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Assessing of the common strengthening methods for existing RC buildings

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ABSTRACT

The technical and economic effects of the two methods of retrofitting with buckling restrain bracing and using concrete shear wall were investigated. The results of this study showed that using reinforcement, the amount of target displacement in the models was significantly reduced and it was observed that the concrete shear wall had a greater impact on the structure in this regard. The reinforcement methods used in this research have a significant impact on improving the technical performance of structures, which has been more in the strengthening method with concrete shear wall. Also, the evaluations showed that despite the fact that the shear wall of reinforced concrete has a better effect on the performance of the structure from a technical point of view, but in terms of weight, it can be seen that using a buckling brace can be more economical.

KEYWORDS

strengthening methods, push-over analysis, concrete shear wall, buckling restrain brace, seismic rehabilitation

1. INTRODUCTION

The variety of human facilities throughout history faced various events other one as floods, storms, earthquakes, etc. Earthquake is one of the most important factors that cause many casualties and financial losses annually. Large populations of people around the world live in areas with a high probability of earthquakes.

Iraq is also one of the earthquake-prone countries in the world. Therefore, people throughout history have tried to use different technique to deal with this natural danger.

1.1. Statement of the problem

The use of reinforced concrete buildings has been common in our country for several decades. Many existing buildings were designed and built at a time when the basics of seismic design were not well understood. Therefore, these buildings do not have sufficient strength, stiffness, and ductility to meet seismic needs. In general, there are various reasons for the strengthening of structures, including the buildings damaged by the earthquake and buildings that are not strong enough due to changes in code or changing of buildings use have been mentioned. In this regard, the country's engineers and researchers are trying to get the best solution with the lowest cost and highest reliability.

Making a building compliant with new code requirements, changing the use of a building, deterioration of materials (use of inferior materials during construction), incorrect design and execution, lack of technical improvement or maintenance of the building, saving money (improvement is less expensive than renovation), inadequate soil characteristics due to erosion and settlement, and others are among the main reasons for improving a building. Iraq has a large number of traditional buildings (without calculation bases), which makes it important to maintain ancient structures. Seismic design techniques based on performance level have also been developed, as has human knowledge of earthquake engineering. The most important factor in performance-based design is the choice of improvement goal.

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Since replacing existing structures with new ones is often not economically applicable. Therefore, finding a suitable solution for repairing and strengthening structures is very important. Compared to building a new structure, strengthening an existing structure can be even more complex; because the structural conditions have already been proven. In addition, access to areas that need reinforcement is not always easy. On the other hand, choosing the wrong method of repair or reinforcement can even worsen the performance of the structure. Traditional methods used as retrofitting techniques, other one as various types of reinforced coatings, shotcrete, post tension cables outside the structure, and the use of steel structure, usually needs to adequate space.

Nowadays, nonlinear static and dynamic analysis methods for rapid seismic evaluation of structures are being developed. Nonlinear dynamic analysis methods require a large amount of computation and are more time consuming. On the other hand, to determine the demand and seismic capacity of structures in design based on performance, accuracy and speed in performing calculations are two important criteria. This has given rise to a variety of new methods based on the concepts of nonlinear static and dynamic analysis. Over the past decade, push-over analysis as an appropriate application tool has played an effective role in the development of performance-based design and has been widely used in codes and guidelines for seismic assessment of structures. With the prevalence of push-over analysis among engineers, extensive studies have been conducted on the advantages and disadvantages of this method. Therefore, in this study, the aim of the economic study is the common methods of strengthening concrete structures, in which nonlinear static analysis will be used.

1.2. Literature review

Maske et al. [1] carry out the push over analysis on multi-storied frame structures by using most popular program SAP2000 (version 14). Two framed buildings of five and twelve stories, respectively, were examined to determine the weak points in the construction and then to decide whether the specific component should be retrofitted or rehabilitated in accordance with the requirements. The findings of this study demonstrate that properly built frames will function effectively under earthquake loads.

