 104862.55 \text{ mm}^2$$

According to 8.5.1.1 (e) of IS 15988:2013, $A'_c = 1.5A_c$

Thus, A'_c =157293.8 mm^2

Assuming the cross sectional details as:

B=400 mm, D=157293.8/400=393.2 mm

Jacketing details of cross section:

B = (400-300)/2=50 mm, D = (393.2-300)/2=46.6 mm

However, According to the code specified above, Minimum jacket thickness shall be 100 mm as per 8.5.1.2 (c) of IS 15988:2013

Thus, New size of the column: B = 300+100 +100=500mm, D =300 +100 +100=500mm

New concrete area=500 × 500=250000mm^2 > A_c= 104862.55 mm^2

Area of steel, A_s =0.8% × 500 × 500=2000 mm^2

But according to 8.5.1.1 (e) IS 15988:2013, $A'_s = (4/3)\ A_s = (4/3) \times 2000 = 2666.67$ mm^2

Assuming 16mm Ø bars,

Thus, number of bars, N =2666.67 × 4/ ($\pi \times 16^2$) = 13.236 bars

Provide 10 NO. -16mm Ø bars for jacketed section. Therefore, revised jacketed section will be 500mm × 500 mm.

Design of Lateral Ties:

As per 8.5.1.2 (e) of IS 15988: 2013, Minimum diameter of ties shall be 8 mm and not less than one-third of the longitudinal bar diameter.

Diameter of bar =1/3 of Ø of largest longitudinal bar = 1/3 × 16 = 6mm ….take 8mm

Spacing of ties as per 8.5.1.1 (f) of IS 15988:2013- The code suggests that the spacing of ties to be provided in the jacket in order to avoid flexural shear failure of column and provide adequate confinement to the longitudinal steel along the jacket is given as:

$s = (f_y \times d_h^2)/(\sqrt{f_{ck}} \times t_j) = (415 \times 16^2)/(\sqrt{35} \times 200) = 89.8$ mm

Provide 8mm Ø @90mm c/c.

4.2.3 Column No- 65

Height of column= 3000mm ;Width (b) =300mm ; Depth (D)=400mm; d= 360mm;
Reinforcement provided= 4,20Ø=1256.64 mm^2 ; f_y = 415MPa; f_{ck}=30MPa.
P = 992.776 kN ;P_u = 1489.16 kN
M = 29.639 kNm ;M_u = 44.4585 kNm

$$Pu = 0.4 \times f_{ck} \times A_c + 0.67 \times f_y \times A_{sc}$$

According to the provisions provided in to 8.5.1.2 (a) of IS 15988: 2013, Concrete strength shall be at least 5 MPa greater than the strength of the existing concrete. Thus, taking value of f_{ck} = 35 N/mm^2 and assuming A_{sc} = 0.8% Ac

$$1489.16 \times 10^3 = 0.4 \times 35 \times A_c + 0.67 \times 415 \times (0.8\,\%A_c)$$

$$1489.16 \times 10^3 = 14 \times A_c + 2.224 \times A_c$$

$$1489.16 \times 10^3 = 16.224 \times A_c$$

$$A_c = 91787.48\ mm^2$$

According to 8.5.1.1 (e) of IS 15988:2013, $A'_c = 1.5A_c$

Thus, $A'_c = 137681.2\ mm^2$

Assuming the cross sectional details as:

B=325 mm, D=137681.2/325=423.63 mm

Jacketing details of cross section:

B = (325-300)/2=12.5 mm, D = (423.63-400)/2= 11.815 mm

However, According to the code specified above, Minimum jacket thickness shall be 100 mm as per 8.5.1.2 (c) of IS 15988:2013

Thus, New size of the column: B = 300+100 +100=500mm, D =400+100 +100=600mm

New concrete area=500 × 600=300000$mm^2 > A_c$= 91787.48 mm^2

Area of steel, A_s =0.8% × 500 × 600=2400 mm^2

But according to 8.5.1.1 (e) IS 15988:2013, $A'_s = (4/3)\ A_s = (4/3) \times 2400 = 3200\ mm^2$

Assuming 16mm Ø bars,

Thus, number of bars, N =3200 × 4/ (π × 16^2) = 15.915 bars

Provide 12 NO. -16mm Ø bars for jacketed section. Therefore, revised jacketed section will be 500mm × 600 mm

Design of Lateral Ties:

As per 8.5.1.2 (e) of IS15988: 2013, Minimum diameter of ties shall be 8 mm and not less than one-third of the longitudinal bar diameter.

Diameter of bar =1/3 of Ø of largest longitudinal bar = 1/3 × 16 = 6mm ….take 8mm

Spacing of ties as per 8.5.1.1 (f) of IS 15988:2013- The code suggests that the spacing of ties to be provided in the jacket in order to avoid flexural shear failure of column and provide adequate confinement to the longitudinal steel along the jacket is given as:

$s = (f_y \times d_h^2)/(\sqrt{f_{ck}} \times t_j) = (415 \times 16^2)/(\sqrt{35} \times 200) = 89.8$ mm

Provide 8mm Ø @90mm c/c.

4.2.4 Column No- 72

Height of column= 3000mm ;Width (b) =300mm ; Depth (D)=400mm; d= 360mm;
Reinforcement provided= 4,20Ø=1256.64 mm^2 ; f_y = 415MPa; f_{ck}=30MPa.
P = 1164.52 kN ;P_u = 1746.78 kN
M = 21.098 kNm ;M_u = 31.647 kNm

$$P_u = 0.4 \times f_{ck} \times A_c + 0.67 \times f_y \times A_{sc}$$

According to the provisions provided in to 8.5.1.2 (a) of IS 15988: 2013, Concrete strength shall be at least 5 MPa greater than the strength of the existing concrete. Thus, taking value of f_{ck} = 35 N/mm^2 and assuming A_{sc} = 0.8% Ac

$$1746.78 \times 10^3 = 0.4 \times 35 \times A_c + 0.67 \times 415 \times (0.8\,\%A_c)$$
$$1746.78 \times 10^3 = 14 \times A_c + 2.224 \times A_c$$
$$1746.78 \times 10^3 = 16.224 \times A_c$$

$$A_c = 107666.42 \text{ mm}^2$$

According to 8.5.1.1 (e) of IS 15988:2013, $A'_c = 1.5A_c$
Thus, A'_c =161499.63 mm^2

Assuming the cross sectional details as:
B=350 mm, D=161499.63/350=461.43 mm

Jacketing details of cross section:
B = (350-300)/2=50 mm, D = (461.43-400)/2=30.715 mm

However, According to the code specified above, Minimum jacket thickness shall be 100 mm as per 8.5.1.2 (c) of IS 15988:2013

Thus, New size of the column: B = 300+100 +100=500mm, D =400 +100 +100=600mm

New concrete area=500 × 600=300000mm^2 > A_c= 107666.42 mm^2

Area of steel, A_s =0.8% × 500 × 600=2400 mm^2

But according to 8.5.1.1 (e) IS 15988:2013, A'_s = (4/3) A_s= (4/3) × 2400 = 3200 mm^2
Assuming 12mm Ø bars,

Thus, number of bars, N =3200 × 4/ (π × 12^2) = 28.29 bars

Provide 18 NO. -12mm Ø bars for jacketed section. Therefore, revised jacketed section will be 500mm × 600 mm

Design of Lateral Ties:

As per 8.5.1.2 (e) of IS15988: 2013, Minimum diameter of ties shall be 8 mm and not less than one-third of the longitudinal bar diameter.

Diameter of bar = 1/3 of Ø of largest longitudinal bar = 1/3 × 12 = 4mm ….take 8mm

Spacing of ties as per 8.5.1.1 (f) of IS 15988:2013- The code suggests that the spacing of ties to be provided in the jacket in order to avoid flexural shear failure of column and provide adequate confinement to the longitudinal steel along the jacket is given as:

$s = (f_y \times d_h^2)/(\sqrt{f_{ck}} \times t_j) = (415 \times 12^2)/(\sqrt{35} \times 200) = 50.506$ mm

Provide 8mm Ø @55mm c/c.

NOTE :- In jacketing of 6 storey building even , it is been noticed that maximum axial load is coming on column no- 72 , of 1164.52 KN which is of c\s - 400mm × 300mm.Still in jacketing of this column , jackets are of 100 mm thickness. So, it can be concluded that any coulomb with less axial force will bear jackets also of 100 mm thick only.

The reason behind column after nos-72 have less axial load than column no 72,because they are columns of 1st floor, that's why load reduces.

4.3 Cost of RC Jackets of Column No 63

The formula for calculation of materials for required volume of concrete is given by equation given as follows.

$$V_C = \frac{W}{1000} + \frac{C}{1000S_C} + \frac{F_a}{1000S_{fa}} + \frac{C_a}{1000S_{ca}} \quad \text{-------(1)}$$

Where, V_c = Absolute volume of fully compacted fresh concrete ;W =Mass of water; C = Mass of cement ; F_a = Mass of fine aggregates ; C_a = Mass of coarse aggregates; S_c, S_{fa} and S_{ca} are the specific gravities of cement, fine aggregates and coarse aggregates respectively.

Let, V_{cj} = Vol of concrete in jacketed section - Vol of reinforcement

$=[(500^2-300^2)-(10\times\pi\times16^2\div4)] = 0.482\ m^3$

V_R = Vol of lateral & transverse reinf.

$= 6.13\times10^{-3} + 3.52\times10^{-3} = 9.65\times10^{-3}\ m^3$

Let, M_R= Mass of reinf.= 7850 kg/m^3 $\times9.65\times10^{-3}$ = 75.75 kg

Consider concrete with mix proportion of 1:1.5:3 where, 1 is part of cement, 1.5 is part of fine aggregates and 3 is part of coarse aggregates of maximum size of 20mm. The water cement ratio required for mixing of concrete is taken as 0.45.

Assuming bulk densities of materials

- Cement = 1500 kg/m^3
- Sand = 1700 kg/m^3
- Coarse aggregates = 1650 kg/m^3

Specific gravities of concrete materials

- Cement = 3.15
- Sand = 2.6
- Coarse aggregates = 2.6.

