Retrofitting of RC Frame Buildings for Seismically Deficient using ETABS

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Abstract— *Several more old structures are not code compliance, and some were created using outdated codes. Such structures may be lacking in strength and ductility. These require adequate retrofitting. In this case, two types of retrofitting procedures were used: I member jacketing and (ii) shear wall. Member jacketing is referred to as a local form of retrofitting, whereas the utilization of shear walls in retrofitting is referred to as a global type of retrofitting. In this study, a comparison was done between member jacketing and the use of shear wall. Analyzing the differences between local and global retrofitting strategies has been attempted. Three existing RC frame building plans of varying heights were considered, and their safety in design was checked in accordance with code. Buildings have been retrofitted using both of the approaches listed above, using ETABS software. Nonlinear analyses were performed to evaluate the performance of retrofitted structures. The retrofitting of buildings, with both the techniques, improve the overall performance of the buildings; although material required for retrofitting with shear wall is substantially higher than that required for member jacketing. This makes global retrofitting look less sustainable than local retrofitting and hence, the areas where building materials are not easily available local retrofitting techniques can be utilized for strengthening of RC frames.*

Keywords: ETABS, retrofitting, RC frames, Shear wall jacketing

I. INTRODUCTION

To increase the safety of these buildings against earthquakes and make them permanent, a series of strengthening measures can be taken depending on the type of building, size, location and expected useful life. Another important factor to consider is the cost associated with the overall process. Cost-benefit analyses must be carried out before the project starts.

This study analyses the different methods available for modernization. Two of these methods were implemented and compared based on design safety. Non-linear analyses were carried out on real and reconstructed buildings and the improvement of several construction parameters was evaluated. A sustainability analysis was also carried out for this project in order to reach valid conclusions. It was assumed that three buildings of 11 m, 14.3 m and 17.6 m in height are located in Zone V of the earthquake zone of India. The three buildings were re modeled with techniques of bar mantle and cutting wall. As both techniques pursue different approaches to improve the strength of the buildings, a comparative study between these two techniques was carried out.

In Linear analysis there is a linear relationship between input factor and output factor, e.g. relation between stress and strain up to Hook's limit for elastic material. It is generally used in the structures where stresses for materials used remains in linear elastic zone. Linear analysis takes less time in comparison to nonlinear analysis so it is always performed prior to nonlinear analysis. Linear analysis may be classified in two categories, linear static analysis and linear dynamic analysis. In Linear static analysis load and displacement relationship is linear and it has no variation with time. In linear dynamic analysis, although load displacement relationship is linear, the output quantities can be calculated with varying time steps.

II. RESPONSE SPECTRUM ANALYSIS

Response Spectrum Analysis (RSA) is linear dynamic analysis which measures the contribution of each natural mode of vibration to evaluate the maximum likely response of an elastic structure. RSA measures the dynamic response of a structure in the terms of pseudo spectral acceleration, velocity or displacement vs time for a given damping. A structure with shorter period, experience higher value of acceleration whereas, the structure with longer period of vibration experience higher value of displacement.

A. Response Spectra

Response spectra are the curves plotted between maximum response of single degree of freedom structure and its time period. The response of the structure is defined by the number of its modes. IS 1893:2002 specifies the response spectra that depends upon the site property is shown in Fig 1.

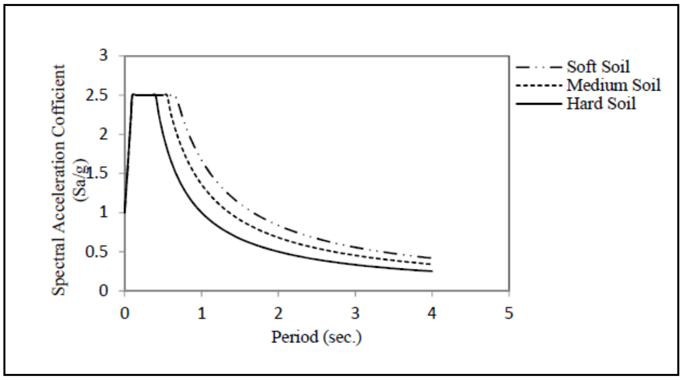

Fig 1 Response Spectra

B. Results of Modal Analysis

Here modal periods of first 6 modes of the buildings before and after retrofitting has been shown, and an attempt has been made to show the change in modal period that occurred in buildings after retrofitting. Modal period for first six modes increases as the building height increase. The comparison shows that there is reduction in modal period of vibration after retrofitting. However, reduction in case of shear wall is higher as compared to jacketing.

