Vertical Extension & Retrofitting of the Existing Reinforced concrete Structure

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ABSTRACT:

In India population is witnessing annual growth and cities like Mumbai are facing limited land availability for horizontal expansion, the necessity for vertical building extensions becomes increasingly evident. This paper focuses on the feasibility of vertically extension existing reinforced concrete building to address this demand. This experiment Includes the use of ETAB software, as it undertakes a comprehensive analysis and design process. Initially, the existing building is modeled, analyzed, and designed to establish its structural integrity. Subsequently, a simulated vertical story extension is evaluated to assess the performance of structural members in both the original and extended structures. The study highlights the necessity for strengthening existing columns after extension, proposing practical solutions such as RCC jacketing. Furthermore, comparing maximum vertical reaction forces of columns from ETAB with the vertical reaction forces which are calculated manually based on tributary area. These forces being used to calculated the required the sizes of the footing by checking punching shear and one-way shear. Which indicates the necessity for strengthening existing footings after extension, hence proposing practical solutions such as RCC jacketing. These findings contribute valuable insights into the viability of vertical expansion as a sustainable solution for urban growth in Mumbai and similar cities, emphasizing the importance of structural integrity and practical strengthening measures. It concludes that the proposed solutions successfully enable the building to withstand vertical extension.

Keywords: Reinforced concrete structure, Vertical Extension, Retrofitting, RCC jacketing, Punching Shear, One-way shear.

1 Introduction

Urban areas are becoming more crowded, making it important to find ways to use space more efficiently. [1,2] One effective method is to add floors to existing buildings. This approach allows us to make the most of the space we already have and reduces the need for new construction. Adding floors to a building can also help the environment by using fewer resources compared to building new structures from scratch. [3,4] It takes advantage of the existing foundation and infrastructure, which is more sustainable [5-7]. While some studies have explored building extensions [8-10], there remains a significant unresolved technical challenge associated with vertical additions that require further investigation.[11]
The focus is on designing a strong and safe plan for adding new floors to an existing building This research focuses on the vertical extension of an existing reinforced concrete in using the Etab software. Both the reference and extended buildings are modeled, analyzed, and designed. The study compares the buildings in terms of stresses and structural capacity considering required retrofitting.

2 Methodology

The methodology of this project includes modelling, analysis, and designing a multi-story commercial reinforced concrete building utilizing ETAB software. The building is modelled, analyzed, and designed using the available data and based on Indian standards [12,13]. methodology also includes some manual calculations such as vertical reactions of columns, Axial capacity of the column, one-way and Two-way shear check of footings, etc. The study examines the impact of adding floors to the top of the building, assessing whether such an extension is feasible with or without structural Retrofitting.

3 Specifications

The reference building comprises Basement Floor + Ground Floor + 6-stories + Terrace and will be having Extension of 10-Floor above Existing Terrace Level. The height of the structure from the ground level to 7th floor level (Existing Terrace level) is 30.6m and the height from the ground level to the proposed terrace level will be 69.60m. Foundations were designed for an Allowable Bearing Capacity of 55 Tn/m2. RCC beam and Flat-slab framing system is Adopted up to Existing Terrace Floor (Basement to Terrace Floor), And for Extension 9th to 17th Floor (Terrace Floor) will be Same RCC beam and Flat-slab framing system is Adopted.

Table 1. Floor Height of the Building

Floor Description	Floor Height
Basement	3.25 m
Ground Floor to Existing Terrace Floor	4.20 m
Terrace Floor (7th Floor) to 8th Proposed Floor	3.90 m
Proposed 8th Floor to 17th (Terrace Floor)	3.90 m

4 Modelling reference building

The study was conducted with modelling of the building in ETABS meticulously inputted all necessary data, including the building's dimensions, floor plans, and elevations, generated the structural elements such as columns, beams, slabs, according to the Available structural drawings. After that defined the properties of these elements.

