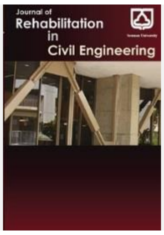
Journal of Rehabilitation in Civil Engineering 13-4 (2025) 110-130



Journal of Rehabilitation in Civil Engineering

Journal homepage: https://civiljournal.semnan.ac.ir/

Seismic Resilience Enhancement of a Typical Infilled RC Frame Residential Building with Fiber Reinforced Polymer Material: A Case Study in Kabul City, Afghanistan

Mohammad Ali Eltaf [1,*]; Abdul Ali Raoufy [2]

1. Assistant Professor, Department of Civil and Industrial Construction, Kabul Polytechnic University, Kabul, Afghanistan
2. Associate Professor, Department of Civil and Industrial Construction, Kabul Polytechnic University, Kabul, Afghanistan

* Corresponding author: *m.eltaf@kpu.edu.af*

ARTICLE INFO

Article history:
Received: 16 September 2024
Revised: 23 November 2024
Accepted: 14 January 2025

Keywords:
Fiber reinforced Polymer;
Soft story mechanism;
Diagonal pattern;
Nonlinear dynamic time history analysis;
Perform 3D.

ABSTRACT

Seismic assessment and retrofitting of existing non-engineered buildings in Afghanistan remain significant challenges. This study evaluates the effectiveness of Fiber Reinforced Polymer (FRP) in retrofitting of a typical infilled reinforced concrete (RC) frame residential building located in Kabul City, Afghanistan. The solid infill panels, as vulnerable non-structural elements, are selected as retrofitting members. A three-dimensional (3D) nonlinear finite element model of a building with four and a half story RC building with three bays of varying lengths in both directions was developed and analyzed using CSI Perform 3d software. The building is studied in three different models: bare RC frames, infilled RC frames, and retrofitted infilled RC frames. Considering the materials and elements nonlinearity, therefore nonlinear dynamic time history analysis is performed. The analysis revealed that the soft story mechanism is applicable, primarily due to extensive damage at the first floor's infill walls and columns fiber hinges. Therefore, the FRP laminates arranged as diagonal patterns on the selected infill walls. The retrofitting significantly improved the lateral strength and stiffness of the building's model, thus the failure mechanism is controlled. Moreover, the interstory drift ratio of the model reduced substantially from 2.36% to 0.6% and from 3.2% to 0.8% in the x and y directions, respectively. As a result, the building's retrofitted model gained sufficient resistance to stand well under extreme seismic ground motions. The findings underline the potential of FRP as an effective retrofitting method for vulnerable RC frame buildings in seismically active regions.

E-ISSN: 2345-4423

How to cite this article:
Eltaf, M. A. and Raoufy, A. A. (2025). Seismic Resilience Enhancement of a Typical Infilled RC Frame Residential Building with Fiber Reinforced Polymer Material: A Case Study in Kabul City, Afghanistan. Journal of Rehabilitation in Civil Engineering, 13(4), 110-130. https://doi.org/10.22075/jrce.2025.35308.2167

1. Introduction

The majority of buildings in Kabul City, Afghanistan, are constructed without any available structural engineering standards considerations. As the country is located within a seismically active zone on the global seismic map, the existed buildings are highly susceptible to damage from seismic events. The structural and non-structural deficiencies in these buildings significantly increase the risk of catastrophic failure under the moderate to strong ground motions [1]. In earthquake scenarios, the failure and collapse of non-structural elements are primary contributors to fatalities. Moreover, the non-structural element includes the main part of crumbling buildings worldwide [2]. A seismic vulnerability assessment conducted on 79 hospital buildings in Kabul City, Afghanistan, revealed significant variations in structural resilience. Among these buildings, one building has steel moment resistance frames, 60 buildings have infilled RC frames, and 18 buildings have unreinforced masonry structures. The assessment indicated that steel frame hospital building has the lowest possibility of collapse (1.44%) and unreinforced masonry buildings have the highest possibility of collapse (100%).The findings underlined that, the existing assessed buildings need for comprehensive retrofitting and rehabilitation measures to enhance their seismic performance and ensure safety [3]. A case study on the seismic vulnerability of existing buildings in Khost province, Afghanistan, following the 22 June 2022 earthquake reaveled probabilities of damage at 11% for heavy damage, 45.5% for moderate damage, and 17.5% for slight damage. The result indicateded that while the surveyed buildings retain their primary performance, they are susceptible to moderate damage at this level of earthquake excitation. Key factors contributing to the observed intensity of destructive include the low quality of construction materials, non-standard layout of townships, and non-engineering practices of building structures/constructions [4]. To enhance the serviceability of buildings and prevent human tragedies and loss of life, most of the public and private hospital buildings in Afghanistan need a comprehensive vulnerability assessment and rehabilitation/retrofitting design. The result based on FEMA P-154 methodology shows that the likelihood of collapse for hospital buildings in Kabul ranges from 3.16% to 59.2% under level 1 and from 3.16% to 64% under level 2 seismic excitations. The findings highlight am immediate need for proactive measures to increase the structural resilience of hospital buildings [5]. A detailed study conducted by UN-Habitat, which included the development of a vulnerability index for retrofitted buildings in Kabul City, Afghanistan, demonstrated that training of local welders and masons can reduce damage by 15% to 20% against PGA 0.3 g and higher [6]. A detailed research study analyzed the seismic vulnerability of existing 34 infilled RC frame school buildings using fragility curves under design based earthquake (DBE) and maximum considered earthquake (MCE) scenarios, with 24 input ground motion records. The analysis indicated significant damage condition across different seismic zones and scenarios, highlighting the urgent need for retrofitting design and strengthening [7]. Buildings are often initially designed as bare frames; however, the addition of infill panels, especially those with openings, changes the behavior of buildings remarkable under lateral and cyclic loadings. These panels significantly increases the lateral stiffness and strength of reinforced concrete (RC) frames, influencing their overall seismic performance [8]. The presence of window and door openings in infill panels directly affects their seismic performance, particulary in terms of failure modes. Based on the past earthquake damage observations of the infill wall failure modes under lateral forces, this rigid and vulnerable element of buildings is suggested to be modeled as only diagonal compression struts [9]. One of the most effective and cost-efficient methods for strengthening and retrofitting of a building is use of masonry infill walls on the first story to prevent the soft story mechanisms and minimize the vertical irregularity [10]. Based on the result from a finite element model developed for nonlinear seismic analyses using the time history loading method, the installation of infill walls decreases the time period of the model. Particularly, the time period decrease by 44% with clay blocks, 44.3% with burnt clay brick, and 35.5% with concrete blocks infill walls. While the base shear increased by adding of infill walls significantly [11]. A comprehensive study concluded that the use of textile reinforced mortar as strengthening method resulted in a 37.5% increase in base shear, while the ductility of a typical mid-rise RC frame building decreased by approximately 23.4%.[12]. RC frame structures often exhibit weak performance under shear loading and need for an effective retrofitting technique. Infill panels in RC frame structures play a critical role in their seismic performance. Plan and elevation irregularities of infill walls can lead to the high level of in- and out-of-plan damage and collapse of infill panels at a local or global level under strong or moderate earthquake excitation. This is the most critical failure, which poses a high threat to human life and loss estimation. Therefore, retrofitting of infill walls is a key consideration for improving the seismic resilience of existing buildings [13]. Carbon-Fiber Reinforced Polymer (C-FRP) has proved to be an exceptional and promising retrofitting method for enhancing the shear capacity of an existing RC frame buildings [1]. The using of FRP laminates as a strengthening material not only enhance the strength and stiffness of RC structures but also extends their service life and enhance the durability of concrete structures [14]. FRP, as a composite material, is an an excellent alternative for conventional methods. Easy handling, light weight nature, high stiffness and strength, and anti-corrosion characteristics make it an exceptional and rewarding retrofitting material in the construction industry [15]. Another comprehensive study states that the use of anchored CFRP sheets enhanced the initial stiffness, strength, energy dissipation, and displacement ductility ratio of an RC building by 11%, 72%, 10%, and 13%, respectively [16]. RC frames with infill panels experience excessive lateral vibration under earthquake excitations, causing them to behave like diagonal compression struts. As a result,the infill canseparated from the frame in the opposite direction. To create an analytical model of retrofitted infill panel with FRP sheet, a compression strut is used to represent the nonlinear behavior of infill wall, while a tension tie is developed to represent the behavior of FRP strip [17]. A detailed experimental study on FRP-strengthened infilled RC frame identified two predominant failure modes. The first mode was anchoring failure, which manifested as a combined pull-out and slip failure. When the anchors failed, the load-bearing path switched to the diagonal compression struts, which leading to the collapse of the infill walls' corners. De-bonding of FRP from the infill wall caused the second failure mode to start [18]. According to the previous experimental tests, anchor failure and de-bonding of FRP laminates usually occur at strain level of approximately 0.002 and beyond 0.006 respectively [19]. The use of such innovative material for retrofitting comprehensively improved the strength and stiffness of the case study building's model. By applying of the proposed method, there is a significant reduction on the lateral displacement of frame elements and a great improvement in the damage conditions of infill panels.