Using SAP2000, Deep and Raju [2] used non-linear static analysis (pushover analysis) to comprehend the behavior of a G+9 multistory residential building situated in India's seismic zones II, III, IV, and V that share comparable geometrical attributes. Investigations into the force-displacement relationships, inelastic structural behavior, sequential hinge formations, and other aspects of multistory building behavior have been conducted. Base shear, displacement, and time period all gradually increased as seismic activity's intensity increased from zone II to zone V, the analysis's findings show. Additionally, based on the importance of the structure, columns in the lower stories can be retrofitted and damage to a building is typically small.

The Bank Tabungan Negara (BTN) office building in Madiun City, Indonesia was reanalyzed by Rohman et al. [3] to determine the building's performance level. Pushover analysis was employed with ETABS version 9.00 software for structure analysis. Analysis shows that the BTN office building performs at a level that is claimed to be life safety to collapse prevention Life Safety to Collapse Prevention (LS-CP).

In Khartoum, Sudan, Ismaeil [4] examined the seismic damage to an existing 5-story reinforced concrete structure. The study took into account three performance levels, including immediate occupancy, life safety, and collapse prevention. Utilizing SAP2000, the gravity push was performed utilizing the force control method and the lateral push with displacement control. Push curve is produced via pushover analysis and contains the demand spectrum, capacity spectrum, and performance point. It displayed the level of building component performance as well as the maximum base shear carrying capacity. It has been observed that different building elements need to be strengthened.

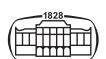
In 2018, Handana and Karolina [5] inspected the existing structures, including the Wari Medan Building on Brigjen Katamso Road. The obtained results show that the building under consideration is included in the criteria of immediate occupancy, which means that in the event of an earthquake, the structure does not sustain structural or nonstructural damage, making it safe and suitable for immediate usage.

Using ETABS software, Murthy and Ashwini [6] provide a summary of the nonlinear static pushover analysis of medium rise reinforced concrete bare frame and high rise Reinforced Concrete (RC) in-filled structure with soft stories at various levels. The findings showed that as soft stories were introduced at higher levels, the intensity of hinge creation decreased, whereas base shear and displacement increased.

Sultan et al. [7] studied the seismic behavior of concrete structures strengthened by Fiber-Reinforced Polymer (FRP). In this study, FRP concrete beams were compared with non-FRP concrete beams, and the results showed that fiber-reinforced beams increased the resistance of the entire concrete building and reduced the roof displacement of the structure.

Ismail [8] examines the performance of three multi-story structures of various heights that are situated in an area with a high seismic danger. Three retrofitting methods were presented: X-Steel bracing, composite braces with buckling restraints, and composite concrete-steel plate shear walls. According to the structure's basic period, maximum inter-story drift, and maximum base shear-to-weight ratios, the seismic performance improvement of the analyzed structures was assessed. To choose the retrofit approach with the lowest fundamental material cost, the costs of retrofitting material for each approach were also assessed and compared.

Wibowo et al. [9] utilized the pushover analysis with ETABS version 9.00 software to determine the performance level of the existing RC building structure in Indonesia. This building has a moment-resistant frame structural system. The seismic resistance design standard for building structures, SNI 1726:2012 [10] is the foundation for the



equivalent static load analysis used in seismic load calculations. A reasonably straightforward approach for Performance-Based Seismic Evaluation (PBSE) is the pushover analysis. Results analysis shows that the Building Parking of Pasar Besar Madiun City performs at a level of life safety to collapse prevention.

Nawrot [11] provides a numerical and analytical evaluation of the load-bearing capacity of a beam-to-column joint. The two alternatives of a reinforced joint with a fixed haunch on the side of a compressed flange of a beam and an unreinforced joint have been investigated. Calculations have been made to determine the joint's rotational stiffness and load-bearing capability. Specific joint components' distributions of stresses and deformations have been identified. Comparing the results of analytical and numerical computation demonstrates that, while the load-bearing capacity of the joint measured using the analytical approach generally yields safer results (for both reinforced and non-reinforced joints), it may occasionally result in the connection being oversized.