Table 1 Modal Period of Vibration for Building 1

Mode	Before Retrofitting	After Retrofitting	
		Jacketing	Shear wall
1	0.478	0.472	0.184
2	0.478	0.472	0.184
3	0.413	0.401	0.126
4	0.151	0.13	0.043
5	0.151	0.13	0.043
6	0.132	0.113	0.03

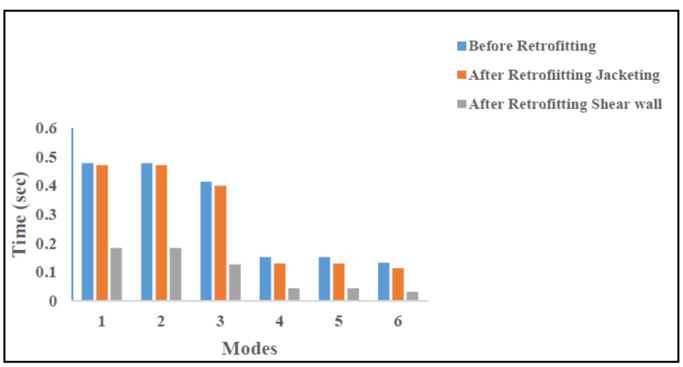

Fig 2 Variation of Modal period of Vibration after Retrofitting of Building 1

Table 2 Modal Period of Vibration for Building 2

Mode	Before Retrofitting	After Retrofitting	
		Jacketing	Shear wall
1	0.532	0.404	0.215
2	0.532	0.384	0.215
3	0.447	0.332	0.147
4	0.167	0.126	0.047
5	0.167	0.123	0.047
6	0.141	0.106	0.032

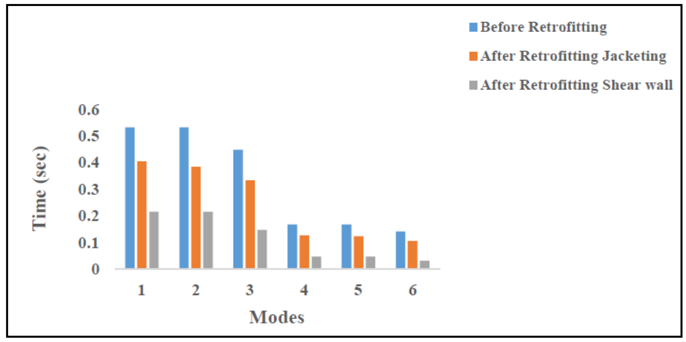

Fig 3 Variation of Modal period of Vibration after Retrofitting of Building 2

Table 3 Modal Period of Vibration for Building 3

Mode	Before Retrofitting	After Retrofitting	
		Jacketing	Shear wall
1	0.859	0.637	0.243
2	0.859	0.619	0.243
3	0.774	0.558	0.164
4	0.273	0.205	0.059
5	0.273	0.192	0.059
6	0.247	0.174	0.048

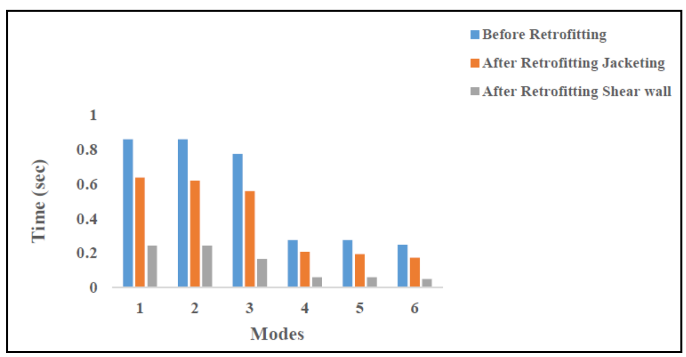

Fig 4 Variation of Modal period of Vibration after Retrofitting of Building 3

III. PUSHOVER ANALYSIS

The Pushover Analysis (POA) is a nonlinear static method for the analysis of structures. A predetermined lateral load pattern is applied on the structure and gradually increased to identify yielding and plastic hinge formations and the load at which failure of the various structural components occur. It helps in understanding the performance of a building during earthquake and also gives fair idea about the plastic hinge formation. Pushover analysis is based on the

37 assumptions that the structure has one dominant eigenvalue and mode shape. It is also assumed that this eigenvalue remains the same during the elastic and inelastic response. The results of the analysis are plotted in the form of capacity curve which is a graph between base shear force versus the horizontal roof displacement of the building. Pushover analysis transforms a dynamic problem to a static problem

A. Pushover Curve

Pushover curve is a plot of base shear vs displacement of a controlled point (generally at roof), where base shear is plotted on Y-axis and displacement is on X-axis. Using dynamic characteristics of first mode, the pushover curve is converted in a capacity curve. The design spectrum is presented in the ADRS format, i.e. spectral pseudo acceleration plotted as a function of spectral displacement. "Performance point" (displacement) coordinate is determined after plotting capacity curve and demand curve together. The reliability of this method is dependent up on the correct determination of performance point.