2. Methods and materials

This section outlines the procedure followed to achieve the objective of the study. First, the case study building and the reasons for the selection are discussed. Then, selection of ground motions, analysis procedures, and retrofit design scheme are explained, respectively.

2.1. Case study building (CSB)

An ordinary residential building located in the 13th district, Kabul city, Afghanistan, was selected as a case study in this study. This city is located on the Kabul Block, where it is surrounded by the Paghman, Sarobi, and Gardez faults, the Chaman's fault northern extension, and an oblique convergence fault between the Euroasian and Indo-Australian Plates [20]. The Case Study Building (CSB) consists four and a half stories, each with an identical story height of 3 m. The building features three bays of varying sizes in the longitudinal x and transverse y directions. The architectural layout of the structure is asymmetrical in y direction and its plan and side view are shown in Figures (1 and 2).

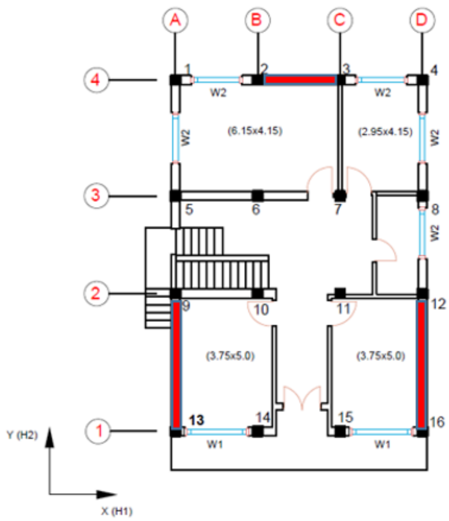


Fig. 1. Floor plan and the location of FRP (Red lines).

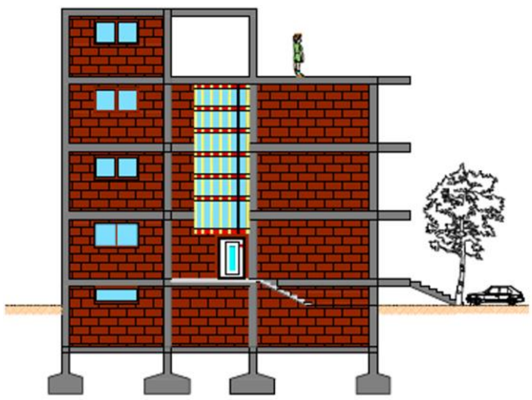


Fig.2. Side elevation.

Kabul City mostly consists mid-rise, non-engineering buildings, many of which are constructed in unplanned areas[21]. As such, selecting a four and a half-story RC-frame residential building serves as a representative model of the building stock in this area. Moreover, the prolonged conflicts and civil wars in this region make it impossible to carry out any research and investigation on buildings and urbanization. Consequently, it is evident that the existing buildings require strength evaluation, seismic performance assessment, and rehabilitation/retrofitting design.

2.2. Materials properties and design loads

The nominal properties of construction materials are based on the BUILDING MANUAL (Ministry of Rural Rehabilitation and Development, Afghanistan) standard. These properties are then, adjustedusing factors derived from ASCE 07-17 for numerical analysis of the building. Table 1 presents the mechanical properties of FRP, which are sourced from research carried out by [22] and [23] and then applied to the CSB building analytical model. Table 1 also includes the mechanical properties of the used materials in the building's model.

Table 1. CSB materials properties.

Concrete Strength (MPa)	20
Modulus of Elasticity of Concrete (MPa)	25495
Longitudinal rebar yield strength(MPa)	420
Transverse rebar yield strength(MPa)	280
Modulus of Elasticity of steel(MPa)	200000
Masonry prism strength (MPa)	6
Beaing capacity of soil ($\boldsymbol{Ton}/_{\boldsymbol{m^2}}$)	18
FRP Tensile strength (MPa)	3900
Young Modulus of Elasticity of FRP (MPa)	230000
FRP sheet Thickness (mm)	0.131
FRP effective strain	0.004
Complete failure strain of FRP	0.012
Slab Thickness (mm)	150
Exterior wall thickness (mm)	350
Interior wall thickness (mm)	150

The ASCE 7-22 standard [24] provides the design live load and superimposed dead load according to the occupancy level of the building. However, for nonlinear analysis, only 25% of the live load is considered to be effective. The weight of slabs is lumped at nodes according to their tributary area. Superimposed dead loads and live loads are given in Table 2.

Table 2. Superimposed dead load and live loads.

Superimposed Dead Load ($^{kN}/_{m^2}$)		Live load ($^{kN}/_{m^2}$)	
Floor finished	1.8	Corridor	3.83
Ordinary flat roof	0.96	Balcony	2.87
Infill wall	6.82	All rooms	1.44

2.3. Nonlinear modeling

The behaviors of the construction materials used in the modeled is presented as nonlinear. The nonlinear fiber modeling approach is used for defining the inelastic behavior of frame elements.

Defined fibers are located at both ends of the beams and columns [25]. The infill panels are modeled based on the concept proposed by [9], as bi-diagonal only compression struts. The FRP sheets are applied diagonally to the analytical model of the infill walls, acting as both compression struts and tension ties. The defined analytical model of CSB has been calibrated with experimental research on strengthened infilled masonry walls under cyclic loads with CFRP as diagonal strips [26].

2.3.1. Methods of analysis and selection of ground motions

Due to the presence of minor to major damages in the structures, linear analysis is not suitable for accurate response prediction. Therefore, nonlinear analysis is used to obtain a more precise evaluation of building response. According to the study by [27], earthquakes in Afghanistan are generally classified as intermediate-depth earthquakes. The peak ground acceleration (PGA) values range from 0.06g to 0.66g for a 475 years, 0.09g to 0.82g for a 975 years, and 0.13 g to 1.1 g for a 2475 years return period. Higher PGA values are observedin Kabul, Takhar, Badakhshan, and Kunduz provinces, which are located near the active faults zones of the Pamir and Hendukush ranges [28]. Due to the lack of earthquake databases from past events in the region, four pairs of ground motions from the Next Generation of Ground Motion Attenuation Models (NGA) project from the PEER strong ground motion database were selected for nonlinear analysis of CSB models, and they were applied only in the weaker x-direction. The records have been shown with their Record Sequence Number (RSN) and other important characteristics in Table 3.

Table 3. Characteristics of selected ground motions.

