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# Seismic Risk Assessment and Rehabilitation Method of Existing RCC Structures Using Micro Concrete

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**Abstract**

Aging reinforced concrete (RC) building structures typically experience more severe damage and are prone to collapse during earthquakes, constituting a primary factor in casualties and direct economic losses. To enhance the seismic performance of these old structures, this paper proposes a seismic risk assessment and a micro-concrete restoration method. It applies the process to an existing three-story reinforced concrete structure. A practical framework for mitigating structural vulnerabilities in seismic-prone regions was proposed. Then an as-built survey was conducted to create as-built architectural and structural drawings. Concrete core tests, ferroscans, and rebar tests were also performed. Based on field surveys and test data, nonlinear static and dynamic analyses have been used to evaluate structural safety. Concrete column jacketing was used to strengthen weak existing columns with micro-concrete. In assessing the structural response of retrofitted buildings, a comparison was made to their initial state. The comparison shows that applying concrete column jacketing with micro concrete can reduce other structural elements' demand capacity ratio (DCR), minimize maximum displacements, and enhance overall stiffness. The results indicate that the proposed method effectively evaluates the seismic risk of aging structures and enhances seismic resilience in existing buildings. Moreover, the application to the actual structure demonstrates that micro-concrete is highly durable and compatible with parent-concrete.

*Keywords:* Seismic Load; Lateral Load; RC Column Strengthening Technique; Drift and Deflection; Concrete Jacketing.

## 1. Introduction

Reinforced concrete (RC), valued for its affordability and resilient structural characteristics, is widely employed in the construction industry, particularly in the context of multi-story structures classified as low-rise buildings [1]. Because China is notorious for seismic disasters, strong earthquakes seriously threaten cities and communities since building collapse has historically been a significant factor in human fatalities and economic losses [2]. Reinforced concrete (RC) structure strengthening and retrofitting has been viewed as a joint research area for several reasons, including increasing the structural load-carrying capacity, mitigating environmental degradation, and satisfying the requirements of new design codes, particularly when it comes to seismic provisions [3].

Performance-based seismic evaluation and practical retrofit techniques for buildings have been conducted by Wang et al. [4], who observed that retrofitting and seismic risk assessment are efficient ways to reduce earthquake risks. Júlio

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et al. [5] investigated the seismic risk of RCC structures in earthquake-prone areas. They observed that vulnerable columns can suffer significant damage or collapse and fail dramatically beneath lateral loads. Many traditional upgrading techniques have been proposed and employed, including jacketing the columns with concrete or steel, adding shear walls, and techniques frequently based on novel materials like fiber-reinforced polymers (FRP) [6]. Ramírez [7] tested ten rehabilitation methods, and the results indicated that concrete jackets are among the most practical, affordable, and easy to construct.

Vandoros & Dritsos [8] demonstrated through an experimental study that CFRPs and RC jacketing significantly increased the strength and flexibility of the columns. Natraj et al. [9] researched strengthening the structural members with CFRP and observed that CFRP retrofitting can significantly increase column capacity. By doubling the cross-sections of ten strengthened RC columns with concrete column jacketing, Krainskyi et al. [10] observed that the capacity increased by almost 290% while maintaining the same design process and loadings. Hong et al. [11] researched the effect of reinforced concrete jacketing on the axial load capacity of reinforced concrete columns. This technique increases the original column's axial strength, bending strength, and stiffness [5]. Antoniou [12] authored a comprehensive work to elucidate the intricacies and hurdles associated with retrofitting building infrastructure, offering a meticulous exposition of each available strengthening technique and a thorough examination of their respective merits and drawbacks. Zhang et al. [13] experimented. They proposed a theoretical model for maintaining RC members and found that RC columns jacketed by ECC exhibited improved failure mode, hysteresis response, flexural strength, plastic deformation, and energy dissipation. Barham et al. [14] researched repairing damaged columns and beams with micro-concrete and detected that it could enhance the stiffness of old columns and beams. Nayak et al. [15] reported that micro-concrete could give significantly higher compressive strength, and the compressive strength of the micro-concrete does not influence any bonding strength calculations.

Although there are many types of research based on different retrofitting methods and using other materials, there are few types of research based on concrete column jacketing using micro concrete. Most of the previous studies were grounded in experimental tests [13, 16–19], but very few studies were implemented in the practical engineering field. In this study, FEM analysis data and laboratory test data have been used to evaluate structural safety, and practical application has been done to observe the challenges and overcome strategies during retrofitting construction. The current structure was examined to assess the stability of existing structural members. Chinese GB50011-2010 load and load combination combinations were considered when performing and modifying the existing structural analysis. Developed deflection and floor drift were compared to lateral loads to determine their serviceability.

