RETROFITTING TECHNIQUES FOR EXISTING MULTISTORIED BUILDING

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Abstract: In the present global scenario, there exist different kinds of structures namely reinforced concrete structures, steel structures and composite structures. These structures have to withstand the gravity, seismic, wind loads, etc., during their design life time. But many existing buildings may get deteriorated or need to be upgraded for any of the following reasons:

1. ***Building not designed to code***
2. ***Subsequent update of code and design practice***
3. ***Subsequent upgrading of seismic zone***
4. ***Deterioration of strength and aging***
5. ***Modification of Existing structure***
6. ***Change in use of the building as per the client requirements, etc.,***

In some cases like modification of the existing structure it is economic to strengthen the existing structure using retrofitting techniques rather than demolishing the existing structure and constructing an entirely new structure.

The strengthening of the existing buildings to withstand the additional loads as required is termed as "Retrofitting". The existing building can be retrofitted using various techniques like Jacketing existing beams, columns or joints, by Fiber Reinforced Cement, Confinement of column by embedded composite grid, use of metal shear Panels (Steel and Aluminum), Use of steel fiber reinforced mortar, use of steel wire reinforced polymer, steel bracing, shape modification in column, external pre-stressing and post-tensioning existing beams, columns, or joints.

In this project work, one of the buildings in Hyderabad city had to be reanalyzed at the request of the client for the increased imposed loads. The building was reanalyzed using advanced structural engineering software ETABS and suitable retrofitting techniques were suggested. This work covers the techniques like Concrete jacketing method for the Beams and Columns, Fixing of steel beams for the slabs, and Area enlargement for the Footings.

I.INTRODUCTION

GENERAL:

- Retrofitting refers to the addition of new technology or features to older systems.
- Retrofitting is the process of modifying something after it has been manufactured, like; Power plant retrofit, improving power plant efficiency / increasing output / reducing emissions, Home energy retrofit, the improving of existing buildings with energy efficiency equipment, Seismic retrofit, the process of strengthening older buildings in order to make them earthquake resistant.
- For buildings, Retrofitting means making changes to the systems inside the building or even the structure itself at some point after its initial construction and occupation.
- Upgrading of certain building systems (existing structures) to make them more resistant to seismic activity and to withstand additional loads (both LL+DL).
- Retrofitting proves to be a better economic consideration and immediate shelter to problems rather than replacement of a building.
- Retrofits of existing buildings represent an opportunity to upgrade the energy performance of commercial building assets for their ongoing life. Often retrofit involves modifications to existing commercial buildings that may improve energy efficiency or decrease energy demand. Energy efficiency retrofits can reduce the operational costs, particularly in older buildings, as well as help to attract tenants and gain a market edge.

Concept of Retrofitting:

Retrofitting is a technical intervention in structural system of a building that enhances the load carrying capacity of various structural elements and may also improve the resistance to earthquake by optimizing the strength, ductility and earthquake loads. Strength of the building is generated from the structural dimensions, materials, shape, and number of structural elements, etc. Ductility of the building is generated from good detailing, materials used, degree of seismic resistant, etc. Earthquake load is generated from the site seismicity, mass of the structures, importance of buildings, degree of seismic resistant, etc. Due to the variety of structural condition of building, it is hard to develop typical rules for retrofitting. Each building has different approaches depending on the structural deficiencies. Hence, engineers are needed to prepare and design the retrofitting approaches. In the design of retrofitting approach, the engineer must comply with the building codes. The results generated by the adopted retrofitting techniques must fulfill the minimum requirements on the buildings codes, such as deformation, detailing, strength, etc.

Decision for Retrofitting:

Retrofitting is needed when the assessment of structural capacity results in insufficient capacity to resist the forces of expected intensity and acceptable limit of damages. It is not merely poor quality of materials and damage of structural elements serves as the reasons to retrofit a building. Change of the building's function, change of environmental conditions, and change of valid building codes could also be the reasons for retrofitting.