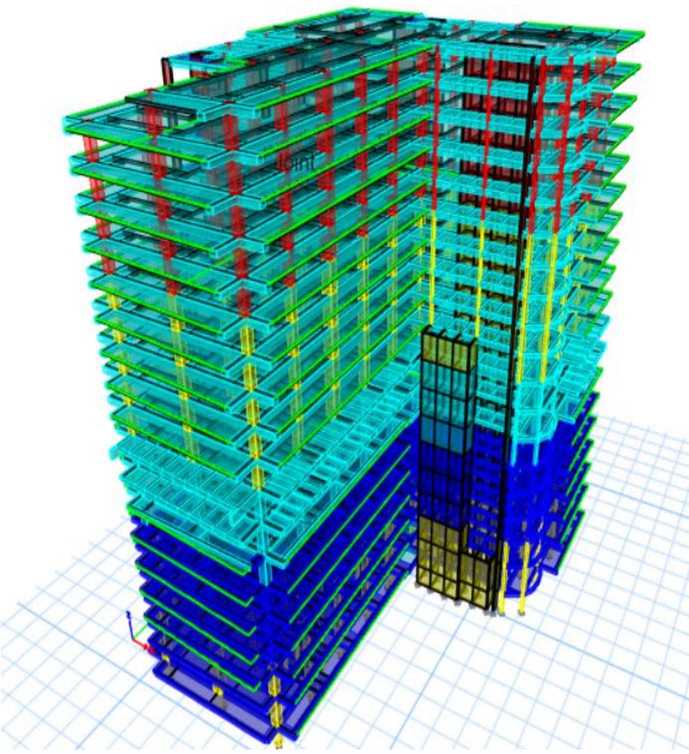

Fig. 1. ETABS Model Of the building

After the completion of building modelling, the subsequent phase involved defining the various loads for the structure. For the flooring, live loads and dead loads were specified at 4 kN/m² and 2 kN/m², respectively, and were uniformly distributed on the slab. In the toilet area, the live load and dead load for the flooring were applied 2 kN/m² and 5.62 kN/m², respectively. Additionally, different uniformly distributed loads were accounted for on beams, including loads from glass cladding (4 kN/m), windows (3.5 kN/m), R.C.C. walls in refuge floors (18 kN/m), lightweight block walls of various thicknesses, and parapet wall loads on the terrace (5.2 kN/m). The completely modelled building was then analyzed.

5 Outcomes and Results

The results derived from the analyses and designs of both the reference and extended buildings from the ETABS are presented and subsequently discussed. The vertical reaction forces of the columns from the reference and extended buildings are illustrated in Table 3-4 respectively.

Table 2. Vertical reaction forces of the reference building

Column	Output Case	P (kN)	Column	Output Case	P (kN)
C1	DL+LL	-10431.8	C28	DL+LL	-15422
C2	DL+LL	-14821.9	C29	DL+LL	-14954.9
C3	DL+LL	-11118.5	C30	DL+LL	-12796.8
C4	DL+LL	-11279.6	C38	DL+LL	-13395.9
C5	DL+LL	-11447.5	C41	DL+LL	-8596.17
C6	DL+LL	-11377.7	C42	DL+LL	-8449.5
C12	DL+LL	-9425.46	C43	DL+LL	-8689.41
C14	DL+LL	-11337.8	C44	DL+LL	-8709.41
C16	DL+LL	-6983.5	C45	DL+LL	-10534.2
C18	DL+LL	-10202.7	C47	DL+LL	-5402.38
C19	DL+LL	-12920.3	C48	DL+LL	-6994.15
C20	DL+LL	-8735.02	C49	DL+LL	-7970.43
C22	DL+LL	-10328.2	C50	DL+LL	-8408.48
C23	DL+LL	-10702.5			

Table 3. No.04 Vertical reaction forces of the Extended building

Column	Output Case	P (kN)	Column	Output Case	P (kN)
C1	DL+LL	-20114.41	C28	DL+LL	-32670.68
C2	DL+LL	-29265.53	C29	DL+LL	-32992.64
C3	DL+LL	-23891.04	C30	DL+LL	-24618.29
C4	DL+LL	-19866.02	C38	DL+LL	-27947.62
C5	DL+LL	-22680.47	C41	DL+LL	-17359.50
C6	DL+LL	-23866.62	C42	DL+LL	-16485.16
C12	DL+LL	-19517.11	C43	DL+LL	-17580.79
C14	DL+LL	-24627.33	C44	DL+LL	-16983.83
C16	DL+LL	-12387.90	C45	DL+LL	-23293.82
C18	DL+LL	-21948.96	C47	DL+LL	-9884.07
C19	DL+LL	-25932.69	C48	DL+LL	-14962.25
C20	DL+LL	-17489.71	C49	DL+LL	-16990.75
C22	DL+LL	-22583.65	C50	DL+LL	-19249.13
C23	DL+LL	-21342.21			

