International Journal of Recent Research and Review, Vol. XVII, Issue 2, June 2024
ISSN 2277 – 8322

SEISMIC RETROFITTING: COMPARATIVE STUDY ON R.C JACKETING AND X TYPE STEEL BRACING

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Abstract: **India, being the second most populous country in the world has a high demand for infrastructure to serve its people. India is one of the most earthquake-prone countries in the world and has experienced several major or moderate earthquakes during the last 15 years. Existing buildings in these earthquake-prone zones require protection and adequate performance against seismic events. Therefore, retrofitting becomes crucial, as it enhances the safety and performance levels of existing buildings over the long term.**

This research examines the seismic performance of an assumed existing building proposed for retrofitting by comparing two unique retrofitting methods: RCC jacketing and steel bracing. The study evaluates the benefits and drawbacks of each method to determine the most effective approach.

For this Purpose, A 25 year old RCC-Residential Building with Special Moment Resisting Frame having Stilt+10 story, in seismic zone 4, constructed as per the requirement of IS 1893:2002 is considered.

After the Static & Dynamic analysis as per IS 15988: 2013 and IS 1893: 2016 of existing structure with two different retrofitting techniques i.e providing X type bracing at periphery and concrete jacketing of columns, the results indicate that story displacement decreases by approximately 90% with the bracing system, compared to a 20% reduction using the column RCC jacketing system. Additionally, the inter-story drift decreases by about 93% with the bracing system, compared to a 33% reduction with column RCC jacketing. Retrofitting the structure by providing X bracing around the periphery significantly increases stiffness. The base shear and story forces show negligible increases in the retrofitted structure compared to the existing condition. The findings advance the knowledge of sustainable construction by extending the lifespan of structures, thereby saving costs, time, and materials.

Keywords: Retrofitting, Reinforced Cement Concrete Jacketing, Steel Bracing, Non-Destructive Test, Seismic analysis, ETABS.

I. INTRODUCTION

An earthquake is a sudden shaking of the ground caused by the movement of the tectonic plates both in direction and magnitude. This creates horizontal forces in the structures, which are termed seismic forces. Older buildings, even if constructed in compliance with prevailing standards, may not comply with the stringent specifications of the latest standards. The existing buildings can become seismically deficient since design code requirements are constantly upgraded. Hence, the existing structures should be made seismic resistant by incorporating various seismic retrofitting techniques to meet the present safety requirements and codal provisions.

The need for seismic retrofitting of an existing building can arise due to several reasons like building not designed as per code, subsequent updating of code and design practice, subsequent upgrading of seismic zone, deterioration of strength and aging, modification of existing structure, change in use of the building, etc. Seismic retrofit is primarily applied to achieve public safety, with various levels of structure and material survivability determined by economic considerations.

Various retrofitting options available in the market include Concrete jacketing, Steel Caging, Steel jacketing, CFRP Carbon-Fiber-Reinforced-Polymers, Steel bracing. Furthermore. The Selection depends on various criteria such as cost, optimal performance, and compatibility of structures. (A. Goswami and S. Das Adhikary, 2019Z. Q. Hassan and S. Al-Wazni, 2023)

Steel Bracing: Steel bracing enhances structural strength and stiffness, reducing the seismic load on existing members, albeit to a lesser extent than reinforced concrete shear walls. Adjusting the number and size of braces allows for control over this enhancement, maintaining a uniform elevation profile. This method is particularly useful for reinforcing soft ground stories, where steel braces are primarily applied to the lower levels. In the absence of supplementary energy dissipation devices, buildings must rely on inelastic deformations to dissipate seismic energy. Therefore, integrating such devices is crucial for preventing severe damage during earthquakes (Soleymani & Saffari, 2024), (Sahib Ali et al., 2024). These systems provide a high level of durability and are able to withstand the stress exerted by earthquakes (T. Shan and E. M. Lui, 2024).Various common steel bracing systems are illustrated in Figure 1