Retrofitting must be conducted by experts from each field. In most retrofitting process, an engineer plays the main role. An engineer must assess and analyze the structural capacity. An engineer must also design and suggest the best retrofitting techniques to strengthen the structural deficiencies. The role of the novice is restricted to identify the possibility of insufficiency of the building capacity.

some factors that should be considered in order to decide whether to retrofit or not are:

a) Technical aspect:
The technical aspects include the testing of materials and structural analysis. These measures are important to understand the condition of the structures related to the recent building codes.

b) Importance of building:

Each building is built for its own purpose. Some old buildings have extra values, it strongly affect the final decision.

II. LITERATURE REVIEW

There has been a lot of research done over the years on the retrofitting of existing multistoried buildings for the past few years. These works covered a variety of retrofitting techniques .A summary of some of these works referred, is given here under. Gnanasekaran Kaliyaperumal and Amlan Kumar Sengupta (2009) One way of retrofitting the columns in reinforced concrete multi storied buildings is concrete jacketing. The present study has investigated the effect of jacketing on the flexural strength and performance of columns. First, slant shear tests were conducted to study the interface between the old and new concrete. Second, column specimens were tested to study the strength. Third, beam-column-joint sub-assemblage specimens were tested to study the ductility (or energy absorption) and energy dissipation. Analytical investigations were carried out to predict the experimental results. A lamellar approach and a simplified method of analysis were used for the prediction of the axial load versus moment interaction curves and moment versus curvature curves for the retrofitted columns. An incremental nonlinear analysis was adopted to predict the lateral load versus displacement behaviour for a retrofitted sub-assemblage specimen. Guidelines for the retrofitting of columns by concrete jacketing are provided.

Dragos Banu and N. Taranu (2010) deals with different traditional solutions for strengthening reinforced concrete slabs. Different strengthening techniques have been developed so far for the reinforced concrete slabs with or without cut-outs. The development of these methods was a necessity due to different causes, such as inadequate maintenance, overloading of the reinforced concrete member, corrosion of the steel reinforcement and other different situations that appeared in time. Each of the techniques that are presented in this paper is better suited for a given situation and come with their advantages and disadvantages.

These techniques are considered to be traditional do to their long usage in time and that they involve only traditional construction materials such as concrete and steel. The five techniques from this paper have been and are the most effectively used, in the past and present days, worldwide and a short presentation of the methods and the way they are applied is presented in this paper. The selection of one of these methods is imposed by a sum of technological and economical factors.

Shri. Pravin B. Waghmare (2011) had give guidelines about the materials and jacketing techniques for retrofitting of structures. 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. Innovative techniques of the structural repairs have many advantages over the conventional techniques. Some guidelines regarding selection of materials for repair work such as steel, fiber reinforced polymer, has been discussed in the present paper. The selection of materials and techniques to be used depend on many aspects that may be viewed from different prospectives i.e. requirement and availability of financial resources, applicability and suitability of materials for the repair of damaged structures. Use of standard and innovative repair materials, appropriate technology, workmanship, and quality control during implementation are the key factors for successful repair, strengthening and restoration of damaged structures.

V. T. Badari Narayanan, A. K. Sengupta and S. R. Satish Kumar (2012) had explained about the concrete jacketing. For a reinforced concrete framed building designed for gravity loads, the sagging (positive) flexural capacity of a beam near the joint tends to be deficient due to inadequate amount and discontinuity of the bottom reinforcing bars. One way of retrofitting such beams is concrete jacketing. The present study investigated the effect of a certain scheme of jacketing on the positive flexural behaviour of beam specimens in the span region, and that of the beams of sub-assemblage specimens near the joint. The specimens were tested under monotonic and cyclic loads. From the tests, it was found that the strength, ductility and energy absorption capacities of the retrofitted specimens were higher than the corresponding reference specimens as per the prediction.

Bhavar Dadasaheb (2013) had investigated a building in Nasik city. A health building in the heart of Nasik city is being strengthened to overcome the future disorders. From the physical and experimental investigations it was concluded that the building either should be demolished or at least should be retrofitted with suitable technique to increase its service life. It was then decided to implement RCC column jacketing technique due to its feasibility and ease for execution.