## 2. Research Methodology

### 2.1. Background of Research Project and Building Information

A three-story RC building of a substation in China participated in this study. It was a three-story MRF RC structure. RC columns, beams, and slabs are the prominent load-carrying members. There is no shear wall or any other structural members to resist lateral loads. It is still being determined whether the existing building was designed according to seismic design. The state of the existing buildings was evaluated through a preliminary assessment, and then several recommendations were made in light of the findings. Several visual examinations were conducted to get accurate architectural and structural as-built data on this structure. As-built data was gathered for all structural elements, including vertical and lateral load-bearing members, machine load, dead load, and live load-producing equipment. A foundation was dug to determine the type of foundation.

Moment Resisting Frame (MRF) was discovered to be the structural system, and isolated footing foundation systems were found to be the foundation systems. Different material tests have been done to determine concrete strength and rebar strength. CSI ETABS 2016 v16.2.2 design analysis software was employed for the sufficiency and testing of structural members. In this study, the structural frame was a moment-resisting frame system. This building uses a combination of flat plate and RCC beam slabs on various floors. The following information is provided regarding this RCC structure: The building is 14.17 m in height, 23.31 m in length, and 12.80 m in width. Column sizes were 10” X20”, 12” X20”, and 14” X20” at the corner zone, edge zone, and middle zone, respectively. The beam size was 15” X18” and 15” X15”, slab thickness was 5”, and the stair waste slab thickness was 7”. The foundation system has been found to be a cast in situ pile and pile-cap foundation. The main entrance area, the parking lot, and the generator portion are on the first floor. There are offices and a store room on the second floor. The other utility and equipment rooms are on the second and third floors. Figure 1 shows the image of the building, while Figure 2 shows the building's column, beam, and slab layout.

**Figure 1. Exterior view of the building**

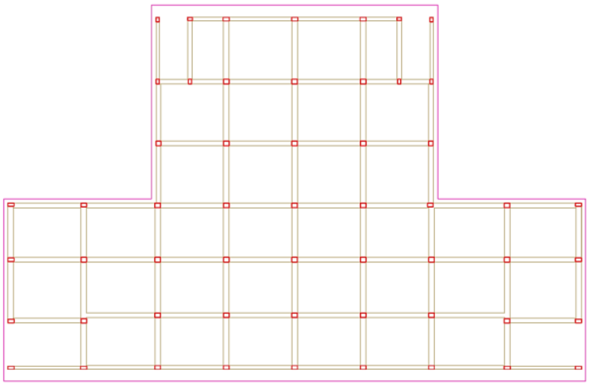

**Figure 2. Floor, column, beam, and slab layout**

## 2.2. Assessment of Live and Dead Load

The building's floors, working areas, equipment room, store room, water tanks, toilet built-up areas, furniture, interior partition walls, outside walls, machine rooms, storage areas, and other work areas were all examined, and the live load and dead load calculations were made by taking these factors into account. The dead load was calculated per load-producing member; 42 psf of the live load was employed on the typical working floor, 30 psf, and 84 psf in the roof and stair zone, respectively.

## 2.3. Test of Materials

A set of drilled concrete cores was collected, and core tests were done in the laboratory to determine the concrete's strength as well as the strength of the reinforcing. A ferro-scan was also performed to verify the provided reinforcements in RC members. The concrete strength was assessed using the ACI-562 method, which was found to be 1913 psi. The tensile strength of the rebar used was 60000 psi.

## 2.4. Structural Analysis

In this study, ETABS software will be used to model and analyze reinforced cement concrete (RCC) framed structures. The response of the foundation for the Structure was evaluated using a range of analyses following the gathering of structural and material data as built. Soil site class B and seismic zone III have been considered and the importance factor, I as 1.2. The damping ratio is assumed to be five percent. Base support was regarded as pinned during modeling. Applied as a body load in a direction consistent with the expected wind movement to the structure's foundational elements. The floor slab was modelled as shell elements and treated as a semi-rigid diaphragm. The three-dimensional finite element model of this structure is depicted in Figure 3. That has been collected from ETABS.

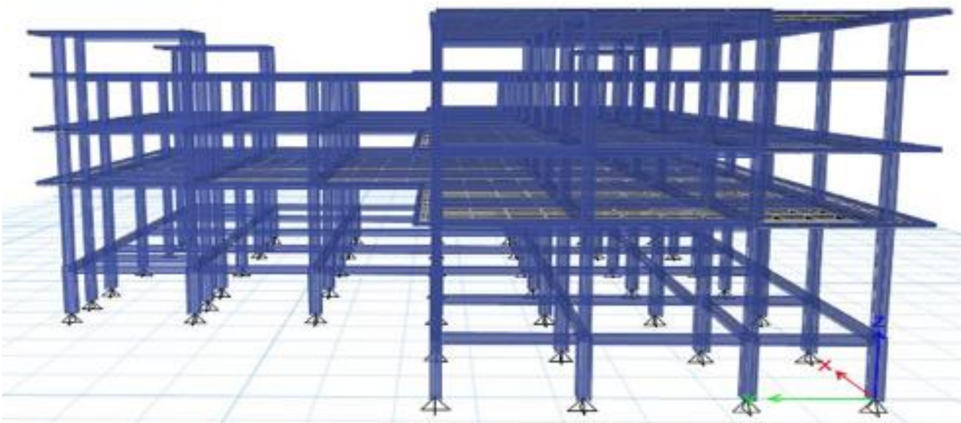

**Figure 3. 3D Finite element model of the three-storied RCC building**

The steel member demand capacity ratio data was gathered from the design program ETABS. ETABS Software was used to model the building's existing structural system while considering wind, earthquake, dead, and live loads according to structure’s current condition.