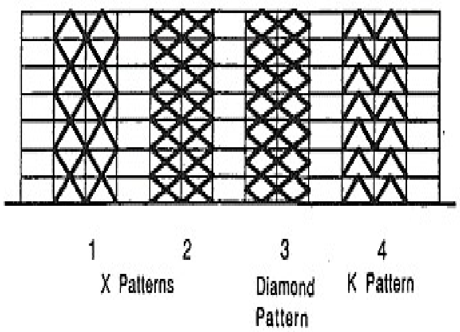

Figure 1: Different Bracing System (Sahib Ali et al., 2024)

Numerous studies have been conducted over years globally to examine the steel-bracing-retrofitting system. Utilizing steel-bracing systems to enhance the lateral resistance of reinforced concrete frames that have insufficient strength is a feasible solution. Sahib Ali et al., 2024 analysis found that earthquake-induced lateral forces considerably impacted the base shear. Among the models tested, the vertical X model experienced the greatest rise in base shear, while the V with I model had the smallest increase. The increase in demand for structural members is caused by the global stiffness boost resulting from adding bracings. Concerning roof displacement, the implementation of diagonal bracing effectively reduced roof motions. On the other hand, utilizing a distributed X arrangement led to a 32% rise in base shear and a significant 60.64% enhancement in roof displacement. Al-Safi et al., 2021 research undertakes a comparative analysis of four bracing systems i.e. V-bracing, inverted V-bracing, one-story X-bracing, and multistory X-bracing systems concerning their cost, base shear, base moment, and story drift. The results emphasize the substantial influence of bracing systems on the base shear and displacement of structures, augmenting their strength and stiffness in comparison to unbraced systems. The inverted V-bracing system is the most cost-effective choice for 10- and 15-story buildings, providing the best economic benefit. Rahimi & Maheri, 2020 research focuses on 4, 8, and 12-story structures. The findings demonstrated that adding steel X braces to RC frames substantially decreased the maximum lateral displacements across all three building heights. Nevertheless, the 4-story structure exhibited distinct behavior, mostly attributed to its elevated stiffness, leading to shear-dominated motions. Conversely, the 8 and 12-story structures had a combination of shear and bending forces, with the influence of bending becoming more prominent as the height of the building climbed. The examination of base shear indicated that the retrofitted frames exhibited an elevated need for base shear as the building height grew. Navya & Agarwal, 2016 study involved the installation of steel bracings organized diagonally in an X pattern, which enhanced the building's elasticity and post-yield behavior. The analysis reveals a significant decrease in the probability of collapse and extensive harm. Faella et al., 2014 had conducted analysis by creating three unique patterns of steel bracing and showed that pattern 3 shown in Figure 2 leads to the lowest levels of stress (axial, shear, and bending) in the reinforced concrete (RC) components.

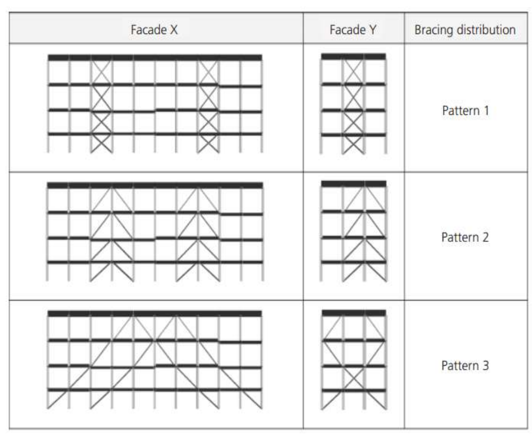

Figure 2 Configurations of steel bracings in the two directions (Faella et al., 2014)

Badoux & Jirsa, 1990 Analysis of braced frame behavior under cyclic lateral loading, especially in frames with weak short columns, highlighted the negative impact of inelastic brace buckling. Nonetheless, integrated braces yielding in compression or elastically buckling at low axial loads can avert instability, while modifying beams in frames with weak short columns can promote a more favorable, ductile failure mechanism.

Reinforced Cement Concrete Jacketing: This method entails the application of an additional layer of concrete and reinforcement to the current structure, as depicted in Figure 3, with the main objective of enhancing its ability to bear weight, longevity, and resistance to seismic activity. The conventional procedure for concrete jacketing is, first roughening of concrete then the Installation of bars then the erection of steel reinforcement then coating with epoxy and in the last pouring of concrete and a concrete jacketing as shown in Figure 4.