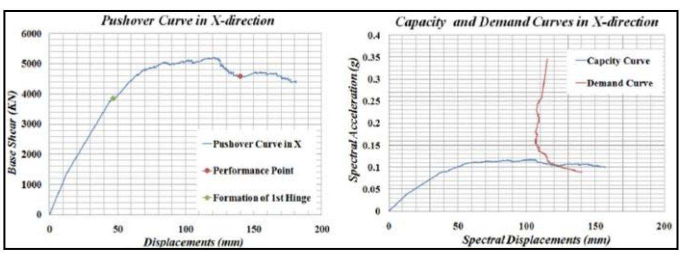

Fig 5 a) Pushover Curve b) Capacity and Demand Curve

B. Pushover Analysis results of Buildings

Displacement controlled pushover analysis has been performed for the buildings before as well as after retrofitting. Monitored displacement is taken as 4 percent of building height i.e. 440 mm, 572 mm, and 704 mm for the building one, two and three respectively. The pushover curves of the retrofitted buildings are shown in following figures

- **Pushover Curve for Building 1**

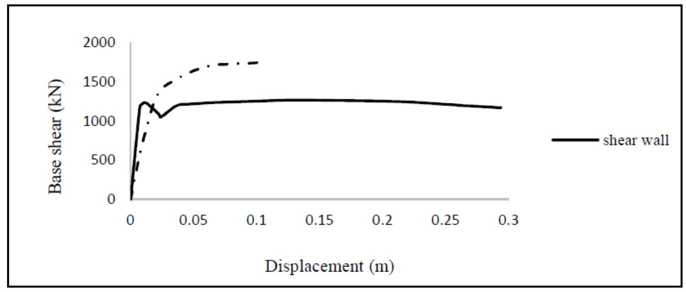

Fig 6 Pushover Curve for Building 1

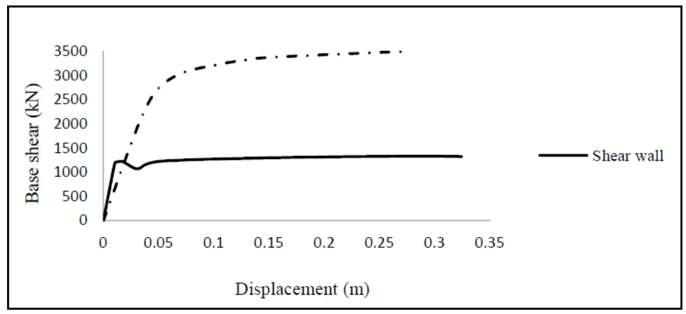

Fig 7 Pushover Curve for Building 2

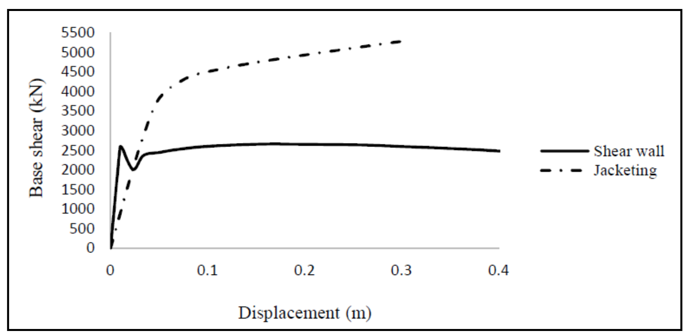

Fig 8 Pushover Curve for Building 3

VI. SUSTAINABILITY ANALYSIS OF THE RETROFITTING

Sustainability is the way of satisfying needs of present time without harming the interest of future generation, i.e. it is a balancing act that preserve the resources for next generation by utilizing only adequate amount of resources involved in a process. Sustainability analysis has generally three legs: environmental impact, externalities, and economics and financing.

A. Results of Sustainability Analysis

1) Manufacturing Energy

Manufacturing energy is the energy required for producing the building materials like concrete and reinforcement. Manufacturer of the materials generally provides these details, but in the absence of data the excerpts of a study done by Andersen et al. in 1993, have been used. These energy requirements, if available in advance, help in management of resources during construction and also help in monitoring and readjustment of materials. The formula given in Equation 6.1, has been used to calculate the manufacturing energy (kWh).