The mix proportion of 1:1.5:3 by dry volume of materials can be expressed in terms of masses as:

Cement = 1 × 1500 = 1500 kg ; Sand = 1.5 × 1700 = 2550 kg

Coarse aggregate = 3 × 1650 = 4950 kg

Therefore, the ratio of masses of these materials w.r.t. cement will as follows =1:(2550/1500):(4950:1500) = 1 : 1.7 : 3.3

So, from above data, C= 179.15 kg ; F_a= 304.55 kg ; C_a = 591.18 kg

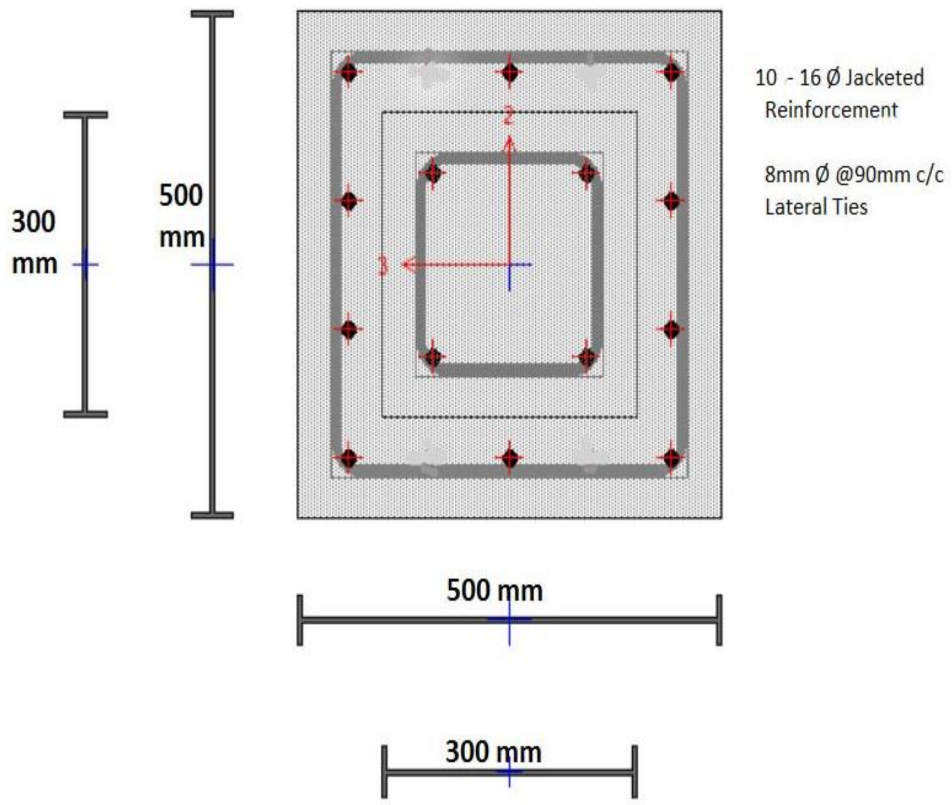
Therefore, cost of concrete = Cost of (Cement + FA + CA + Reinf.)

=(179.15÷50×Rs350)+(304.55÷1700×Rs882)+(591÷1650×Rs2258) =Rs 2220

Cost of Reinf. = Rs 50/kg× 75.75 kg= Rs 3788.

Therefore, Total cost of material= INR 6008.

4.4 Design of C/S of Jacketed Column in E-Tabs



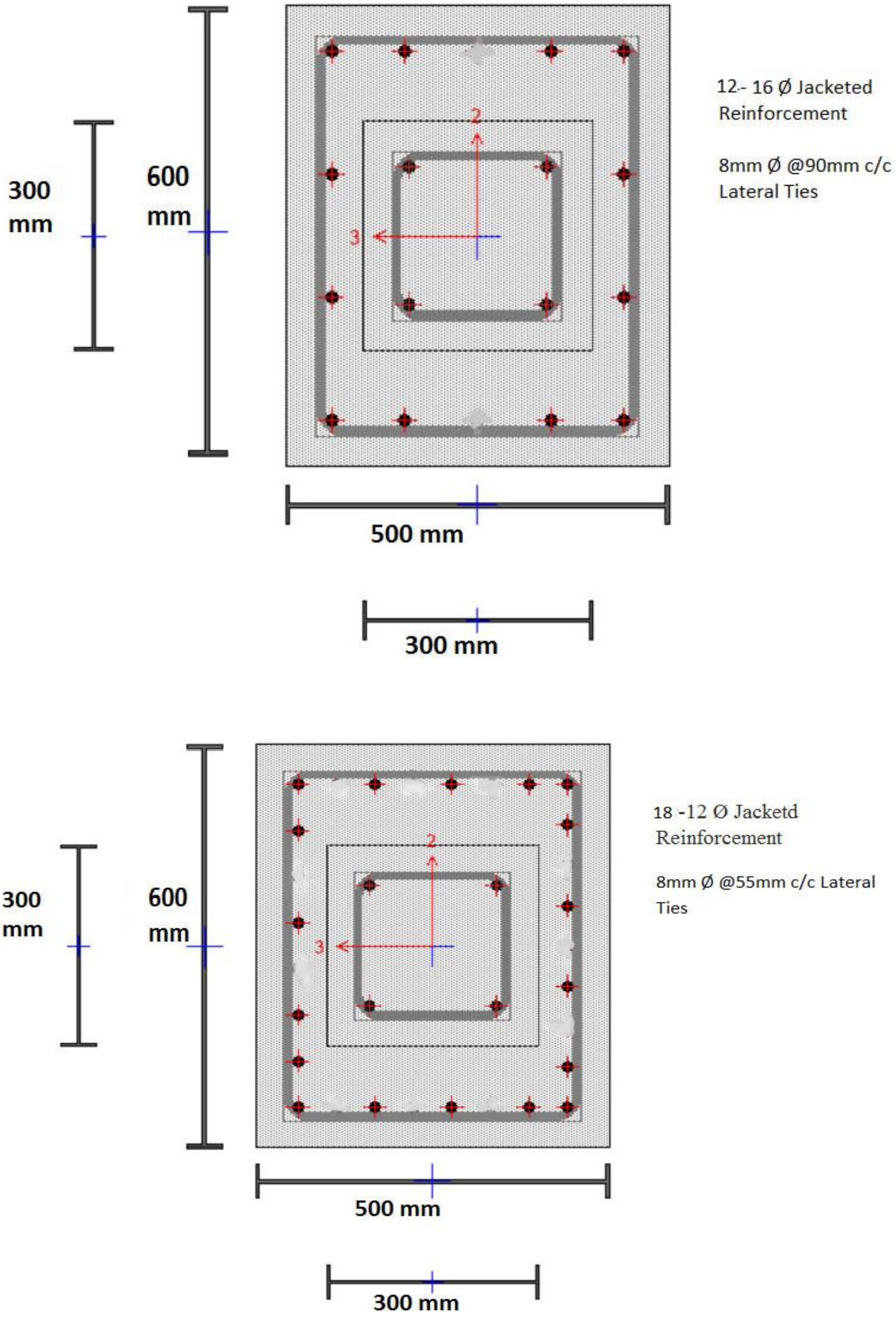


Fig 4.1: Design of C/S of Jacketed columns in E-Tabs

CHAPTER 5

DESIGN OF FRP JACKETING

5.1 Design of FRP Jacketing of Failed Column No-63

The given dimensions are, b =300 mm,   d =260mm;

f_{ck} provided = 30 Mpa; f_{ck} required = 35 Mpa,

Pt % provided = 0.8% of A_c = 720mm^2,

Area of concrete = 89280 mm^2,

P_u = 1447.734 kN, M_u = 22.961 kNm

Data provided from manufacturer for jacket is as follows :

Ultimate strain in carbon fibre (ε_f) = 1.5% ;   Effective fibre thickness(t_f) =0.33mm

Elastic modulus of carbon fibre (E_f) = 137000 N/mm^2;   No of Wrap (n) =2 No.

Effectively Confined Core for Non Circular Section

Total Plan Area of Unconfined concrete is obtained as per FIB (2010) [11].

b' = b - 2 × r_c = 300- 2 ×25 =250 mm ; r_c=Radius of rounded corners of column

d' = d- 2 × r_c = 260- 2 ×25 = 210 mm

A_u = (b'2+d'2)÷3 =35533.33 mm^2

The confinement effectiveness coefficient k_e considering ratio (A_c-A_u)/A_c as per Fib 14 eq^n 6.29 is given as,

$K_e = 1-[(b'^2+d'^2)/\{3A_g(1-\rho_{sg})\}]=$ 0.602 ;

$\rho_{sg} = A_s/A_g = (\pi\times16^2/300^2) = 0.00893$

The Lateral confining pressures induced by the FRP wrapping as per Fib eqn 6.30 is given as

Along direction b,   Along direction d,

$K_{confb} = \rho_b\, k_e\, E_f$ $K_{confd} = \rho_d\, k_e\, E_f$

Where, ρ_b =2ntf/b = 0.0044; and ρ_d =2ntf/d= 0.0051

K_{confb} = 362.89 ; K_{confd} = 420.62

Effective confining pressure, along direction b; Along direction d

$f_{lb} = (K_{confb} \times \varepsilon_f)/2K_e = 4.52\ N/mm^2$ $f_{ld} = (K_{confd} \times \varepsilon_f)/2K_e = 5.24\ N/mm^2$

Taking min value: $f_l = 4.52\ N/mm^2$

Maximum confining pressure as per equation 6.5 of FIB [11], which is given as,

$f_{cc} = f'_c\ [2.254\sqrt{(1+7.94f_l / f'_c)} - 2f_l/f'c - 1.254]$

$f_{cc} = 53.552\ N/mm^2$

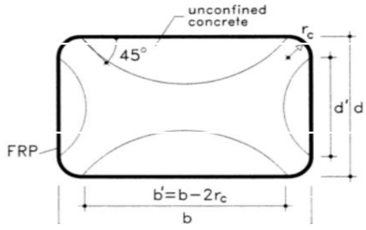


Fig5.1: Effective confined core for non circular sections.

"Hence provide 2 layer of FRP jacket."

5.1.1 Cost of FRP Jackets of Column No 63

Since, Cost of FRP Jackets is around Rs 2600 - Rs4600 per m^2

And area to be jacketed = 3.65 m^2

So, total cost of FRP Jacket per column(2 layer)= INR 18980

All columns for 5&6 storey posses same cost per column.

5.2 Design of FRP Jacketing of Failed Column No-65 of 6 Storey

The given dimensions are, b =300 mm, d = 360mm;

f_{ck} provided = 30Mpa; f_{ck} required = 35Mpa,

Pt % provided = 0.8% of A_c = 953.5 mm^2,

Area of concrete = 119195.75 mm^2,

Pu = 1489.16 kN, Mu = 44.46 kNm

Data provided from manufacturer for jacket is as follows :

Ultimate strain in carbon fibre (ε_f) = 1.5% ; Effective fibre thickness(t_f) =0.33mm

Elastic modulus of carbon fibre (E_f) = 137000 N/mm^2; No of Wrap (n) =2 No.

Effectively Confined Core for Non Circular Section

Total Plan Area of Unconfined concrete is obtained as per FIB (2010) [11].