NGA No	Earthquake Name (Year)	Station Name	Magnitude (Mw)	Mechanism	PGA(g)
RSN 174	Imperial Valley (1979)	EI Centro Array #11	6.53	Strike Slip	0.35
RSN 68	San Fernando (1971)	LA-Hollywood Store FF	6.61	Reverse	0.22
RSN 143	Tabas (1978)	Tabas	7.35	Reverse	0.8
RSN 848	Lander (1992)	Coolwater	7.28	Strike Slip	0.28

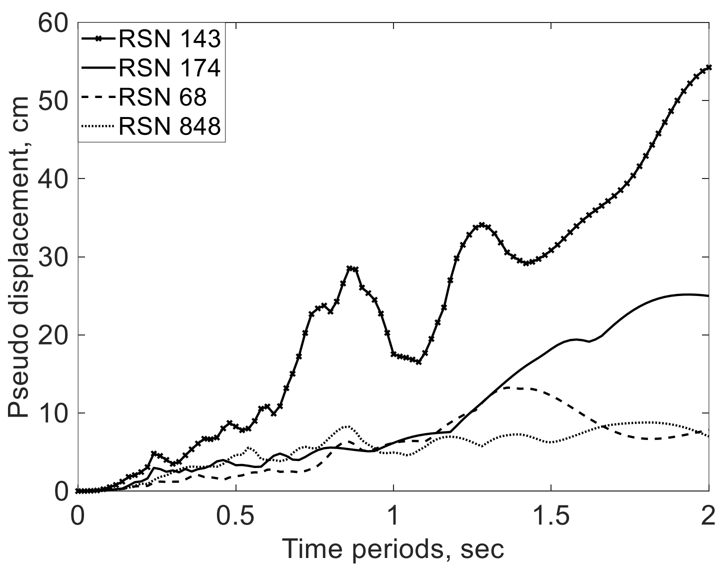


Fig. 3. Pseudo displacement of the ground motions.

Figure 3 shows the pseudo displacement of the selected ground motions and figures 4 to 7 show the acceleration records of the selected ground motions.

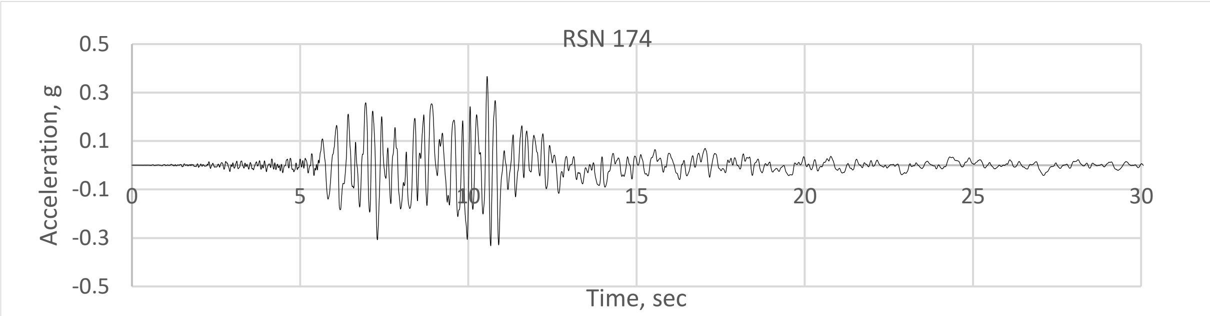


Fig. 4. RSN 174 earthquake acceleration record.

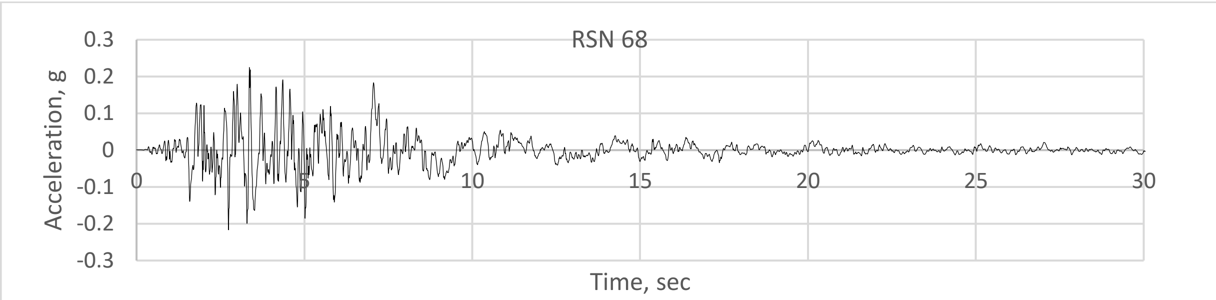


Fig. 5. RSN 68 earthquake acceleration record.

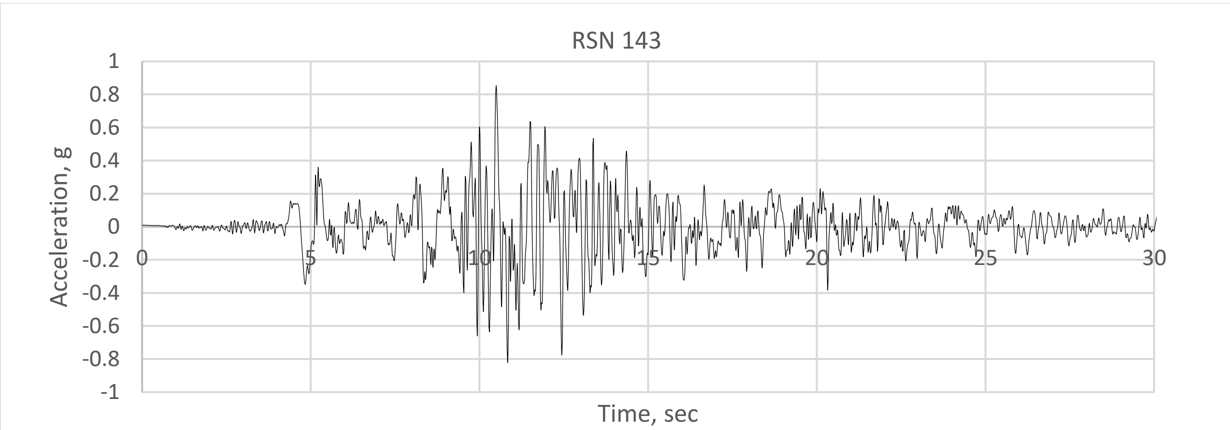


Fig. 6. RSN 143 earthquake acceleration record.

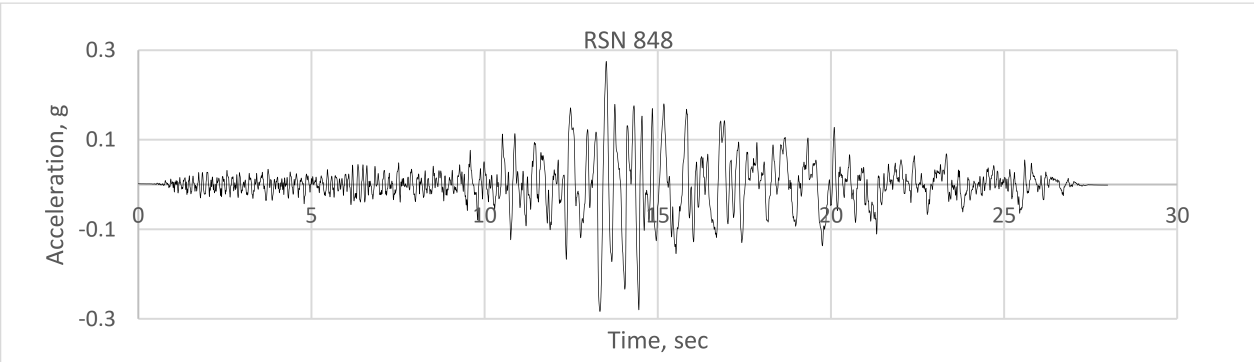


Fig. 7. RSN 848 earthquake acceleration record.

The overall methodology process summarized as follow:

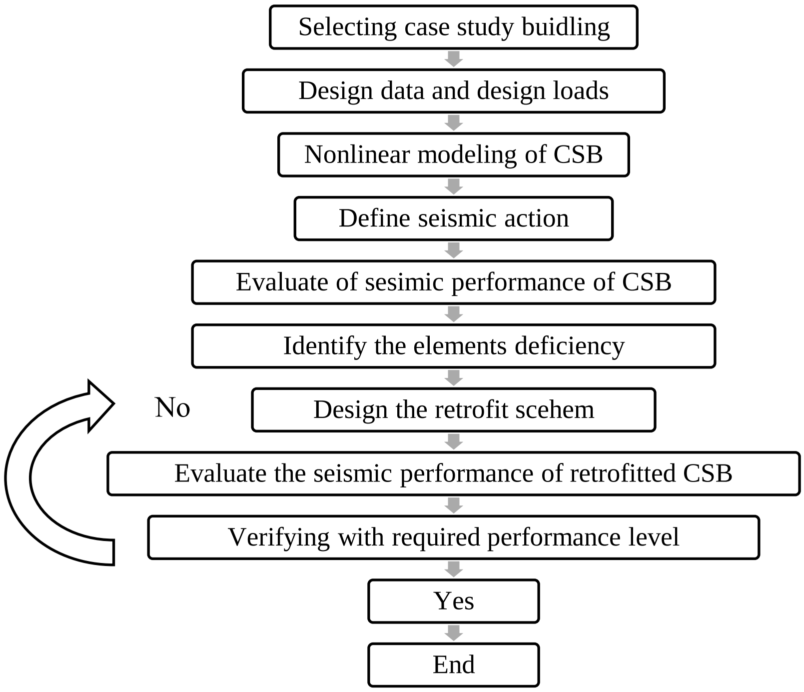


Fig. 8. The overall methodology process.