The vertical reaction forces of the columns of the reference building and extended building were observed to known the how much amount of force are increases after adding more floors, and it shows that after extension all of the columns had higher vertical reaction forces than those of the reference building because of the additional floors. There were also manual calculations of the vertical reaction forces are carried out for comparing with the vertical reaction forces gated from ETABS. Table no.05 present the manual calculation of vertical reaction forces of the column considering tributary area were all the dead loads, live loads, Floor finishes, Wall load, etc. are considered and calculated the load on the column from each floor.

Table 4. Calculation of vertical reaction forces of the column (C1) considering tributary area

Level	Average Floor Thickness	Floor Finish	Floor Ht.	Load intensity	From This Floor	At This Floor
	mm	mm	m	kN/m^2	kN	kN
Roof	475	200		23.88	1190	
16	475	75	3.9	19.18	955	2145
15	475	75	3.9	19.18	955	3100
14	475	75	3.9	19.18	955	4056
13	475	75	3.9	19.18	955	5011
12	475	75	3.9	19.18	955	5966
11	475	75	3.9	19.18	955	6922
10	475	75	3.9	19.18	955	7877
9	475	75	3.9	19.18	955	8832
8	475	75	3.9	19.18	955	9788
7	475	75	3.9	19.18	955	10743
6	475	75	4.2	19.28	960	11698
5	475	75	4.2	19.28	960	12659
4	475	75	4.2	19.28	960	13619
3	475	75	4.2	19.28	960	14579
2	475	75	4.2	19.28	960	15540
1	475	75	4.2	19.28	960	16500
GF	475	100	4.2	19.78	985	17460
B	475	75	3.25	19.83	988	18446
Foun-dation			3.25			19433

After calculations of axial load for column (C1) based on tributary area basis and the result then compared to the column force of (C1) arrived from the ETAB. It was found that the results were almost similar. As after the extension of the building Columns had higher vertical reaction forces than those of the reference building due to the vertical extension these columns and as well as their footings needed strengthening.

The calculated load then compared with the design capacities of the structural elements and their sizes. Fig.04 depicts three distinct columns, each representing a different modelling approach to accommodate the addition of floors. The first column is designed based on the existing sizes, incorporating the additional floors into its structure. In contrast, the second column is modelled to assess the necessity of enlarging the column through RCC jacketing to withstand the increased load resulting from the added floors. Lastly, the third column is devised to evaluate the required dimensions of steel plates for strengthening the column via steel jacketing, aimed at supporting the augmented load due to the additional floors. Applying the load on each floor in the model, which were calculated previously based on tributary area. These modelling scenarios provide a comprehensive analysis of the structural adjustments required for accommodating the increased vertical loads resulting from floor additions.

