Retrofitting of an existing structure design and techniques

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ABSTRACT: Retrofitting of any given structure is done to improve its strength and performance. In most scenarios, retrofitting is done to improve seismic resilience and performance, however in this investigation retrofitting techniques are utilized to change the functional use of a structure, to be more precise, the agenda is to transform a commercial 10 storey structure into a data center building. In order to encompass the additional load parameters, instead of complete reconstruction, retrofitting solutions are to be adopted, which reduces cost, labor and is very energy and environment conscious. The said structure was modelled using the E-Tabs software, with appropriate load parameters. Furthermore, the altered load parameters for the data center would likewise be examined to understand the extent of failure and would help in indicating the appropriate retrofitting solution to ameliorate the situation. This project is cutting edge in the sense that a sustainable approach in the construction industry is sought to, looking at the need for energy efficiency.

1. Introduction

Throughout the time, the construction industry promotes sustainable strategies and practices that are environmentally friendly. Although all of them need the right infrastructure to live in, renovation and change are increasingly necessary. In addition, any place’s civil infrastructure should be modified in accordance with the requirements of that time. There are a few issues with the same problem, and this document identifies one and suggests an alternative approach to circumventing the problem.

If a structure is to be transformed from one function to another, likewise changing a building site for a commercial facility, the most common way is demolishing and reconstructing. This approach causes a lot of pollution and produces a lot of waste. An alternative approach and the objective of this paper is to use retrofitting solutions to change structural functionality. Several research works on this topic present the impact of usage of such retrofitting techniques on the reduction of greenhouse gas emissions of various energy conservation measures implemented in building stocks. Certain studies provide specific strategy for the evaluation of the effects on residential case studies and various energy efficiency strategies. Polak.M[1] presents an exploratory and analytical study guarantee sufficient ductility and rotating capacity for reinforced slab-column connections. This article is about the impact on the rotational capacity of slab-column connections by transverse reinforcement. In order to strengthen punched shear capacity on heavily damaged plate/column connections Silva.M.A.L et al. [2] have investigated CFRP (Carbon-Fiber Reinforced Polymer) external strengthening as a non-damaging method. To increase punching shear capacity, the use of the final anchoring in the external CFRP reinforcement scheme and the consequences in the critical shear region of the application of a multilayered CFRP were studied. Wu.X et al (2019) [3] talked about how the concrete plate can be punched into a shortened cone surface when the reaction force of a plate exerts concentrated load on a plate column connection. The punching shear due to the internal and external forces applied to the surface of the plate is a critical fault mode for flat plate or flat shear.
The contextual investigation of the deep renovation of multi-storey existing residential houses by Salvalai, G et al. [4] has focused on the analysis of energy refurbishment trends in the residential building inventory in the Lombardy region. The retrofitting of a structure as an alternative to reconstruction has several advantages in addition to energy efficiency. It is cost-effective, reduces workforce, reduces overall project duration and increases structural sustainability. This is why any projects that deem fit should be supported with retrofitting. In this paper, a 10-storey commercial park is taken as the first building and is analyzed for its behavior with appropriate loading as per Indian Standard codes 875 part I and part II. This structure is then altered to serve the functional purpose of being a data center building, and appropriate loading parameters are then applied. Once the loads are applied, the weak or failure zones in the data center building are observed and identified. In order to overcome the said failure zones, appropriate retrofitting strategies are recommended. This investigation was carried out using the E-tabs software. Through this analysis, what is trying to be conveyed is that retrofitting can be utilized as a practical and viable option for renovating a structure to change its functional utility.

2. Study Area

2.1 Literature Review

Hueste, M et. al. [9] examined the seismic performance of a 5-story reinforced concrete frame structure. The primary structural reactions was expected utilizing synthetic ground movement information along with nonlinear static and dynamic analysis. The seismic performance of the case study structure was assessed using the FEMA 356 criteria. A flat slab and perimeter moment-resisting frames with spandrel beams make up the structure's floor system. ACI 318-83, the American Concrete Institute (ACI) Building Code Requirements for Reinforced Concrete, is used to design the structural members. ZEUS-NL, a finite element structural analysis tool designed for nonlinear dynamic, conventional and adaptive push-over, and eigenvalue analysis, was used in the study. A two-dimensional analytical model was used, which is appropriate for the case study building's typical floor plan. Since the contextual analysis building doesn't satisfy the FEMA 356 fundamental security objectives for the Memphis developments, three seismic retrofit approaches were utilized to work on seismic execution: shear dividers, RC section coats, and remotely bonded steel plates to limit the plastic hinge regions. The retrofits increase overall seismic performance, according to the study. Further modification of the retrofit schemes is required to fully meet the FEMA 356 member-level criteria.