3. Nonlinear dynamic analysis

The building's nonlinear performance was evaluated using a nonlinear analytical model under selected ground motions. To assess the vulnerability of the selected building, four performance criteria are selected. The first criterion is the peak floor displacement, which is crucial for minimizing potential damage to infill walls. The second criterion is the peak inter-story drift ratio, based on the ASCE 41-17 standard, this indicates the level of the structural safety in the floors. Peak shear forces is the third component criterion, while the fourth criterion is the peak overturning moment, which is useful for the design of foundations. Additionally, the numerical acceptance criteria: immediate occupancy (IO), life safety (LS), and collapse prevention (CP) for frame elements and infill panels are derived from the ASCE 41-17 standard based on element condition and reinforced detailing. A detailed research study states that the drift ratio of 1.2% crossed the operational level of low- to mid-rise buildings, but it brings a slight structural crack on the elements under numerous seismic excitations [29]. From the given plan, we can see that the building, due to its fewer bay dimensions, is weaker in the x-direction, so the above parameters are just extracted from this direction.

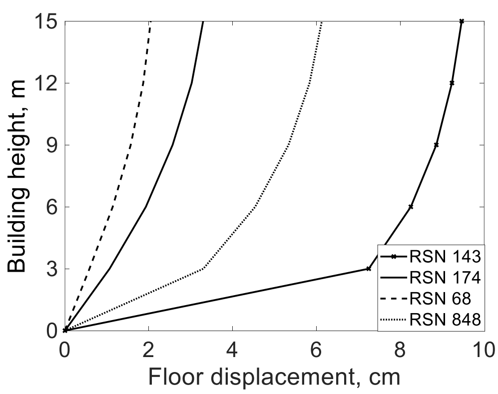


Fig. 9. Floor displacement of CSB against records.

The model's lateral displacement is controlled by the TABAS ground motion, Figure 9. This is most pronounced at the first floor level, and the main reason behind this large amount of displacement is the existence of more openings and less stiffness of this floor. As expected, the large amount of displacement results to a big inter-story drift ratio in the first floor. As indicated in Figure 10, the TABAS earthquake caused 2.36% of the inter-story drift ratio in the first floor level. Other ground shaking resulted in a lower inter-story drift ratio compared to RSN 143.

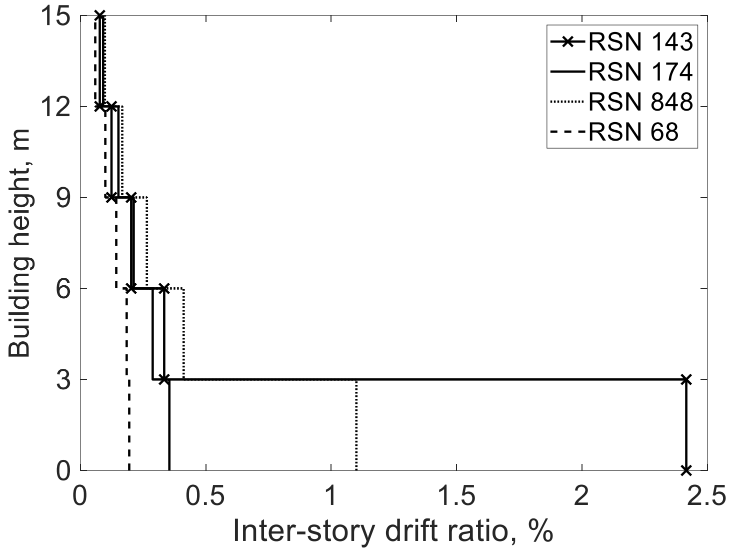


Fig. 10. Interstory drift ratio of CSB against records.

The extracted result as per Figure 11, for the story shear indicates that the normalized maximum story shear for all the floors is less than one.

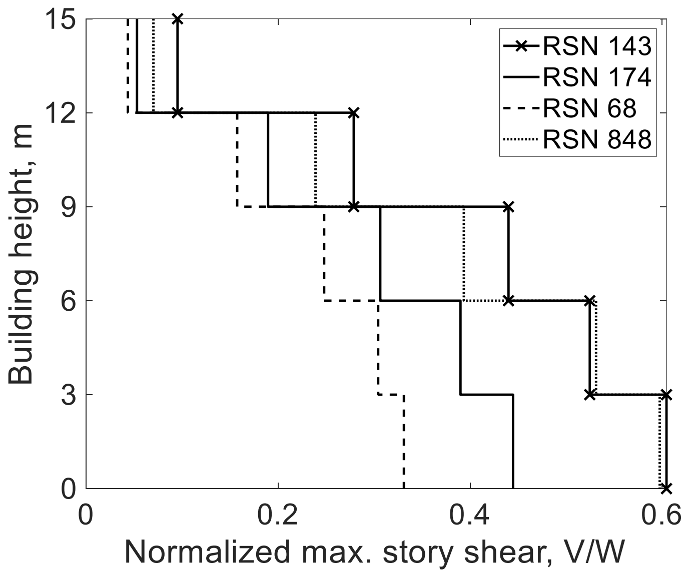


Fig. 11. Normalized story shear of CSB against selected records.

As expected, Figure 12 indicates that the TABAS earthquake governs the overturning moment in the building. However, as with story shear, its normalized maximum amount is less than one for all selected ground motions.

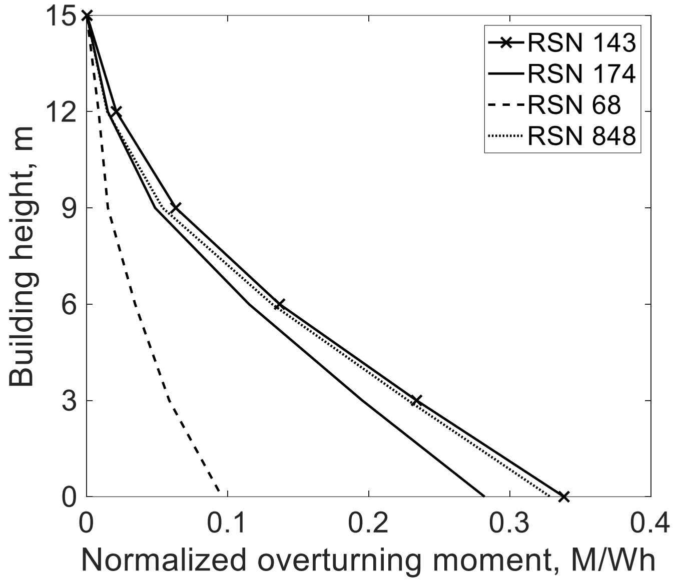


Fig. 12. Normalized overturning moment of CSB against records.

The extracted responses indicate that among the selected ground motions, RSN 143 has the most significant impact on the building performance. Consequently, the response ofthe CSB's model are evaluated exclusively against this ground motion. The plastic rotation of fiber hinges at both ends of first-floor columns is generally bellow one. However, as shown in Figure 13, only the front-side columns (columns numbers 13, 14, 15, and 16 as referenced in Figure 1) exceeded the LS level (0.027). The main reason behind this large rotation is its less in-plan stiffness and existing more openings.