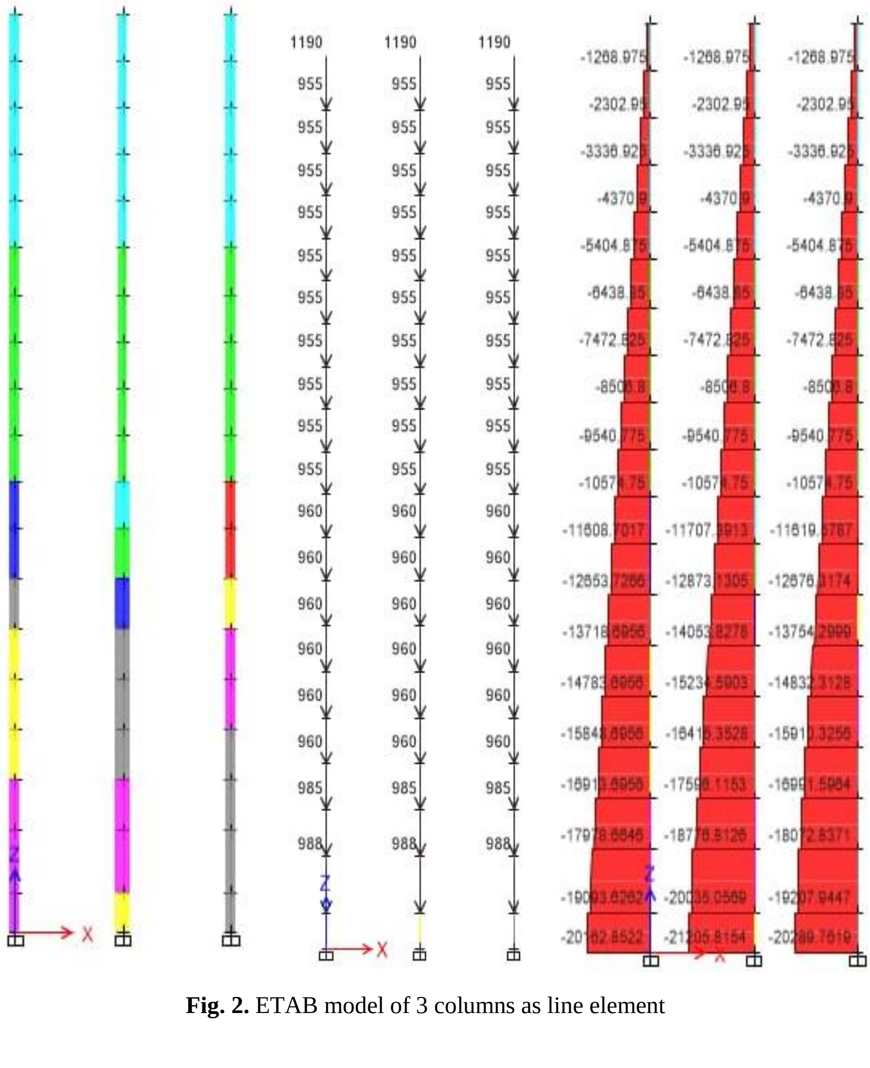

Fig. 2. ETAB model of 3 columns as line element

Subsequently, load combinations were added in the software including the defined loads and load cases. The modelled was then analyzed and designed. The obtained results from these analyses and designs of the columns are presented, within these results, the necessary sizes and thickness of steel plates require for strengthening of the columns are meticulously illustrated in Figure.05

Level	Column size & Concrete Grade	Column size & Concrete Grade	Column size with steel plate & Concrete Grade
Roof	900X900 M40	900X900 M40	900X900 M40
16th	900X900 M40	900X900 M40	900X900 M40
15th	900X900 M40	900X900 M40	900X900 M40
14th	900X900 M40	900X900 M40	900X900 M40
13th	900X900 M40	900X900 M40	900X900 M40
12th	900X900 M50	900X900 M50	900X900 M50
11th	900X900 M50	900X900 M50	900X900 M50
10th	900X900 M50	900X900 M50	900X900 M50
9th	900X900 M50	900X900 M50	900X900 M50
8th	900X900 M50	900X900 M50	900X900 M50
7th	900X900 M25	1350X1350 M25	900X900 M25-12mm
6th	900X900 M25	1400X1400 M25	900X900 M25-12mm
5th	1000X1000 M25	1450X1450 M25	1000X1000 M25-12mm
4th	1000X1000 M30	1450X1450 M30	1000X1000 M30-12mm
3rd	1000X1000 M30	1450X1450 M30	1000X1000 M30-12mm
2nd	1000X1000 M30	1450X1450 M30	1000X1000 M30-15mm
1st	1000X1000 M35	1450X1450 M35	1000X1000 M35-15mm
GF	1000X1000 M35	1450X1450 M35	1000X1000 M35 -15mm
Base	1000X1000 M35	1500X1500 M35	1000X1000 M35 -15mm

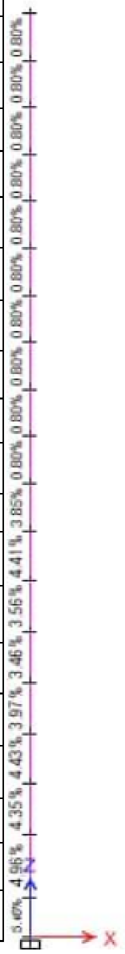

Fig. 3. ETAB model of 3 columns with required % of reinforcement

The Required cross-sectional area of longitudinal reinforcement for the column must be greater than 0.8% and less than 4% as per Indian standard Code- IS 456:2000, With increasing the load on the existing building through vertical extension, it was resulted that the percentage of cross-sectional area of longitudinal reinforcement of the existing building became more than 4%. in fig.05 elaborates those columns which got higher percentage of cross-sectional area of longitudinal reinforcement than 4% due to the extension. As evident from Figure 05, the percentage of cross-sectional area of longitudinal reinforcement decreased following the enlargement of the column size through RCC Jacketing.