Equation 1 expressed the horizontal seismic base shear expression as:

$$F_{EK} = \left(\frac{Tg}{T}\right)^{\gamma} \eta_2 \, \eta \alpha_{max} G_{EK} \quad (1)$$

Where, $F_{EK}$ = design base shear, $T_g$ = characteristic site period, $\gamma$ = attenuation index, $\eta_2$ = damping adjustment coefficient, $\alpha_{max}$ = maximum of earthquake affecting coefficients, $G_{EK}$ = equivalent gravity loads

The expression of wind load for design check of main structures as per Equation 2:

$$W_k = \beta_z \mu_s \mu_z W_0 \quad (2)$$

Where $W_k$ =characteristic value of wind pressure, $\beta_Z$ =dynamic response factor at the height of z, $\mu_S$ = aerodynamic pressure coefficient, $\mu_Z$ = pressure exposure factor, $W_0$ = essential wind pressure

A flow chart of the methodology, structural adequacy evaluation, comparison of existing and retrofitting structure, and rehabilitation method has been shown in Figure 4.

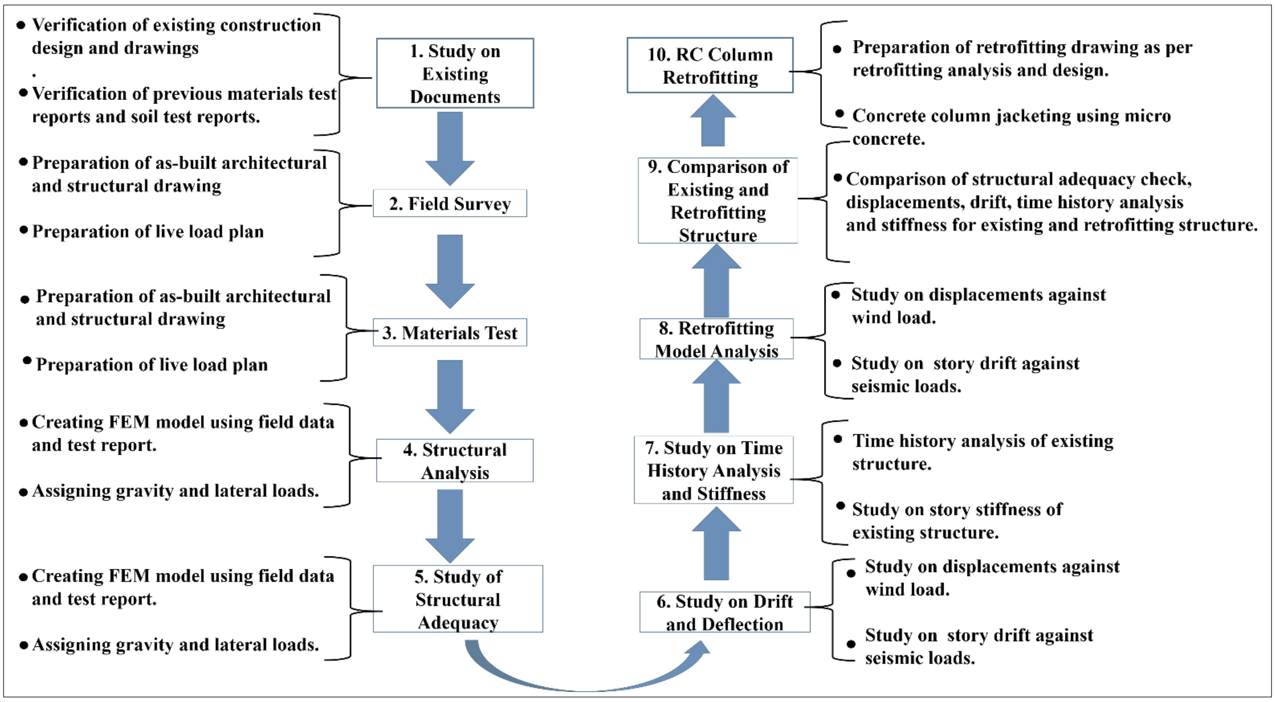


**Figure 4. Flowchart of seismic risk assessment and rehabilitation of RC column using micro concrete**

## 3. Results and Discussion

The existing structure was analyzed first, and structural safety performance was evaluated for all existing structural members. Maximum displacements and story drift have been investigated for all existing structures. Story stiffness and base shear were also studied for an existing system. It was discovered that several of the current structure's RCC columns were insufficient. After analysis by the ETABS column, these were retrofitted with a Demand Capacity (DCR) ratio of more than one considered overstressed. All RC columns have been found adequate after retrofitting. All of the existing foundations, beams, and slabs were judged to be secure. The existing structure was discovered to have excessive deflection, while story drift was found within the allowable limit. After modification of the current structure, story displacements have been found within the permissible limit. Story base shear has been increased after retrofitting the existing over-stressed column. It has been observed that story stiffness has increased by an average of 23.21% after retrofitting by concrete column jacketing with micro concrete. After the building was modified, it was discovered that all structural parts were secure although the adsorbent was prepared through chemicals, and that the building's lateral drift and deflection were satisfactory.