2. CASE STUDY

Building Description: The building, studied in the case analysis, was a 4 storey reinforced concrete building, for offices and shops use. The slab thickness was 20 cm; column section was 35×35 cm with reinforcement area of $12\text{Ø}16$ mm; and the beam section was 25×50 cm with reinforcement area of $4\text{Ø}20$ mm. The height of each level was 3 m; the number of bays in both directions (X and Y) is three; the bays dimensions were 5.7×7 m; the building was located in the Baghdad, Iraq. The vertical and lateral loads according to ASCE 7–16 were applied. Table 1 presents the materials properties of concrete and rebar, where f_{cu} is the compressive strength; f_y is the yield strength; f_u is the ultimate yield strength; E is the modulus of elasticity; ν is the Poisson ratio; w is the specific weight.

Pushover analysis: After finishing the structural model analysis, the pushover analysis was conducted. Modeling, defining material properties, defining static load cases, defining load combinations, assigning loads, and executing analyses are all steps in the analysis process. Designing the concrete frame is the last step. Define nonlinear hinge characteristics initially before performing pushover analysis.

2.1. First model: intermediate concrete moment frame without retrofitting

The first used model is to perform nonlinear analysis on the existing unreinforced building. As it can be seen in Fig. 1,

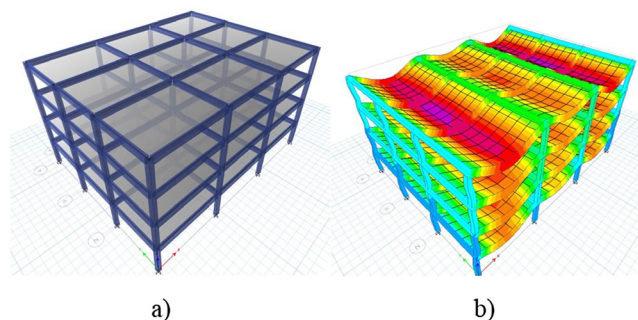


Fig. 1. Overall view of building after modeling and designing for 1st model

after designing the structure, there are some elements of the beam and column are failed, so it becomes clear that the structure needs to be strengthened. Therefore, two common models were suggested for strengthening the building (buckling restrain bracing and concrete shear wall). Figure 1a represents the shape of the building without any method of strengthening. Figure 1b shows the deflection failure in the concrete members of the building as a result of exposure to lateral loads or earthquakes.

After performing equivalent static analysis and observing the design status of the structure, nonlinear static analysis in this structure was investigated. For this purpose, after applying the desired loads in this analysis method, the results of this analysis can be seen in Fig. 2 for uniform loading mode.

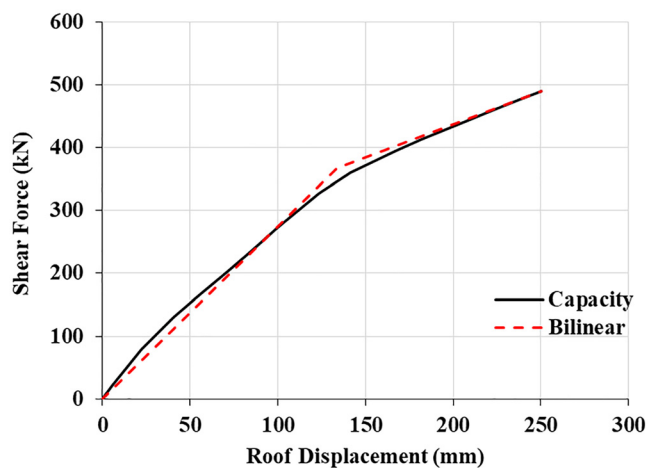


Fig. 2. Base shear, roof displacements diagram

Table 1. Material properties

Materials Name	f_{cu} (MPa)	f_y (MPa)	f_u (MPa)	E (MPa)	ν	w kg m ⁻³
Concrete	28	—	—	24,870	0.2	2,400
Rebar	—	400	620	200,000	0.3	7,850

2.2. Second model: intermediate concrete moment frame retrofitted by concrete shear walls

Shear walls are incorporated to the structural system to offer lateral resistance against lateral loads brought on by wind or seismic forces [12]. Buildings with non-ductile RC frames typically employ shear walls for retrofitting. Cast-in-place concrete elements or precast concrete elements can be used as the shear walls (additional elements). It is preferable to add new components to the building's exterior. Not favored inside the building to prevent inside mouldings [13].