Polak, M. [6] gives an experimental and analytical study on how to give reinforced concrete slab-column connectors suitable ductility and rotational capacity. The influence of transverse reinforcement on the rotational capacity of slab-column connections is the focus of this paper. To detect either punching or flexural failure modes of slabs with or without shear reinforcement, a finite element approach based on layered shell elements is used. Punching shear or general longitudinal reinforcement yielding are two ways for a reinforced concrete slab-column connection to reach its peak load. After attaining a peak load corresponding to general yielding of in-plane reinforcement, a flat slab in lack of a shear reinforcement failing in flexure will still be ductile. However, after the reinforcement at the slab column connection has yielded, the connection's rotations and flexural cracks diminish the concrete's shear capacity, which can eventually lead to a punching failure. The goal of the experiment was to see how effective shear reinforcement is at strengthening slab-column connections, with a focus on shear bolt performance for retrofitting existing slabs. All of the specimens were full-scale and represented parts of a slab-column continuous system, which was defined by the contraflexure lines surrounding the column. The elements must account for shear deformations in order to address transverse shear problems of the structure, and this study uses shell finite elements based on concepts similar to Mindlin theory for plates to do so. Finally, the performance of shear bolts, a novel type of shear reinforcement developed for retrofitting existing slabs in buildings, was highlighted. Shear bolt shear reinforcement in flat RC slabs can significantly improve the connections' strength and ductility.

Silva, M. A. L et. al. [1] investigated the use of CFRP (Carbon fibre reinforced polymer) external strengthening as a nondestructive approach to improve the punched shear capacity of extensively damaged slab column connections. The effect of applying multilayered CFRP with alternate bond arrangements at the shear critical region, as well as the use of end anchorage on the external CFRP strengthening scheme, have been investigated to further develop the punching shear capacity. For this study, a total of twenty-six highly damaged flat slab-column connections were prepared. The Rebound
Hammer method was used to determine compressive strength. The specimens were simply supported by four I sections and subjected to a transient point load through the centre stub column until they failed. An in situ chip aggregate concrete mixture was used to restore the previous, damaged concrete. After 28 days of cure, the repaired specimens were strengthened utilising the CFRP external strengthening technique. Using a hydraulic jack with a 500 kN capacity, a point load of 0.5 kN/mm was applied through the stub column specimen. End anchoring on CFRP can help prevent CFRP fortifying plans from flopping prematurely prematurely due to debonding. There are two sorts of end anchorage systems dependent on how the anchor is applied to the hosting body: damaging end anchorage and nondamaging end anchorage. ABAQUS, a commercially available software, was used to create a numerical model. The Concrete Damage Plasticity Model (CDPM) was used to assign material features since it can define damage characteristics in tension and compression as well as entire inelastic behaviour. The use of unidirectional externally bonded CFRP to boost the flexural reinforcement ratio was found to be an efficient technique to improve the punched shear capacity while improving the flexural capacity of flat slabs. End anchors increase stress distribution while decreasing stress localisation. The radial placement of CFRP on the tension face of a slab's shear critical area could improve the flat slab's punched shear capacity.

Das. S et al. [2] have talked about as architects become more inclined to create seamless structures for aesthetic reasons, the prevention of lateral loading and seismic strengthening of flat slab, ribbed slab, and waffle slab structures has become an essential need. This investigation approach was utilized to lead building reliability tests in the United States, and the study found that flat slab buildings built before the 1960s might sustain severe damage during moderate-intensity earthquakes. For concrete frame design in Bangladesh, flat slab design follows ACI code 318-99. Article 6.5 of the National Building Code specifies the unified design of flat slabs, flat plates, and edge supported slabs. The danger of punched failure of connections and the possibility for collapse must be investigated first in order to establish cost-efficient and successful retrofit possibilities for ameliorating the safety of seismically inadequate flat slab buildings. Actual earthquake data, probability analysis, and engineering judgement can all be used to generate fragility data. To improve lateral stiffness, shear walls, masonry infills, or a bracing system can be used. Pushover analysis (a static, nonlinear procedure for determining seismic structural deformations) was did on a number of eight, ten, and twelve-story buildings with two types of slabs: flat slab and beam supported slab, both of which were built according to BNBC 1993 and lateral loading according to UBC 97. The pushover research proved beyond a shadow of a doubt that beam-supported buildings are quite effective at handling seismic loads on flat slabs.

