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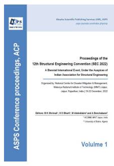

Comparative Study on Seismic Performance of Existing Building with and without Retrofitting Using Lateral Load Resisting Systems

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Abstract

Due to the lack of awareness and practice of implementing earthquake resistant structures in the past, a huge number of buildings today do not comply with the existing/updated seismic codes in India. This issue is predominant in existing residential buildings which involves a high probability of loss of lives. The increase in population and clustered city areas make code non-compliance dangerous and risky especially in the Northern and North Eastern regions which come under seismic zones IV and V. Retrofitting strategies are thus an important aspect of building and life safety. This study involved the seismic performance of an adapted existing residential building taken in the North-East region. The seismic response analysis of the RC building was studied in terms of peak responses (deflection). The performance of the building was based on response spectrum and time history analysis. The main objective of this study is to provide a comparison between the most commonly used retrofit strategies – shear wall, bracings and viscous dampers. The responses of the building with the mentioned strategies and their varied configurations were modelled and analysed through ETABS software. This study outlined the feasibility of each retrofit strategy based on the optimum configuration for deflection control and basic cost estimate.

Keywords: Retrofitting, Shear wall, Bracings, Viscous dampers, ETABS.

1. Introduction

Retrofitting of a structure is a long-known construction practice. A lot of structures in the past were built without considering seismic response. Also, with changing seismic codes and the recent updates, there is a need to retrofit structures to make them code compliant. Traditional methods of retrofit are sometimes inefficient or infeasible. This is where various innovative strategies like energy dissipation devices come into picture [1]. Different case studies of actual buildings where traditional and innovative retrofitting methods have been applied were reviewed [2]. To verify the retrofitting method, a six storey building was considered and the aim was to increase the structural sustainability in an environment prone to higher seismic hazard than in the initial structural design. This study included the different restrictions involved in retrofitting and choosing an optimal method which is cost effective. [3] One of the ways for the structure to withstand moderate earthquakes is by providing a semi rigid frame with relatively weaker beams and connections with lesser stiffness [4]. Furthermore, a nonlinear analysis can help determine an estimate of the peak responses by taking into account varying degrees of semi-rigidity. However, the scope of this study is limited to linear analysis with rigid frames and various retrofit strategies to withstand moderate earthquakes.

Bracings are one among the most widely used retrofit strategies owing to its ease of construction and minimal hindrance offered to the functioning of the building since it is mostly provided on the periphery of buildings. Bracings are versatile in the sense that they can be used as a retrofit strategy as well as can be designed for new buildings. Steel bracings are often used as a lateral force resisting system in steel framed buildings and shear walls are used for the same purpose in reinforced concrete framed buildings. However, in recent years methods have been adopted to use steel bracings in RC buildings due to its ease of construction and relatively low cost [5]. The addition of sufficient stiffness to the building

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by using this strategy allows for pre-existing but structurally weak buildings to be retrofitted and the resulting increase in stiffness will contribute to a longer service life while additionally providing architectural advantages [6]. Steel bracing has been used as a retrofit and found to display adequate performance as seen in a survey conducted on earthquake affected buildings of Tohoku, Japan [7].

In recent studies, equivalent static as well as static methods provided as per Indian Standard codes were incorporated for evaluating the building strength and its performance in STAAD ProV8i with shear wall as retrofit method [8]. A residential medium-rise building was analysed for earthquake and wind force along with in filled frame structural systems having different positions of shear walls [9]. Another study was carried out to determine the optimum structural configuration of a multi-storey building by changing the shear wall locations radically [10]. Research as mentioned has proven the adequacy of shear walls in resisting earthquake loads and it can be inferred that location of shear walls plays a vital role in lateral load resistance.

In recent years, fluid viscous dampers (FVD) have gained popularity for seismic retrofit due to its good response reduction capacity and ease of installation. [11] Tong Guo et al. discussed a case study in which a twenty-one storey hotel built in 1991 was seismically upgraded using viscous dampers. Only the first six stories were allowed to be structurally modified resulting in constraints on damper layout. The proposed design procedure suggested the use of fifty-six FVDs for that building. The design principles used in this study were used as a reference. Certainly, real-life applications could have various limitations such as architectural constraints, construction budget and required performance level. [12] Shanshan and Stephen have shown that the retrofits that additionally incorporated FVDs greatly improved performance of the case-study building of 35 storey at both design earthquake levels. While the dampers used were effective in reducing the seismic response, they were huge in size to carry the large loads coming on them. This paper further explored different ways to minimize the number of dampers required. The out of phase response of FVDs results in no requirement for strengthening other structural members. While mostly linear dampers have been studied, non linear dampers could result in better capacity [13]. Linear and nonlinear viscous dampers are first optimally designed for various types of frame buildings located in various seismic environments. Then, their behavior in terms of various responses of interest is examined to reveal their pros and cons.