After designing the structure, all the beam and column elements in the structure have responded by applying this method of reinforcement (shear walls) as it can be seen in Fig. 3.

As it can be seen in Fig. 3, the maximum target displacement values in this model are 250.5 mm. Also, to evaluate the modality of the structure, the period of the first mode of this structure can be considered as the next figure, the value of which is 1.46 s.

Figure 3a represents the location of the strengthening method with concrete shear wall in the building. Figure 3b illustrates the deflection of the structure's concrete members as a result of lateral loads or earthquakes, however no failure of those components occurred because the building was strengthened with shear walls.

After performing equivalent static analysis and observing the design status of the structure, nonlinear static analysis in this structure was investigated. For this purpose, after applying the desired loads in this analysis method, the results of this analysis can be seen in Fig. 4 for a uniform loading mode.

So, from Fig. 4 can be seen that the maximum target displacement value in this model is 25.7 mm. Also, to evaluate the modality of the structure, the period of the first mode of this structure can be considered as the next figure, the value of which is 0.16 s.

2.3. Third model: intermediate concrete moment frame retrofitted by buckling restrain bracing

Adding steel bracings: If you need large openings, adding steel bracing is a good solution. Potential benefits include increased strength and stiffness, the ability to install windows for natural light, reduced labor requirements due to the

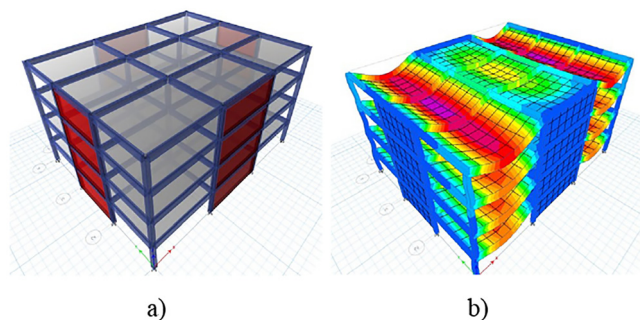


Fig. 3. Overall view of building after modeling and designing for 2nd model

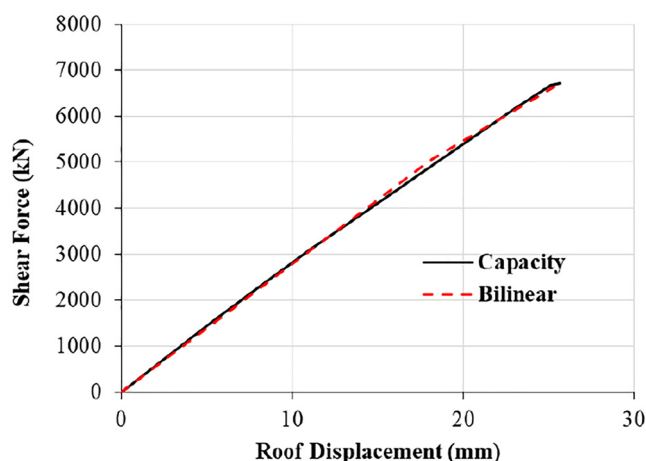


Fig. 4. Base shear, roof displacements diagram for 2nd model (shear wall)

potential reduction of foundation costs, and significantly reduced weight added to the existing building [13].

In a framed building, bracing is an efficient and cost-effective way to withstand horizontal forces. In both RC and steel buildings, braced frame systems are used. The structure typically consists of columns and beams whose main function is to transfer gravity load. When bracings are attached to it, the entire group of components creates a vertical structure resembling a cantilever truss to withstand horizontal forces.

The building uses bracing components as a horizontal load-resisting mechanism to increase the frame's rigidity for seismic forces. The connection for braces might be fixed-ended or pin-ended. With a pin-ended connection, axial forces will be applied, and it typically fails under a compressive load through global buckling. Once the buckling has happened, it loses strength over the following cycles. However, maximum tensile strength in following cycles will not undergo considerable modifications. The fundamental benefit of utilizing braces is that they dissipate energy without causing harm to the structure, and they can also be easily replaced when they are damaged [14].