According to M. Navarro et al. (2019) [10], RCC slabs are the principal components of high-rise buildings. However, failure in RCC slabs happens in a brittle way without notice, and tends to break owing to punching shear. This form of failure is difficult to predict, occurs practically instantly, and can have disastrous repercussions. To simulate the punching shear effect on reinforced bolt-retrofitted concrete flat slabs with bolts positioned in three distinct positions around the support, ABAQUS software is used to analyse a set of non-linear numerical models. Following that, Adetifa and Polak's exploratory information were utilized to do the initial calibration of a finite element model. A parametric analysis was then used to determine the impact of the retrofitting geometrical elements. During the test, the load was transferred via the column studs until brittle punching shear failure occurred. The experimental layout was modelled to be the polar opposite of a real structure. As previously stated, ABAQUS was used to calibrate a numerical model for finite element analysis (FEA). It contains the Concrete Damage Plasticity model, which has been proven to be effective. The ABAQUS FEM models were utilized to investigate the performance of various retrofitting schemes for RC slab-to-column connections that were subjected to punching shear. Certain conclusions were drawn from the parametric analysis, such as an increase in bolt-to-column and bolt-to-bolt spacing, as well as an increase in the diameter and number of bolts, could reduce the ultimate load despite increasing the total transverse area for reinforcement. It is definitely felt that the findings gained have cleared the way for future research aimed at methodically determining the best design parameters.

Marco Valente (2012) [3] presents the results of a numerical investigation on the seismic performance and retrofitting of an R/C flat-slab prototype structure. This was done in a lab with the goal of determining the seismic behaviour of a flat slab structure. The test structure's numerical models were
created, and dynamic and nonlinear static evaluations were performed. The SeismoStruct computer code was used to numerically model the full-scale R/C prototype structure. A fibre model was used to characterise the inelastic behaviour of any member throughout its length and inside its cross-section. To match experimental results, effective slab widths were calculated and calibrated. The R/C rectangular section was utilized to describe the cross-sections of the columns, while the R/C T-section was used to describe the cross-sections of the beams and slabs. It's worth noting that Nonlinear dynamic studies were used to numerically mimic the pseudo-dynamic tests performed on the prototype structure at the JRC ELSA Laboratory. The model can determine the maximum drift at the second level based on the drift profiles. In terms of shear force, a suitable agreement is confirmed. In this work, two potential retrofitting strategies for increasing the seismic performance of the R/C prototype structure were investigated. The structure's columns had a strength and stiffness intervention utilising R/C jacketing. In order to allow the structure to endure significant seismic activities, a second retrofitting approach employing fibre-reinforced polymer (FRP) laminates was put forward. For the seismic upgrade of the R/C structure, these two retrofitting treatments targeted at enhancing column strength or ductility were simulated and investigated. The R/C jackets significantly enhanced the rigidity and strength of the structure, hence lowering the displacement of the structure, according to the numerical modelling of the first suggested retrofitting technique, which was not experimentally examined at the JRC ELSA Laboratory. The FRP retrofitting of columns boosted the local ductility capacity of column end sections just as the structure\'s overall ductility capacity. The demand-to-capacity ratio values for the columns of the FRP retrofitted structure were significantly reduced. However, based on the foregoing observations, the structure ought to be incorporated with other structural elements to provide much greater lateral stiffness, such as structural walls, braces, or stiff frames, in the event of severe seismic actions.

3. Analysis 1 – (10 – Storey commercial building)

All the data which was applied on the software were taken from the field investigation and design document from the consultant. Data taken directly is the dimension of each structural element. The other data such the grade of concrete and grade of steel is taken from the design document. The building structure was modelled and analyzed by using ETABS program. The structure was carried out for analysis where, data of strips forces and failure modes was obtained based on which the behavior of the structure due to gravity loads was identified.