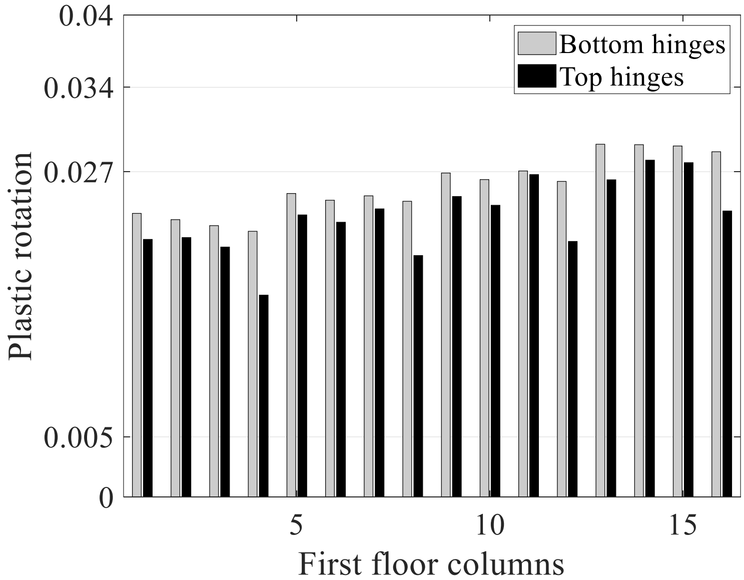


Fig. 13. Plastic rotation of first floor columns against RSN 143.

The normalized story shear at all columns in the firslt floor plan are less than one, so there is no concern of shear failure at all Figure 14.

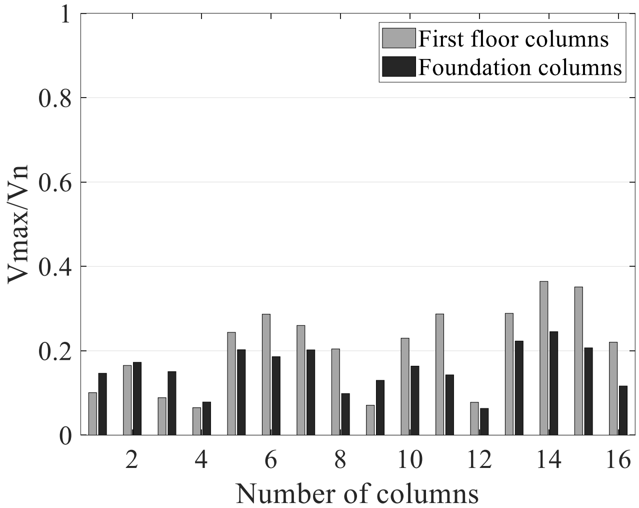


Fig. 14. Normalized story of first floor columns against RSN 143.

The ratio of demand over capacity (D/C) and normalized punching shear (Vmax/Vn) in the foundations are less than one at all cases Figure 15.

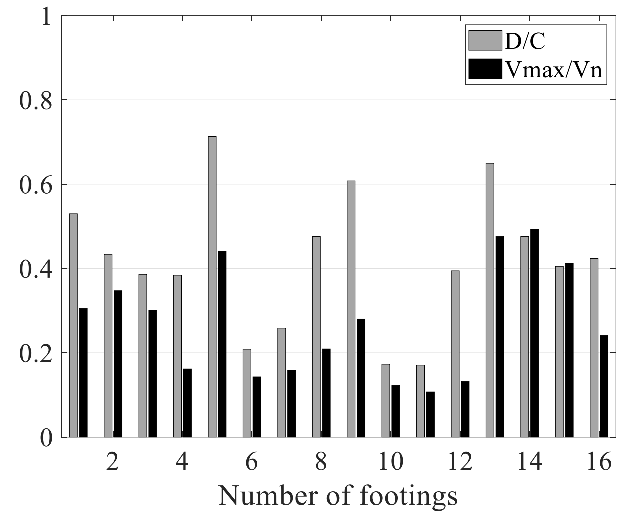


Fig.15. Normalized demand over capacity ratio (D/C) and normalized punching shear (Vmax/Vn) of footings against RSN 143.

4. Result and discussion

The overall seismic performance of the building's analytical model does not meet the acceptability criteria. The concentration of the inter-story drift ratio at the first floor level has triggered a soft story mechanism into the building. This also resulted in the formation of plastic hinge at both ends of the first floor columns. Additionally, the infill walls of this floor completely cracked/collapsed, while the infill panels of the upper floors experienced extensive to operational levels of damages/cracks condition, respectively. The normalized story shear and overturning moment for all the stories against all ground motions are less than one, indicating no immediate concern of shear and bending failures in the building model. The plastic rotation of the first-floor columns remain mostly within the of LS level, except the columns along axis 1 crossed this level. Furthermore, the demand-over-capacity (D/C) ratio of foundations bearing capacities is less than one, although the edges and corners foundations experienced higher bearing pressure due to their small sizes compared to inner footings.

In summary, the significant inelastic deformation at the first floor-level elements has lead to the formation of plastic hinges in the columns and the collapse of infill panels. Consequently, the CSB model requires strengthening intervention.

5. Seismic retrofitting design

The retrofitting and seismic performance of the CSB were evaluated according to ASCE 41-17 standard [30]. The primary objective of applying FRP laminates on the infill panels of the CSB's model is to mitigate damage to the infill walls by reducing story drift and controlling column rotation to remain withinthe Life Safety (LS) level against strong ground motions.

The selected building features unreinforced brick masonry walls in nearly all of its frames. These non-structural elements are highly vulnerable due to several factors, including lack of ductility, complex dynamic behavior, limited experimental data, challenging in modeling, and the interaction of masonry with structural frame elements. Since it has been determined that the columns collapsed through the development of plastic hinges at the ends, this concept of failure results in diagonal cracks in the infill walls. Therefore, the diagonal fiber-reinforced polymer (FRP) patterns have been used as a retrofit strategy. Since the previous section highlighted that the RSN 143 dominated the seismic performance of the building, so in this section the performance of CSB's model is evaluated only under this ground shaking. Given the lack of experimental data on the modeling and design of FRP retrofitting of infill walls with openings, only solid panels are selected as retrofitted members in this study. Retrofitting the first-floor infill panels effectively shifted the soft-story mechanism to the second floor. Subsequently, pasting of FRP sheets on both the first and second floors selected infill panels caused a significant drift ratio in the third story. Finally, retrofitting of selected infill walls in the three-story CSB's model was adopted as a final scheme for strengthening.

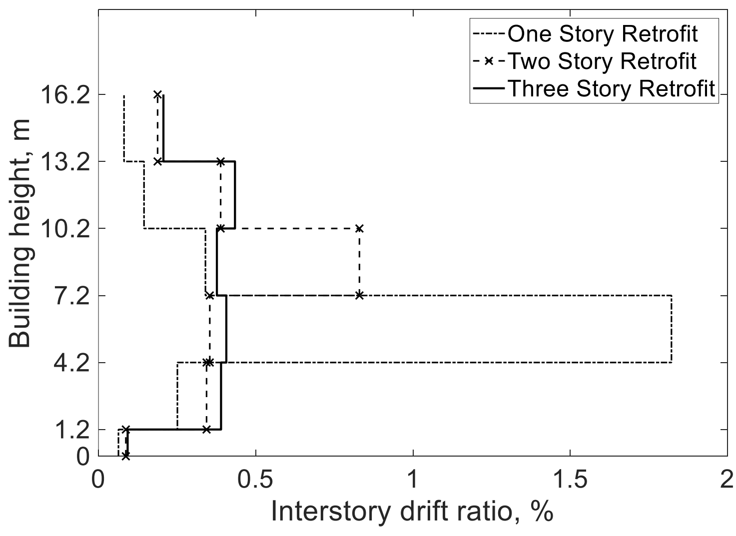


Fig. 16. Inter-story drift ratio of CSB for retrofitting of different story against RSN 143.

Table 4 indicates that the applied method reduced the time period of the building's model in the different modes significantly.

Table 4. Natural period of time of original and retrofitted CSB for different modes.

Mode No	Un-retrofitted (second)	Retrofitted (second)
1	0.41	0.289
2	0.37	0.257
3	0.308	0.212

The method reduced the lateral displacement of the building remarkably. The plotted result in Figure 17 shows a reduce of 30.4% in the roof displacement.