$b' = b - 2 \times r_c = 300- 2 \times 25 = 250$ mm ; r_c=Radius of rounded corners of column

$d' = d - 2 \times r_c = 360- 2 \times 25 = 310$ mm

$A_u = (b'2+d'2) \div 3 = 52866.67$ mm^2

The confinement effectiveness coefficient k_e considering ratio $(A_c-A_u)/A_c$ as per Fib 14 eq^n 6.29 is given as,

$K_e = 1-[(b'^2+d'^2)/\{3A_g(1-\rho_{sg})\}] = 0.556$;

$\rho_{sg} = A_s/A_g = (\pi \times 16^2/300 \times 400) = 0.0067$

The Lateral confining pressures induced by the FRP wrapping as per Fib eqn 6.30 is given as

Along direction b, Along direction d,

$K_{confb} = \rho_b \, k_e \, E_f$ $K_{confd} = \rho_d \, k_e \, E_f$

Where, ρ_b =2ntf/b = 0.0044; and ρ_d =2ntf/d= 0.0037

$K_{confb} = 335.16$; $K_{confd} = 281.84$

Effective confining pressure, along direction b; Along direction d

$f_{lb} = (K_{confb} \times \varepsilon_f)/2K_e = 4.52$ N/mm^2 $f_{ld} = (K_{confd} \times \varepsilon_f)/2K_e = 3.81$ N/mm^2

Taking min value: $f_l = 3.81$ N/mm^2

Maximum confining pressure as per equation 6.5 of FIB [11], which is given as,

$f_{cc} = f'_c \, [2.254\sqrt{(1+7.94f_l / f'_c)} - 2f_l/f'c - 1.254]$

$f_{cc} = 56.206$ N/mm^2

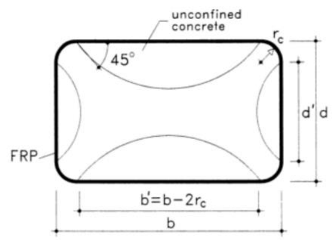


Fig5.2: Effective confined core for non circular sections.

"Hence provide 2 layer of FRP jacket."

5.2.1 Cost of FRP Jacketing of column no 65

Since, Cost of FRP Jackets is around Rs 2600 - Rs4600 per m^2

And area to be jacketed = 4.27 m^2

So, total cost of FRP Jacket per column(2 layer)= INR 22204

All columns for 5&6 storey posses same cost per column.

Table - 5.1: Details of Jacketing of 5 storey Building

Column No	P_u (kN)	M_u (kNm)	RC Jacketed section Reinf.	RC Jacketed C/S (mm^2)	RC Jacketed Lateral Ties	Layer of FRP Jacketing
63	1447.734	22.961	10-16 ø	500 × 500	8mm ø @90mm c/c	2
64	1143.31	33.297	10-16 ø	500 × 500	8mm ø @90mm c/c	2
74	1213.04	27.633	10-16 ø	500 × 500	8mm ø @90mm c/c	2
79	1114.122	36.228	10-16 ø	500 × 500	8mm ø @90mm c/c	2
80	1113.09	18.011	10-16 ø	500 × 500	8mm ø @90mm c/c	2
179	1147.68	22.127	10-16 ø	500 × 500	8mm ø @90mm c/c	2

Table - 5.2: Details of Jacketing of 6 storey Building

Column No	P_u (kN)	M_u (kNm)	RC Jacketed section Reinf.	RC Jacketed C/S (mm^2)	RC Jacketed Lateral Ties	Layer of FRP Jacketing
62	1281.795	19.23	10- 16 ø	500 × 500	8mm ø @90mm c/c	2
63	1701.29	19.75	10- 16 ø	500 × 500	8mm ø @90mm c/c	2
64	1379.89	31.793	10- 16 ø	500 × 500	8mm ø @90mm c/c	2
65	1489.16	44.46	12- 16 ø	500 × 600	8mm ø @90mm c/c	2
66	1155.173	28.475	10- 16 ø	500 × 500	8mm ø @90mm c/c	2
67	1176.81	18.022	10- 16 ø	500 × 500	8mm ø @90mm c/c	2
69	1529.952	45.003	10- 16 ø	500 × 600	8mm ø @90mm c/c	2
70	1249.54	27.315	10- 16 ø	500 × 500	8mm ø @90mm c/c	2
72	1746.78	31.647	18- 12 ø	500 × 600	8mm ø @55mm c/c	2
73	1278.425	24.305	10- 16 ø	500 × 500	8mm ø @90mm c/c	2
74	1443.320	24.912	10- 16 ø	500 × 500	8mm ø @90mm c/c	2
77	1030.506	24.417	10- 16 ø	500 × 500	8mm ø @90mm c/c	2
78	1099.292	33.303	10- 16 ø	500 × 500	8mm ø @90mm c/c	2
79	1327.931	33.684	10- 16 ø	500 × 500	8mm ø @90mm c/c	2
80	1328.136	17.301	10- 16 ø	500 × 500	8mm ø @90mm c/c	2
179	1402.355	18.495	10- 16 ø	500 × 500	8mm ø @90mm c/c	2
180	1154.202	44.043	10- 16 ø	500 × 500	8mm ø @90mm c/c	2
189	1063.838	32.985	10- 16 ø	500 × 500	8mm ø @90mm c/c	2
190	1196.936	29.49	10- 16 Ø	500 × 500	8mm Ø @90mm c/c	2

CHAPTER 6

DESIGN OF STEEL FIBRES REINFORCED CONCRETE JACKETS

6.1 Design of SFRP Jacketing of Failed column no-63

b=300 mm; d=300 mm;   Effective cover of column(a) = 40 mm

Steel reinforcement(2,16Ø) in the compression zone of cross sectional area(A_s')=402.12 mm^2

Steel reinforcement(2,16Ø) in the tensile zone of cross sectional area(A_s)=402.12 mm^2

And, their yielding point, f_y=210 MPa;

After rehabilitation, the column will have to undergo an axial force, F=1447.73kN and a bending moment, M=22.96 kN.m. The column cannot support these efforts without strengthening.

The design column height(H_0) =3.05 m.

Solution:

Let us choose the strengthening materials: Steel fibre

Compressive strength($f_{c}'{}_{ad}$) =17.72MPa ; Tensile strength(f_t)=1.37 MPa;

Ultimate compressive strain(ε_u)=0.00337

The factor defining the intensity of compressive stress on the equivalent rectangular stress block for fibre reinforced concrete, $\gamma_f = 0.85+0.03\,(WL/D)/450 \leq 0.88$;Where WL/D is the percentage of steel fibres by weight. In this case, γ_f =0.861 is taken.

Additional steel reinforcing bars in the jacket: $A_{s\,ad}' = A_{s\,ad}$; $f_{y\,ad}$=280 MPa.

For this design, rectangular stress block is to be used.

Let us assume the thickness of the SFRC(t)=150 mm.

The sizes of the strengthened element are, b'=b+2 t=600 mm; d'=d+2 t=600 mm

Loading eccentricity about centroid of the cross section(e_o) = M/F=15.85 mm

Loading eccentricity about centroid of the additional steel reinforcement in the tension zone of the cross section, e= e_o +0.5 d' -a=275.85 mm

Projection of all forces on the longitudinal axis of the column ∑X=0 gives:

$F - C_{s\,ad} - C_{c\,ad} + T_s' + T_s + T_f + T_{s\,cad}=0$ ———————— (1)

Where the resultant force in the additional compression and in the tension reinforcing steel bars, $C_{s\,ad}$ =28 A_s' =28 A_s = $T_{s\,ad}$ =11259.36 mm^2

The resultant force in the compression fibre concrete, $C_{c\,ad} = \gamma_f\, f_c'{}_{ad}\, b'(x)$ = 9154.15x.

The resultant force in the existing tension reinforcing steel, initially working in the compression zone, $T_s' = f_y A_s'$ = 210×402.12= 84.45 kN

The resultant force in the existing tension steel, $T_s = f_y A_s$=210×402.12= 84.45 kN

The resultant force in the tension fibre concrete, $T_f = f_t$ b'd =1.37×600×150 =123.3 kN

By replacing the forces by their respective values in the equation (1), the depth of the equivalent rectangular stress block is calculated as, x=190.07 mm.

Taking moments of all forces and equating to zero gives:

$Fe - C_{sad}(d'-2a) - C_{cad}(d'-0.5x-a) + T_s'(d+t-2a) + T_s\,t + T_f(0.5t-a) = 0$ ———— (2)

The following calculations indicate that the additional steel reinforcing bars are not needed. However the design code requires in this case a minimum reinforcement, the amount of which depends on the ratio H_o/H .

Since, H= (*√3/6)* d' =173.21mm ⇒ H_o/H =17.6

Consequently, the reinforcement cross sectional area required by the code

$A_{s\,min}$=0.1% b' (d'-a)=336 mm^2 ⇒ We take 3,12 Ø

Let us check the resistance condition:

$Fe \leq C_{sad}$ (d'-2 a) + C_{cad} (d' -0.5x-a)- T_s' (d+t-2 a)- T_s t -T_f(0.5 t-a)

399.35kN.m<741.29 kN.m (Since, C_{Cad}= γ_f f_{cad}' b'x = 9154.15x=1739.93 kN)

Obviously, the flexural strength of the column is sufficient after the strengthening by the S.F.R.C.

Hence, Jacket of thickness(t)=150 mm.

6.2 Cost of SFRC Jackets of column no 63

Vol. of concrete used in Jacketing

= (150mm×300mm×3050mm)×4=0.549m^3

Vol. of reinforcement used in jacketing

=7850 kg/m^3×0.000336×3.05=8.04 kg

Cost of reinforcement used in jacketing=Rs50×8.04=Rs 402

Cost of concrete used in jacketing derived similar as done in section 2.1=Rs 2530

Since, Cost of SFRC in the market is Rs 20000-Rs 60000/ton

Cost of SFRC used in jacketing=

=(1% of concrete used in jackets)×7900kg/m^3×Rs20 = Rs867.42

So, Total Cost of SFRC=Rs 3800

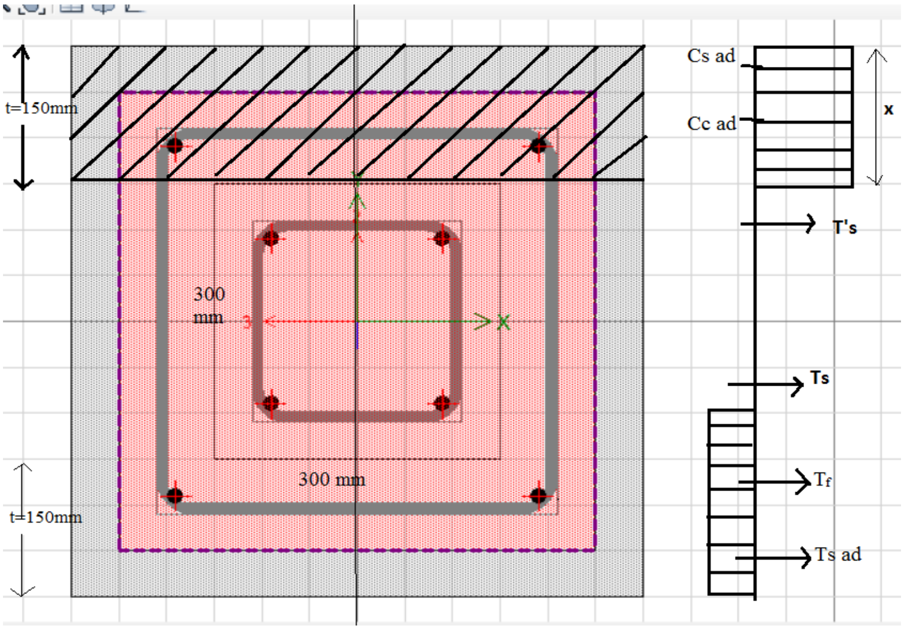


Fig 6.1 : Column Jacketing By Steel Fibre Reinforced Concrete

CHAPTER 7
DESIGN OF STEEL JACKETING

7.1 Design of Steel Jacketing of Column no-63

Moment capacity of strengthened column is two times that of ordinary RC column.

