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Retrofitting of Seismically Deficient RC Frame Buildings using ETABS

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ABSTRACT: Many old buildings are not code compliant and some buildings have been designed using old codes. Such buildings may be deficient in strength and ductility. These need retrofitting of appropriate type. Here two types of retrofitting techniques have been used, namely, (i) Member jacketing, and (ii) Shear wall. Member jacketing is said to be local type and use of shear wall in retrofitting is known as global type of retrofitting. In the present study a comparison has been made between members jacketing and use of shear wall. An attempt has been made to compare the local and global retrofitting techniques analytically. Three existing RC frame building plans with different heights have been considered and their safety in design has been checked as per code. Using ETABS software, buildings have been retrofitted by both the methods as mentioned. To evaluate the performance of retrofitted buildings, nonlinear analyses have been carried out. The results have been presented in the terms of Base Shear, Inter Storey Drift Ratio (IDR), Floor Spectra, and Pushover Curve, etc. Buildings have been rechecked after retrofitting and results are compared in terms of overall material required. At last, sustainability analyses have been carried out to compare both techniques of retrofitting.

I. INTRODUCTION

Due to increasing population, changing demography and fast urbanization a rapid climb in building construction is obvious these days, and satisfying the necessity of this vast population could be a difficult task for the constructor. So, so as to accentuate the construction speed such a large number of shortcuts are being adopted. Due to this, many vital provisions laid by modern Earthquake codes get neglected. That's why not solely the building made in early 90's, but sometimes modern buildings also possess vulnerability towards earthquake. These buildings altogether pose a very serious risk for the dwellers during earthquake. If we look at the aftermath of Bhuj Earthquake in 2001, this negligence caused the huge loss of life and property.

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.

A. PRINCIPLES OF RETROFITTING OF RC BUILDINGS

Retrofitting of RC buildings is based on following two principles: (i) reduce earthquake demand by base isolation or by supplemental energy dissipation, and enhancing the capability of building's element or building as a whole to withstand the earthquake forces. (ii) Improving ductility demand capability of the deficient members by strengthening that will increase hysteretic damping. Some other aspect of retrofitting is also there, like removing configurationally irregularities and completion of load path.

B. TECHNIQUES OF RETROFITTING

These techniques can further be divided in two broad categories, which are strengthening of the structure as a whole or, strengthening of deficient members only.

1) Strengthening of Structures as a Whole

Most important component of the building during earthquake is the lateral load resisting system, which is severely damaged if proper detailing of the components is not done. So evaluation of the lateral load carrying capacity of the



building should be done before choosing the methods of retrofitting. Strengthening of building as a whole can be done in several ways. Before selection of any method its economic as well as functional requirements should be considered.

- Addition of New Members
- Braced Frames
- Buttresses

2) Strengthening of Seismically Deficient Members

In seismic retrofitting of the buildings sometimes strengthening of individual members may be required. A number of techniques are available for retrofitting with this technique like member jacketing, FRP jacketing and steel/FRP plate bonding. Depending upon strength and weakness of members, any of these can be adopted. The transfer of load between new and old material is complex and require good knowledge of materials available in area. Proper bonding of materials should be ensured to achieve the desired strength. Some considerations need to be made before opting this method of retrofitting, which are:

- Strengthening of Slabs
- Strengthening of Beams
- Strengthening of Columns

II. STATE OF DEVELOPMENT

Literature survey related to the field of seismic retrofitting of RC buildings. Various data collected through the experimental analysis, their outcomes and precautions laid down by the researchers are also discussed. It is tried to gather data required for strengthening through jacketing and shear wall as much as possible. Theories and formulas present for the sustainability analyses are also elaborated.

Cardone and Flora (2013) studied the cost of intervention incurred during retrofitting a building through seismic isolation in Italy. This cost has been compared in the terms of benefit of retrofitting, obtained in terms of cost saving, improvement of building strength, and reduction of direct and indirect seismic losses. The building performance before and after retrofitting has been compared in the terms of Expected Annual Loss.

Foraboschi (2016) studied the role of steel in improving the performance of buildings which are already inadequately detailed and have chances of failure during any seismic activity. Various design and functional properties of steel have been utilized in the form of cold-formed members, welded element, thin-walled sections, and steel-concrete vertical and horizontal members.