After designing the structure, all the beam and column elements in the structure have responded by applying this method of reinforcement (steel bracings) as it can be seen in Fig. 5.

Figure 5a represents the location of the retrofitting with buckling restrain bracing in the building. Figure 5b illustrates the deflection of the structure's concrete members as a result of lateral loads or earthquakes, however no failure of those components occurred because the building was strengthened with steel bracings.

After performing equivalent static analysis and observing the design status of the structure, nonlinear static analysis in this structure was investigated. For this purpose, after applying the desired loads in this analysis method, the results of this analysis can be seen in Fig. 6 for uniform loading mode.

As it can be seen in Fig. 6, the maximum target displacement value in this model is 78.8 mm. Also, to evaluate the modal of the structure, the period of the first mode of this

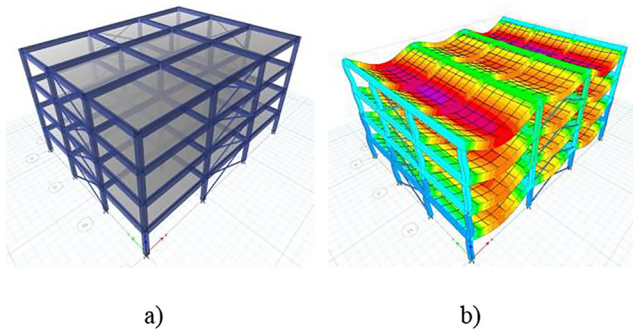


Fig. 5. Overall view of building after modeling and designing for 3rd model

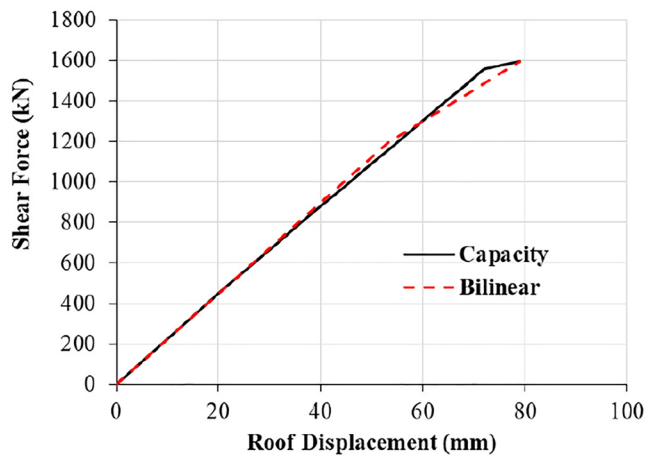


Fig. 6. Base shear, roof displacements diagram for 3rd model

structure can be considered as the following figure, the value of which is 0.59 s.

3. RESULTS DISCUSSION

It was observed that in this study, with the aim of technical and economic study of reinforcement methods, the technical and economic effects of two methods of reinforcement with BRB and reinforcement using concrete shear wall were investigated. According to the necessary indicators and criteria as well as the financial estimation of each of the executive methods based on the elements of materials, manpower, machinery and tools and based on daily prices along with push-over analysis, economic studies and evaluations were also performed. In this section, as a summary, the results will be reviewed in the form of diagrams.

In Figs 7 and 8, a comparison of the target displacement can be seen in the studied models. As it can be seen in Fig. 7, the value of target displacement in the models has been significantly reduced by using reinforcement, and it is clear that the concrete shear wall has a greater impact on the structure in this regard.