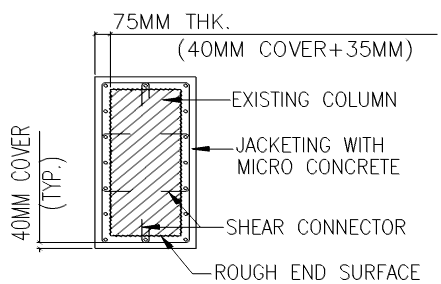

Figure 3 Concrete Jacketing of Column

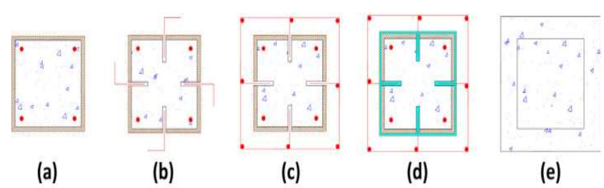

Figure 4 Concrete Jacketing Procedure

The Studies on concrete jacketing shows promising results as retrofitting measure. Selim et al., 2023 proposed a retrofitting strategy which included installing new grid beams at the basement level, replacing the existing basement floor slab, and adding reinforced concrete (RC) jackets to all basement columns. Response spectrum analysis (RSA) revealed that RC jacketing substantially improved the building's lateral behavior, enhancing stiffness and load capacity while reducing inter-story drifts, thereby complying with allowable seismic provisions. C et al., 2022 conducted experimental and analytical investigations on RC jacketed columns. The experimental findings were validated using the finite element model (FEM). Six columns constructed from M25-grade conventional concrete were tested under ultimate load conditions. The study concluded that concrete jacketing strengthens columns by enhancing the uniform distribution of strength and stiffness. Zaiter & Lau, 2021 study assesses the impact of jacket height and reinforcement on reinforced concrete (RC) square columns retrofitted with normal concrete. Results indicated that increasing the jacket height from h/4 to h/2 led to an increase in stiffness. The study recommends using h/4 jacket to achieve a 35% increase in lateral strength, and h/2 jacket when a doubling of lateral strength is required. Anand & Sinha, 2020 study investigates the effect of reinforced concrete jackets, with thicknesses of 25mm and 35mm, on the performance and structural response of RC columns under axial loads. The results indicate that increasing the thickness of the jacketing improves the axial load-carrying capacity of the columns. Mohamed Sayed et al., 2020 study investigates the behavior of RC columns that have been externally strengthened by jacketing after cracking. Fifteen RC columns with different cross-sectional shapes were subjected to static load tests The results indicated that pre-existing cracks reduce the maximum load capacity of RC columns. Notably, square, rectangular, and circular RC columns strengthened after cracking demonstrated lower load capacities than those strengthened before cracking. Raza et al., 2019, studied various strengthening and repair techniques for reinforced concrete (RC) columns, categorizing them into six distinct methods: reinforced concrete/mortar jacketing, steel jacketing, externally bonded fiber-reinforced polymer (FRP) jacketing, near-surface mounted FRP jacketing, shape memory alloy (SMA) jacketing, and hybrid jacketing. For RC/mortar jacketing, it has been summarized that this method enhances the seismic performance and ductility of columns. Moreover, changes in cross-sectional size can impact the structure's stiffness and seismic demands, and the inherently brittle nature of concrete results in only a modest increase in ductility. Rodrigues et al., 2018 study analyzed the efficiency of RC jacketing in reducing the seismic vulnerability of soft-storey buildings. It was observed that RC jacketing of all ground-story columns significantly mitigated the soft-story mechanism and substantially improved the building's strength capacity.

II. REQUISITE STEPS & METHODOLOGY

A. *ANALYSIS-WORKFLOW*

The structural analysis procedure used in the current study is shown in figure 5 below. Key phases include designing and simulating the structural models, applying various retrofitting techniques, and comparative performance assessments.