### 3.1. Adequacy Check of RCC Structural Members

The sufficiency check of every RCC column is shown in Figure 5's given demand capacity ratio (p-m-m). The structural analysis and design software program ETABS was used to gather all of these analysis results—structures with p-m-m ratios greater than one are regarded as insufficient and marked in red color. The demand capacity ratio of columns and the critical existing column interaction diagram for axial and bending moments are shown in Figure 5.

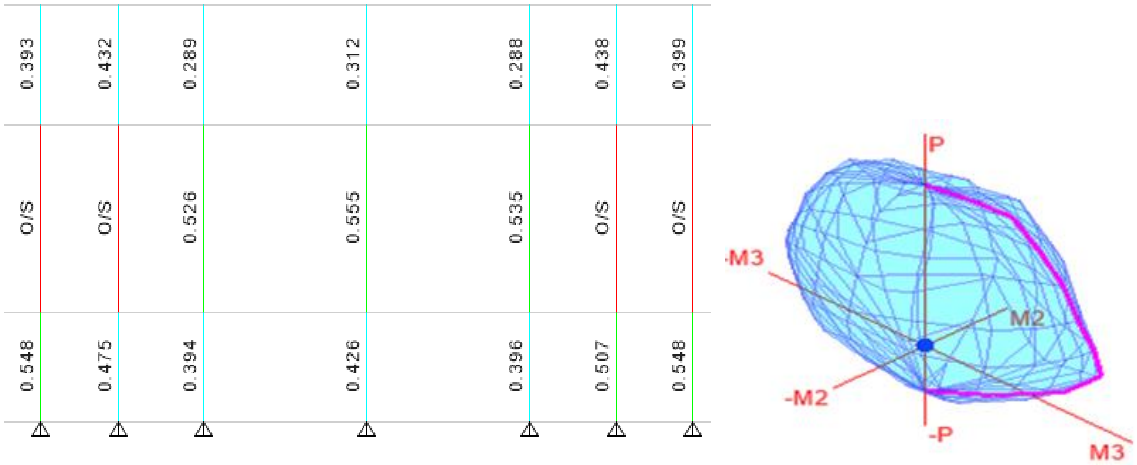


**Figure 5. Demand capacity ratio of critical columns and interaction diagram of existing structure**

A model for retrofitting industrial buildings was created by modifying an existing model. After retrofitting, the earthquake load was revised as well. Following a retrofitting study, all structural members were determined to be adequate against all lateral loads and gravity loads. The demand capacity ratio, or the ratio of all columns that are less than 1, has been considered structurally safe. The demand capacity ratio of columns and the critical retrofitting column interaction diagram for axial and bending moments are shown in Figure 6.