Another viable option is apparent from Figure 05, where the purple and yellow color lines signify elements that have not failed subsequent to the implementation of steel plates. These figures distinctly demonstrate the feasibility of the proposed retro-fitting methods, as they yield acceptable outcomes in terms of preventing column failure due to extensions. The comprehensive analysis presented in Figures 05 under-scores the effectiveness of the retrofitting strategies in enhancing the structural integ-rity and resilience of the columns against the increased loads associated with building extensions.

According to the Indian Standard code IS 13920:2016, it is stipulated that the fac-tored axial compressive stress must not exceed 0.4 times the characteristic compres-sive strength of the concrete. This criterion is evaluated both before and after the strengthening of the column. Sample calculations demonstrating this check are pre-sented in Table 6 for the condition before strengthening and in Table 7 for the condi-tion after strengthening.

Table 5. Calculation of axial compressive stress of the column (C1) before strengthening.

Story	Column	Concrete Grade (mpa)	Column Dimension (bxd)		P (kN)	Axial Stress in column	Allowable stress	CHECK
roof	C1	40	900	900	-1903.46	2.350	16	Okay
16th	C1	40	900	900	-3454.42	4.265	16	Okay
15th	C1	40	900	900	-5005.38	6.179	16	Okay
14th	C1	40	900	900	-6556.35	8.094	16	Okay
13th	C1	40	900	900	-8107.31	10.009	16	Okay
12th	C1	50	900	900	-9658.27	11.924	20	Okay
11th	C1	50	900	900	-11209.23	13.839	20	Okay
10th	C1	50	900	900	-12760.2	15.753	20	Okay
9th	C1	50	900	900	-14311.16	17.668	20	Okay
8th	C1	50	900	900	-15862.12	19.583	20	Okay
7th	C1	25	900	900	-17413.05	21.498	10	Not Okay
6th	C1	25	900	900	-18980.58	23.433	10	Not Okay
5th	C1	25	1000	1000	-20578.04	20.578	10	Not Okay
4th	C1	30	1000	1000	-22175.54	22.176	12	Not Okay
3rd	C1	30	1000	1000	-23773.04	23.773	12	Not Okay
2nd	C1	30	1000	1000	-25370.54	25.371	12	Not Okay
1st	C1	35	1000	1000	-26967.99	26.968	14	Not Okay
GF	C1	35	1000	1000	-28640.43	28.640	14	Not Okay
Base	C1	35	1000	1000	-30244.27	30.244	14	Not Okay

Table 6. Calculation of axial compressive stress of the column (C1) after strengthening

Story	Column	concrete grade (mpa)	Column Dimension (bxd)		P (kN)	Axial Stress in column	Allowable stress	CHECK
roof	C	40	900	900	-1903.46	2.349954	16	Okay
16th	C1	40	900	900	-3454.42	4.264722	16	Okay
15th	C1	40	900	900	-5005.38	6.179491	16	Okay
14th	C1	40	900	900	-6556.35	8.094259	16	Okay
13th	C1	40	900	900	-8107.31	10.00903	16	Okay
12th	C1	50	900	900	-9658.27	11.9238	20	Okay
11th	C1	50	900	900	-11209.23	13.83856	20	Okay
10th	C1	50	900	900	-12760.2	15.75333	20	Okay
9th	C1	50	900	900	-14311.16	17.6681	20	Okay
8th	C1	50	900	900	-15862.12	19.58287	20	Okay
7th	C1	25	1350	1350	-17561.08	9.635713	10	Okay
6th	C1	25	1400	1400	-19309.69	9.851886	10	Okay
5th	C1	25	1450	1450	-20080.74	9.550888	10	Okay
4th	C1	30	1450	1450	-22851.88	10.86891	12	Okay
3rd	C1	30	1450	1450	-24623.02	11.71131	12	Okay
2nd	C1	30	1450	1450	-25094.17	11.9354	12	Okay
1st	C1	35	1450	1450	-28165.21	13.39606	14	Okay
GF	C1	35	1450	1450	-29052.58	13.81811	14	Okay
Base	C1	35	1500	1500	-31308.72	13.91499	14	Okay