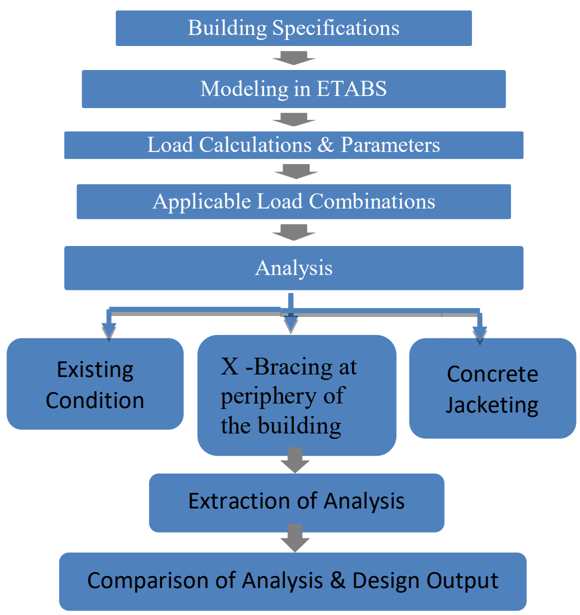

Figure 5 Analysis workflow chart

B. *Building Specifications*

Below, in Table 1 the building specifications are shown, including the type of structure, materials, and properties used in this study. This table provides a comprehensive overview of the critical parameters and characteristics of the building model, such as dimensions, material grades, and specific structural elements.

Table 1 -Building Specifications

Type of Frame	**R.C.C Frame**
Building Type	**Residential**
Geometry of Building	**Symmetrical**
Dimensions in X-Direction	**24 m**
Dimensions in Y-Direction	**24 m**
Number of Stories	**Stilt + 10**
Typical Story Height (H)	**3 m**
Total Height of Building (h)	**35 m**
Foundation	**2 m below Ground Level**
Beam Size (bxd)	**300 x 450 mm**
Column Size	**450x450 mm**
Thickness of Slab	**150 mm**
Super Structure	**Brick Masonry**
Thickness of wall	**230 mm.**
Grade of Concrete (f_{ck})	**M25**
Grade of Steel (f_y)	**FE 500**
Method of Analysis	**Static Analysis / Response Spectrum Analysis**

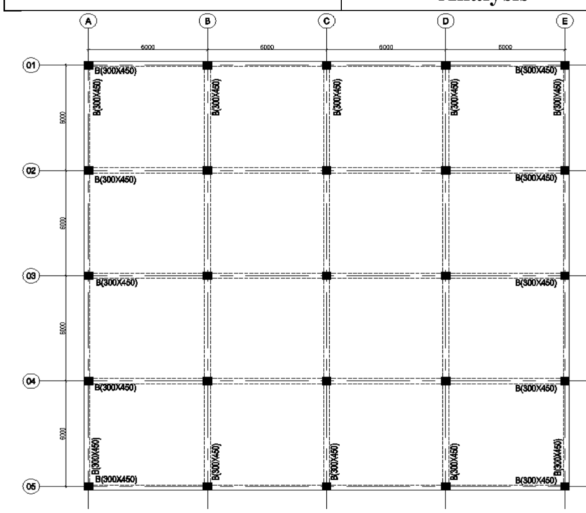

Figure 6 Beam Framing Plan

C. *Basis of Evaluation*

The existing structure is evaluated in accordance with the provisions of IS: 1893:2016(Part-1) [26] and IS: 15988-:2013 [24].

The IS: 15988:2013[24] provides criteria for seismic evaluation of existing structures, which differ from the design criteria of new structures. This Indian Standard provides a method/approach to evaluate the ability of an existing structure to reach an adequate level of performance /capacity for the life safety of occupants. For new structures, the IS: 1893 Part-I-2016 [26] is the relevant standard.

In IS: 15988:2013[24], appropriate modifications are made to address the issues of reduced serviceable life and acceptable risk for higher importance.

The inputs for determining earthquake forces, such as seismic zones, types of buildings, fundamental time period, and response reduction factors, are to be taken directly from IS 1893:2016 (part 1) [26]. The code provides for lateral load modification factors for existing buildings. The lateral force determined for strength-related checks should be modified for reused, useable or balanced service life. The usable life factor U should be multiplied by the new building's lateral force (base shear) as specified in IS 1893:2016(part 1) [26].

The code specifies that factor U may be applied for all buildings except having a requirement of critical safety. In such cases, U shall be 1.0. The code also specifies modified factors for materials.