In general, various retrofit strategies have been studied independently. This study aims to apply the general guidelines from the above literatures and produce a comparative study of three most common options of a retrofit strategy available to an engineer. This will ensure a general idea of the feasibility, efficiency and cost effectiveness of each approach as per the requirements.

The paper is organized as follows: Section 2 specifies the general structural details and performance without any protective system. The specifications and codes used are also discussed. Next, Section 3 describes the three different retrofit strategies utilized for better seismic response of the building. Section 4 discusses the results and basic cost estimate obtained after retrofitting. This is followed by the concluding remarks and the future scope, in Sections 5 and 6, respectively.

2. General Structural Specifications

2.1 Parameters of Building

For this research, G+4 building is modelled and analysed in ETABS. This building is designed keeping in mind the scenario of the North-East region of India and the model resembles a building of that area. It has 2 bedrooms, 1 hall and 1 kitchen. There are 4 flats on each floor. It also has a terrace and one water tank in addition. Staircases are used for access from one floor to another. Each floor has a corridor of area 5m X 4m. The plan, elevation and isotropic views of the building are given in fig 1,2 & 3 respectively. The parameters of the building are given in table 1.

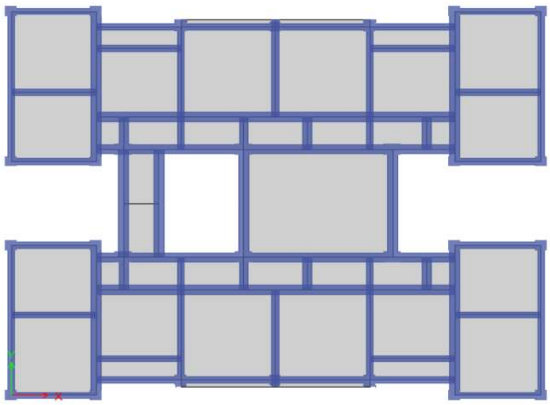

Fig 1: Plan of model

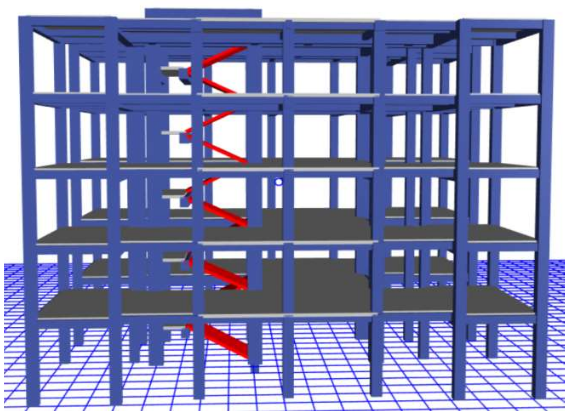

Fig 2: Elevation of model

Table 1: Parameters of a building

No. of stories	G+4 Stories
Storey height	3 m
Concrete grade	M-25
Steel grade	Fe-500
Beam dimensions	230 × 350 mm 300 × 450 mm 350 × 500 mm
Column dimensions	400 × 550 mm 450 × 600 mm
Slab thickness	125 mm
Exterior wall thickness	230 mm
Interior wall thickness	150 mm

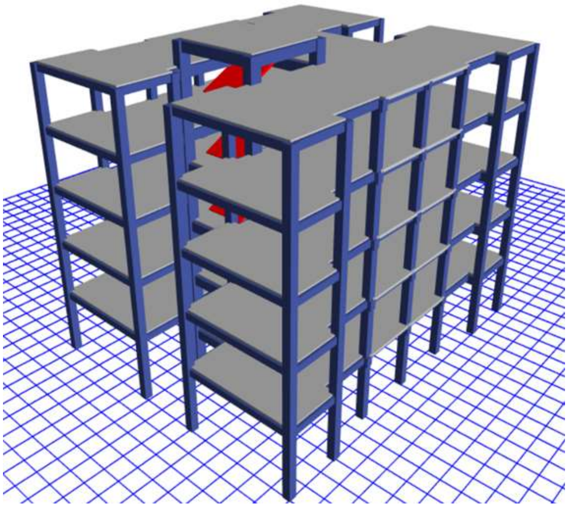

Fig 3: 3-D view of model

2.2 Details of load considered

2.2.1 Dead load and Live load

List of the dead loads and live load are:

Self-weight of beam, columns and slab	
Floor finish	1 kN/m^2
Wall load Exterior frame (230 mm thick wall) Interior frame (150 mm thick wall)	 14 kN/m 7 kN/m
Waterproofing	1 kN/m^2
Sunk load	18 kN/m^2
Water tank	25 kN/m^2
Live load	2 kN/m^2

2.2.2 Static analysis

Seismic loading was calculated as per IS 1893:2016

- Direction and eccentric loading x and y direction with eccentric ratio 0.05
- Loading was acting from to Ground floor to Terrace
- Response Reduction, R = 5
- Seismic Zone factor, Z = 0.36
- Soil type = III
- Importance factor = 1

2.2.3 Dynamic analysis

2.2.3.1 Response spectrum

Same inputs were given as in static analysis with other parameters as

- Scale factor as 9806.65 in load type acceleration
- Modal combination Method = CQC
- Directional combination type = SRSS
- Modal damping constant at 0.05

2.2.3.2 Time History Analysis

Four earthquakes were matched to Indian Response Spectrum so as to obtain more accurate results in terms of site context as given in fig 4 & 5.

- Bhuj Earthquake
- Chamba Valley Earthquake
- Uttarkashi Earthquake
- Loma Prieta Earthquake

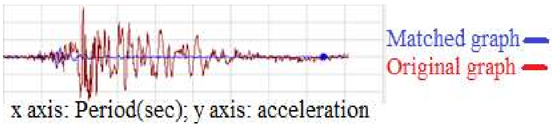

Fig 4: Reference/Spectrally matched acceleration Time History

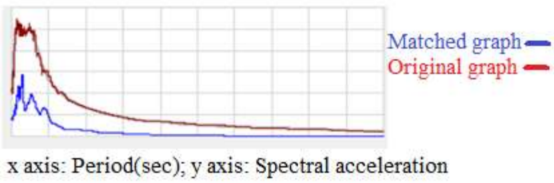

Fig 5: Target/Matched Response Spectrum

2.3 IS 15988:2013 Codal Provision

For the analysis of an existing building IS 15988: 2013 [14]. Seismic Evaluation and Strengthening of Existing Reinforced Concrete Building - Guidelines.

Following evaluation criteria for retrofit were considered:

1. Lateral load modification factor

Usable Life Factor(U)
Design Life: 50 years
Considered age of building: 10 years
Hence, U considered= $(40/50)^{0.5} = 0.894$

2. Modified Material factor

Based on probable material strengths in the building.
Considered Knowledge Factor: 0.9
Hence,
Modified Modulus of Elasticity= 5000√fck*0.9*

3. Retrofit Strategies

3.1 Shear Wall

These are vertical components of the horizontal force resisting system. And are constructed to counter the reaction of lateral load acting on a structure. In residential buildings, shear walls are direct external walls that generally form a box that provides all of the lateral support for the building. When they are planned and constructed properly, they will have enough stiffness and strength to withstand the horizontal forces. In building construction, a rigid vertical diaphragm is efficient in carrying lateral forces from roof, walls (load bearing or partition) and floors to the foundation in a direction parallel to their planes. Examples are reinforced-concrete walls or vertical trusses. Lateral forces caused by wind, earthquake, and uneven settlement loads, in addition to the load of a structure and its occupants, create powerful twisting forces. These forces can literally tear a building apart. Reinforcing a frame by attaching or placing a rigid wall inside it maintains the form of the frame and prevents rotation at the joints. Shear walls are mostly important in high-rise buildings subjected to lateral wind and seismic forces. In the last two decades, shear walls have become an important part of mid and high-rise residential buildings. As a part of earthquake-resistant building design, these walls are placed in building plans and help in reducing lateral displacements under earthquake loads.

