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# Retrofitting of an Existing Open Ground Store Building by Using Shear Wall

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**ABSTRACT:** Reinforced concrete (RC) shear walls are widely used in medium- to high-rise buildings to provide the lateral strength, stiffness and energy dissipation capacity required to resist lateral loads arising from wind or earthquakes. In the past few decades, there has been considerable advancement in the design of RC walls for new construction. The newly adopted performance evaluation methodology and capacity design principles are examples of these important advancements in seismic engineering. Therefore, there is an essential need to upgrade the seismic performance of existing RC shear walls so that they can meet the requirements of the new performance-based seismic design techniques. Several retrofit techniques using different materials are reported in the literature. The paper discusses the advantages and disadvantages of each retrofit technique and the corresponding characteristic enhancements. The objective of this paper is to provide a state-of-the-art on the recent advancements and challenges in the area of retrofit of RC shear walls.

**KEYWORDS:** Reinforced concrete, shear walls, seismic, retrofit, rehabilitation, strengthening

## I. INTRODUCTION

### 1.1 General Introduction:

Seismic retrofitting is the modification of existing structures to make them more resistant to seismic activity, ground motion, or soil failure due to earthquakes. With better understanding of seismic demand on structures and with our recent experiences with large earthquakes near urban centers, the need of seismic retrofitting is well acknowledged. Prior to the introduction of modern seismic codes in the late 1960s for developed countries (US, Japan etc.) and late 1970s for many other parts of the world (Turkey, China etc.), many structures were designed without adequate detailing and reinforcement for seismic protection.

The retrofit techniques outlined here are also applicable for other natural hazards such as tropical cyclones, tornadoes, and severe winds from thunderstorms. Whilst current practice of seismic retrofitting is predominantly concerned with structural improvements to reduce the seismic hazard of using the structures, it is similarly essential to reduce the hazards and losses from non-structural elements. It is also important to keep in mind that there is no such thing as an earthquake-proof structure, although seismic performance can be greatly enhanced through proper initial design or subsequent modifications.

The addition of new reinforced concrete shear walls is the most often practised device which has proved to be effective for controlling global, lateral drifts and for reducing damage in frame members. Steel braces are used for stiffening the existing buildings. Concentric or eccentric bracing schemes may be used, in the selected bays of an RC frame contributing to increase the lateral resistance of the structure. Infill wall may be employed for strengthening of reinforced concrete buildings, which has been effective in the case of one to three storey buildings that may be extended up to five stories. The lateral strength of existing columns can be increased by adding wing walls (side walls) or buttresses similar to infilling. These techniques are not so popular because it may require a vacant site around the building, and enough resistance from piles or foundation of the buttress (CEB, 1997). At some occasions it might be possible to achieve the retrofitting objectives by means of global mass reduction. Mass reduction can be accomplished by removal of upper stories, heavy cladding, partitions and stored good. Increasing the strength or stiffness of structural members such as slabs and shear wall can be achieved by thickening of members. The concept of seismic base isolation is based on decoupling of structure by introducing low horizontal stiffness bearing between the structure and the

foundation. This is found to be efficient for seismic protection of historical buildings where superstructure has a limited seismic resistance and intervention is required only at foundation level. The supplemental damping devices such as addition of viscous damper, visco-elastic damper, frictional damper in diagonals of bays of frame substantially reduce the earthquake response by dissipation of energy. Local retrofittings are typically used either when the retrofit objectives are limited or direct treatment of the vulnerable components is needed. The most popular and frequently used method in local retrofitting is jacketing or confinement by the jackets of reinforced concrete, steel, fiber reinforced polymer (FRP), carbon fiber etc. Jacketing around the existing members increases lateral load capacity of the structure in a uniformly distributed way with a minimal increase in loading on any single foundation and with no alternative in the basic geometry of the building.



(Figure1: Before After Retrofit in India)

*Retrofitting* is the process of addition of new features to older buildings, heritage structures, bridges etc. Retrofitting reduces the vulnerability of damage of an existing structure during a near future seismic activity. Retrofit in structures is done to increase the survivability functionality.

In India, there exists a number of old and existing buildings that are either constructed without taking into account the effects of earthquake forces or that are previously damaged or are likely to be damaged in the near future during the shaking of the ground. There are various ways of retrofitting these buildings so as to mitigate the effect of future earthquake.