Width of column, b =300mm; Depth of column, D=300mm; Storey height, h=3000mm; Clear cover, d_c=40mm; Reinforcement provided= 4,16Ø=804.25 mm^2

Stirrups=8mm diameter@90mm c\c, Young's modulus of steel, E =200GPa

f_y = 415 MPa; f_{ck}=30 MPa.

P = 965.156 kN ; M = 15.307 kNm; P_u = 1447.734 kN ; M_u = 22.961 kNm

Moment capacity of ordinary RC column M_u=22.961 kNm.

Axial compressive load P_u = 1447.734 kN.

Thus, the minimum required moment capacity of strengthened column should be M_{st}= 45.922 kNm.

Let us choose 4 steel angle sections ISA 30×30×5mm@2.2kg/m [5].

Yield strength of angle section, f_y= 250MPa; Thickness of angles, t' =5mm;

Width of single leg of angles, c=30mm; Sectional area, a= 2.77cm^2;

Distance of centre of gravity from the edge of section, C_{xx} =9.2 mm;

Moment of inertia, I_{ang}=2.1cm^4; Section modulus, Z_{ang}=1cm^3

Section properties of steel cage are computed only from four angles placed at four corners of RC column

Moment of inertia, I =1200 cm^4; Section modulus, Z =80 cm^3; Moment capacity of angle sections, $M_{ang}= f_y \times Z_{ang}$=0.25kNm; Moment capacity of steel cage, $M_{nv}= f_y \times Z$ =20 kNm;

Centre-to-centre spacing of angles,$b'=b_y+2(t'-C_{xx})$=291.6mm

Clear spacing of angles, $b_{cl}=b_y+2(t'-c)$=250 mm

Assume, Ten numbers of 6mm thick battens used on each face of the steel cage, i.e. N =10, t =6mm

Design shear force on battens, $H'_{ba}=1.25\times M_{nv}/(2\times b'\times N)$= 4.29 kN

Design bending moment on battens, $M'_{ba}=H'_{ba}\times b_{cl}/2$= 0.54 kNm

Required depth of battens = $\sqrt{[6\times M'_{ba}/(t\times f_y)]}$= 46.47 mm

Since, Design yield strength of battens, f_y= 250MPa

Required clear spacing, $h'=4\times M_{ang}\times h/M_{nv}$=150 mm

Required c/c spacing, $s=h[\sqrt[3]{4I_{ang}/\{I(N-1)\}}]$=275.89 mm

Provide 6mm thick and 50 mm width plates as battens at a c/c spacing of 275 mm, which gives a clear spacing of 225 mm. For economy purposes, only requirements of batten depth and centre-to- centre spacing were preferred over clear spacing requirements. Width of end battens can be taken as 75 mm, which is about 1.5 times that of intermediate batten.

Effective confinement width $b_{xe} = b_x + 2(t'-c)$=250mm, $b_{ye}=b_y+2(t'-c)$=250mm

Gross area of column A_c=900cm^2; Area of reinforcement A_{st}=8.04 cm^2; Area of concrete A_{cc}=891.96cm^2

Reinforcement ratio $\rho_{sl}= A_{st}/A_{cc}$=0.009

Lateral confining pressures along x- and y-directions can be given by $\sigma_x = 2A_s f_y/b_y s$=1.82 MPa $\sigma_y = 2A_s f_y/b_x s$=1.82 MPa ;$A_s$=6×50=300 mm^2

Effective spacing of battens, $s_e=s-(d+2c)$= 165 mm

$$\sigma_{xe} = \frac{\left(1-\frac{b_{xe}^2+b_{ye}^2}{3b_xb_y}\right)\left(1-\frac{s_e}{2b_x}\right)\left(1-\frac{s_e}{2b_y}\right)}{(1-\rho_{sl})}\frac{2td}{sb_y}f_y \qquad \sigma_{ye} = \frac{b_y}{b_x}\sigma_{xe}$$

Effective confining stresses in both directions, σ_{xe}/f_{co}=0.048, σ_{ye}/f_{co}=0.048

Confining strength ratio, k=1.35 ;Confined compressive strength of concrete $f_{cc}=k\times f_{co}$=40.5 MPa

Peak and ultimate strain of concrete $\varepsilon_{cc}=\varepsilon_{co}[1+5(k-1)]$=0.0055 ; ε_{co}=0.002

$\varepsilon_{cu}=0.0035+0.1((\sigma_{xe}+\sigma_{ye})/f_{co})$=0.013.

Using confined stress–strain properties of concrete and geometric properties of column section, the moment capacity of column concrete, M_c is computed as 76.32 kNm, as per Indian Standard code 456:2000 provisions [4].

Thus, the design moment capacity of strengthened column, $M_s=M_c+M_{nv}$= 96.32 kNm, which is greater than the desired value of 45.922 kNm. Hence, the design is *satisfactory*.

7.2 Cost of Steel Jacketing of Column no 63

Amount of steel angle sections ISA 30×30×5mm@2.2kg/m=4×10×2.2= 88 kg

Amount of braces required=Mild Steel Flats@2.4 kg/m= 4×10×0.3×2.4=28.8 kg

Total amount of Steel used= 116.8 kg

Cost of Steel used @Rs 50/kg= 50×116.8=Rs 5840

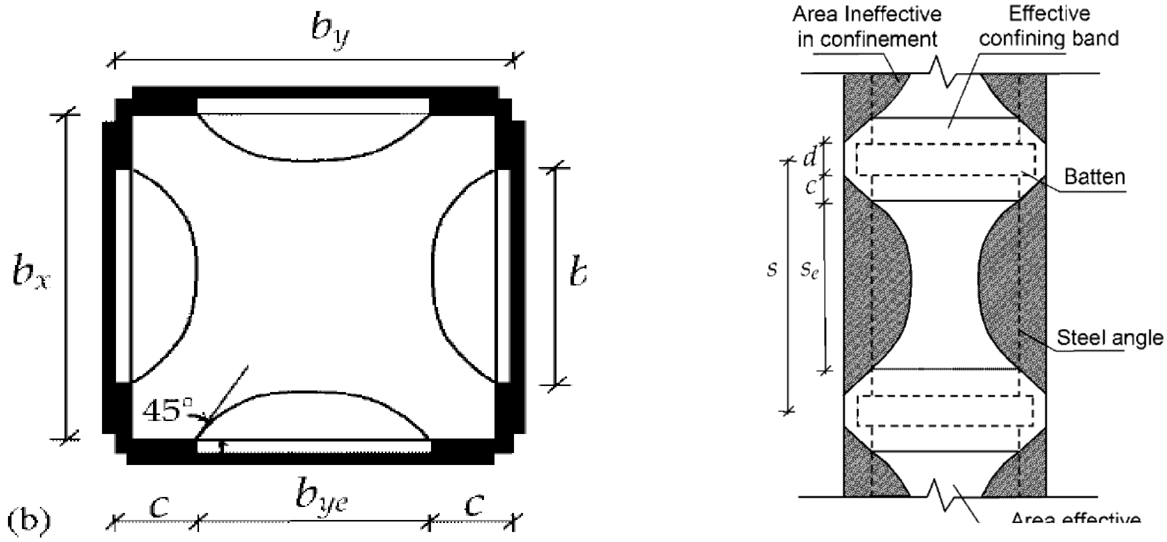


Fig 7.1: Confinement of RC column due to steel caging in plan and elevation.

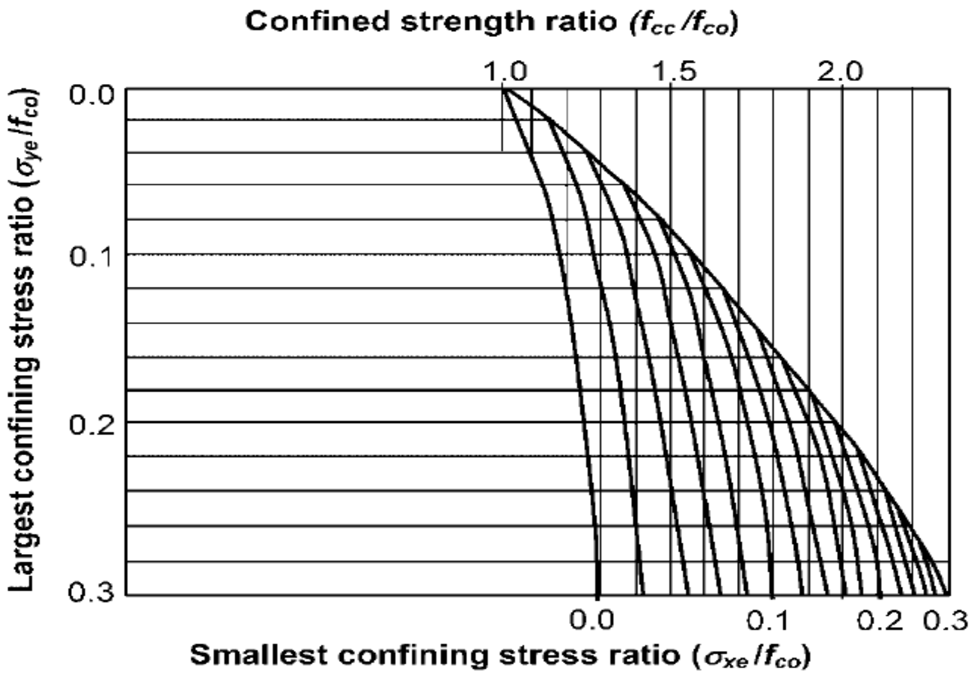


Fig 7.2: Confinement strength ratio due to lateral confining stresses.

CHAPTER 8

CONCLUSIONS

The following table shows a detailed comparison of RC, FRP, SFRC and STEEL Jacketing

Table 8.1 : Comparison of RC, FRP, SFRC and STEEL Jacketing.