3.1 Data of Existing Structure

A 10-storey commercial park with suitable top view layout and framing layout given as shown in figure 1and2 is taken for the study. The structure is composed of a moment resisting RC frame with a flat plate of 250mm thickness. The structure members are made of the reinforced concrete structure. The floor height of the building is 4m. The column size is taken as 800mmx800mm for all the columns, perimeter beam is incorporated for the building of cross section 800mmx600mm. The design strips were put for the 4th storey for the y axis (layer A) and the x axis (layer B). The strips are further divided into column and middle strips. The proposed structure is said to have a core wall comprising of 6 lift and a staircase where, a shear wall of thickness 300mm is provided and the dimensions of beam used in the core region is 600mmx450mm and the flat plate used in the core region is of thickness 200mm. The 3D model of the building structure is developed in ETABS program, as shown in figure 3and4. Beam and column sections were designed as frame elements. The strip forces and the moment generated are shown in figure5.

The building is examined for gravity loads, considering all the design load combinations specified in the IS: 456 standard codes. The RC frame structure was analyzed according to IS: 456 standard codes. The suitable live and dead loads was taken from IS: 875 (Part-I). The compressive strength of concrete is taken as 25 MPa; the yield strength of steel reinforcement bars is 500 MPa for both longitudinal and transverse reinforcement, respectively.
Figure 1. The plan layout of the building

Figure 2. The framing layout of the building
Figure 3. The 3D model of the existing building by using ETABS

Figure 4. The structural model of the existing building by using ETABS
Figure 5. The strip forces along the x and y axis and its structural moment reactions

Figure 6. The analyzed model shows no modes of failure occurring on the structural elements

Figure 7. The analyzed model shows the encompassed flat slab is stable against punching shear
3.2 Load Bearing Capacity of the Existing Structure

From the results of structural analysis, the cross-section capacity of the structural elements such as bending and shear for beams, shear for columns and strip moments were obtained. From the results, the ability of structural elements to withstand the combination of loads can be determined as no failure modes was identified on columns and slabs.

3.3 Beam Capacities

The review of beams capacity was carried out with various section and position. This analysis was conducted to find out the flexural and shear nominal (capacities) of the beams compared to the internal forces of beam occurred due to the loads. The 450mmx600mm beam provided at the core was found to withstand the bending moment and shear forces.

| Table 1. Beam family |
|----------------------|
| **Type** | **Beam name** | **Size** |
| Beam | B1 - B18 | 800mm x 600mm |
| | B27, B20 | 450mm x 600mm |
| | B19, B21-B26, B28-B30 | 300mm x 600mm |

| Table 2. Properties of Steel |
|-----------------------------|
| **Property** | **Value** |
| Density | 7850kg/m3 |
| Young's Modulus | 210000MPa |
| Poisson's Ratio | 0.3 |

| Table 3. Reinforcement details for beam |
|----------------------------------------|
| Beam | **Reinforcement bars provided for commercial building** | **Bending Moment** |
| | **Top and bottom reinforcement** | **Distribution bars** | |
| B1 @ 450 x 600 mm support | 20 mm Φ bars. 4 Nos. | 10 mm Φ @ 100 mm spacing | 284 kNm |
| B1 @ 450 x 600 mm midspan | 20 mm Φ bars. 4 Nos. | 10 mm Φ @ 200 mm spacing | 284 kNm |
Table 4. Reinforcement details for slab

| Slab | Reinforcement bars for commercial building, (Top and bottom bars) | Bending Moment |
|------|------------------------------------------------------------------|----------------|
| 250 mm thickness column strip @ support | 200 mm Φ @ 100 mm spacing | 744 kNm |
| Column strip @ middle span | 12 mm Φ @ 100 mm spacing | 305 kNm |
| Middle strip @ support | 10 mm Φ @ 200 mm spacing | 211 kNm |
| Middle strip @ mid span | 12 mm Φ @ 100 mm spacing | 80 kNm |

Figure 8. The P-M interaction graph for columns (Commercial Building)

3.4 Column capacities

P-M interaction diagrams illustrate the ability or capacity of a column to carry the axial and bending moment due to the working loads, as shown in Figure 8. The points illustrate the combination of axial force and bending that acting in the column. In the column C1, the internal forces acting on the column are still within the nominal moment and axial reduction limit so that the columns are still able to resist the internal forces due to the loads. Based on shear force capacity, all columns are able to withstand the shear force acting on the structure. Hence, while identifying the failures, the columns were found to be stable and are within the permissible limits.
3.5 Flat plate against punching shear