Coffman et al. (1993) have presented the seismic durability of retrofitted reinforcement concrete columns. The columns have been retrofitted with circular hoops located at various positions along the height of the column. A concentric axial load was applied until column lost its structural integrity. Results based on the location of the hoops have been compared.

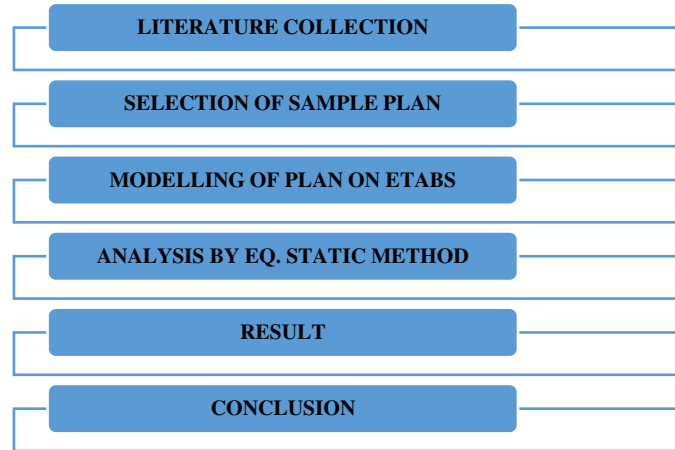
Soyoz et al. (2013) have tested an RC building with seismic retrofitting against ambient and forced vibration. Building was retrofitted with member jacketing, addition of structural walls and construction of mat foundation. Ambient and forced vibration result data for building, before and after retrofitting has been compared.

Dey et al. (2015) have studied seismic performance of a composite plate shear wall is presented. A nonlinear finite element model of the building was prepared and material and geometric nonlinearity was also included. Results were analysed and thickness of C-PSW was calculated.

Fahjan et al. (2010) have presented different approaches for linear and nonlinear modelling of the shear wall used in structure at various positions. The concrete and reinforcement inside the elements are modelled as multi-layered model. The results of the analyses have been compared after the evaluation of overall behaviour of structure. It has been concluded that to take material nonlinearity in account, shear wall should be modelled as multi layered shell element.



III. METHODOLOGY



IV. SYSTEM DEVELOPMENT

A. Details of the Buildings before Retrofitting

Three buildings of height 11 m, 14.3 m and 17.6 m have been taken and retrofitted with the methods discussed earlier. In the subsequent sections the configurations of the buildings will be explained one by one. The materials used for the construction of original buildings consist of concrete of grade M20 and reinforcement of grade Fe250. Main wall is assumed to be made of masonry with thickness of 225 mm, whereas parapet wall is of thickness 100 mm.

• Building 1 (11 m height)

This building has 3 floors of height 3.3 m each. Beam has cross-section of 250x400 mm and column’s cross section is 400x400 mm. Beam is reinforced with 5 bars of 16 mm diameter and 1 bar of 12 mm diameter whereas columns are reinforced with 8 bars of 16 mm diameter.

• Building 2 (14.3 m height)

Building 2 has height of 14.3 m and it has 4 floors of 3.3 m each. Cross section of beam is 250x400 mm and cross section of column is 400x400 mm Beam is reinforced with 6 bars of 16 mm diameter, and column is reinforced with 8 bars of 16 mm diameter.

• Building 3 (17.6 m height)

Building 3 has height of 17.6 m and it has 5 floors of 3.3 m each. Cross-section of beams is 250x400 mm and cross-section of columns is 450x450 mm. Beams are reinforced with 6 bars of 16 mm diameter whereas columns are reinforced with 4 bars of 20 mm diameter and 4 bars of 16 mm diameter. Building with 11 m height is named as building 1, building with 14.3m height is named as building 2, and building with 17.56 m height is named as building 3.