	RC Jacketing	FRP Jacketing	SFRC Jacketing	STEEL Jacketing
Minimum width of Jacket	• Width of jackets used is 100 mm which will reduce carpet area of building. .	• Width of jackets used is 0.66mm which is very less and will not pose any changes in carpet area of building.	• Width of jackets used is 150 mm which is even more than RC Jacketing.	• Width of jackets used is 6 mm which greater than FRP Jacketing.
Properties of Jacket	• Match with the concrete of the existing structure.	• Completely different with that of existing structure.	• Match with that of RC as well as FRP Jacketing because concrete, reinforcement, and steel fibre	• Completely different with all of three.
Cost of Jacket	• **INR** 6000 per column	• **INR** 18900 per column	• **INR** 3800 per column	• INR 5840 per column
Factored Load and Moment	• Factored load is only used for the design of RC Jacketing.	• Neither Factored load nor moment is used for the design of FRP Jacketing.	• Factored load as well as moment is used for design of SFRP Jacketing.	• Factored load as well as moment is used for design of STEEL

In addition to above, the following can also be concluded:

1. In RC and SFRC Jacketing , sizes of the sections are increased and the free available usable space becomes less and also huge dead mass is added.
2. In RC and SFRC Jacketing , drilling of holes in existing column, slab, beams and footings are required which cause further damage to the columns.
3. All four methods of retrofitting technique can significantly improve in Moment resisting capacity, shear strength capacity in Beam and Axial load carrying capacity in column.

4. FRP Jacketing is costlier as compared to RC, SFRC and STEEL Jacketing but better than all of three.
5. Confinement by FRP Jackets enhanced the performance of concrete columns.
6. After Jacketing, the building was again modelled in Stadd Pro and now all columns were found to be safe.
7. The performance of deficient RC columns under combined axial and cyclic lateral loading can be greatly improved by steel caging (Steel Jacketing) technique without using any binder material in the gap between concrete column and steel angles and thus making it simpler to implement at the site.

CHAPTER 9

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ANNEXURE I

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Retrofitting of Columns of an Existing Building by RC, FRP and SFRC Jacketing Techniques

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ABSTRACT: *The objectives of this paper is to design RC, FRP and SFRC Jacketing of failed columns of an existing building and to compare suitability of these three methods of retrofitting. The presented work also describes design procedure of Reinforced Concrete, Carbon Fibre Reinforced Polymer Jacketing and Steel Fibre Reinforced Polymer Jacketing for strengthening an existing columns. There is a large world-wide need for simple and reliable methods to repair and strengthen aging infrastructure and buildings. The use of FRP Jacketing offers several advantages over the RC and SFRC Jacketing but it is slightly expensive.*

Keywords - *Concrete Jacketing, FRP Jacketing, SFRC Jacketing, Retrofitting.*

1. INTRODUCTION

Jacketing of columns consists of added concrete with longitudinal and transverse reinforcement around the existing columns. This type of strengthening improves the axial and shear strength of columns while the flexural strength of column and strength of the beam-column joints remain the same. It is also observed that the jacketing of columns is not successful for improving the ductility. A major advantage of column jacketing is that it improves the lateral load capacity of the building in a reasonably uniform and distributed way and hence avoiding the concentration of stiffness as in the case of shear walls. This is how major strengthening of foundations may be avoided. In addition, the original function of the building can be maintained, as there are no major changes in the original geometry of the building with this technique. Jacketing of columns is needed when the load carried by the column is increased due to either increasing the number of floors or due to mistakes in the design. Jacketing is practiced when the compressive strength of the concrete or the percent and type of reinforcement are not according to the codes' requirements and also when columns is exposed to an earthquake, an accident such as collisions, fire, explosions.
The most common types of jackets are steel jacket, reinforced concrete jacket, fibre reinforced polymer composite jacket, jacket with high tension materials like carbon fibre, glass fibre etc.

1.1 Problem Statement

The building that is considered for this work has been modelled in STADD PRO software. This residential building is situated in Patna, Bihar. This building is initially designed to be built upto 4 storey in approx 2000 sq. feet . For its foundation there are 22 Live piles which are 9 meter deep in the soil and 9 Dead piles which are 7 meter deep in the soil. It has 31 tie beams of dimension 0.300 m × 0.300 m. It has 5 rooms , 4 bathrooms, a store room ,a dining hall, a drawing hall ,a kitchen, and with 4 balconies for each room. Room sizes are 3.66 m by 3.35 m, size of dining hall is 3.20 m by 6.55 m and that of drawing hall is 6.55 m by 3.35 m, bathroom size are 2.44 m by 1.52 m & 1.52 m by 1.52 m . Kitchen has a dimensions of 3.2 m by 2.13 m. Its columns sizes are of 0.3m×0.3m, 0.36m×0.3m, and 0.4m×0.3m & beams are of 0.3m×0.25m , 0.3m×0.3m, 0.25m×0.25m,0.36m×0.3m. slab has a thickness of 5 inch i.e 0.125 m. For the present work, (G+3) storey building with storey height 3 meter for all, with plan 18mx9m is taken. Buildings has bays in irregular form in both X & Y axis. For this 4 storey building, load was applied as per IS code 1875:1987 (Part 2), to show that no column failed for 4 storey. And as we increase the storey of building by 1 storey, then it's 6 columns failed due to increase in load. And as we modelled this building to 6 storey , it's 19 columns failed, only at ground and first floor level.

- As existing building was modelled as per cross-section of columns provided and load applied & analyse in Stadd Pro V8i and found that till 4 storey there is no any deficient (failed) columns (as shown in fig1) because initially building was designed as per 4 storey.
- As we model 5 storey ,some of columns (six columns) of building failed. Columns(highlighted) that fails are 63 , 64 , 74 , 79 , 80 are of cross-section 300mm×300mm as shown in fig 2.
- As we model 6th storey, many columns failed. Columns(highlighted) which fail are 62,63,64,65,66,67,69,70,72,73,74,77,78,79,80,179,180,189,190 are of cross-section 300mm×300mm & 400mm×300mm as shown in fig 3.

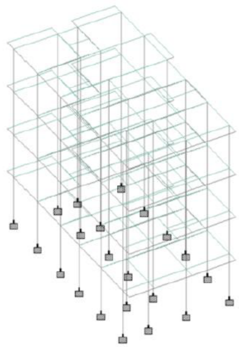
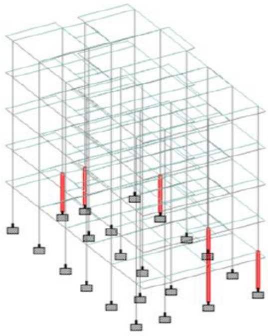
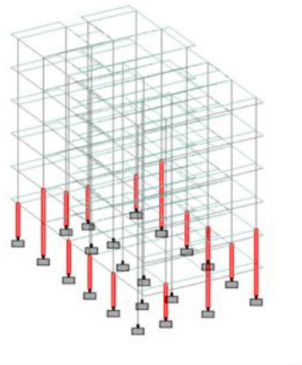




Fig 1: 4 Storey building - No column failed   Fig 2: 5 Storey Building -6 columns failed   Fig 3: 6 Storey Building -19 columns fail

2. DESIGN OF RC JACKETING OF FAILED COLUMNS FOR 5 STOREY BUILDING

For 5 storey building, A total of six columns failed as shown in fig 2. RC Jacketing to these columns are designed as per IS code 15988:2013.
One design example for column no 63 is given here:

Column No- 63
Height of column= 3000mm ; Width (b) =300mm ; Depth (D)=300mm; d= 260mm;
Reinforcement provided= 4,16Ø=804.25 mm^2 ; f_y = 415 MPa; f_{ck}=30 MPa.
P = 965.156 kN ; M = 15.307 kNm; P_u = 1447.734 kN ; M_u = 22.961 kNm
Since, $P_u = 0.4 \times f_{ck} \times A_c + 0.67 \times f_y \times A_{sc}$
According to the provisions provided in to §8.5.1.2 (a) of IS 15988: 2013, Concrete strength shall be at least 5 MPa greater than the strength of the existing concrete. Thus, taking value of f_{ck} = 35 N/mm^2 and assuming A_{sc} = 0.8% A_c
$1447.734 \times 10^3 = 0.4 \times 35 \times A_c + 0.67 \times 415 \times (0.8\% A_c)$; Therefore, A_c = 89234.10 mm^2
According to §8.5.1.1 (e) of IS 15988:2013, $A'_c = 1.5 A_c$; Thus, A'_c =133851.15 mm^2
Assuming the cross sectional details as:
B = 400mm ; D = 133851.15/400 = 334.63 mm
Jacketing details of cross section: B = (400-300)/2 = 50 mm; D = (334.63-300)/2 = 17.315 mm
However, According to the code specified above, Minimum jacket thickness shall be 100 mm as per §8.5.1.2 (c) of IS 15988:2013
Thus, New size of the column: B = 300+100 +100 = 500mm, D =300 +100 +100 = 500mm
New concrete area=500 × 500 = 250000 mm^2 > A_c = 89234.10 mm^2
Area of steel, A_s = 0.8% × 500 × 500 = 2000 mm^2
But according to §8.5.1.1 (e) IS 15988:2013, $A'_s = (4/3) A_s = (4/3) \times 2000 = 2666.67$ mm^2
Assuming 16mm Ø bars, Thus, number of bars, N = 2666.67 × 4/ (π x 162) = 13.263 bars
Therefore, 14 no. -16mm Ø bars is for whole sections. So, providing 10 NO. -16mm Ø bars for jacketed section. And jacketed section will be 500mm x 500 mm. Details of all jackets with their reinforcement details are given below in Table 1.

Table 1 Detailing of RC Jacket for 5 storey building

Column	Pu (kN)	Mu (kNm)	Jacketed	Jacketed C\S (mm^2)	Lateral Ties
63	1447.73	22.96	10-16 ø	500 x 500	8mm ø @90mm c/c
64	1143.31	33.29	10-16 ø	500 x 500	8mm ø @90mm c/c
74	1213.04	27.63	10-16 ø	500 x 500	8mm ø @90mm c/c
79	1114.12	36.23	10-16 ø	500 x 500	8mm ø @90mm c/c
80	1113.09	18.01	10-16 ø	500 x 500	8mm ø @90mm c/c

179	1147.68	22.13	10-16 ø	500 x 500	8mm ø @90mm c/c

Similarly for six storey building, size of jacket is calculated as per design steps given above and given in Table 2 for all Failed columns.