The flat plate incorporated in the structure was found to be safe against punching shear as shown in figure 7. The punching shear ratio is 1.36 which is less than 1.5. The nominal shear stress (t_v) was found to be 1.69 N/mm², permissible shear stress for the M25 grade concrete is 1.25 N/mm² and the maximum permissible shear stress was calculated as 1.88 N/mm². Thereby, t_{max} > t_v > t_c. Hence the section was found to be safe with addition of shear reinforcement.

In view of the aftereffects of the strength and performance evaluation of the existing commercial building structure, it very well may be presumed that the building structure is able to withstand the combination of loads. Presently to alter the functionality of the building from a commercial building to a data center building, the said building was later converted to a data center storage building where the imposed Live load was examined to have increased from 5 kN/m² to 10 kN/m² as per IS code (875 Part-II).

4. Analysis 2 – (Data centre building)

The same structure was then decided to be changed into a data center building. For this analysis, the same structure as that for the commercial building is adopted with the only distinction being the change in the loading parameter. The same 10 storey building is taken, dimensions such as the floor height, beam and column dimensions, and material properties were as per the aforementioned data. The load combinations were taken as per Indian standard code 456 and the live/dead load parameters were taken with accordance to the Indian Standard code 875 (part I and part II). The dead load parameters remained the same (3 kN/m²) but the live load parameter is changed from 5 kN/m² (light weight – industrial) to 10 KN/m² (heavy duty – industrial), depicted in figure 9. After which the structure was carried out for analysis where, data of strips forces were obtained, shown in figure 10. Failure modes were also obtained, shown in figure 11 and 12, based on which the behavior of the structure due to gravity loads was obtained.

Figure 9. The structure is depicted with 10 kN/m² live load applied to it.
Figure 10. Strip forces along the x and y axis and its structural moment reactions

Figure 11. The analyzed model showing severe column failure

Figure 12. Layout showing column failure in the ground storey
Figure 13. Layout showing column failure in the first storey

Figure 14. Layout showing failure due to punching shear

Figure 15. Failure of beam cross-section (450 x 600 mm) in the core walls due to shear

4.1 Load bearing capacity of the structure.

From the outcomes displayed above as for the structural behavior, elements such as bending and shear for beams were obtained. It is clear that for this analysis the load bearing capacity for the beams and columns have exceeded their maximum permissible limit. The slabs also face predominant failure through punching shear.

4.2 Beam capacities

The review of beams capacity was carried out with various section and position. This analysis was conducted to find out the flexural and shear nominal (capacities) of the beams compared to the internal
forces of beam occurred due to the loads. The beams of the core wall (450 x 600 mm) fail due to shear, shown in figure 15.

Figure 16. P-M Column interaction graph for columns (for Data centre building)

4.3 Column capacities

P-M interaction diagrams illustrate the ability or capacity of a column to carry the axial and bending moment due to the working loads, as shown in Figure 16. The points illustrate the combination of axial force and bending that acting in the column. In the column C1, the internal forces acting on the column are still within the nominal moment and axial reduction limit so that the columns are still able to resist the internal forces due to the loads. Based on shear force capacity, the columns faced failure due to shear. Specifically, the columns of the ground and first storey faced severe failure.

4.4 Flat plate against punching shear

The flat plate incorporated into the structure was identified as not being safe against punching shear as shown in figure 14. The punching shear ratio is 1.83 which is greater than 1.5. The nominal shear stress ($t_n$) was found to be 2.28 N/mm$^2$, permissible shear stress for the M25 grade concrete is 1.25 N/mm$^2$ and the maximum permissible shear stress was calculated as 1.88 N/mm$^2$. Thereby, $t_{\text{nom}} < t_n < t_c$. Hence the section was found to not be safe with addition of shear reinforcement.

Through this analysis, it is clearly evident that the building structure cannot withstand the combination of loads so that the structure needs to be strengthened. This study offered retrofitting ways to increase the building's performance using concrete jacketing and shear wall. To assess the improvement in performance owing to the addition of concrete jacketing and column capital, the performance of the existing building and the retrofitted building are compared.