III. LOAD CALCULATIONS

A. Seismic Load

As per IS-1893-2016, the building in the current study is classified under Zone IV. With medium type soil having importance factor of 1.2. Damping Ratio of 0.05 is considered.

B. Live Load

Imposed load are taken as per IS 875 Part-2, Load values for all rooms & roof in model considered are 2 KN/m2 & 1.5 KN/m2 respectively.

C. Dead Load.

Below Table 2 illustrate the various types of dead loads carried by the structure and their respective calculations.

Table 2 Dead Load Calculations

S.no	Particulars	Values	Units
1	Unit Weight Brick Masonry	20	kN/m3
2	Brick Wall Thickness	0.230	m
3	Height of Wall Excluding Beam Depth	2.55	m
4	Wall Load	11.73	kN/m
5	Floor Finish Thickness	50	mm
6	Floor Finish Load	1.5	kN/m^2

D. Lateral load modification factor (U)

As per Clause 5.4 of IS 15988:2013 lateral load modification factor is calculated and their calculations are shown below in the Table 3.

$$\text{Modification Factor (U)} = (T_{Rem} / T_{Des})^{0.5} \qquad \text{Eq. (1)}$$

$$= (25/25)^{0.5}, \quad U = 0.70$$

Where, T_{Des} is Design Life and

T_{Rem} is Remaining Life

This lateral load modification factor has been applied to lateral loads in load combinations.

E. Base Shear

$V_B = A_{h.}W$

V_B = Base Shear

A_h = Design Horizontal Acceleration Coefficient

W = Seismic Weight of the Building

$$A_h = \frac{\left(\frac{Z}{2}\right)\left(\frac{S_a}{g}\right)}{\frac{R}{I}} \qquad \text{Eq. (2)}$$

$$T_a = 0.075h^{0.75}$$

$$T_a = 0.075 \text{ X } 35^{(0.75)}$$

T_a = 1.079 sec

$$\frac{S_a}{g} = \frac{1.36}{T}$$

Sa/ g = 1.26

$$A_h = \frac{0.24 \text{ X}1.2\text{X}1.26}{2 \text{ X}5}$$

A_h = 0.0363

Table 3 Base Shear Calculations

Building Description	Design Horizontal Acceleration (A_h)	Seismic Weight as per ETAB Analysis kN (W)	Base Shear (V_B)
Existing Condition as per updated code	0.0363	62102.06	2254.3
Retrofitted With Bracing	0.0363	63735.41	2313.6
Retrofitted With Jacketing	0.0363	65205.02	2366.9

F. Load Combinations

Various Load combinations assigned after applying modification factors in the ETABS shown below in 4 below.

Table 4 Load Combinations

S.No	LOAD COMBINATIONS
1	0.9DL-(0.7 X 1.5RSX/RSY)
2	0.9DL+(0.7 X 1.5RSX/RSY)
3	1.2(DL+LL-0.7RSX/RSY)
4	1.2(DL+LL+0.7RSX/RSY)
5	1.5 (D.L-LL)
6	1.5(DL-0.7RSX/RSY)
7	1.5(DL+0.7RSX/RSY)
8	DL+0.8LL+0.8RSX/RSY
9	DL+0.8LL-0.8RSX/RSY

G. Mass Source

Mass Source is defined as per Table 10 of IS-1893:2016 shown in Table 5 below

Table 5 Mass Source for Base Shear

D.L	100%
L.L<3kN/m^2	25%
L.L>3kN/m^2	50%

H. Stiffener Modifiers

The concept of stiffness modifiers is introduced in IS 1893 (Part 1):2016 clause no. 6.4.3.1 of the code defines requirements for structural analysis shown in Table 6 below

Table 6 Stiffener Modifiers

S.no	Elements	Value
1	Beam	0.35
2	Column	0.70

IV. STRUCTURAL ANALYSIS

A. Existing Condition as Per Updated Code

This Existing building is modeled in accordance with the latest seismic code parameters as per IS-1893-2016[26]. A simulation of the same building in 3D rendered view is shown in figure 7 below.