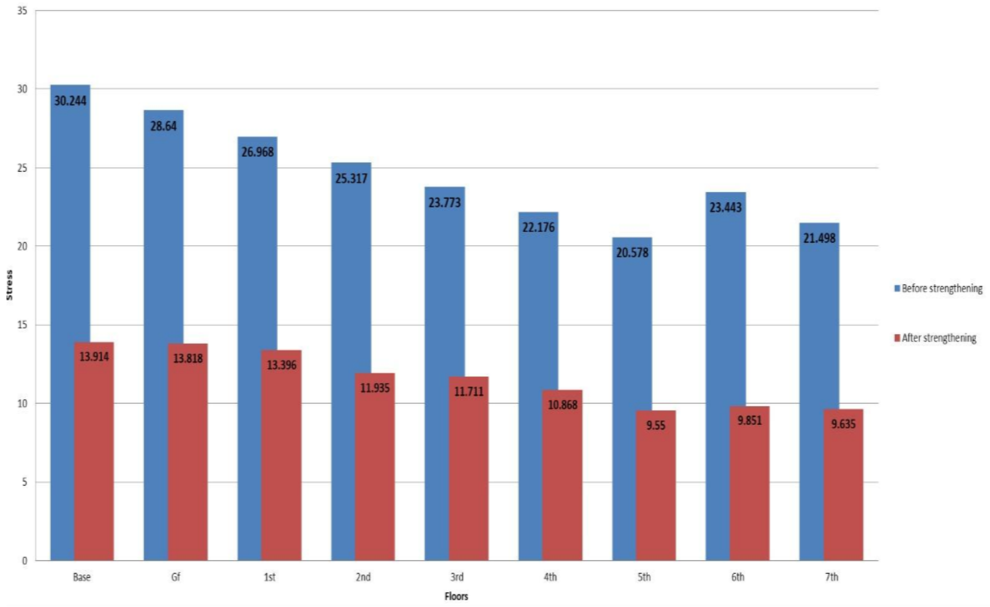

Fig. 4. Comparison of stresses on columns before and after strengthening

6 Determining the necessary dimensions for the footing following the extension of the building.

A study was undertaken to assess the new dimensions of the foundation. The focus of this analysis involved expanding the footing sections to increase their capacity for bearing loads, thereby accommodating the additional load demand. The calculations encompassed evaluations for both one-way shear and punching shear in accordance with the specifications outlined in the Indian standard IS 456:2000. According to the code, the critical section for punching shear is determined at a distance equal to half of the effective depth of the footing from the face of the column. whereas, for one-way shear, the critical section is situated at the effective depth of the footing from the column face. Based on these required sizes of footings was carried out and showed in below table no.07.

Table 7. Calculation of axial compressive stress of the column (C1) after strengthening

Column No.	Unfactored Load (KN)	Existing Column Dimension at Base (mm)		Required Footing Depth (mm)	Existing Depth (mm)
C1	20114	1000	1000	1850	1100
C6	23867	1200	1200	1950	1950
C12	19517	1200	1200	1750	1950
C14	24627	1200	1200	2000	1950
C2	29266	1300	1300	2200	1100
C3	23891	1000	1000	2050	1100
C16	12388	1000	1000	1350	1950
C18	21949	1200	1200	1850	1950
C19	25933	1200	1200	2050	1950
C20	17490	1000	1000	1700	1950
C22	22584	1200	1200	1900	1950
C23	21342	1200	1200	1850	1950
C28	32671	1300	1300	2350	1950
C29	32993	1300	1300	2350	1950
C30	24618	1200	1200	2000	1950
C38	27948	1200	1200	2150	1950
C41	17360	1200	1200	1600	1950
C42	16485	1000	1000	1650	1950
C43	17581	1000	1000	1700	1950
C44	16984	1000	1000	1650	1950
C45	23294	1200	1200	1950	1950
C47	9884	1200	1200	1100	1950
C4	19866	1100	1100	1800	1950
C48	14962	1200	1200	1450	1950
C49	16991	1200	1200	1600	1950
C50	19249	1200	1200	1700	1950

For strengthening process small holes were drilled into the surface of existing footings, and epoxy grout were applied. Dowel bars were then inserted into these holes. These bars help to connect the new concrete to the existing footing, enhancing the structural bond. New Reinforcement bars were arranged around the footing and Fresh concrete was subsequently cast and compacted to cover the enlarged footing area.