Table 2 Detailing of RC Jacket for 6 storey building

Column No	Pu (kN)	Mu (kNm)	Jacketed section	Jacketed C\S	Lateral Ties
62	1281.79	19.23	10- 16 ø	500 x 500	8mm ø @90mm c/c
63	1701.29	19.75	10- 16 ø	500 x 500	8mm ø @90mm c/c
64	1379.89	31.79	10- 16 ø	500 x 500	8mm ø @90mm c/c
65	1489.16	44.46	10- 16 ø	500 x 600	8mm ø @90mm c/c
66	1155.17	28.48	10- 16 ø	500 x 500	8mm ø @90mm c/c
67	1176.81	18.02	10- 16 ø	500 x 500	8mm ø @90mm c/c
69	1529.95	45.01	10- 16 ø	500 x 600	8mm ø @90mm c/c
70	1249.54	27.32	10- 16 ø	500 x 500	8mm ø @90mm c/c
72	1746.78	31.65	25- 12 ø	500 x 600	8mm ø @55mm c/c
73	1278.43	24.31	10- 16 ø	500 x 500	8mm ø @90mm c/c
74	1443.32	24.92	10- 16 ø	500 x 500	8mm ø @90mm c/c
77	1030.51	24.42	10- 16 ø	500 x 500	8mm ø @90mm c/c
78	1099.29	33.30	10- 16 ø	500 x 500	8mm ø @90mm c/c
79	1327.93	33.68	10- 16 ø	500 x 500	8mm ø @90mm c/c
80	1328.14	17.30	10- 16 ø	500 x 500	8mm ø @90mm c/c
179	1402.36	18.49	10- 16 ø	500 x 500	8mm ø @90mm c/c
180	1154.20	44.04	10- 16 ø	500 x 500	8mm ø @90mm c/c
189	1063.84	32.99	10- 16 ø	500 x 500	8mm ø @90mm c/c
190	1196.94	29.49	10- 16 ø	500 x 500	8mm ø @90mm c/c

2.1 Cost of RC Jackets of column no 63

The formula for calculation of materials for required volume of concrete is given by equation given as follows.

$$V_C = \frac{W}{1000} + \frac{C}{1000S_C} + \frac{F_a}{1000S_{fa}} + \frac{C_a}{1000S_{ca}} \quad \text{-------(1)}$$

Where, V_c = Absolute volume of fully compacted fresh concrete ;W =Mass of water; C = Mass of cement ; Fa = Mass of fine aggregates ; Ca = Mass of coarse aggregates; S_c, S_{fa} and S_{ca} are the specific gravities of cement, fine aggregates and coarse aggregates respectively.

Let, Vcj = Vol of concrete in jacketed section - Vol of reinforcement ; V_R= Vol of lateral & tranverse reinf. $= 6.13\times10^{-3} + 3.52\times10^{-3} = 9.65\times10^{-3}$ m^3

$=[(500^2-300^2)-(10\times\pi\times16^2\div4)] = 0.482$ m^3

Let, M_R= Mass of reinf.= 7850 kg/m^3 $\times9.65\times10^{-3}$ = 75.75 kg

Consider concrete with mix proportion of 1:1.5:3 where, 1 is part of cement, 1.5 is part of fine aggregates and 3 is part of coarse aggregates of maximum size of 20mm. The water cement ratio required for mixing of concrete is taken as 0.45.

Assuming bulk densities of materials	Specific gravities of concrete materials
Cement = 1500 kg/m^3	Cement = 3.15
Sand = 1700 kg/m^3	Sand = 2.6
Coarse aggregates = 1650 kg/m^3	Coarse aggregates = 2.6.

The mix proportion of 1:1.5:3 by dry volume of materials can be expressed in terms of masses as:

Cement = 1 × 1500 = 1500 kg ; Sand = 1.5 × 1700 = 2550 kg

Coarse aggregate = 3 × 1650 = 4950 kg

Therefore, the ratio of masses of these materials w.r.t. cement will as follows =1:(2550/1500):(4950:1500)
= 1 : 1.7 : 3.3

So, from above data, C= 179.15 kg ; F_a= 304.55 kg ; C_a = 591.18 kg

Therefore, cost of concrete = Cost of (Cement + FA + CA + Reinf.)
=(179.15÷50×Rs350)+(304.55÷1700×Rs882)+(591÷1650×Rs2258) =Rs 2220

Cost of Reinf. = Rs 50/kg× 75.75 kg= Rs 3788.
Therefore total cost of material= **INR** 6008.

3. DESIGN OF FIBRE REINFORCED POLYMER JACKETING

FRP Jacketing is used because Carbon fibre is flexible and can be made to contact the surface tightly for a high degree of confinement due to its high strength and high modules of elasticity. The use of FRP in strengthening solutions has become an efficient alternative to some of the existing traditional methods due to some advantages such their features in terms of strength, lightness, corrosion resistance and ease of application. Such techniques are also most attractive for their fast execution and low labour costs. FIB Model Code for concrete Structures 2010 is the code which is used in the design of FRP Jacketing.

3.1 Design of FRP Jacketing of Failed column no-63

The given dimensions are, b =300 mm, d =260mm;
f_{ck} provided = 30Mpa; f_{ck} required = 35Mpa,
Pt % provided = 0.8% of A_c = 720mm^2,
Area of concrete = 89280 mm^2, Pu = 1447.734 kN, Mu = 22.961 kNm
Data provided from manufacturer for jacket is as follows :
Ultimate strain in carbon fibre (ε_f) = 1.5% ; Effective fibre thickness(t_f) =0.33mm
Elastic modulus of carbon fibre (E_f) = 137000 N/mm^2; No of Wrap (n) =2 No.

Effectively Confined Core for Non Circular Section

Total Plan Area of Unconfined concrete is obtained as per FIB (2010).
b' = b - 2 × r_c = 300- 2 ×25 =250 mm ; r_c=Radius of rounded corners of column
d' = d- 2 × r_c = 260- 2 ×25 = 210 mm
Au = $(b'^2+d'^2)\div 3$ =35533.33 mm^2
The confinement effectiveness coefficient k_e considering ratio $(A_c-A_u)/A_c$ as per Fib 14 eq^n 6.29 is given as, $K_e = 1-[(b'^2+d'^2)/\{3A_g(1-\rho_{sg})\}]$= 0.602 ; $\rho_{sg} = A_s/A_g$
The Lateral confining pressures induced by the FRP wrapping as per Fib eqn 6.30 is given as
Along direction b, Along direction d,
$K_{confb} = \rho_b k_e E_f$ $K_{confd} = \rho_d k_e E_f$
Where, ρ_b =2ntf/b = 0.0044; and ρ_d =2ntf/d= 0.0051
K_{confb} = 362.89 ; K_{confd} = 420.62
Effective confining pressure, along direction b; Along direction d
$f_{lb} = (K_{confb} \times \varepsilon_f)/2K_e$= 4.52 N/mm^2 $f_{ld} = (K_{confd} \times \varepsilon_f)/2K_e$ = 5.24 N/mm^2
Taking min value: f_l = 4.52 N/mm^2

Maximum confining pressure as per equation 6.5 of FIB, which is given as,
$f_{cc} = f'_c\,[2.254\sqrt{(1+7.94f_l / f'_c)} - 2f_l/f'c - 1.254]$
f_{cc} = 53.552 N/mm^2
"Hence provide 2 layer of CFRP jacket."
Cost of FRP Jackets is around Rs2600 - Rs4600 per m^2
And area to be jacketed = 3.65 m^2
So, total cost of FRP Jacket per column(2 layer)= **INR** 18980
All columns for 5&6 storey posses same cost per column.

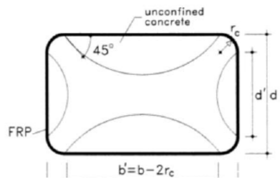


Fig4: Effective confined core for non circular

4. DESIGN OF STEEL FIBRES REINFORCED CONCRETE JACKETS

During recent years, steel fibre reinforced concrete has gradually advanced from a new, rather unproven material to one which has now attained acknowledgement in numerous engineering applications. Lately it has become more frequent to substitute steel reinforcement with steel fibre reinforced concrete. Steel Fibres are generally distributed throughout a given cross section whereas reinforcing bars or wires are placed only where required. Steel fibres are relatively short and closely spaced as compared with continuous reinforcing bars of wires. It is generally not possible to achieve the same area of reinforcement to area of concrete using steel fibres as compared to using a network of reinforcing bars of wires. Steel Fibres are typically added to concrete in low volume dosages (often less than 1%), and have been shown to be effective in reducing plastic shrinkage cracking. It do not significantly alter free shrinkage of concrete, however at high enough dosages they can increase the resistance to cracking and decrease crack width. Steel Fibres in Concrete can improve Crack, Impact, Fatigue Resistance, Shrinkage Reduction, Toughness. Benefits of SFRC is that it distributed localized stresses, Reduces maintenance and repair cost and Resistance to freezing and thawing.

4.1 Design of SFRP Jacketing of Failed column no-63

b=300 mm; d=300 mm; Effective cover of column a=40 mm
Steel reinforcement(2,16Ø) in the compression zone of cross sectional area(As')=402.12 mm^2
Steel reinforcement(2,16Ø) in the tensile zone of cross sectional area(As)=402.12 mm^2
And, their yielding point, f_y=210 MPa;
After rehabilitation, the column will have to undergo an axial force, F=1447.73kN and a bending moment, M=22.96 kN.m. The column cannot support these efforts without strengthening.
The design column height(H_0) =3.05 m.

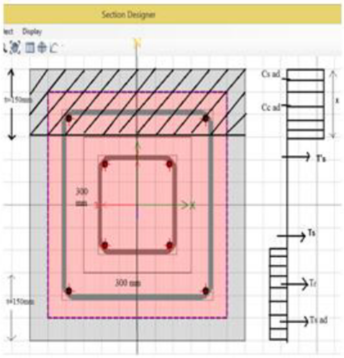
Solution.

Let us choose the strengthening materials: Steel fibre
Compressive strength($f_c{}'_{ad}$) =17.72MPa ; Tensile strength(f_t)=1.37 MPa;
Ultimate compressive strain(ε_u)=0.00337
The factor defining the intensity of compressive stress on the equivalent rectangular stress block for fibre reinforced concrete, γ_f=0.85+0.03 (WL/D)/450 ≤ 0.88 ;Where WL/D is the percentage of steel fibres by weight. In this case, γ_f =0.861 is taken.