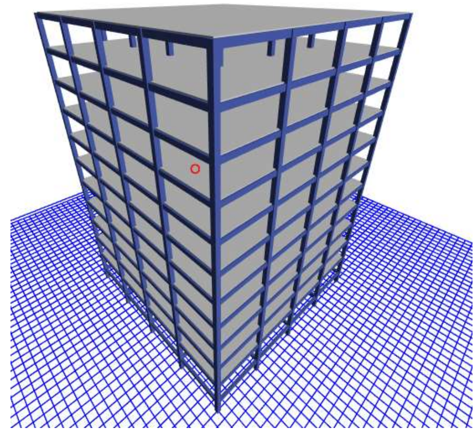

Figure 7 3D Rendered View of Existing Condition with Updated Code

B. Retrofitted With Bracing

In the model retrofitted with bracing, X-type bracing has been utilized at the periphery of the structure shown in figure 8 Channel sections with the property of MC200 have been used for the bracing.

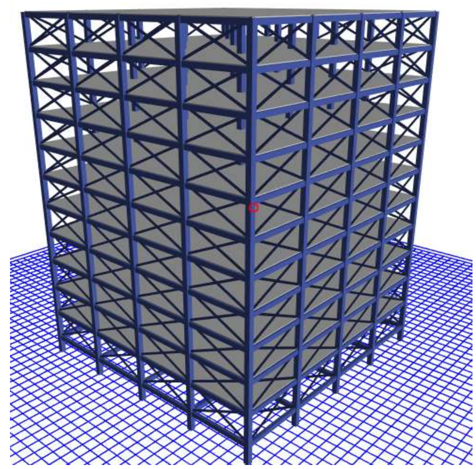

Figure 8 3D Rendered View of Building Retrofitted with X Bracing

C. Retrofitted With Jacketing

In the retrofitted model with jacketing, the column size has been increased from 450x450 mm to 600x600 mm. A 3D rendered view of the same retrofitted shown in figure 9 below.

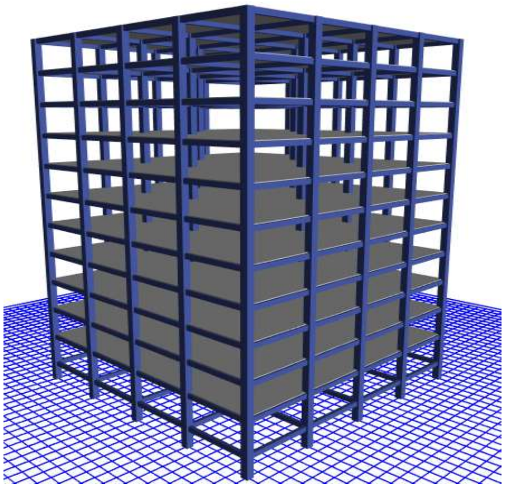

Figure 9 3D Rendered View Building Retrofitted with Jacketing

V. RESULTS AND DISCUSSION

A. Base Shear

The base shear values indicates that implementing bracing at periphery for retrofitting purposes leads to a 2.68% rise in base shear, while structure retrofitted with jacketing, the base shear is 5.36% compared to the existing condition.

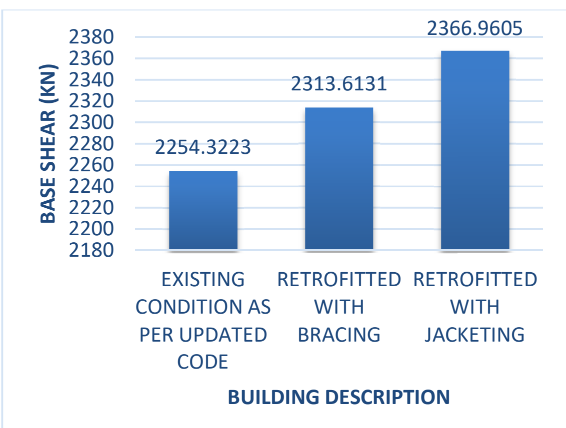

Figure 10 illustrates the base shear comparison for different conditions

B. Story forces

It is observed that the story forces increased slightly in both the retrofitting options. This is due to additional self-weight of bracing and increased column size. The increment is around 2.6 % in bracing option and 5% in jacketing option which is negligible.