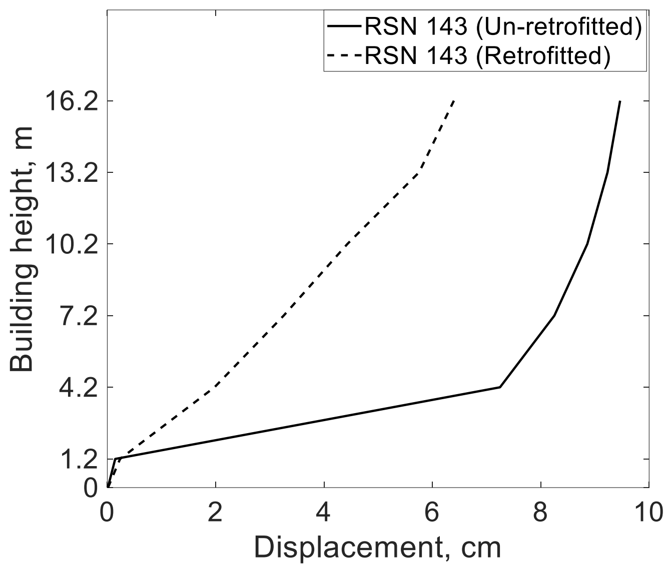


Fig. 17. Lateral displacement of the CSB's model for retrofitted and un-retrofitted schemes against RSN 143.

The reduction of roof displacement leads to a significant decrease in the inter-story drift ratio. The compared result at Figure 18 shows a reduction of 74.57% of the first floor inter-story drift ratio under RSN 143. However, due to their high amount of differentiated displacement, there is a slight increase of the inter-story drift ratio at upper floors level.

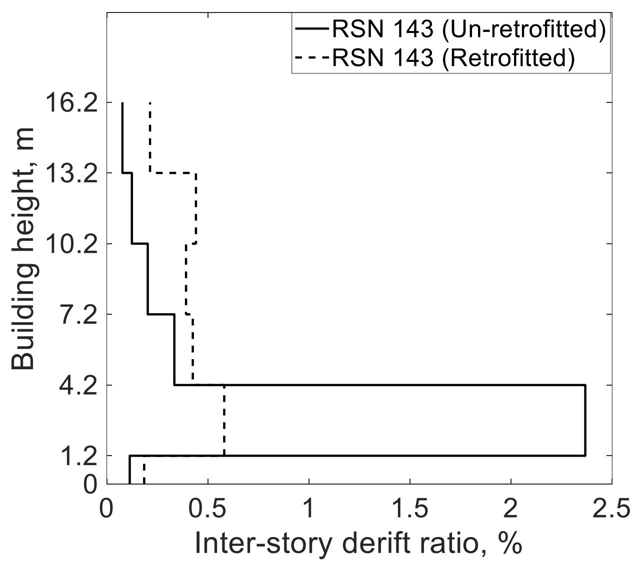


Fig. 18. Inter-story drift ratio for un-retrofitted and retrofitted schemes against RSN 143.

In contrast, there is an improvement in normalized story shear and overturning moments, Figures 19 and 20. The normalized base shear and overturning moment increase from 45.3% to 87% and 35% to 58%, respectively. However, these ratios are less than one in both cases.

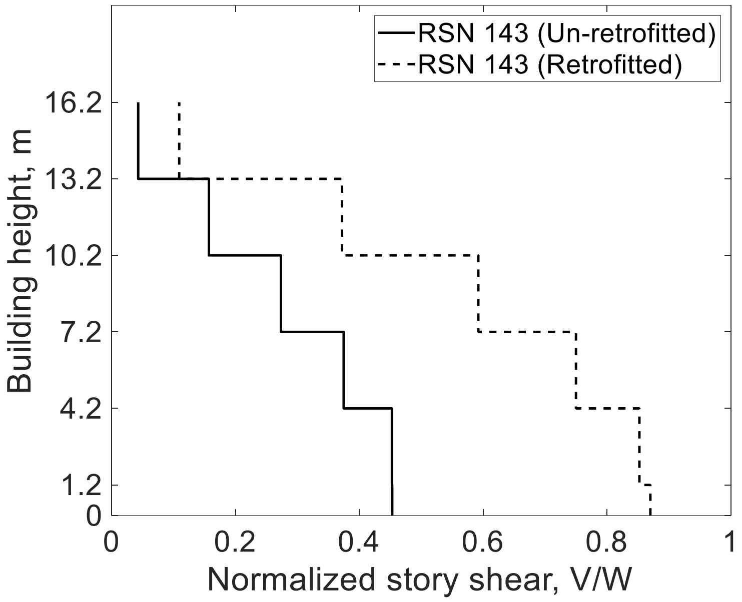
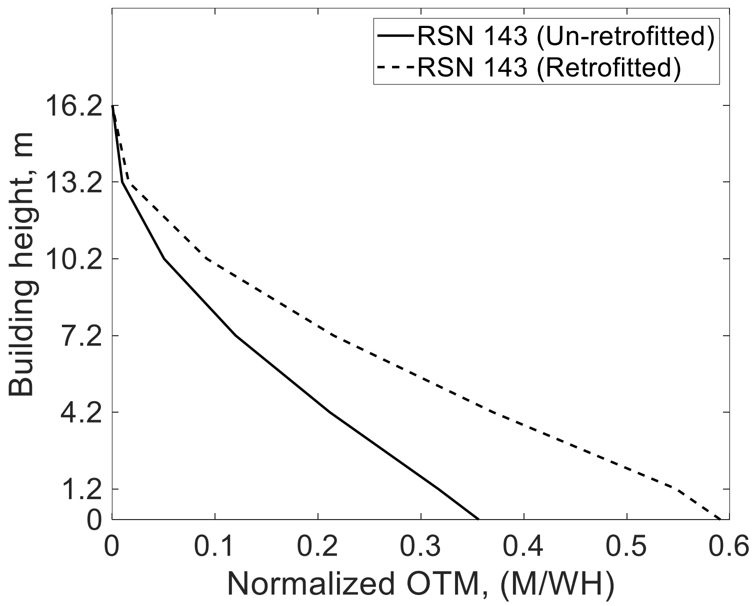


Fig. **19**. Normalized story shear against RSN 143.



Fi. 20. Normalized OTM against RSN 143.

Adopted method decreased the plastic rotation of the first floor columns most effectively. The obtained results in Figures 21 and 22 show that the inelastic deformation (plastic rotation) for all the columns is within the IO limit. This feature is very less in the columns of the foundation's level and upper stories, so their plotting and studying are ignored.

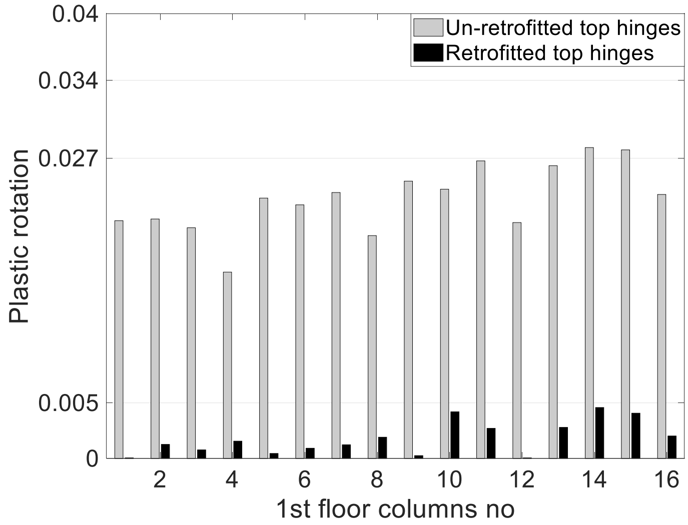
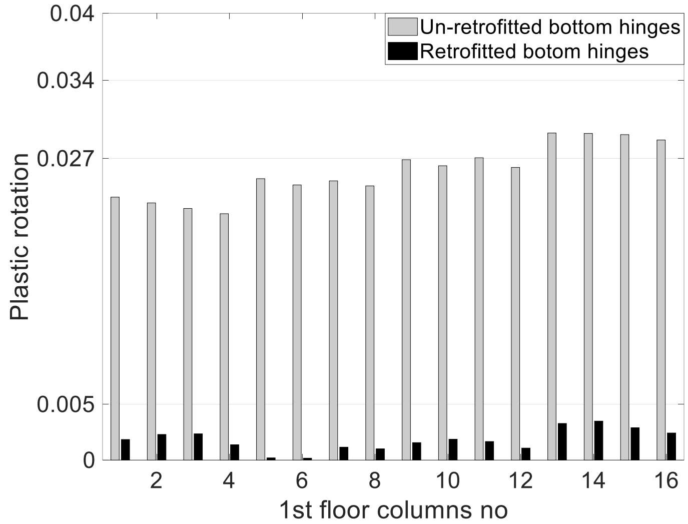


Fig. 2. Plastic rotation of retrofitted and unretrofitted top hinges of the 1st floor columns against RSN 143.