Elsamny M. Kassem, Abd El Samee W. Nashaat (2013) carried out the retrofitting and strengthening of existing building foundation. some methods of strengthening existing foundation concrete buildings to resist lateral and vertical loads are presented. A study case of an existing sweet factory in Cairo area is presented. Deterioration of some concrete elements due to old age has been found. The said condition of the foundation was due to washing floors with chemicals to remove sticky sweets. However, no adequate disposal system was found (waste water collection). The analyses of the structural elements of that existing building showed that it is seismically unsafe. Retrofitting of existing damage and deteriorated foundation was done by adding new raft foundation and considering the old foundation as plain concrete. The addition of new shear and wing walls was undoubtedly the best method of strengthening the existing structure to improve seismic performance. The walls were cast-in-site. The shear and wing walls were connected to the foundation.

Minakshi V. Vaghani, Sandip A. Vasanwala and Atul K. Desai (2014) gave review about the advanced retrofitting techniques for RC buildings. The existing building can be retrofitted using various techniques like Jacketing existing beams, columns, or joints, Use of Fiber Reinforced Cement, confinement of column by embedded composite grid, use of metal shear Panels (Steel and Aluminum), Use of steel fiber reinforced mortar, use of steel wire reinforced polymer, steel bracing, shape modification in column, external pre-stressing and post-tensioning existing beams, columns, or joints. So, in this paper, efforts are made to describe the different retrofitting techniques available and its suitability for particular conditions. Jacketing is excellent for column but it may not be too effective for beam or slab.

R.Hemaanitha and Dr. S.Kothandaraman, (2014) had critically review the strengthening techniques developed so far with reference to the effect of each technique and their salient features in enhancing the strength of RC beam elements. However, it is hoped that the review on the use of different techniques for retrofitting of RC beams presented in this paper will widen the horizon to retrofitting technology as a cost effective and easy to execute method.

Dgale Ashish B. and Raut Harshalata R. (2014) had studied about the beam-column joints.The performance of beam-column joints have long been recognized as a significant factor that affects the overall behaviour of Reinforced Concrete framed structures subjected to large lateral loads. The reversal of forces in beam-column joints during earthquakes may cause distress and often failure, when not designed and detailed properly. One of the techniques of strengthening the reinforced concrete structural members is through external confinement by high strength fiber composites which can significantly enhance the strength and ductility which will result in large energy absorption capacity of structural members.

III.RE ANALYSIS OF AN EXISTING BUILDING

3.1Structural Geometry and Occupancy:

The existing building is a 7 storey (sub cellar, cellar, ground, and 4 typical floors) structure. The height of the base is 2m, sub cellar, cellar and ground floor are 3m, 4 typical floors are of height 3.3m.The width of the structure is 65’11” and the length of the building is 192’9”.The structure chosen is a commercial building. The importance factor (I) for the building according to the code is 1.5 (refer Table 6, IS 1893(Part1): 2002).

3.2 Site Location and Site Class:

The building is located in the Hyderabad, India. The Indian code follows a zoning system and the zone factor (Z) for Hyderabad is 0.1 as it lies in the Seismic Zone II, (as per Annex- E, IS 1893(Part 1): 2002). The site soil is classified as a Type II: Medium Soils as per Table 2-3.

3.3Details of the Existing building:

As the title of the project is reanalysis and retrofitting of an existing building, we have to define the properties and loadings of the building before going to define the reanalysis results.

3.4Plan of the Existing building:

The existing building is a 7 storey structure comprises of

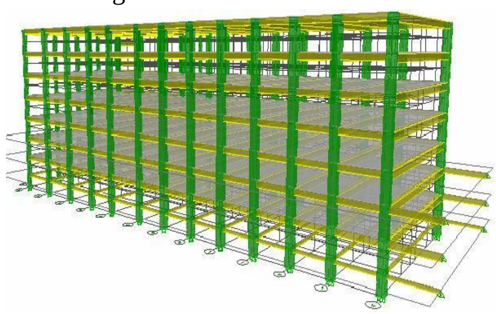
1. Sub cellar
2. Cellar
3. Ground floor
4. typical floors

3.4.1New requirements of the existing building:

The new loading requirements for the building are as follows:

- ETABS can analyze any type of building components, but designs only Beams and Columns
- SAFE(8.08) can be used to design the slabs
- Foundations are designed manually.