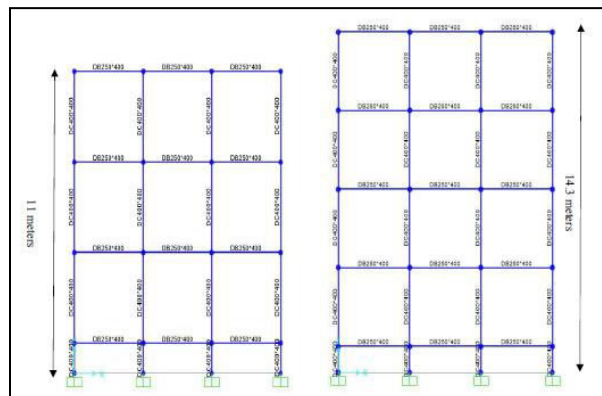


Fig 1 Elevation of Building 1 and Building 2

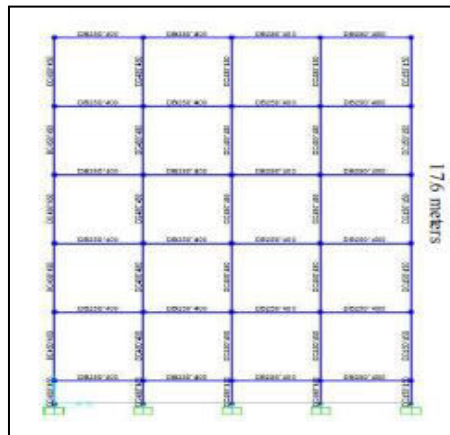


Fig 2 Elevation of Building 3

B. Details of the Buildings after Retrofitting

Members are retrofitted with RC jacketing, and the thickness of jackets and diameter of the reinforcement bars depends upon the design requirement of section concerned. A number of design iterations have been performed for retrofitted buildings and the combination of jacket thickness and rebar diameter which gives the best improvement in design result are taken as final combination. Beams are retrofitted with 50mm RC jackets on three sides, except the top, whereas columns are jacketed with 50mm RC jacket on all four sides.

Building 1: The retrofitted sections and diameter of bars are mentioned in Table 1

Section	Name of Section	Jacket Details
Beam	DB250×400	Original Beam
	DB350×450	4-16 mm bars at corner & 5-12 mm bars at edges
Column	COLUMN400×400	Original Column
	COLUMN500×500(1)	4-16 mm bars at corner & 8-12 mm bars at edges
	COLUMN500×500(2)	4-20 mm bars at corner & 8-12 mm bars at edges
	COLUMN500×500(3)	4-20 mm bars at corner & 8-16 mm bars at edges

Building 2: The retrofitted sections and diameter of bars are mentioned in Table 2.

Section	Name of Section	Jacket Details
Beam	DB250×400	Original Beam
	DB350×450(1)	4-20 mm bars at corner & 3-20 mm bars at edges
	DB350×450(2)	4-20 mm bars at corner & 5-20 mm bars at edges
Column	COLUMN400×400	Original Column
	COLUMN500×500(1)	4-20 mm bars at corner & 4-20 mm bars at edges
	COLUMN500×500(2)	4-20 mm bars at corner & 8-20 mm bars at edges
	COLUMN500×500(3)	4-25 mm bars at corner & 8-20 mm bars at edges
	COLUMN500×500(4)	4-25 mm bars at corner & 8-25 mm bars at edges

Building 3: The retrofitted sections and diameter of bars are mentioned in Table 3.

Section	Name of Section	Jacket Details
Beam	DB250×400	Original Beam
	DB350×450(1)	4-20 mm bars at corner & 3-20 mm bars at edges
	DB350×450(2)	4-20 mm bars at corner & 5-20 mm bars at edges
Column	COLUMN450×450	Original Column
	COLUMN550×550(1)	4-20 mm bars at corner & 4-20 mm bars at edges
	COLUMN550×550(2)	4-20 mm bars at corner & 8-20 mm bars at edges
	COLUMN550×550(3)	4-25 mm bars at corner & 8-20 mm bars at edges

C. Retrofitting with Shear Wall

Shear wall used here for retrofitting is 200mm thick and is modelled as multi layered shell element. Reinforcement is distributed both in lateral and longitudinal direction at an equal spacing. The diameter of reinforcement bar is calculated based on design results