Table 5. Beam capacity vs demand

| Beam       | Zone     | Normal loading | Data Centre Loading | Capacity Exceeding in % |
|------------|----------|----------------|---------------------|-------------------------|
|            |          | Moment         | Capacity            | required                | exceeding               |
| Beam       | Zone     | Required       | Moment              | Capacity                |                         |
| B27,B20    | Support  | 284 kNm        | 327 kNm             | 363 kNm                 | 36 kNm                 | 9.92 %                  |
| Stair case | Mid Span | 133 kNm        | 327 kNm             | 171 kNm                 | Sufficient             |                         |
| 450 mm X 600 mm |          |                 |                     |                         |                          |                         |
| Element                        | Normal Loading Moment Required | Normal Loading Moment Capacity Provided | Data Centre Loading Moment Required | Capacity Exceeds in Percentage |
|-------------------------------|--------------------------------|----------------------------------------|-----------------------------------|--------------------------------|
| Column strip at mid span      | 305 kNm                        | 357 kNm                                | 410 kNm                           | 53 kNm                         | 12.93%                        |
| Column strip at support       | 743 kNm                        | 759 kNm                                | 998 kNm                           | 239 kNm                         | 23.95%                        |
| Middle strip at mid span      | 212 kNm                        | 357 kNm                                | 285 kNm                           | -                              | -                             |
| Middle strip at support       | 80 kNm                         | 174.63 kNm                             | 104 kNm                           | -                              | -                             |

5. Analysis of retrofitted model

Retrofitting is the addition of features to an existing section of a structure to improve its strength or load bearing capacity. Acknowledging that the structure faces severe column failure, column jacketing is recommended.

5.1 Retrofit - Column Jacketing

Column jacketing is a method in which the size of a column can be increased by adding jackets to the column. The jacket can be of different materials such as Fiber Reinforced Polymer, steel, concrete etc. Because it follows the same design and construction techniques as RC columns, concrete jacketing is a common type of retrofit. By strengthening confinement and providing additional steel reinforcement, the jacket can improve axial and flexural strength. Modelling columns and beams that jacketed on ETABS is done by enlarging the cross-sectional dimensions and adding reinforcement according to the amount planned for columns and reinforcing beams.

In this particular situation a concrete jacket of dimensions 100 mm on each side, increasing the column size from 800 x 800 mm to 1000 x 1000 mm. Since the percentage of steel is exceeding in the data center, a composite section for the column to accommodate the bars were adopted. The position of the column after jacketing is shown in figure 17.
Load-bearing capacity. The capacity of the columns is increased by the concrete jacketing method so that the structure is capable of carrying axial and bending moments. Likewise, we find that the columns after jacketing are able to carry the working loads that work significantly in column capacity, especially there is an increase in moment capacity. Based on the analysis, we find that there is a decrease in the percentage of steel from 6.43\% to 2.954\% which is not exceeding the limit as given by IS: 456. Thereby, we can accommodate 32mm\(\Phi\) bars in a column which is enough to overcome the problems that occurred on the ground floor and 1st floor columns that have not to carry the working bending moment.

Table 7. Column table

| Condition                   | Commercial Utility | Data Centre Building | Column Jacketing |
|-----------------------------|--------------------|----------------------|------------------|
| Section                     | 800 x 800 mm       | 800 x 800 mm         | 1000 x 1000 mm   |
| % Of steel                  | 4.2\%              | 6.34 \% > 6\% (IS 456 Condition) | 2.954\%          |
| Flexural reinforcement Bars | 34 Nos., 32 \(\Phi\) mm | Cannot accommodate bars | 36 Nos., 32 \(\Phi\) mm |
5.2 2nd Retrofit – Column Capital

The second retrofitting strategy introduced is **Column Capital**, elucidated in figure 18. A column capital is a crowning member of the column providing structural support and mediates the column and the load acting upon it. The reason for introducing this feature is to prevent slab failure due to punching shear. Previous to the addition of the column capital the punching shear ratio obtained is 1.577 which is greater than the allowable ratio which is 1.5. The nominal shear stress (t_v) was found to be 2.28 N/mm², permissible shear stress for the M25 grade concrete is 1.25 N/mm² and the maximum permissible shear stress was calculated as 1.88 N/mm². Thereby, \( t_{\text{max}} < t_v < t_c \). Consequently the column capital is introduced to upgrade load bearing capacity. The dimension for the column capital adopted is 100 x 100 mm on each side of the column.