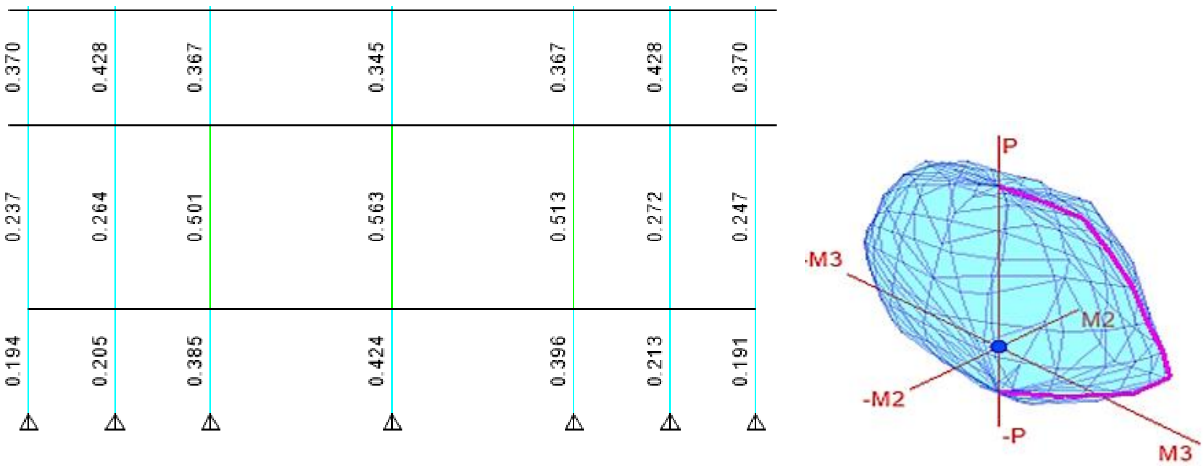


**Figure 6. Demand capacity ratio of critical columns and interaction diagram of retrofitting structure**

## 3.2. Study on Displacements

One of the serviceability variables that must be taken into account is deflection, which should be designed to be within the range permitted by structural requirements for the conditions of the operating load [20]. Even if a reinforced concrete (RC) structure is strong enough to meet safety regulations, excessive deflection or cracking hinders its ability to perform and inconveniences users [20]. As a result, it is necessary to assess the serviceability of RC structures. The present ACI building code [21] and many other structural standards are built on the concept of ultimate strength. Serviceability evaluation for deflection or cracking is advised since the maximum strength design approach considers the materials' ultimate state in the design. Current seismic design specifications include narrative drift or lateral displacement restrictions that must be evaluated to calculate outcomes from structural analysis [22]. The deflection values provided by the structure were obtained from ETABS. It has been observed that when existing conditions were developed, displacements were not within the allowable limit, but after modification of the structure, the value became within the allowable limit. In the existing structure, the maximum developed displacements in X direction for wind load are 0.694 inches, which is not within the permissible limit; in the retrofitting structure, this value has been decreased and found to be 0.565 inches, which is within the allowable limit. In the Y direction, the maximum developed existing structure's displacements against wind load have been found to be 1.19 inches; in the retrofitting structure, this value has decreased and is 1.01 inches. The maximum tory value for the existing and retrofitted conditions has been shown in Figure 7 for the X and Y directions.

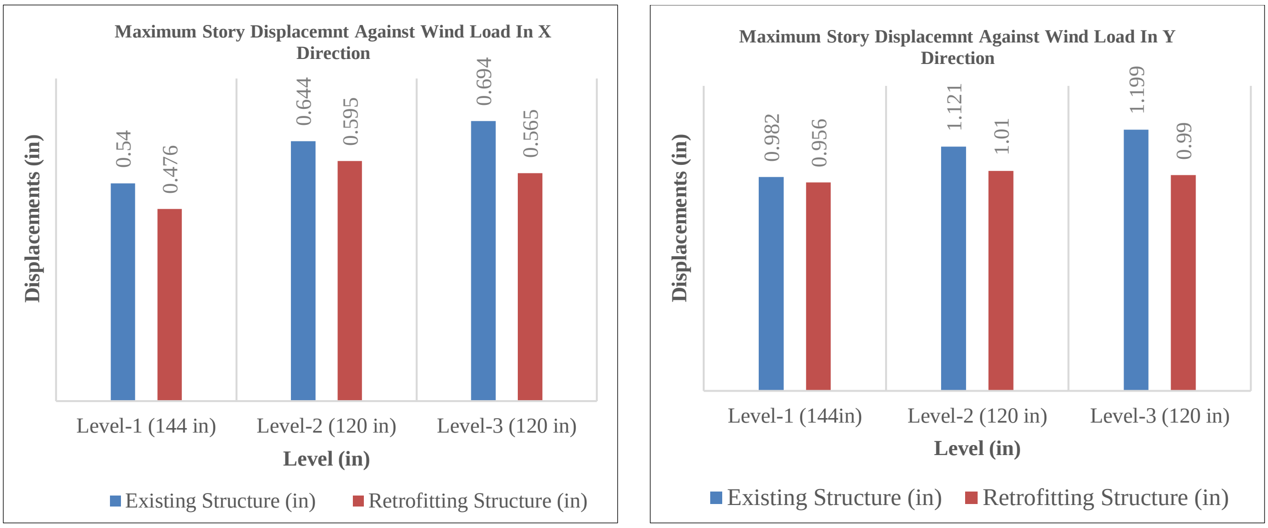


**Figure 7. Maximum story displacements against wind load in X and Y direction**

## 3.3. Study on Drift

The difference in lateral displacement between two neighboring stories is referred to as story drift [23]. Large lateral forces can be applied to structures during an earthquake, and lateral displacement and drift have three main effects on a structure: they impact structural elements (like beams and columns), non-structural elements, and neighboring structures [23]. Large displacements and drifts can negatively affect structural, non-structural, and neighboring structures if they are not taken into account during the design stage [23]. With performance-based seismic design (PBSD), a structure's performance under a potential seismic hazard is specifically assessed [24]. It enables the design of new structures or the upgrading of existing structures while considering the likelihood of fatalities and financial loss brought on by potential earthquakes [25]. Therefore, checking the developed drift and allowable limit is important. In the existing structure, the maximum developed story drift in the X direction for seismic load is 0.873 inches; in the retrofitting structure, this value has been decreased and found to be 0.752 inches. In the Y direction, the maximum developed story drift against seismic load is 1.043 inches; in the retrofitting structure, this value has decreased and is 0.826 inches. The developed story drifts were within the permissible limit for existing and retrofitting structures. A comparison of maximum story drift for existing and modified structures against seismic load has been shown in Figure 8 for the X and Y directions, respectively.