After creating all the building elements the final 3D model of the building



Superimposed dead load	$=2.0 kN/m^2$
Services	$=1.0 kN/m^2$
Imposed load	$= 6.0 kN/m^2$
Floor finish	$= 1.5 kN/m^2$

The ramp intensity, water tanks and lift room loads are same as explained in 3.3.3

3.5 Modeling and Analysis of Structure in ETABS:

The structure is modeled three dimensionally in the structural analysis and design software ETABS (Version 9.7.4). The bases of the columns are taken as fixed supports. Rigid floor diaphragm is assumed for the floors. The column and the beam members are modeled with a full gross moment of inertia. Dead load and live load are applied as static load on the structure, while seismic load is applied as per Response Spectrum method. To account for accidental eccentricity, the seismic load on each floor is applied with an eccentricity of 5% of the dimension of the structure perpendicular to the direction of the applied forces, with respect to the C.G of the story as per clause 7.9.2, IS 1893(Part 1): 2002. The material used is reinforced concrete with M25 and M30 Concrete (fck =25 N/mm^2, 30 N/mm^2) confirming to IS 456-2000 and Fe 500 Grade Steel (fy=500 N/mm^2) confirming to IS 1768(2008).

3.5.1 About ETABS:

ETABS:

- "Extended Three Dimensional Analysis Of Building Elements"
- It Completely Works On Graphical User Interface(Gui)
- Designs Any Type Of Structure Rcc To Steel

IV.RESULT AND DISCUSSIONS:

4.1 Comparison of Design results:

The existing building was reanalyzed and designed for increased loading by ETABS. For shortfall the building elements should be retrofitted with suitable technique. There are various retrofitting techniques available for strengthening the building components to withstand the extra loads. They are

1. Concrete jacketing
2. Steel jacketing
3. FRP Composites
4. Bonding of steel plates to slabs
5. Fixing of I-Beams for the slabs
6. Widening of the footing size
7. Adding of extra reinforcement mesh based on the design (Footing)
8. Increasing the depth of slab by extra reinforcement, etc..,

Before going for the suitable retrofitting technique, compare the design results for the actual and required loadings so that suitable technique can be suggested for the shortfall design results.

The following table shows the comparison of design results for the actual and required loadings:

ELEMENT	EXISTING (Ast:mm^2)	REQUIRED (Ast:mm^2)	SHORTFALL (Ast:mm^2)
BEAM(ID (B64)): 750mmX750mm SUB CELLAR	TOPAst : 9210 BOTTOM Ast : 7572	TOPAst : 11726 BOTTOM Ast : 9893	TOP Ast : 2516 BOTTOM Ast : 2321
COLUMN(ID (C12)) : 750mmX750mm PLINTH LEVEL	Ast : 9946	Ast : 16346	Ast : 6400
SLAB ID (F1179) : 150mm GROUND FLOOR	MAIN Ast : 631.68 Distribution Ast : T 8@200mm c/c	Ast in along short span:477.57 Ast along long span: T 8@200mm c/c	Negative reinforcement Ast:477.57 above steel beams.
FOOTING ID (F1) :	SIZE : (m x m) (2.92X2.92) A=8.52 m^2 D= 750 mm Pu =3083 kN	SIZE : (m x m) (3.28X3.28) A=10.75 m^2 D= 950 mm Pu : 3917 kN	SIZE : (m x m) (0.36X0.36) A=0.1296 m^2 D= 200 mm Pu : 834 kN

Table 3: Comparison of design results

4.2 Suitable retrofitting technique for the Increased Imposed loads:

This paper explains or suggests the retrofitting techniques are as follows. They are

Concrete Jacketing method for Beams

Concrete jacketing method for columns

Fixing of I-Beams for the slabs

Concrete Jacketing method for footings

4.2.1 Concrete Jacketing method for Beams:

Reinforced concrete beams needs strengthening when the existing steel bars are unsafe or insufficient, or when the loads applied to the beam are increased. In such cases there are several solutions that could be followed. They are

= Concrete jacketing method

= Steel jacketing method

= Adding steel plates to the Beam.

This paper covers the concrete jacketing method for the Beams strengthening.