3.2 Bracing

Steel bracing being a commonly used method for lateral load resistance has been considered in this study. When used for retrofit, prefabricated units can be brought to the site and installed by means of insertion of dowels into old concrete (in the case of reinforced concrete buildings) and grouted using epoxy mortar. These additional members add to the stiffness of the building and counteract lateral load by dissipating it in the form of either tension or compression or both. A major drawback of said bracings is that of its slenderness which causes a local buckling failure in most cases and hence the Indian Standard Code IS 15988 lays down certain limitations to the slenderness in the case of channel members used as bracing and for width-to-depth ratio in the case of angle sections which has been duly considered in this study while modeling the bracings in ETABS and hence Channel sections ISMC 150 and ISMC 350 satisfy the criteria of slenderness and width to depth ratio limits required as per [14] as mentioned above. In addition, material of braces used for analysis was considered E250B recommended as per [15].

3.3 Viscous Damper

General guidelines from [16], [17] ASCE codes and other paper references were taken into account in the placement and trials of different damper configurations and properties. Both linear fluid viscous damper and nonlinear fluid viscous damper were considered during modelling. The trial with damper property and configuration showing least displacement with least possible number of dampers was taken to be the optimized solution. Further, a cost estimation was done for this optimized solution.
As per the guidelines, it was preferred to place the dampers symmetrically and along the perimeter to reduce torsional effects. Also, it is recommended to fulfill the redundancy requirements, i.e., two dampers in each direction on each side. Required total damping ratio was calculated to be approximately 25.9% for the building modelled in ETABS. Thus, the required supplementary damping was approximately 21%. The details of the viscous damper taken from various sources like Taylor devices manual are shown in Table 2.

Table 2: Viscous damper details

Damper type	Symbol	□	C (kN-s/m)	K (kN/m)
Linear (F=250kN)	Fvd1	1	560	109448
Non linear	Fvd0.8	0.8	420	28144
Non linear	Fvd0.3	0.3	700	35000

Different arrangements of the dampers were taken and the building response was compared to obtain the most optimal damper configuration by trial and error.

4. Results

4.1 Shear Wall

In the given model, nine trials were reviewed in the software. Shear walls were added as elements in the existing model in different positions. Economically one model with shear wall constructed on the periphery of a building gave a permissible deflection of 31 mm i.e displacement reduced by 41% shown in fig 6. And if the importance factor of building was increased another model with deflection 10 mm (reduced by 80%) was considered.

The alternatives for category, class, number and size of the included elements depend on the individuality of the already existing building and its functional layout. It can also be included with stiffness that is significantly higher than that of the existing structure. This is realistic for buildings where the interior space is so far partitioned and it could be replaced by earthquake resisting shear walls, or also new walls could be added with no remarkable disturbance of the functional layout. The approximative cost of concrete in India is Rs 4100/m^3 (M30) and Rs 42/kg (Fe 415) which gives 65,600 rupees for concrete and 7,46820 rupees for rebars. Totally around 8.12 lakhs are required for construction materials.

4.2 Bracing

A total of eight trials were considered based on this initial knowledge with the aim of reducing overall displacement and base shear acting on the building. An optimum solution as shown in Fig 7 was identified on the basis of functionality, safety and aesthetics by which the deflection was seen to