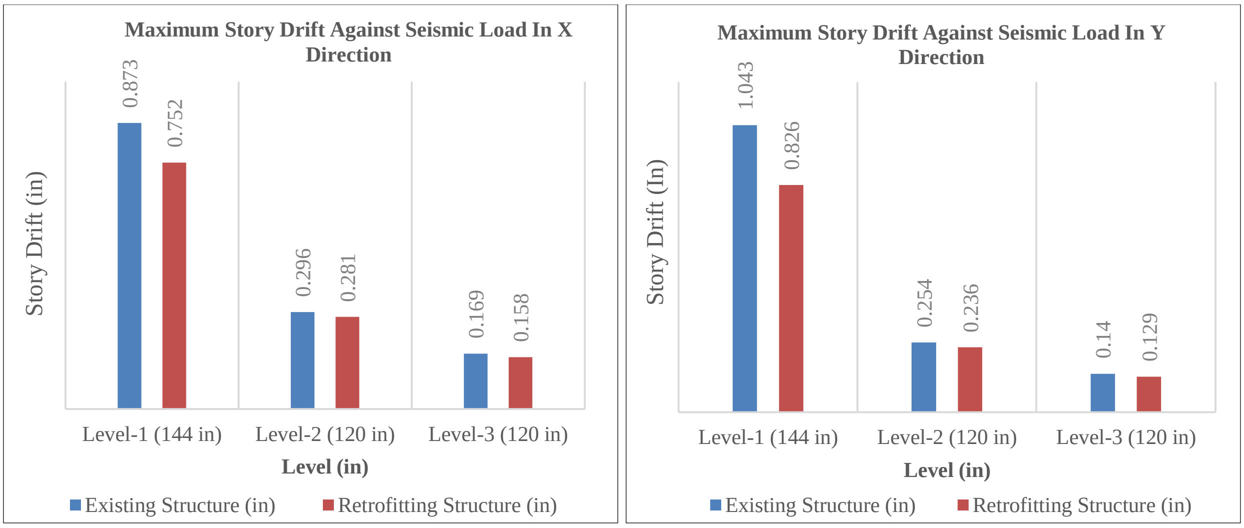


**Figure 8. Maximum story drift against seismic load in X and Y direction**

## 3.4. Time History Analysis

A nonlinear Time History analysis is the only technique that can accurately depict a structure's actual behavior during an earthquake. The approach is based on the direct numerical integration of the motion differential equations while considering the structural element's elastoplastic deformation [26]. Time history analysis has been shown in Figure 9 for both existing and retrofitted structures. Total story-base shear has increased by 44.12% for retrofitted systems.