Table 4 Energy Required for Manufacturing of Materials

Building height	Methods of Retrofitting	Amount of building materials required for retrofitting mi (ton)		Energy required for manufacturing of materials Qmanuf (kWh)
		Concrete	Steel	
11m	Jacketing	47.83	3.5	64812.51
	Shear wall	57.024	4.059	76203.73
14.3m	Jacketing	90.288	12.167	174251.1
	Shear wall	96.096	13.816	193542
17.6m	Jacketing	144.24	17	255615.8
	Shear wall	206.112	25.983	381050.3

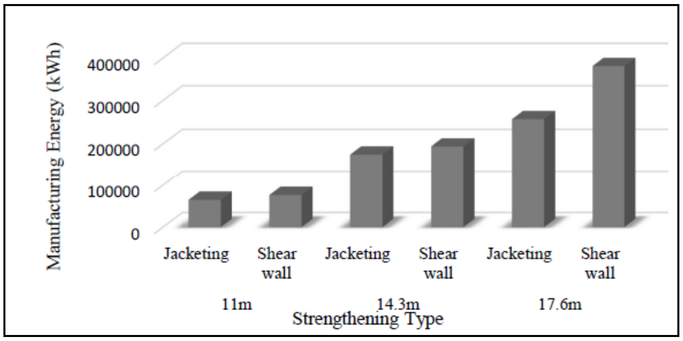

Fig 9 Variation of Manufacturing Energy

2) Transportation Energy

Whenever a construction take place, transportation energy is required for carrying materials from factory to site as well as for carrying demolished material from site to dumping yard. The distance between sites needs to be clearly evaluated to calculate the energy requirement. The formula given in Equation 6.2, is used to calculate transportation energy (kWh).

Table 5 Energy Required for Transportation of Material

Building height	Methods of Retrofitting	Amount of building materials required for retrofitting mi (ton)		Energy required for transportation of materials Qtransp (kWh)
		Concrete	Steel	
11m	Jacketing	47.83	3.5	458.03
	Shear wall	57.024	4.059	545.18
14.3m	Jacketing	90.288	12.167	908.41
	Shear wall	96.096	13.816	973.66
17.6m	Jacketing	144.24	17	1432.03
	Shear wall	206.112	25.983	2059.63

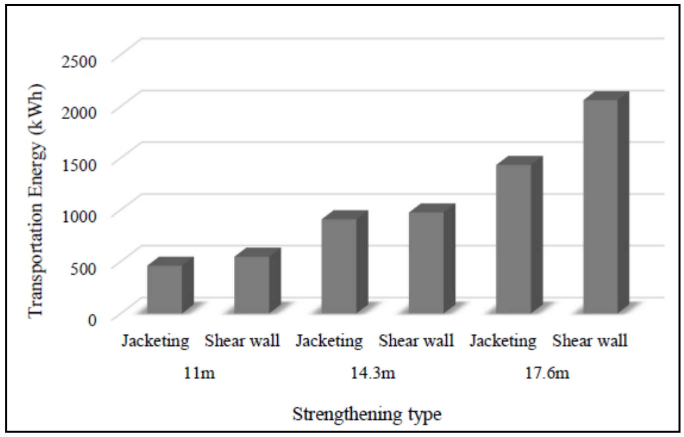

Fig 10 Variation of Transportation Energy

V. CONCLUSIONS

After retrofitting the concerned buildings with both methods and subjecting the original as well as retrofitted buildings to several analysis procedures, a number of results have been obtained. These results can be used to withdraw some valid conclusions out of this study. In this chapter the conclusions obtained after retrofitting projects have been explained, and an attempt has been made to validate the results with several other researches done in past.

- Modal analysis shows that, as the building height increases the time period of vibration also increases, along with that, the period of vibration for shear wall is always lower than that for jacketing irrespective of building height. That means, the improvement in building's stiffness is greater in case of shear wall than jacketing.
- Since requirement of materials for shear wall is always higher than that for jacketing, so it will consume more energy during retrofitting and it can be assumed less sustainable than jacketing. Further, if demolition of building components is also taken into consideration, there will again be requirement of transportation energy, hence there will be further increase in total energy required.
- There is substantial reduction in stiffness, modal period of vibration, and inter-storey drift of buildings after retrofitting, where reduction due to shear wall is higher than reduction due to member jacketing.
- For earthquake of any magnitude, base shear due to jacketing is always higher than base shear due to shear wall.
- Retrofitting a building with global retrofitting techniques is not as sustainable as retrofitting with local retrofitting techniques, but if improvement in building strength is important than sustainability, global retrofitting techniques should be prioritise.