Jacketing of beams is recommended for several purposes as it gives continuity to the columns and increases the strength and stiffness of the structure. Jacketing of beam may be carried out under different ways; the most common are one-sided jackets or 3- and 4-sided jackets. At several occasions, the slab has been perforated to allow the ties to go through and to enable the casting of concrete. The beam should be jacketed through its whole length. The reinforcement has also been added to increase beam flexural capacity moderately and to produce high joint shear stresses. Top bars crossing the orthogonal beams are put through holes and the bottom bars have been placed under the soffit of the existing beams, at each side of the existing column. Beam transverse steel consists of sets of U-shaped ties fixed to the top jacket bars and of inverted U-shaped ties placed through perforations in the slab, closely spaced ties have been placed near the joint region where beam hinging is expected to occur (figure). The main features of reinforcement details of beam jacketing are given in table:

Procedure of concrete jacketing method for Beams:

4) Removing the concrete cover, roughing the surface, cleaning the reinforcement steel bars and coating them with an appropriate material that would prevent corrosion.

5) Making holes in the whole span and width of the beam under the slab at 15-25 cm.

6) Filling the holes with cement mortar with low viscosity and installing the steel connectors for fastening the new stirrups.

7) Installing the steel connectors into the columns in order to fasten the steel bars added to the beam

8) Closing the added stirrups using steel wires and the new steel is installed into these stirrups.

9) Coating the concrete surface with the appropriate epoxy material that would guarantee the bond between old and new concrete, exactly before pouring the Pouring the concrete jacket using low shrinkage concrete.

For the considered Beam element the shortfall reinforcement at the top and bottom is Actual Beam = (750 mm x 750 mm)

Top Ast

Bottom Ast

Provide 25 mm diameter bars at both top & bottom

Number of bars at top

Number of bars at bottom

Therefore, number of bars at both top and bottom are 5 no's.

By providing these required beams by the concrete jacketing by 4-sided jackets, the cross section of the final jacketing model = (900 mm x 875 mm). The final jacketed beam is shown in the figure.

4.2.2 Concrete jacketing method for columns:

Strengthening of R.C columns is needed when:

5) The load carried by the column is increased due to either increasing in the number of floors or due to mistakes in the design.

6) The compressive strength of concrete or percent and type of reinforcement are not according to the codes requirements.

7) The inclination of the column is more than the allowable

8) The settlement in the foundation is more than the allowable

There are two major techniques for strengthening reinforced concrete columns:

- Reinforced concrete jacketing
- Steel jacketing

This paper covers the concrete jacketing method.

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. 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 and
(ii) To improve the column's flexural strength, the longitudinal steel of the jacket is made continuous through the slab system is anchored into 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. 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 as shown in the figure.

Procedure of concrete jacketing method for Columns:

In some cases, before this technique is carried out, we need to reduce the or even eliminate the temporarily the loads applied to the column, this is done by the fallowing steps:

- Putting Mechanical jacks between the floors
- Putting additional props between the floors
- Adding steel connectors into the existing column in order to fasten the new stirrups of the jacket in both vertical and horizontal directions at spaces not more than 50 cm. Those connectors are added into the column by making holes 3-4 mm larger than the diameter of the used steel connectors and 10-15 cm depth.
- Filling the holes with an appropriate epoxy material then inserting the connectors into the holes.
- Adding vertical steel connectors to fasten the vertical steel bars of the jacket fallowing the same procedure in step 1 and 2.
- Installing the new vertical steel bars and stirrups of the jacket according to designed dimensions and diameter.
- Coating the existing column with an appropriate epoxy material that would guarantee the bond between the old and new concrete.

By considering column at the plinth level, the size of the column is (750 mm X 750 mm) the shortfall of reinforcement is:

Actual column = (750 mm x 750 mm)

Ast required = 6400 mm^2

Provide 32 mm bars at the four corners and remaining 25 mm bars

Therefore, Area of 4-T 32 bars = (3.14 x 32 x 32) = 3215.36 mm^2

Therefore, 25 mm bars should be provided for remaining area

Remaining area= 6400 – 3215.36 = 3184.64 mm^2

Number of 25 mm bar= (3184.64 x 4)/(3.14 x 25 x 25) = 6.49.