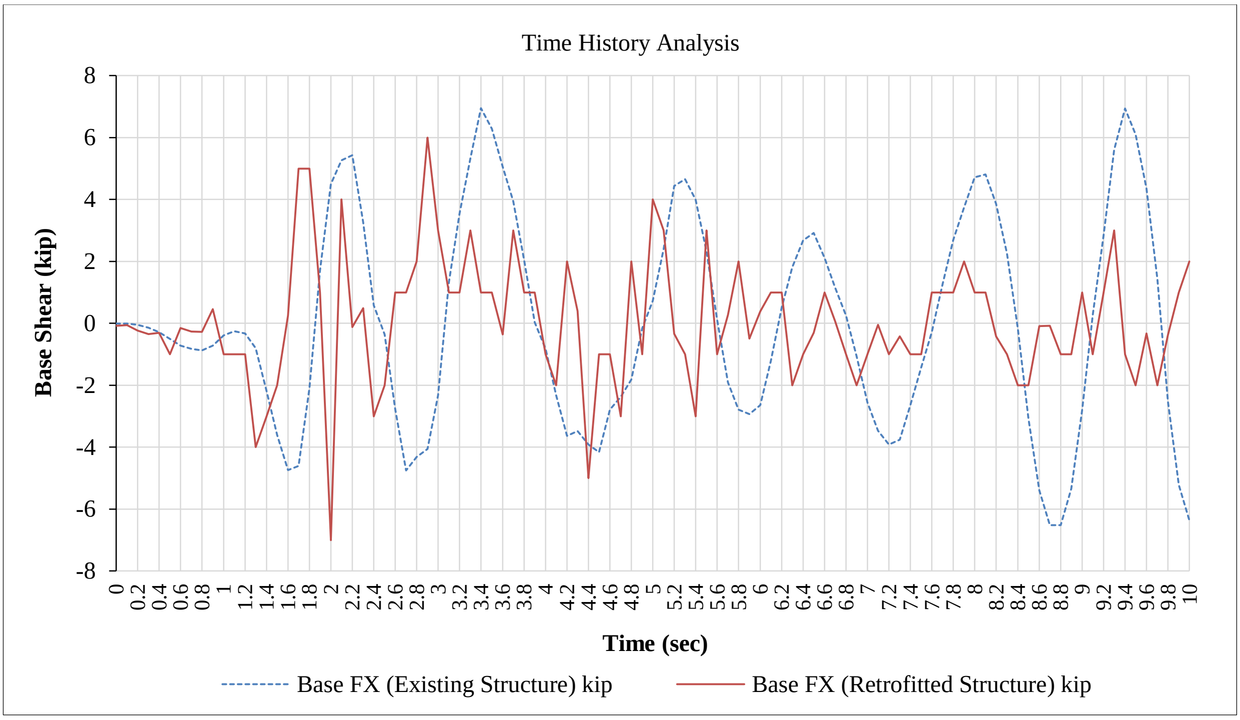


**Figure 9. Time history analysis comparison of existing and retrofitted structure.**

### 3.5. Study on Stiffness

The story stiffness of the frame structure can influence the behavior of the structure to an earthquake. The safety of the frame structure can be increased through rational stiffness distribution optimization [27]. Story stiffness in both the existing and retrofitted structures has been displayed in Figure 10. From time history analysis, it's found that retrofitted structures are stiffer than the old structures. Structure performance has improved significantly regarding lateral load analysis after renovation.

The story stiffness of the existing structure has been found 1055 kip-inch, 984 kip-inch, and 423 kip-inch for level 3, level 2, and level 1, respectively, while the story stiffness of the retrofitting structure has been found 1230 kip-inch, 1090 kip-inch, and 623 kip-inch for level 3, level 2 and level 1 respectively.

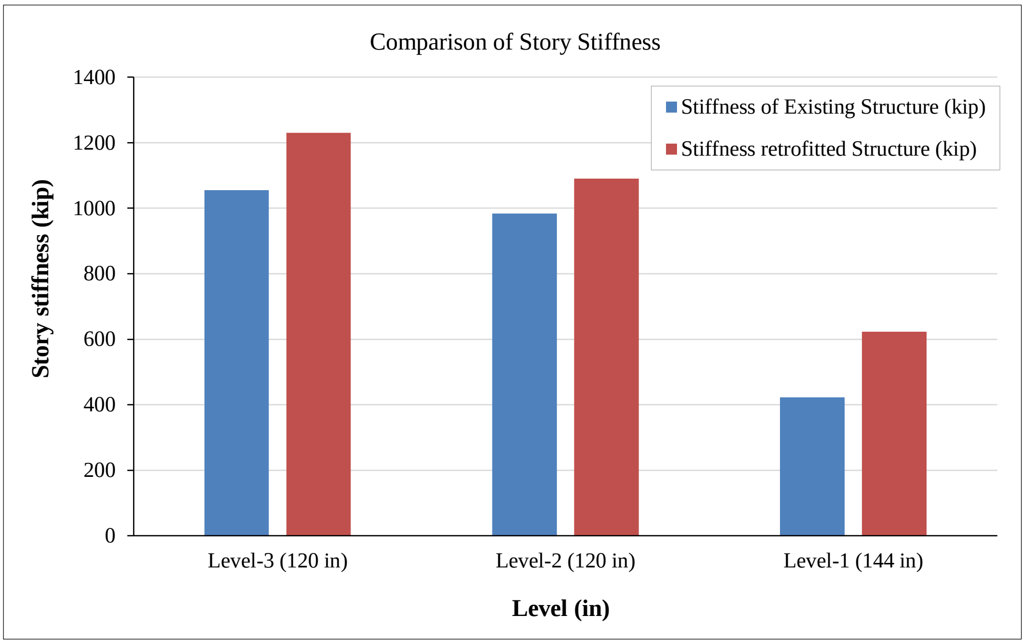


**Figure 10. Story stiffness comparison of existing and retrofitted structure.**

This comparison shows that after retrofitting the existing structure, the story stiffness increased by 42.27%, 10.77%, and 16.59% for levels 1, 2, and 3, respectively.

### 3.6. Retrofitting of RC Column by Concrete Jacketing with Micro Concrete

The investigation into the seismic retrofitting and strengthening of reinforced concrete (RC) columns has been a focal point of scholarly inquiry for an extended duration. At the moment, reinforced concrete jacketing is thought to be the most popular method for supporting and repairing weak and damaged RC columns [28]. This study used reinforced concrete jacketing to strengthen the overstressed column with micro-concrete. Retrofitting structural drawings were created using the retrofitting model for retrofitting the construction of the existing building. In short, it is a technique for enclosing pre-existing structural elements in a concrete layer (jacket) that has been strengthened with longitudinal and transverse steels [29–31]. In conventional reinforced concrete jacketing, a new reinforced concrete/mortar section is cast over a portion or the entire length of the column to extend the column's section. The unused part is fastened to the old section through anchor rebars or strong bolts. It alters the column's cross-sectional area, altering the structure's mass and stiffness in the process. This shortens the structure's natural period, increasing the structure's vulnerability to earthquakes. Because of this, high-performance RC materials have more recently been employed for jacketing purposes in order to reinforce or repair the specimen without changing its cross-sectional dimensions [32].