In Fig. 8, compares the amount of gained strength for each model can be observed. As it is shown in Fig. 8, the strength ratio was also increased by applying strengthening,

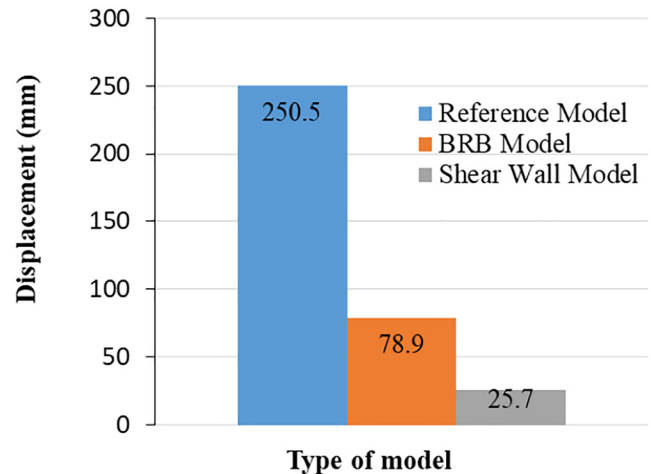


Fig. 7. Comparison of target displacement

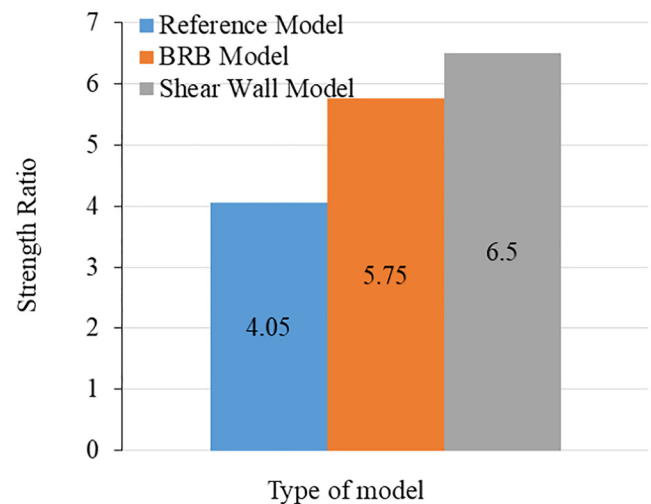


Fig. 8. Comparison of overall strength ratio of models

and this amount was further increased by applying the method of adding concrete shear wall than by adding the Buckling Restrain Bracing (BRB).

Observing these results, it can be concluded that the reinforcement methods used in this research have a significant impact on improving the technical performance of structures, which has been more in the method of retrofitting with concrete shear wall.

Shear wall gives high stiffness to the structure so as the structure will be stable. Applying shear wall can effectively reduce the displacement and story-drift of the structure. This will reduce the destruction comes from lateral loads such as an earthquake.

Providing braces increases the lateral stiffness of the structure. Due to the increase in stiffness, the lateral deformation of the structure is reduced compared to that of the bare frame. The braces act as axially loaded members (truss members) when subjected to lateral seismic forces.

The base shear of the structure heavily increases and makes the structure more stable against seismic force. The

lateral force resisting system has also been well performed while placing shear wall and bracing. The natural time period of the structure has highly reduced after placing shear wall than the bracings, which will improve the stability against earthquake and make the structure more stable. The structure has a minimum lateral displacement with shear wall and bracings compared with bare frame. Structure with shear wall system has a least lateral displacement. From the above discussion it is concluded that shear wall could improve the lateral stability of the structure more than the bracings.

Common strengthening methods (shear walls and bracing) can be used for all reinforced concrete buildings (structure buildings) without restrictions or limitations on the use of these methods.

4. CONCLUSION

The findings of this investigation were distilled into the following:

- By utilizing strengthening, the value of target displacement in the models has been greatly decreased, and it is obvious that the concrete shear wall has a stronger effect on the structure in this regard;
- Strengthening also resulted in an increase in the strength ratio, and this amount was further increased by using the method of adding a concrete shear wall rather than a BRB;
- It can be stated that the strengthening techniques utilized in this study significantly improved the technical performance of the structures, particularly the technique of retrofitting concrete shear walls.

4.1. Recommendations for future work

- Use another strengthening method such as the Fiber Reinforced Cementitious Matrix (FRCM) composite to assess the behavior of existing structural elements.
- The one of the main focus is the shear wall; its width and thickness are fixed but height at which it behaves as an optimum case can be a major study.

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