Provide 8- T 25 diameter bars for the remaining area.

Therefore, the cross section of the final jacketing model = (900 mm x 900 mm)

The Final jacketed column is shown in the below figure.

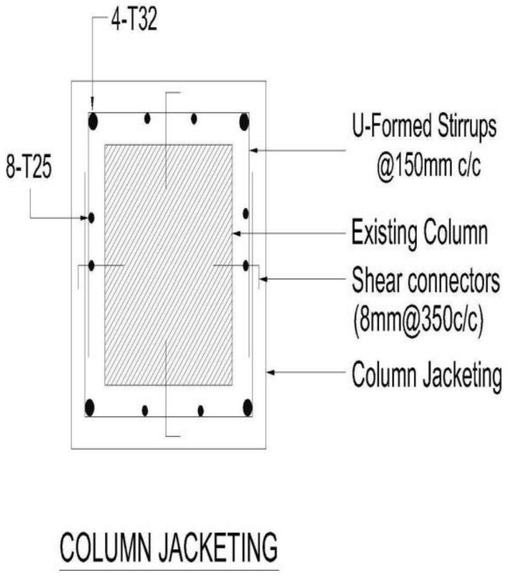


Fig 17: Jacketing of Column

4.2.3 Concrete Jacketing method for footings.

Columns foundations need strengthening in the case of applying additional loads. Widening and strengthening of existing foundations may be carried out by constructing a concrete jacket to the existing footings. The new jacket should be properly anchored to the existing footing and column neck in order o guarantee proper transfer of loads. The size of the

"jacket" shall be selected such that the average maximum foundation pressure does not exceed the recommended allowable value. Attention shall be given during construction in order that the excavations for the new "jackets" do not affect the existing adjacent foundations.

An isolated footing is strengthened by increasing the size of the footing and the reinforcement steel bars as follows:

a) Excavating around the footing

b) Cleaning and roughening the concrete surface.

c) Installing Dowels at 25-30cm spacing in both directions using an appropriate epoxy Material.

The fallowing photos illustrate the practical way of jacketing a footing by reinforced concrete jacketing:

Fig 19: Practical way of Jacketing a footing by Concrete Jacketing

4.2.4 Retrofitting of slabs by fixing steel beams and by providing extra top reinforcement:

Strengthening of R.C Slabs is needed when:

- Due to increasing the applied loads on the slabs or their unsafe design.
- Due to corrosion of the reinforcing the steel bars or cracks in the slabs.

Then one of the following solutions should be made:

- If the slab is unable to carry the negative moment and lower steel is sufficient, upper steel mesh should be added with a new concrete layer.
- If the slab is unable to carry the positive moment, or when the dead load is (that will be added to the slab) is much less than the live load carried by the slab, a new concrete layer on the bottom of the slab should be added.

In order to implement the previous solutions, the following steps should be made:

- Removing the concrete cover.
- Cleaning the reinforcing bars with wire brush or sand compressor.
- Coating the steel bars with epoxy material that would prevent the corrosion.
- If a high percent of corrosion is present in the steel bars, a new steel mesh, designed according to the codes requirements must be added.
- The new reinforcing steel mesh is then installed and fastened vertically to the slab of the roof and horizontally to the surrounding beams with steel dowels.

V. CONCLUSIONS

In this study, the Building was analyzed for the increased loads using ETABS and suitable retrofitting techniques were suggested for the building elements with relevant pictures and drawings. The following are the conclusions:

1. In Footings the size was increased by 26.17% and Depth was increased by 26.66%.These shortfalls were implemented by providing the required additional concrete and steel areas with the help of retrofitting techniques.
2. In columns the reinforcement was increased by 64.34%. This shortfall has been implemented by adopting the concrete jacketing technique.
3. In Beams the top reinforcement was increased by 27.31% and bottom was increased by 30.63%.These shortfalls have been implemented by the suitable retrofitting techniques.
4. In Slabs, for the increased imposed loads the existing slab was strengthened by providing steel beams at suitable intervals and provision of negative reinforcement together with necessary shear connectors.

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