Fi. 2. Plastic rotation of retrofitted and unretrofitted bottom hinges of 1st floor columns against RSN 143.

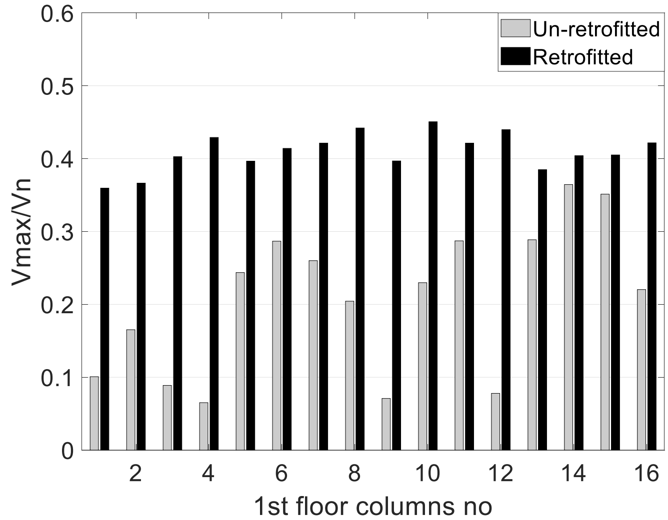


Fig. 23. The normalized story shear in the first floor columns against RSN 143.

As Figures 23 and 24 show the ratio of shear demand over capacity of the first floor and foundation level columns increased by applying the method, but still they are less than one. Figure 24 shows, some internal foundation columns experienced more intense shear conditions, and it is due to their high level of external loads.

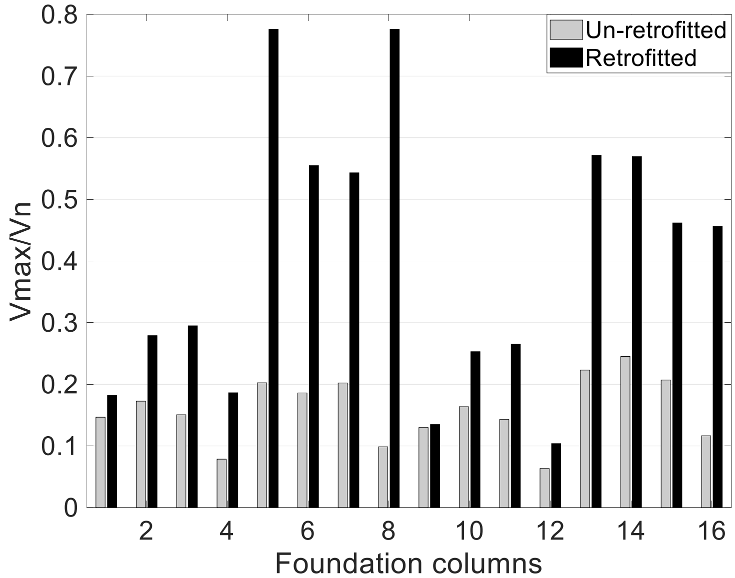


Fig. 24. The normalized story shear in the footings against RSN 143.

In some footings, the ratio of bearing demand over capacity (D/C) and normalized punching shear crossed from one (Figures 25 and 26). These failures mostly occurred at corners and edge footings. Overall, the retrofitted technique is quite effective for reducing inelastic deformation and inter-story drift in the global response of the case study building, but some footings fail due to their lower bearing and shear capacity.

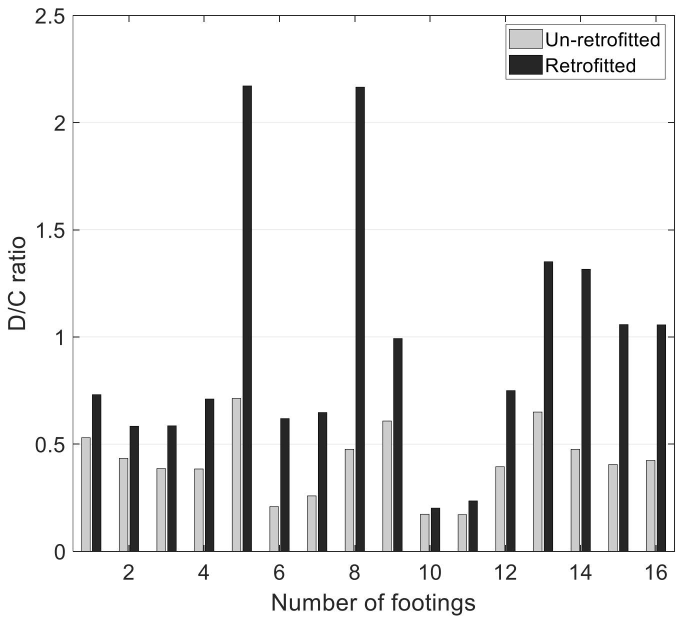


Fig. **25**. The demand over capacity (D/C) bearing ratio in the footings, against RSN 143.

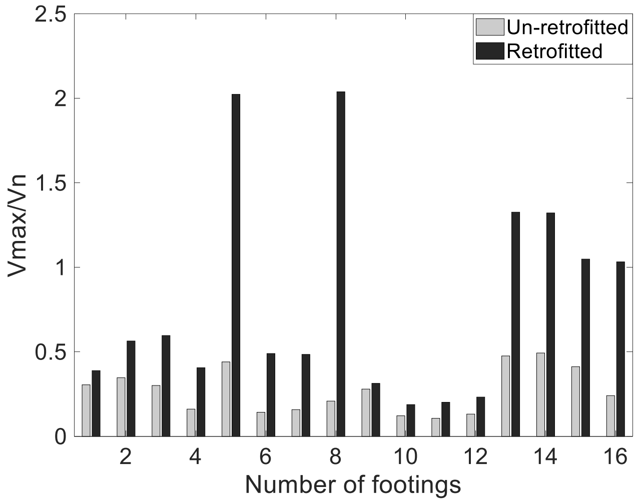


Fig. **26**. The demand over capacity (D/C) bearing ratio in the footings, against RSN 143.

6. Result of the retrofitting

Under the dominated ground motion, the nonlinear behavior and response of the strengthened CSB's model meet the acceptable criteria. The significant reduction of the inter-story drift ratio in the first floor level changed the damage condition of the infill walls in this floor. The infill walls' damage conditions shifted from collapse to extensive cracking. However, the slight increase in drift ratio in the upper floors intensified damage conditions. This is more highlighted in the fourth-floor infill panels. Although the normalized story shear and overturning moment increased at all stories, they are less than one. Plastic rotation of all columns in the retrofitted scheme reduced significantly, as the results show this rotation is within the IO limit for all columns of the first floor level, so there is no concern of plastic hinge formation in the frame elements. In addition, the normalized story shear at both first-floor columns and foundation columns is less than one. Some of the footings failed in bearing pressure and punching shear. The main reasons behind these failures are their small sizes and the high rigidity of the building. These failures are associated with some edges and corners of foundations.