- **Building 1**

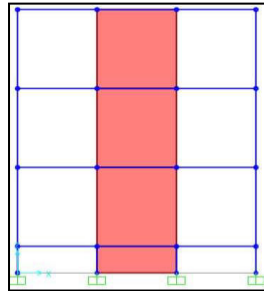


Fig 3 Shear Wall in Building 1

- **Building 2**

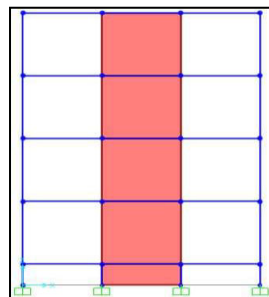


Fig 4 Shear Wall in Building 2

- **Building 3**

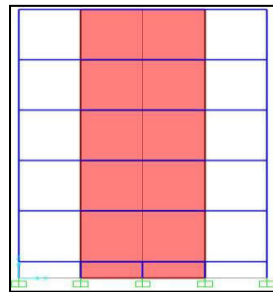


Fig 5 Shear Wall in Building 3

V. DESIGN RESULTS

Design result shows the volume of concrete and reinforcement in cubic meter required for retrofitting with both the methods.

Table 4 Volume of Concrete required for retrofitting (m³)

Building 11 m		Building 14.3 m		Building 17.6 m	
Jacketing	Shear wall	Jacketing	Shear wall	Jacketing	Shear wall
19.932	23.76	37.62	40.04	60.1	85.88

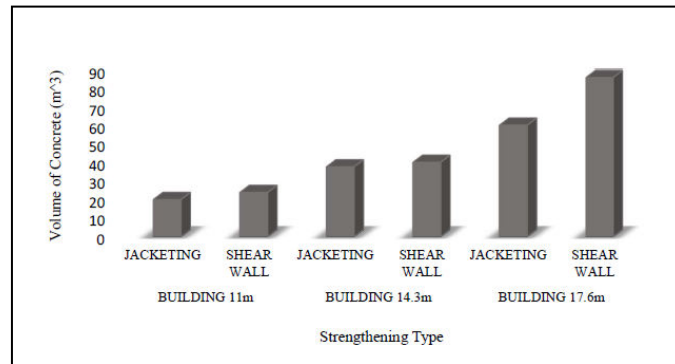


Fig 6 Variation of Concrete Volume required for Retrofitting with Building height.

Table 5 Volume of Rebar required for retrofitting (m³)

Building 11 m		Building 14.3 m		Building 17.6 m	
Jacketing	Shear wall	Jacketing	Shear wall	Jacketing	Shear wall
0.446	0.517	1.55	1.76	2.165	3.31

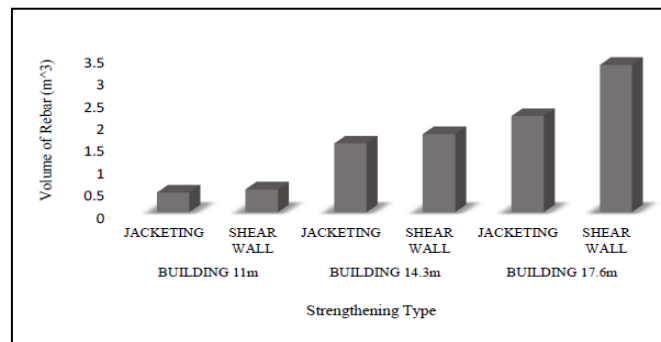


Fig 7 Variation of Rebar Volume required for Retrofitting with height

VI. CONCLUSION

Fig 6 and 7 shows the variation of volume of concrete and rebar required for retrofitting respectively. The amount of concrete required for retrofitting with both the techniques increases by almost 100% for building 2 in comparison to building 1 and it further increases by almost 150% for building 3. In case of reinforcement this requirement increases to 200% with increase in building height.

By observing Table 4 and 5, it can be assured that when building height is small requirement of materials is almost equal for Jacketing and Shear Wall. So, in small buildings any of these techniques can be incorporated for retrofitting depending upon the other factors involved. When building height increases the requirement of materials for shear wall becomes almost two times than jacketing. Hence, while opting the retrofitting alternatives for high rise buildings the materials requirement and its availability should be primary concern

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