7 Conclusion

This study was to evaluate whether building could successfully withstand a vertical extension. The advanced Finite element-based software, was utilized for modeling, analysis.

Key findings from the study include:

- Increased Stresses: The vertical extension led to increased stresses in the structural elements of the first seven storeys. Many members in the extended building exhibited higher stress value compared to the original building. This structural member had stresses exceeding limiting value. Maximum stress is 30.2 N/mm^2 and the limiting Value as per IS 13290 (2016) is 14 N/mm^2.For M35 grade of concrete with member size of 1000x1000mm.
- Strengthening Measures: To address these high stresses, various strengthening solutions were proposed like RCC jacketing and steel jacketing. And determine the required sizes for the jacketing column with RCC and also steel plates. These modifications successfully brought the stresses to 13.9 N/mm^2 which below the limiting value.
- Vertical Reaction Forces: As anticipated, the vertical reaction forces increased due to the extension. Maximum force observed is 14954.9 kN before extension, and after extension it is 32992.64 kN. These excessive forces at base caused the 1.92 N/mm^2 shear stress which fails existing footing in Punching shear. This value is more than the limiting value of Shear stress Tau (c) = 1.47 N/mm^2 for M35 grade of concrete as per IS 456 (2000). For this 20.51% of existing footing depth need to be increased. To address this enlargement of footing are needed with proper execution and with sufficient shear links to provide proper bonding with existing footing.

Overall, the study concludes that the reference building can support the proposed vertical extension, given the applied strengthening solutions. This research is valuable for practical designers and engineers considering similar vertical extensions of RC buildings, providing insights and methodologies for ensuring structural integrity and performance. This method reduces the construction waste and adding floors to a building can help the environment by using fewer resources compared to building new structures from scratch.

8 References

1. A.bahrami, S.deniz and H.moalin "Vertical Extension of a Multi-Storey Reinforced Concrete Building." International Journal of Applied Mechanics and Engineering, vol.27, pp.1-20 DOI: 10.2478/ijame,2022.
2. Blomsterberg A. and Landin A.- Enabling energy-efficient renovation: the case of vertical extension to buildings. Construction Innovation, Volume-19, pp:2-14, 2019.
3. Joan Artés, Gerardo Wadel and Núria Martí. "Vertical Extension and Improving of Existing Building" in The Open Construction and Building Technology Journal, Volume-11, pp. 83-94,2017.
4. Gillott, C., Densley-Tingley, D. and Davison, B. "Sustainable housing provision: a case for the vertical extension of steel framed buildings". pp. 2425-2433. ISSN 2509-7075,2021.
5. Alaa Jaleel Naji, Haider M. Al-Jelawy, Sura Sadoon and Ahmed Taresh Ejeln." Rehabilitation and strengthening techniques for reinforced concrete columns: review" in 2nd International Conference for Civil Engineering Science, Journal of Physics: Conference Series, ICCES, 2021
6. Zumrawi M. M. E and Aldaw H. K. E." A study on Strengthening of Building foundation for Storey Extension." in Journal. Build. Mater. Struct, pp. 218-226,2018.
7. Johansson B. and Thyman M. "Strengthening of buildings for storey extension". – Chalmers University of Technology,2013
8. Parth Shailesh Patel, Vasudev Tulsi Patel, Romil Jatin Shah and Qureshi Mohammad Naved. "Extension of floors in r.c.c. building." in Journal of Emerging Technologies and Innovative Research (JETIR), Volume 9,2022.
9. Koumousis V. - Reinforced concrete frame building with an independent vertical extension. World Housing Encyclopedia, Report - 17, pp:14, 2002.
10. Michael palmer and Joseph E. Caza. "The carey building vertical expansion" in Structure magazine,2017
11. Sundling R. A development process for extending buildings vertically - based on a case study of four extended buildings. – Construction Innovation, 2019.
12. Indian Standard Code IS 456 - 2000 "Plain and Reinforced Concrete", 'Bureau of Indian standards.
13. Indian Standard Code IS 13920 - 1993 "Ductile detailing of reinforced concrete structures subjected to seismic forces", Bureau of Indian standards.