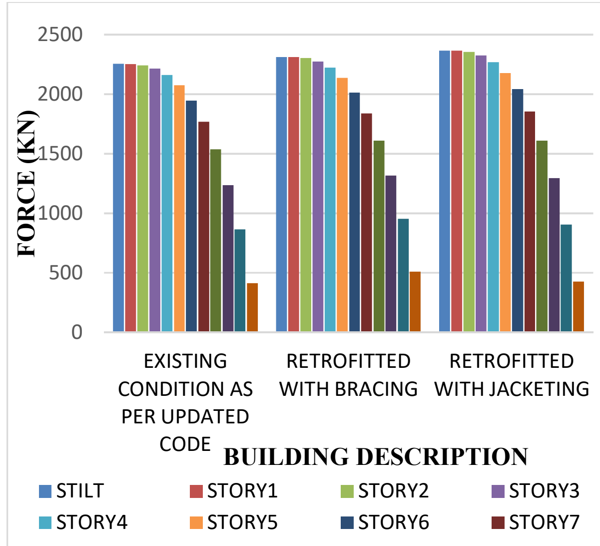

Figure 11 illustrates the comparison of story forces at various levels in buildings

C. Story Drift

Comparative analysis against the existing building conditions reveals a maximum reduction in story drift of approximately 93% for the retrofitted building with bracing. However, retrofitting with jacketing leads to a drift reduction of approximately 33%. This decline in story drift is attributed to the increased stiffness introduced by the jacketing and steel bracing in the retrofitted structures.

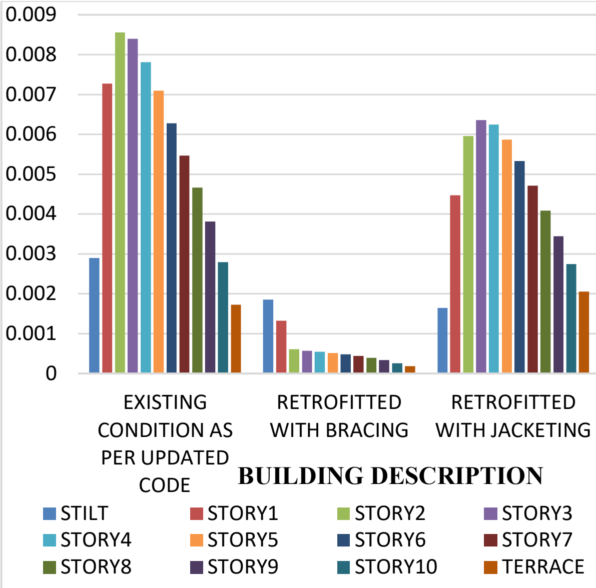

Figure 12 Graphical Comparison of Story Displacement across Building Type

D. Story Displacement

The percentage decrease of story displacement at top floor is around 90% in case of retrofitting option with external bracings. The same is decreased by only 20.3 % in case of retrofitting option with concrete jacketing of columns.

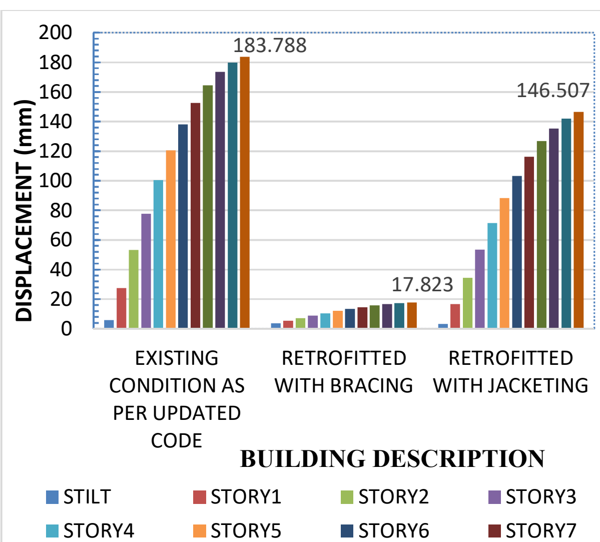

Figure 13 Graphical Comparison of Story Displacement across Building Type

E. Column Design Output

In Figure 14 below graphical representation shows that the reinforcement requirement (average) in internal columns is decreased using external X type bracing without increasing the columns sizes. Similar type of behavior observed in external columns shown in Figure 15. However, rebar percentage will always decrease by increasing the column sizes providing concrete jacketing.