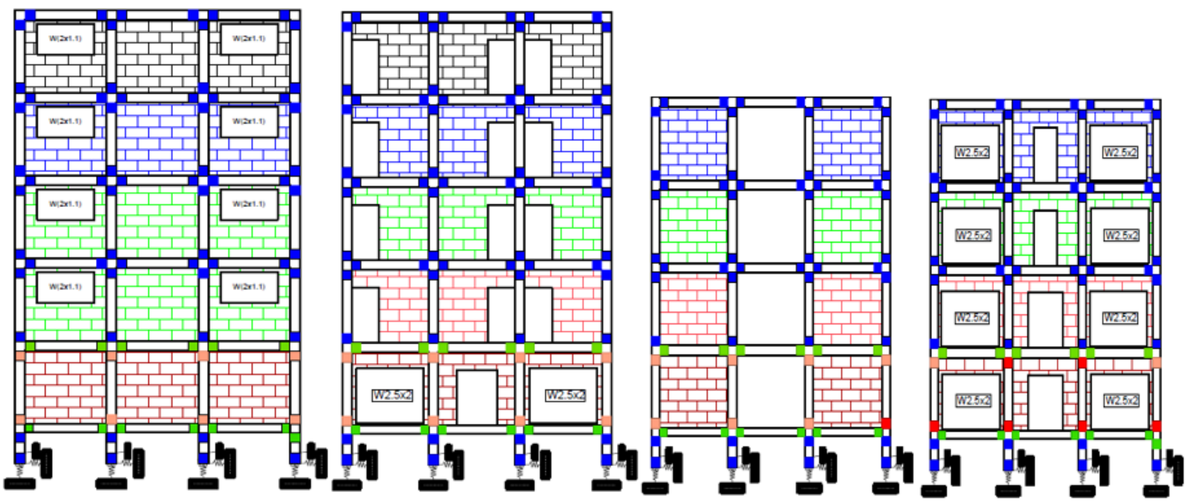


Fig. **27**. Damage notation of infill walls for un-retrofitted case study building against RSN 143.

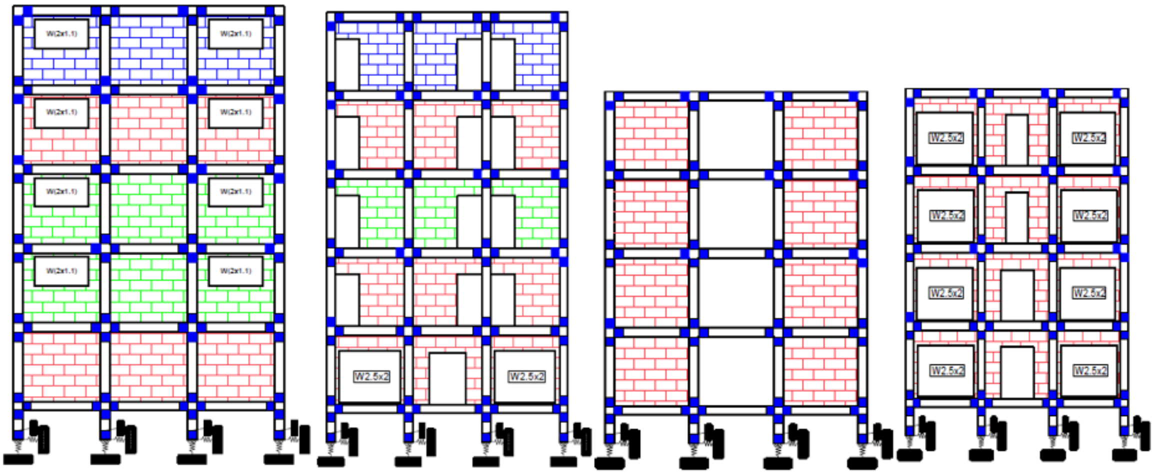


Fig. 28. Damage notation of infill walls for retrofitted case study building against RSN 143.

Legend:

1. The infill walls damage condition are determined based on the inter story drift ratio values. The extracted values are compared with the standard data on ASCE 41-17 related tables and data.
2. The frame elements damage condition are determined based on their defined fiber hinges plastic rotations. The inelastic rotation of the related hinges are compared with the values based on ASCE 41-17 standard in different performance levels.

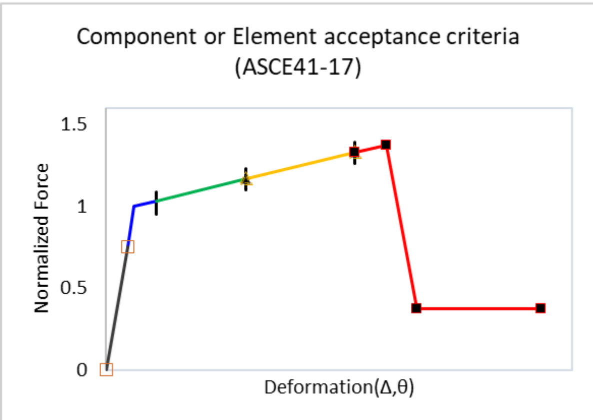


Fig. 29. The damage notation of frame elements is expressed from plastic rotation demand and inter-story drift ratio and compared with different acceptance criteria [30].

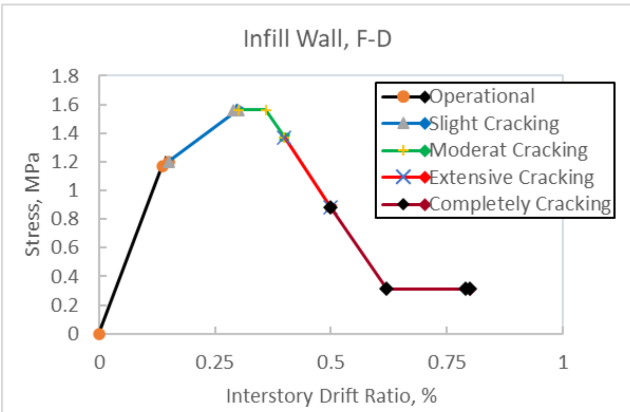


Fig. 30. The damage notation of infill walls is expressed from plastic rotation demand and inter-story drift ratio and compared with different acceptance criteria [30].

7. Conclusions and recommendations

The CSB's analytical model seismic performance is evaluated in terms of roof displacement, inter-story drift ratio, plastic rotation of column fibers, story shear and overturning moment, demand over capacity ratio of foundation bearing capacity, and punching shear. From the study of the aforementioned terms, the following conclusion can be drawn:

1. Overall, the performance of CSB's model in its original condition under selected ground motions is poor. The floors, especially the first floor level, experienced quite a large amount of drift ratio, and the plastic rotation of some columns crossed the LS level. Therefore, all the infill panels in the first floor collapsed, and the upper floors experienced extensive to operational conditions. Moreover, the plastic hinges formed at the fiber hinges of the first floor level, so the soft story mechanism occurred for the targeted analytical model of the building.
2. The ratio of demand over capacity of bearing pressure and punching shear of footings are also checked. The obtained results have shown that these ratios are less than one in all the footings, so there is no concern due to shear and bearing failure of foundations.
3. The used method reduced the level of damage and vulnerabilities of the building's model significantly. Consequently, the damage condition of infill walls in the first floor level shifted from collapse condition to extensive cracking, and due to increasing story drift in the upper levels, their infill panels experienced more damage. Moreover, the plastic rotation of all columns in all floors is within IO, so the method is quite effective for reducing inelastic deformation and fiber hinge rotations.
4. The ratio of shear demand over capacity for all first-floor columns and footings is less than one. But there are some failures due to punching shear and bearing pressure in some footings. The main reasons behind these failures are their small dimensions and the high rigidity of the structure, which results in more story shear.
5. The used method is more effective for reducing inelastic deformation and damage conditions, but the probability of brittle failure due to high frequency and stiffness is a concern.

7. Recommendations

The author recommends the following consideration for the next studies:

1. To take into consideration the effect of the staircase, which makes the building more irregular in plan and elevation.

Funding

This research did not receive any specific fund and grant from public, commercial and private agencies, or not for profit sectors.

Conflict of interest

The authors, Mohammad Ali Eltaf and Abdul Ali Raoufy, declare that they have no known competing financial interests or personal relationships that could have appeared to influence the

work reported in this paper. Both authors are faculty members at Kabul Polytechnic University, Kabul, Afghanistan, and their affiliations do not influence the content or findings of this research.

Authors contribution statement

Mohammad Ali Eltaf: Conceptualization, methodology, data collection, analysis, software, visualization, writing and original draft.

Abdul Ali Raoufy: Supervision, validation, review, editing, and funding acquisition.

All authors contributed to the development and final approval of the manuscript.

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