- Local retrofitting techniques also give substantial improvement of strength, so in case where sustainability is primary concern; local retrofitting techniques should be preferred over global retrofitting techniques. One thing that was observed during the study is that, local retrofitting technique needs long work hour than global retrofitting technique as it involves section by section approach for selection, demolition, and strengthening of members, which can further increase the overall cost.
- The main limitation of Shear wall is excessive destruction at each floor level results in functional disability of the building, possibilities of adequate attachment between the new walls and the existing structure and closing of formerly open spaces can have major negative impact on the interior of the building or exterior appearance.
- Shear walls are efficient, both in terms of construction cost and effectiveness in minimizing earthquake damage in structural and non-structural elements like glass windows and building content.

A. Future Scope of Study

- In this study only one method of local and global retrofitting techniques has been used for comparison. So, for further study other methods can be adopted and observation regarding their behaviour can be made.
- The buildings with configurationally irregularities can be taken to perform this type study, which will further generalize the process of retrofitting.

REFRENCES

1) D. Cardone and A. Flora, "Direct displacement loss assessment of existing RC buildings pre- and post-seismic retrofitting: A case study," Soil Dyn. Earthq. Eng., vol. 64, pp. 38–49, 2014.
2) P. Foraboschi, "Versatility of steel in correcting construction deficiencies and in seismic retrofitting of RC buildings," J. Build. Eng., vol. 8, no. October, pp. 107–122, 2016.
3) X. Song, C. Ye, H. Li, X. Wang, and W. Ma, "Field study on energy economic assessment of office buildings envelope retrofitting in southern China," Sustain. Cities Soc., vol. 28, pp. 154–161, 2017.
4) B. Kissi et al., "Influence of zone type on performance of retrofitted Reinforced Concrete buildings by using Pushover Analysis," Mater. Today Proc., vol. 5, no. 1, pp.
5) 22–29, 2018.
6) M. Valente and G. Milani, "Alternative retrofitting strategies to prevent the failure of an under-designed reinforced concrete frame," Eng. Fail. Anal., vol. 89, no. January 2017, pp. 271–285, 2018.
7) B. H. L. Coffman, M. L. Marsh, and C. B. Brown, "REINFORCED-CONCRETE COLUMNS Experimental Specification Earthquakes in the western Washington region may produce moderately Test Arrangement Control Column (Column t)," vol. 119, no. 5, pp. 1643–1661, 1993.
8) S. Soyoz, E. Taciroglu, and K. Orakcal, "Ambient and forced vibration testing of a reinforced concrete building before and after its seismic retrofitting," J. Struct., vol. 139, no. 10, pp. 1741–1752, 2012.
9) G. Minafò, "A practical approach for the strength evaluation of RC columns reinforced with RC jackets," Eng. Struct., vol. 85, pp. 162–169, 2015.
10) G. I. Kalogeropoulos, A. D. G. Tsonos, D. Konstandinidis, and S. Tsetines, "Preearthquake and post-earthquake retrofitting of poorly detailed exterior RC beam-tocolumn joints," Eng. Struct., vol. 109, pp. 1–15, 2016.
11) G. T. Truong, J. C. Kim, and K. K. Choi, "Seismic performance of reinforced concrete 71 columns retrofitted by various methods," Eng. Struct., vol. 134, pp. 217–235, 2017.
12) S. Dey and A. K. Bhowmick, "Seismic performance of composite plate shear walls," Structures, vol. 6, pp. 59–72, 2016.
13) Y. Fahjan, J. Kubin, and M. Tan, "Nonlinear Analysis Methods for Reinforced Concrete Buildings with Shear walls," 14th econference Earthq. ..., 2010.
14) P. P. Debnath and S. Choudhury, "Nonlinear Analysis of Shear Wall in Unified Performance Based Seismic Design of Buildings," Asian J. Civ. Eng., vol. 18, no. 4, pp. 633–642, 2017.
15) H. H. Jamnani, J. V. Amiri, and H. Rajabnejad, "Energy distribution in RC shear wallframe structures subject to repeated earthquakes," Soil Dyn. Earthq. Eng., vol. 107, no. September 2017, pp. 116–128, 2018.
16) K. Adalberth, "Energy use during the Life Cycle of Buildings : a Method," vol. 32, no. 4, pp. 317–320, 1997.