Additional steel reinforcing bars in the jacket: $A_{s\,ad}{}' = A_{s\,ad}$; $f_{y\,ad}$=280 MPa.
For this design, rectangular stress block is to be used.
Let us assume the thickness of the SFRC(t)=150 mm.
The sizes of the strengthened element are, b'=b+2 t=600 mm; d'=d+2 t=600 mm
Loading eccentricity about centroid of the cross section(e) = M/F=15.85 mm
Loading eccentricity about centroid of the additional steel reinforcement in the tension zone of the cross section, e= e_o +0.5 d' -a=275.85 mm
Projection of all forces on the longitudinal axis of the column ∑X=0 gives:
$F-C_{s\,ad}-C_{c\,ad}+T_s'+T_s+T_f+T_{s\,cad}=0$ ———— (1)
Where the resultant force in the additional compression and in the tension reinforcing steel bars,
$C_{s\,ad}$ =28 A_s' =28 A_s = $T_{s\,ad}$ =11259.36 mm^2
The resultant force in the compression fibre concrete, $C_{c\,ad} = \gamma_f f_{c'ad}$ b'(x) = 9154.15x.
The resultant force in the existing tension reinforcing steel, initially working in the compression zone,
$T_s' = f_y A_s'$ = 210×402.12= 84.45 kN
The resultant force in the existing tension steel, $T_s = f_y A_s$=210×402.12= 84.45 kN
The resultant force in the tension fibre concrete, $T_f = f_t$ b'd =1.37×600×150 =123.3 kN
By replacing the forces by their respective values in the equation (1), the depth of the equivalent rectangular stress block is calculated as, x=190.07 mm.
Taking moments of all forces and equating to zero gives:
Fe- C_{sad} (d'-2 a) - C_{cad} (d' -0.5x-a)+ T_s' (d+t-2 a)+ T_s t + T_f (0.5 t-a) =0 ———— (2)
The following calculations indicate that the additional steel reinforcing bars are not needed. However the design code requires in this case a minimum reinforcement, the amount of which depends on the ratio H_o/H .
Since, H= (√3/6) d' =173.21mm ⇒ H_o/H =17.6
Consequently, the reinforcement cross sectional area required by the code
$A_{s\,min}$=0.1% b' (d'-a)=336 mm^2 ⇒ We take 3,12 Ø
Let us check the resistance condition:
Fe≤ C_{sad} (d'-2 a) + C_{cad} (d' -0.5x-a)- T_s' (d+t-2 a)- T_s t -T_f(0.5 t-a)
399.35kN.m<741.29 kN.m (Since, $C_{Cad} = \gamma_f f_{cad}'$ b'x = 9154.15x=1739.93 kN)
Obviously, the flexural strength of the column is sufficient after the strengthening by the S.F.R.C.
Hence, Jacket of thickness(t)=150 mm.

4.2 Cost of SFRC Jackets of column no 63

Vol. of concrete used in Jacketing
= (150mm×300mm×3050mm)×4=0.549m^3
Vol. of reinforcement used in jacketing
=7850 kg/m^3×0.000336×3.05=8.04 kg
Cost of reinforcement used in jacketing=Rs50×8.04=Rs 402
Cost of concrete used in jacketing derived similar as done in section 2.1=Rs 2530



Since, Cost of SFRC in the market is Rs 20000-Rs 60000/ton
Cost of SFRC used in jacketing=
(1% of concrete used in jackets)×7900kg/m^3×Rs20 = Rs867.42
So, total cost of SFRC=Rs 3800

5. CONCLUSION

The following table shows a detailed comparison of RC, FRP and SFRC Jacketing.

Table 3: Comparison of RC,FRP and SFRC Jacketing

	RC Jacketing	FRP Jacketing	SFRC Jacketing
Minimum width of Jacket	• Width of jackets used is 100 mm which will reduce carpet area of building.	• Width of jackets used is 0.66mm which is very less and will not pose any changes in carpet area of building.	• Width of jackets used is 150 mm which is even more than RC Jacketing.
Properties of Jacket	• Match with the concrete of the existing structure. • Compressive strength greater than that of the existing structures by 5 N/mm^2 or at least equal to that of the existing structure.	• Completely different with that of existing structure. • Compressive strength is greater than that of existing structures by 5 N/mm^2 or equal to that of the existing structure.	Match with that of RC as well as FRP Jacketing because concrete, reinforcement, and steel fibre are used.
Cost of Jacket	• **INR** 6000 per column	• **INR** 18900 per column	• **INR** 3800 per column
Factored Load and Moment	• Factored load is only used for the design of RC Jacketing.	• Neither Factored load nor moment is used for the design of RC Jacketing.	• Factored load as well as moment is only used for design of RC Jacketing.

In addition to above, the following can also be concluded:

1. In RC Jacketing , sizes of the sections are increased and the free available usable space becomes less and also huge dead mass is added.
2. In RC Jacketing , drilling of holes in existing column, slab, beams and footings are required which cause further damage to the columns.
4. RC retrofitting technique are significant improvement in Moment resisting capacity, shear strength capacity in Beam and Axial load carrying capacity in column.
5. FRP Jacketing is costlier as compared to RC & SFRC Jacketing but better than RC and SFRC jacketing.
7. Confinement by FRP Jackets enhanced the performance of concrete columns.

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Fig 10.1:AETM 2016 CERTIFICATE

ANNEXURE II

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Retrofitting of columns of an Existing Building by RC and FRP Jacketing

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The objectives of this paper is to design RC Jacketing and FRP Jacketing of failed columns of an existing building which was modelled in a STADD PRO V8i and to compare suitability of these two methods of retrofitting. The presented work describes about Reinforced Concrete and Carbon Fibre Reinforced Polymer Jacketing for strengthening an existing columns. There is a large world-wide need for simple and reliable methods to repair and strengthen aging infrastructure and buildings. The use of FRP Jacketing offers several advantages over the RC Jacketing but it is more expensive.
Keywords *- Concrete Jacketing, FRP Jacketing, Retrofitting, Structural Capacities.*

1. Introduction

Jacketing of columns consists of added concrete with longitudinal and transverse reinforcement around the existing columns. This type of strengthening improves the axial and shear strength of columns while the flexural strength of column and strength of the beam-column joints remain the same. It is also observed that the jacketing of columns is not successful for improving the ductility. A major advantage of column jacketing is that it improves the lateral load capacity of the building in a reasonably uniform and distributed way and hence avoiding the concentration of stiffness as in the case of shear walls. This is how major strengthening of foundations may be avoided. In addition, the original function of the building can be maintained, as there are no major changes in the original geometry of the building with this technique. Jacketing of columns is needed when the load carried by the column is increased due to either increasing the number of floors or due to mistakes in the design. Jacketing is practiced when the compressive strength of the concrete or the percent and type of reinforcement are not according to the codes' requirements and also when columns is exposed to an earthquake, an accident such as collisions, fire, explosions.
The most common types of jackets are steel jacket, reinforced concrete jacket, fibre reinforced polymer composite jacket, jacket with high tension materials like carbon fibre, glass fibre etc.

1.1 Problem Statement

The building that is considered for this work has been modelled in STADD PRO software. This residential building is situated in Patna, Bihar. This building is initially designed to be built upto 4 storey in approx 2000 sq. feet . For its foundation there are 22 Live piles which are 9 meter deep in the soil and 9 Dead piles which are 7 meter deep in the soil. It has 31 tie beams of dimension 0.300 m.× 0.300 m. It has 5 rooms , 4 bathrooms, a store room ,a dining hall, a drawing hall ,a kitchen, and with 4 balconies for each room.

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Room sizes are 3.66 m by 3.35 m, size of dining hall is 3.20 m by 6.55 m and that of drawing hall is 6.55 m by 3.35 m, bathroom size are 2.44 m by 1.52 m & 1.52 m by 1.52 m . Kitchen has a dimensions of 3.2 m by 2.13 m. Its columns sizes are of 0.3m×0.3m, 0.36m×0.3m, and 0.4m×0.3m & beams are of 0.3m×0.25m , 0.3m×0.3m, 0.25m×0.25m,0.36m×0.3m. slab has a thickness of 5 inch i.e 0.125 m. For the present work, (G+3) storey building with storey height 3 meter for all, with plan 18mx9m is taken. Buildings has bays in irregular form in both X & Y axis. For this 4 storey building, load was applied as per IS code 1875:1987 (Part 2), to show that no column failed for 4 storey. And as we increase the storey of building by 1 storey, then it's 6 columns failed due to increase in load. And as we modelled this building to 6 storey , it's 19 columns failed, only at ground and first floor level.

- As existing building was modelled as per cross-section of columns provided and load applied & analyse in Stadd Pro V8i and found that till 4 storey there is no any deficient (failed) columns (as shown in fig1) because initially building was designed as per 4 storey.
- As we model 5 storey ,some of columns (six columns) of building failed. Columns(bold) that fails are 63 , 64 , 74 , 79 , 80 are of cross-section 300mm×300mm as shown in fig 2.
- As we model 6th storey, many columns failed. Columns(bold) which fail are 62,63,64,65,66,67,69,70,72,73,74,77,78,79,80,179,180,189,190 are of cross-section 300mm×300mm & 400mm×300mm as shown in fig 3.

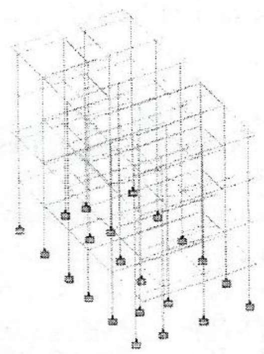

Fig 1: 4 Storey building - No column failed

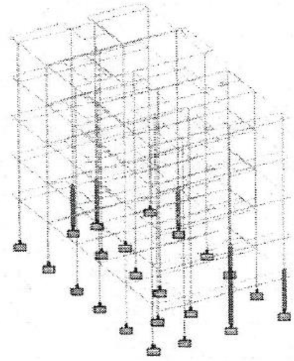

Fig 2: 5 Storey Building -6 columns failed

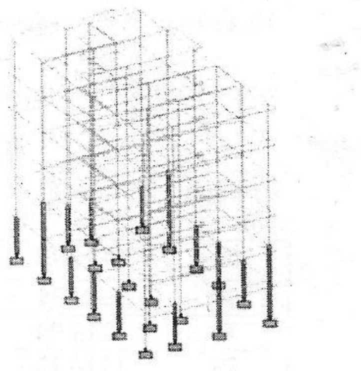

Fig 3: 6 Storey Building -19 columns fail

2 Design of RC Jacketing of failed columns for 5 storey building

For 5 storey building, A total of six columns failed as shown in fig 2. RC Jacketing to these columns are designed as per IS code 15988:2013.
One design example for column no 63 is given here:

Column No- 63
Height of column= 3000mm ; Width (b) =300mm ; Depth (D)=300mm; d= 260mm;
Reinforcement provided= 4,16Ø=804.25 mm^2 ; f_y = 415 MPa; f_{ck}=30 MPa.
P = 965.156 kN ; M = 15.307 kNm; P_u = 1447.734 kN ; M_u = 22.961 kNm

Since, $Pu = 0.4 \times f_{ck} \times A_c + 0.67 \times f_y \times A_{sc}$
According to the provisions provided in to §8.5.1.2 (a) of IS 15988: 2013, Concrete strength shall be at least 5 MPa greater than the strength of the existing concrete. Thus, taking value of f_{ck} = 35 N/mm^2 and assuming A_{sc} = 0.8% A_c

$1447.734 \times 10^3 = 0.4 \times 35 \times A_c + 0.67 \times 415 \times (0.8\ \%A_c)$; Therefore, $A_c = 89234.10\ mm^2$
According to §8.5.1.1 (e) of IS 15988:2013, $A'_c = 1.5A_c$; Thus, $A'_c = 133851.15\ mm^2$

Assuming the cross sectional details as:
B = 400mm ; D = 133851.15/400 = 334.63 mm
Jacketing details of cross section:
B = (400-300)/2 = 50 mm; D = (334.63-300)/2 = 17.315 mm

However, According to the code specified above, Minimum jacket thickness shall be 100 mm as per §8.5.1.2 (c) of IS 15988:2013
Thus, New size of the column: B = 300+100 +100 = 500mm, D =300 +100 +100 = 500mm
New concrete area=500 × 500 = 250000 $mm^2 > A_c =$ 89234.10 mm^2
Area of steel, $A_s = 0.8\% \times 500 \times 500 = 2000\ mm^2$

But according to §8.5.1.1 (e) IS 15988:2013, $A'_s = (4/3)\ A_s = (4/3) \times 2000 = 2666.67\ mm^2$
Assuming 16mm ø bars,
Thus, number of bars, N = 2666.67 × 4/ (π x 162) = 13.263 bars

Therefore, 14 no. -16mm ø bars is for whole sections. So, providing 10 NO. -16mm ø bars for jacketed section. And jacketed section will be 500mm x 500 mm. Details of all jackets with their reinforcement details are given below in Table 1.