![Figure 18. A typical section of a steel column capital](image)

6. Cost – Benefit Analysis

A cost benefit analysis is done for this project. This quantifies how there is a monetary advantage of using the retrofitting methodology over complete reconstruction. This gives an idea for future projects, to identify their financial criterion for the project and make wise choices with respect to the same. There are a few other factors which can be categorized as intangible and therefore cannot be quantified, such as, durability, energy efficiency etc. These factors have been classified based 5-star rating.

**Note** – All of these parameters have been adopted and approximated with reference to current Indian rates.
6.1 Costs – Accounting for 70 years

Table 8. Cost comparative table

| PROJECT PARAMETERS             | RETROFITING | RE-CONSTRUCTION |
|-------------------------------|-------------|-----------------|
| Time of completion            | 4-5 months  | 2-3 years       |
| Erection cost (Rs.)           | 58 lakhs    | 6000 lakhs      |
| Cost of steel                 | 18 lakhs    | 76 lakhs        |
| Manufacturing raw materials (Rs.) | 6.2 lakhs | 106 lakhs       |
| Labour cost (Rs.)             | 104 lakhs   | 200 lakhs       |
| Design life                   | 70 years    | 50 years        |
| Maintenance cost (Rs.)        | 3 lakhs     | 9 lakhs         |
| Total cost (Rs.)              | 2,24,00,000 | 10,39,00,000    |

6.2 Benefits- Accounting for 70 years

Table 9. Cost benefit table

| PROJECT PARAMETERS             | RETROFITING | RE-CONSTRUCTION |
|-------------------------------|-------------|-----------------|
| Durability                    | ****        | ***             |
| Ease of construction          | *****       | **              |
| Energy efficiency             | *****       | ***             |
| Health aspect                 | ****        | ***             |

Figure 19. All rates used for the calculation of this cost benefit analysis have been taken from UCON construction private limited.
6.3 Results of Cost – Benefit Analysis

The project parameters have been showed in the table 6 and the cost comparison chart is shown in figure 19. The life of the structure comes to 70 years when it has been retrofitted as opposed to reconstruction. The cost of erection is approximately 10 times higher for reconstruction with respect to retrofitting. The manufacturing cost is also approximately 25 times more than retrofitting for reconstruction. In total, we can say that the cost of reconstruction is nearly 5 times more than the cost that would be required for retrofitting the structure.

Retrofitting is extremely environment friendly and energy efficient. There is a great amount of CO₂ emission reduction and water conservation in this method. It reduces the usage of natural resources and also ameliorates the effect the construction industry has over climate change. With reduced time for construction, labor force is reduced to a great extent. The structure also increases its durability when it has been retrofitted, thereby increasing its life, as shown above, and also has seismic enhancement properties which would help the structure in calamities such as earthquakes.

In conclusion, we can say that the retrofitting methodology is better in comparison with complete reconstruction as it is better in terms of cost, energy efficiency and structural performance.

7. Conclusion

The agenda of this research is to convert a commercial building into a data center building by the means of using retrofitting techniques. From the above analysis the following conclusions can be drawn:

• The structure when analyzed for commercial utility is safe. Its loading parameters are well within the maximum permissible loads for the columns, beams and slabs.

• The structure when analyzed as a data center building, encounters severe column load, particularly in the ground and first floor. The slabs face failure due to punching shear. A section of the core wall beams fails as well.

• Column jacketing is adopted to improve the load bearing capacity of the column.

• Once column jacketing (100 mm on each side) is done, the columns are safe.

• Nevertheless, a pertaining problem is that even after the inclusion of the column jacketing, due to the lack of a drop panel in the flat slabs that are there in the building, the structure still faces an amount of punching failure.

• To address this, a column capital of size 100 x 100 mm on each side is introduced. After this addition all the values are well within its permissible limits.

From this analysis, it is understood is that for changing the functional utility of a given structure, an alternate approach would be to use retrofitting to renovate the structure. This kind of approach is not only cost and time efficient, but its ability to conserve energy makes it a very sustainable approach, which is a key, as the construction industry is garnering sustainable development and would be pivotal for the future.

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