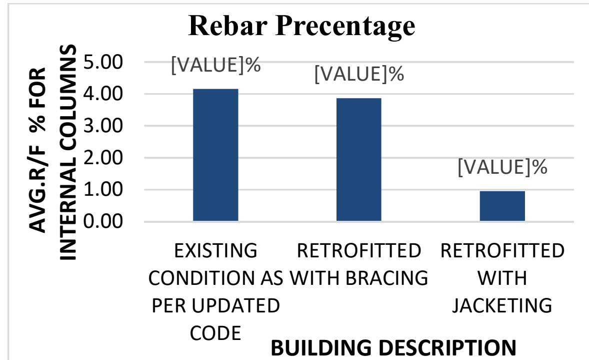

Figure 14 Graphical Comparison of Rebar Percentage for Internal Columns across Building Type

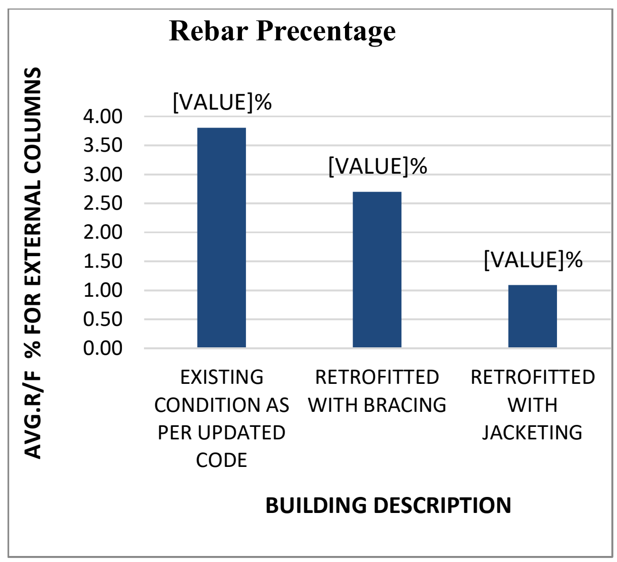

Figure 15 Graphical Comparison of Rebar Percentage for Internal Columns across Building Type

VI. CONCLUSION

After the analysis of the existing structure with providing X type bracing at periphery and Concrete Jacketing of columns, it has been concluded that:

- The structure retrofitted by Providing X bracing in the periphery provides higher stiffness Compared to RCC jacketing of the columns.
- The increase in base shear and story forces due to retrofitting is negligible compared to the existing condition, primarily because of the added self-weight of bracing members and concrete jacket thickness.
- The story displacement decreases by approximately 90% using bracing system compared to the 20% using RCC jacketing.
- The steel bracing system significantly reduced reinforcement demand without altering column sizes. Increasing column sizes through jacketing also decreases reinforcement demand, confirmed by the results.
- Retrofitting with X-type steel bracing on the periphery provides better seismic performance and is more feasible to execute with less disturbance to residents compared to RCC concrete jacketing of columns.

VII. FUTURE SCOPE

- This study assumed the RC-columns were undamaged before strengthening. However, real-world scenarios often involve strengthening of deteriorated columns. Future research should prioritize examining load application before reinforcement.
- The impact of RC jackets can be assessed by varying the types and grades of concrete. Furthermore, a comparative analysis can be prepared to evaluate their performance in seismic conditions.
- A study should be conducted by changing the type of bracing (e.g., zigzag bracing or V bracing) and adjusting the positioning of the bracing.
- The simulation of the same structure can be conducted using various design software such as STAAD, SAP2000, and ANSYS, ABAQS enabling improved comparative analysis.
- Further studies may be performed on performance-based design.

ACKNOWLEDGEMENT

The authors extend their profound gratitude to Kautilya Institute of Technology & Engineering, Sitapura, Jaipur, and the Civil Engineering department faculty for their invaluable support and the opportunity to undertake this project. Special thanks and heartfelt appreciation go to Er. Aman Deep, Director, and the colleagues of Creative Design Consultants and Engineers Pvt. Ltd.

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