Lehman et al. reconstructed moderately to severely damaged circular RC columns with recently cast concrete-headed reinforcement and mechanical couplers. They found that while the strength and flexibility were totally recovered for somewhat damaged columns, the stiffness was not. The restoration method could not restore the behavior of highly damaged specimens [33]. This study carried out retrofitting construction following the retrofitting structural design and drawing. Retrofitting structural drawings have been done as per the analysis model. The concrete column section has been increased, and additional vertical reinforcements have been inserted per the demand for column analysis and calculation. The RCC concrete cover of the column was removed, exposing all of the longitudinal bars [34]. New rebars were installed on all column faces with appropriate epoxy grout. Enough anchoring of new concrete with old concrete was provided.

Fresh rebar was inserted into the column's corners, and welded bent bars were used to connect them to the old rebar. New bars must be installed at the corners to prevent the beams' piercing. Micro-concrete has been used for `retrofitting column casting. After casting, the concrete cylinder was checked, and it was found that the definite strength value was higher than the old concrete strength. For jacketing, the concrete strength must be more than or at least equivalent to the existing columns. Figure 11 depicts the rebar configurations of the retrofitting column section. For this study, an existing building was `renovated without compromising the working environment or the available space. Figure 14-15 depicts the working process for column jacketing. Figure 12 shows the chipping of the old column; Figure 13 shows the insertion of new reinforcements; Figure 14 shows the formwork and micro concrete casting; Figure 15 shows the casting completion of half-length of the column; and Figure 16 displays images taken after the retrofitting work is finished.

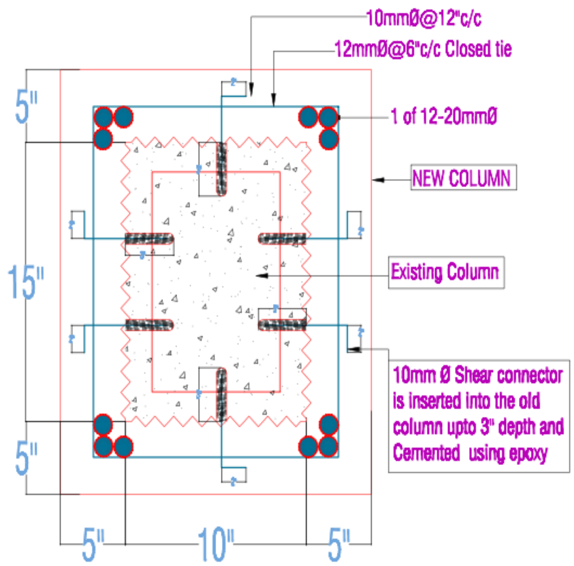


**Figure 11. Concrete column jacket drawing**

**Figure 12. Chipping of the old column**

**Figure 13. Insertion of vertical reinforcement**

**Figure 14. Formwork and micro-Concrete casting**

**Figure 15. During concrete casting**

**Figure 16. After completion of jacketing**

## 4. Conclusion

Rehabilitating a building is restoring it to its original condition of usefulness through repairs, modifications, or alterations to make it a safer place for people to live and work. After a thorough analysis, the most effective seismic retrofitting options were applied to a three-story reinforced concrete building that lacked stirrups and longitudinal reinforcements. An analysis and comparison are conducted between the initial and retrofitted models' structural member adequacy. The story drifts and displacements have been assessed and compared for the retrofitted and old structures. Time history analysis and narrative stiffness evaluation have been completed and compared for both the original and retrofitted structures. The current building was reinforced using micro-concrete technology and concrete column jacketing to ensure structural safety.

The use of concrete jacketing with micro-concrete to strengthen RC columns has demonstrated briefly how simple and effective this strengthening method is. The adequacy of each beam, slab, and column for lateral loads, dead loads, live loads, and various types of gravity loads was examined. Despite certain columns being overstressed and hazardous, all the beams, slabs, and foundations were deemed to be secure. While narrative drift was within the acceptable limit under the circumstances, tale displacements were not. After alterations to the current structure, story displacements were discovered to be within the permitted range. All structural parts in the renovated building were judged to be secure against all lateral and vertical loads per Chinese code GB50011-2010. The retrofitted structure is stiffer than the existing structure against seismic loads.

### 4.1. Recommendation and Further Work

To advance the comprehension and application of retrofitting methods and materials for improved accessibility and effectiveness, it is recommended to promote further research in this field. Encouraging exploration of alternative evaluation methods and repairing materials is also advised to enhance the comprehensive understanding of retrofitting solutions.

# 5. Declarations

## 5.1. Author Contributions

Conceptualization, J.Y. and J.W.; methodology, D.T.; software, T.C.; validation, Y.Y., L.J., and J.M.; formal analysis, X.Y.; investigation, J.Y.; resources, D.T.; data curation, Y.Y.; writing—original draft preparation, J.M.; writing—review and editing, J.Y.; visualization, L.J.; supervision, T.C.; project administration, X.Y.; funding acquisition, J.Y. and J.W. All authors have read and agreed to the published version of the manuscript.

## 5.2. Data Availability Statement

The data presented in this study are available in the article.

## 5.3. Funding

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## 5.4. Conflicts of Interest

The authors declare no conflict of interest.

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