Table 1 Detailing of RC Jacket for 5 storey building

Column No	Pu (kN)	Mu (kNm)	Jacketed section Reinf.	Jacketed C\S (mm^2)	Lateral Ties
63	1447.73	22.96	10-16 ø	500 x 500	8mm Ø @90mm c/c
64	1143.31	33.29	10-16 ø	500 x 500	8mm Ø @90mm c/c
74	1213.04	27.63	10-16 ø	500 x 500	8mm Ø @90mm c/c
79	1114.12	36.23	10-16 ø	500 x 500	8mm ø @90mm c/c
80	1113.09	18.01	10-16 ø	500 x 500	8mm ø @90mm c/c
179	1147.68	22.13	10-16 ø	500 x 500	8mm ø @90mm c/c

Similarly for six storey building, size of jacket is calculated as per design steps given above and given in Table 2 for all Failed columns.

Table 2 Detailing of RC Jacket for 6 storey building

Column No	Pu (kN)	Mu (kNm)	Jacketed section Reinf.	Jacketed C\S (mm^2)	Lateral Ties
62	1281.79	19.23	10- 16 ø	500 x 500	8mm Ø @90mm c/c
63	1701.29	19.75	10- 16 ø	500 x 500	8mm Ø @90mm c/c
64	1379.89	31.79	10- 16 ø	500 x 500	8mm ø @90mm c/c
65	1489.16	44.46	10- 16 ø	500 x 600	8mm ø @90mm c/c
66	1155.17	28.48	10- 16 ø	500 x 500	8mm ø @90mm c/c
67	1176.81	18.02	10- 16 ø	500 x 500	8mm ø @90mm c/c
69	1529.95	45.01	10- 16 ø	500 x 600	8mm ø @90mm c/c
70	1249.54	27.32	10- 16 ø	500 x 500	8mm ø @90mm c/c
72	1746.78	31.65	25- 12 ø	500 x 600	8mm ø @55mm c/c
73	1278.43	24.31	10- 16 ø	500 x 500	8mm ø @90mm c/c

74	1443.32	24.92	10- 16 ø	500 x 500	8mm ø @90mm c/c
77	1030.51	24.42	10- 16 ø	500 x 500	8mm ø @90mm c/c
78	1099.29	33.30	10- 16 ø	500 x 500	8mm ø @90mm c/c
79	1327.93	33.68	10- 16 ø	500 x 500	8mm ø @90mm c/c
80	1328.14	17.30	10- 16 ø	500 x 500	8mm ø @90mm c/c
179	1402.36	18.49	10- 16 ø	500 x 500	8mm ø @90mm c/c
180	1154.20	44.04	10- 16 ø	500 x 500	8mm ø @90mm c/c
189	1063.84	32.99	10- 16 ø	500 x 500	8mm ø @90mm c/c
190	1196.94	29.49	10- 16 ø	500 x 500	8mm ø @90mm c/c

2.1 Cost of RC Jackets of column no 63

The formula for calculation of materials for required volume of concrete is given by equation given as follows.

$$V_c = \frac{W}{1000} + \frac{C}{1000S_c} + \frac{F_a}{1000S_{fa}} + \frac{C_a}{1000S_{ca}} \quad \text{-------(1)}$$

Where, V_c = Absolute volume of fully compacted fresh concrete ;W =Mass of water; C = Mass of cement ;Fa = Mass of fine aggregates ; Ca = Mass of coarse aggregates; S_c, S_{fa} and S_{ca} are the specific gravities of cement, fine aggregates and coarse aggregates respectively.

Let, Vcj = Vol of concrete in jacketed section - Vol of reinforcement ; V_R= Vol of lateral & tranverse reinf. $= 6.13\times10^{-3} + 3.52\times10^{-3} = 9.65\times10^{-3}$ m³

$=[(500^2-300^2)-(10\times\pi\times16^2\div4)] = 0.482$ m³

Let, M_R= Mass of reinf.= 7850 kg/m³ $\times 9.65\times10^{-3}$ = 75.75 kg

Consider concrete with mix proportion of 1:1.5:3 where, 1 is part of cement, 1.5 is part of fine aggregates and 3 is part of coarse aggregates of maximum size of 20mm. The water cement ratio required for mixing of concrete is taken as 0.45.

Assuming bulk densities of materials

Cement = 1500 kg/m³
Sand = 1700 kg/m³
Coarse aggregates = 1650 kg/m³

Specific gravities of concrete materials

Cement = 3.15
Sand = 2.6
Coarse aggregates = 2.6.

The mix proportion of 1:1.5:3 by dry volume of materials can be expressed in terms of masses as:

Cement = 1 × 1500 = 1500 kg ; Sand = 1.5 × 1700 = 2550 kg
Coarse aggregate = 3 × 1650 = 4950 kg
Therefore, the ratio of masses of these materials w.r.t. cement will as follows =1:(2550/1500):(4950:1500) = 1 : 1.7 : 3.3

So, from above data,
C= 179.15 kg ; F_a= 304.55 kg ; C_a = 591.18 kg
Therefore, cost of concrete = Cost of (Cement + FA + CA + Reinf.)
=(179.15÷50×Rs350)+(304.55÷1700×Rs882)+(591÷1650×Rs2258) =Rs 2220
Cost of Reinf. = Rs 50/kg× 75.75 kg= Rs 3788.

Therefore total cost of material= **INR** 6008.

3. Design of Fibre Reinforced Polymer Jacketing

FRP Jacketing is used because Carbon fibre is flexible and can be made to contact the surface tightly for a high degree of confinement due to its high strength and high modules of elasticity. The use of FRP in strengthening solutions has become an efficient alternative to some of the existing traditional methods due to some advantages such their features in terms of strength, lightness, corrosion resistance and ease of application. Such techniques are also most attractive for their fast execution and low labour costs. FIB Model Code for concrete Structures 2010 is the code which is used in the design of FRP Jacketing.

3.1 Design of FRP Jacketing of Failed column no-63

The given dimensions are, b =300 mm, d =260mm;
f_{ck} provided = 30Mpa; f_{ck} required = 35Mpa,
Pt % provided = 0.8% of A_c = 720mm^2,
Area of concrete = 89280 mm^2, Pu = 1447.734 kN, Mu = 22.961 kNm

Data provided from manufacturer for jacket is as follows :
Ultimate strain in carbon fibre (ε_f) = 1.5% ; Effective fibre thickness(t_f) =0.33mm
Elastic modulus of carbon fibre (E_f) = 137000 N/mm^2; No of Wrap (n) =2 No.

Effectively Confined Core for Non Circular Section

Total Plan Area of Unconfined concrete is obtained as per FIB (2010).
$b' = b - 2 \times r_c = 300 - 2 \times 25 = 250$ mm ; r_c=Radius of rounded corners of column
$d' = d - 2 \times r_c = 260 - 2 \times 25 = 210$ mm
$Au = (b'^2+d'^2) \div 3 = 35533.33$ mm^2
The confinement effectiveness coefficient k_e considering ratio $(A_c-A_u)/A_c$ as per Fib 14 eq^n 6.29 is given as, $K_e = 1-[(b'^2+d'^2)/\{3A_g(1-\rho_{sg})\}] = 0.602$; $\rho_{sg} = A_s/A_g$

The Lateral confining pressures induced by the FRP wrapping as per Fib eqn 6.30 is given as
Along direction b, Along direction d,
$K_{confb} = \rho_b k_e E_f$ $K_{confd} = \rho_d k_e E_f$
Where, ρ_b =2ntf/b = 0.0044; and ρ_d =2ntf/d= 0.0051
K_{confb} = 362.89 ; K_{confd} = 420.62
Effective confining pressure, along direction b; Along direction d
$f_{lb} = (K_{confb} \times \varepsilon_f)/2K_e$ = 4.52 N/mm^2 $f_{ld} = (K_{confd} \times \varepsilon_f)/2K_e$ = 5.24 N/mm^2
Taking min value: f_l = 4.52 N/mm^2

Maximum confining pressure as per equation 6.5 of FIB, which is given as,
$f_{cc} = f'_c\,[2.254\sqrt{(1+7.94f_l / f'_c)} - 2f_l/f'c - 1.254]$
f_{cc} = 53.552 N/mm^2
"Hence provide 2 layer of CFRP jacket."
Cost of FRP Jackets is around Rs2600 - Rs4600 per m^2
And area to be jacketed = 3.65 m^2
So, total cost of FRP Jacket per column(2 layer)= **INR** 18980

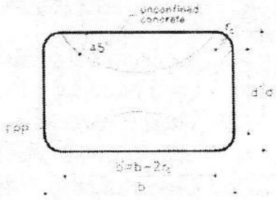

Fig4: Effective confined core for non circular sections.

All columns for 5&6 storey posses same cost per column.

4. Conclusions

The following table shows a detailed comparison of RC and FRP Jacketing

Table 3 Comparison of RC and FRP jacket

	RC Jacketing	FRP Jacketing
Minimum width of Jacket	• Width of jackets used is 100 mm which will reduce carpet area of building.	• Width of jackets used is 0.66mm which is very less and will not pose any changes in carpet area of building.
Properties of Jacket	• Match with the concrete of the existing structure. • Compressive strength greater than that of the existing structures by 5 N/mm^2 or at least equal to that of the existing	• Completely different with that of existing structure. • Compressive strength is greater than that of existing structures by 5 N/mm^2 or equal to that of the existing structure
Cost of Jacket	• **INR** 6000 per column	• **INR** 18900 per column

In addition to above, the following can also be concluded:

1. In RC Jacketing , sizes of the sections are increased and the free available usable space becomes less and also huge dead mass is added.
2. In RC Jacketing , drilling of holes in existing column, slab, beams and footings are required which cause further damage to the columns.
3. Factored moment do not play any role in design of RC Jacketing of columns.
4. RC retrofitting technique are significant improvement in Moment resisting capacity, shear strength capacity in Beam and Axial load carrying capacity in column.
5. FRP Jacketing is costlier as compared to RC Jacketing but better than RC jacketing.
7. Confinement by FRP Jackets enhanced the performance of concrete columns.

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Fig 10.2:Race 2016 Certificate