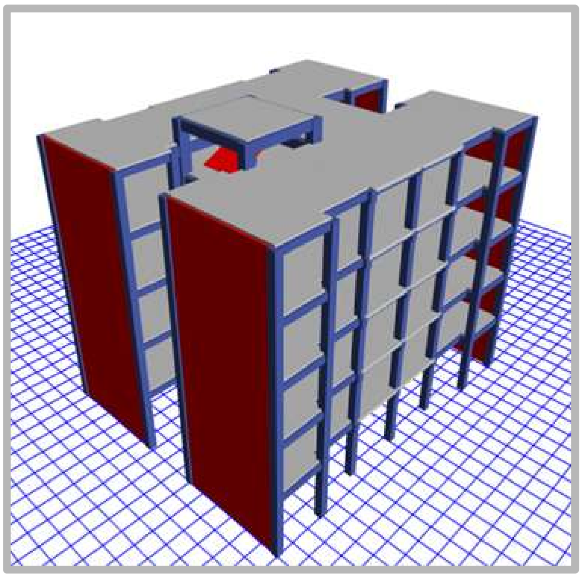

Fig 6: Shear wall in an existing building

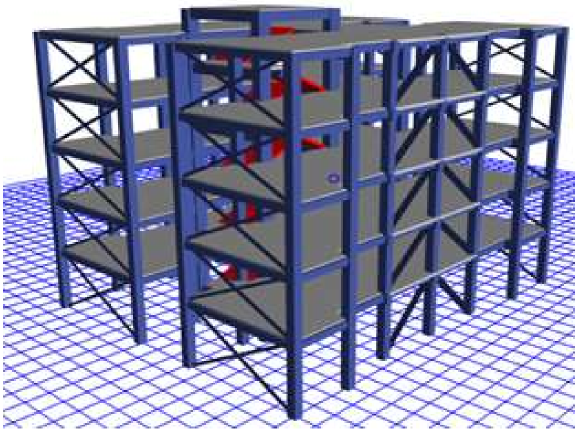

Fig 7: Optimum solution for usage of bracing as retrofit to existing building

reduce by 66%. It can be seen from the conducted trials and results obtained that the use of steel bracings proves to be a feasible retrofit strategy in terms of installation as well as cost. The overall deflection of the building is seen to have sufficiently reduced and can be controlled easily to a level well below the prescribed deflection limits as per Indian Standards. Also, the storey drifts have significantly reduced with the addition of braces to the structure.

The number of trials done and the possible combinations considered is in no way exhaustive and hence further studies can be done on the optimisation of the position,dimensions and type of these steel braces.

Material cost for the above-mentioned optimal bracing strategy was calculated based on current market rates of steel channel sections and was found to be roughly around 4.5 lakhs in Indian rupees.

4.3 Viscous Damper

The trial was started with dampers at the edge bays at all corners and all floors and slowly reduced to find the optimised locations. Fig 8 and 9 shows the results for initial trials with different damper types.

This showed a maximum decrease of around 58% obtained in the model with linear damper. However, the number of dampers used were 40. Thus, the damper location was optimised by trial and error and the optimised damper result taking linear damper are shown in Fig 10 and 11.

Fvd1_40 represents 2 dampers on each floor at the edge bays along all directions, totalling to 40 dampers overall. Fvd1_24 represents 2 dampers on edge bays till the 3rd floor in both directions amounting to 24 dampers in total. Fvd1_20 represents 2 dampers till 3rd floor in Y direction at the edge bays and 2 dampers till 2nd floor in X direction. This makes a total of 6 dampers on each side in Y direction and 4 dampers on each side in X direction, totalling to 20 dampers overall.

Fig 8: Storey displacement along X direction for different FVDs

Fig 9: Storey displacement along Y direction for different FVDs

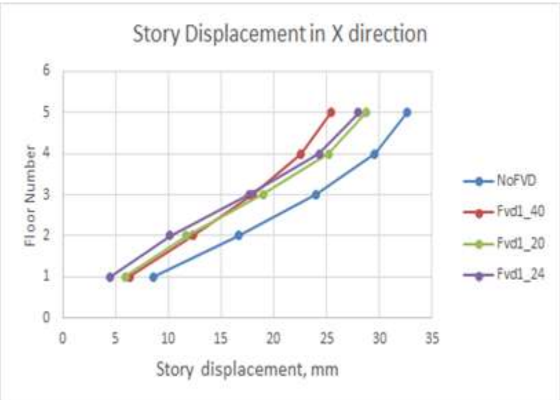

Fig 10: Comparison of storey displacement in X direction for linear damper in different locations

Fig 11: Comparison of storey displacement in Y direction for linear damper in different locations

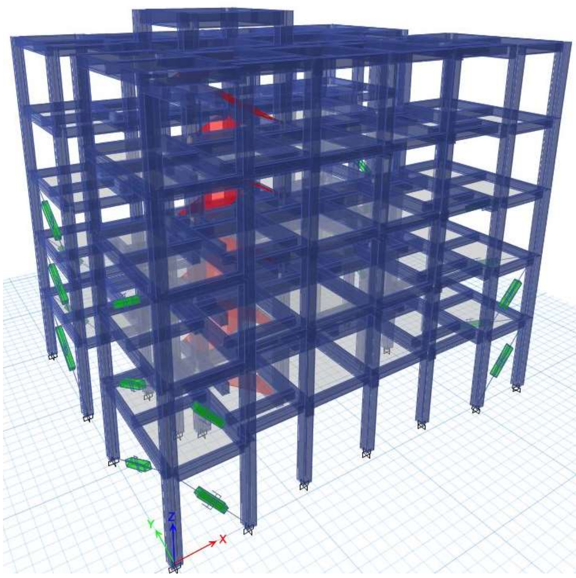

Fig 12: Optimum solution of using FVDs as retrofit (20 linear FVDs in total)

The optimized results show that a total of 20 linear FVDs are needed to comply with the displacement limits as shown in Fig 12. A decrease of around 11.8% and 43.7% was found in X and Y direction storey displacement respectively.

An approximate cost estimate was obtained for the dampers. [18] Taylor devices were used as the reference as the linear damper properties used in modelling are taken from their design manual. The cost for one damper unit including installation is approximately 5000 USD, as mentioned by taylor devices inc. Thus, the cost per damper, installation and

Fig 13: Comparison of storey displacement for the three retrofit strategies (optimal configuration)

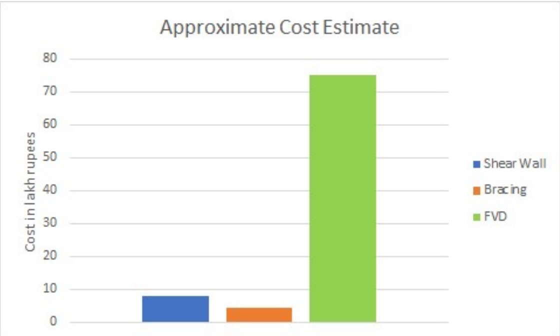

Fig 14: Approximate cost estimate of retrofit strategy for this building

steelwork for F=250kN diagonal connection is around 3.78 lakh rupees. This implies that the total cost of 20 FVDs used in this retrofitting will be around 75 lakh rupees.

4.4 Comparison

Three retrofit strategies discussed have shown good results in improving the building performance by decreasing the deflection within the codal limits. Fig 13 shows that bracing has been most efficient for this building in decreasing the response of the structure.

The comparison of the costs of three optimal retrofit strategies is shown in Fig14. This is only a general idea of the cost involved. It could vary high with the feasibility and other factors included in implementing these strategies.

5. Conclusion

This project was aimed at estimating the most efficient and cost effective system for retrofitting of the five storey building considered in the NorthEast region. The building was modelled in ETABS software. It was chosen over other softwares because of its ease of use and advanced computation algorithms.

The building, modelled without any retrofitting system, produced a maximum storey displacement of 32.6 mm and 51.7 mm in X and Y direction respectively from response spectrum analysis. The limiting value of storey displacement was 31 mm as per IS code. Thus, the structure needed to be retrofitted to comply with the code specifications.

After numerous trial and error analysis, the near optimal configuration of each protective system was taken into consideration for cost estimation. Shear wall was found to give a reduction of 70% in displacement with a wall thickness of 200 mm in the corner configuration. Bracing on the other hand resulted in around 66% reduction in displacement. This was obtained by using a combination of X-bracing and diagonal bracing of ISMC 150 and 350 sections on all floors and selected bays. Further, the retrofit with fluid viscous damper reduced the displacement by 44%. A total of 20 linear dampers, 8 along X direction and 12 along Y direction, were symmetrically placed on the edge bays in diagonal configuration to attain this result.

Finally, the cost analysis of the most optimized configuration amongst the three systems resulted in bracings being the most efficient and cost effective retrofit solution for this building and considered site conditions. Retrofit with bracings was estimated to be around 4.5 lakh rupees, followed by shear wall retrofit of around 8 lakh rupees. A retrofit with viscous damper in this particular case was found to be quite expensive costing around 75 lakh rupees.

Thus, the use of bracings was found to be the most efficient retrofit solution for the retrofitting of this building. However, it does not necessarily mean it always will be the most optimum solution. Relocation and evacuation costs, building usability, increase in seismic demand of the columns and foundations due to increase in stiffness and post yield stiffness and re-centring capabilities are other important factors to be considered for cost analysis as per site and environment conditions.

6. Scope For Improvement

Further, nonlinear analysis with performance based design can be implemented to better understand the actual performance of each retrofitting technique. Also, hybrid retrofitting systems could be checked for its feasibility.

Disclosures

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