The technique of infilling/adding new shear walls is often regarded as the best and simple solution for improving seismic performance.

### 1.2 Retrofitting Strategy:

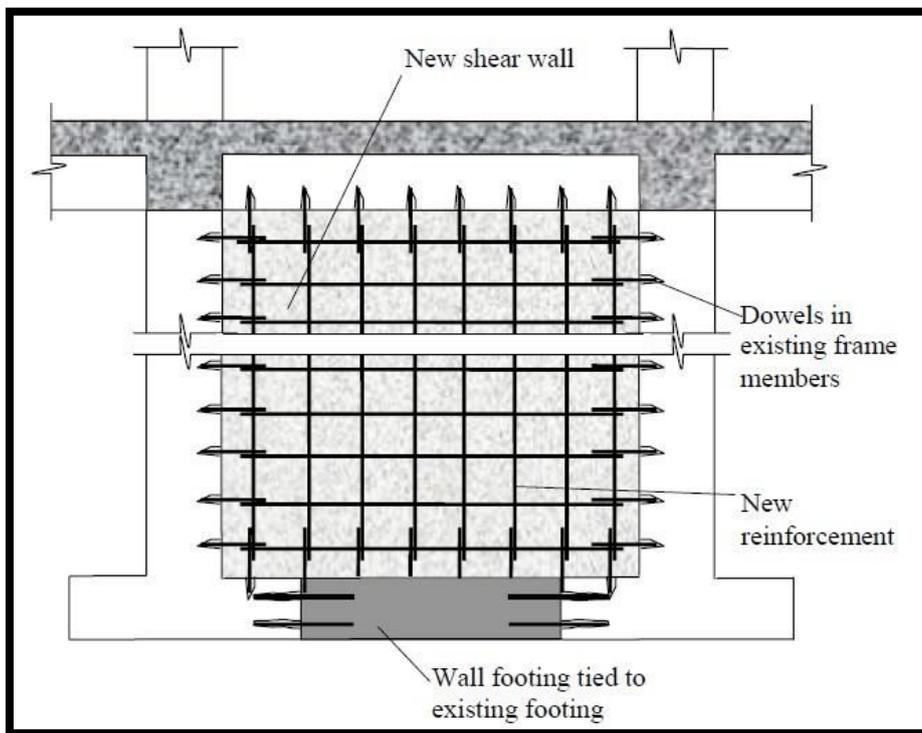
- Specify the performance requirement for the structural member that needs to be retrofitted.
- Then, set an overall plan from inspection phase to retrofitting method selection, the design of retrofitting structure, and execution of retrofitting work.
- After the finalization of plan, inspect the structural element that needs to be retrofitted.
- Evaluate the performance of the structural element based on the findings of the inspection work.
- Check whether the structural element fulfills performance requirements.
- If the structure does not fulfill performance requirements, and if continued use of the structure through retrofitting is desired, proceed with the design of the retrofitting structure.
- Select an appropriate retrofitting method.
- Specify materials to be used, structural specifications and construction method.
- Evaluate the performance of the structure after retrofitting and verify that it fulfills performance requirements.

- If it is determined that the retrofitting structure is capable of fulfilling performance requirements with the selected retrofitting and construction methods, implement the retrofitting work.

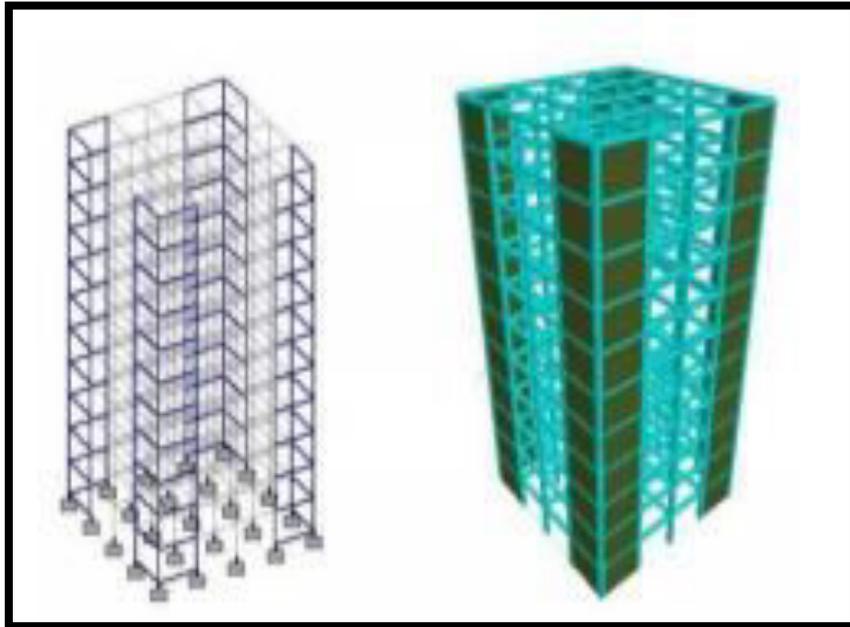
### 1.3 RETROFITTING USING SHEAR WALL:

Seismic Retrofitting can be done by adding shear wall, adding infill wall, base isolation etc. The technique of adding new shear walls is often taken as the best and simple solution for improving seismic performance.

Therefore, it is frequently used for retrofitting of non-ductile reinforced concrete frame buildings. The added elements can be either cast-in place or pre-cast concrete elements. New elements preferably are placed at the exterior of the building; however it may cause alteration in the appearance and window layouts. Placing of shear walls in the interior of the structure is not preferred.



(Figure 2:Retrofitting Using Shear Wall)



(Figure 3: Corner Shear Wall)

#### *Retrofitting Methods for RCC Structural Members-*

- Fiber Reinforced polymer (FRP) composites.
- External plate bonding.
- Near Surface Mounted FRP bars or Strips.
- Section enlargement.
- External post-tensioning.
- Grouting.
- Epoxy Injection

#### **1.4 GOALS OF SEISMIC RETROFIT:**

- To increase the lateral strength and stiffness of the building
- To increase the ductility in the behaviour of the building, this aims to avoid the brittle modes of failure.
- To increase the integral action and continuity of the members in a building
- To eliminate or reduce the effects of irregularities
- To enhance redundancy in the lateral load resisting system, this aims to eliminate the possibility of progressive collapse.
- To ensure adequate stability against overturning and sliding

To decide the retrofit scheme, a performance based approach can be adopted. The performance based approach identifies a target building performance level under an anticipated earthquake level. For retrofit of the buildings covered in this project, the basic safety objective can be selected. Under this objective, the dual requirement of life safety under design basis earthquake (DBE) and structural stability under maximum considered earthquake is aimed at.

#### **1.5 NEED FOR SEISMIC RETROFITTING:**

- To ensure the safety and security of a building, employees, structure functionality, machinery and inventory.
- Essential to reduce hazard and losses from nonstructural elements.
- Important buildings must be strengthened whose services are assumed to be essential just after an earthquake like hospitals.

## 1.6 PURPOSE & OBJECTIVES:

The main purpose of this study is to increase knowledge and proficiency in earthquake resistant design and seismic rehabilitation of existing structures and to gain familiarity with modeling and analyzing buildings against seismic loads by using computer software.

(I) to investigate the effects of earthquake forces on buildings and literature search on earthquake resistant design

(II) to evaluate the feasibility of seismic evaluation of buildings and advantages of applying the retrofit measures developed for strengthening

(III) to analyze performance based design and compare different seismic analysis method

(IV) to model a real building with a structural analysis software and investigate the earthquake effects with different analysis methods prescribed in codes & standards and propose appropriate rehabilitation methods in terms of the performance.

## II. LITERATURE REVIEW

There are three key concepts in seismic design that were fully developed by researchers and engineers.

*First*, earthquake ground motions generate inertial loads that rapidly change with time. Thus, it is common that calculations include a term labeled with a unit of time (usually seconds) and these terms include periods of vibration or their inverse, frequencies; accelerations and velocities. In many other structural engineering problems such as calculations of gravity loads, no unit of time is used.

**(Benjamin & Cornell, 1970):**

*Second*, due to the large uncertainty associated with the forces and structural responses, probabilistic analysis is central to earthquake engineering (Benjamin & Cornell, 1970). The earthquake occurrence time, its magnitude, rupture surface features and dynamic response behavior of the structure cannot be predicted with certainty. Methods of probability and statistics are required to include these uncertainties and their effects on the structural performance evaluation and design.

**(Newmark & Veletsos, 1960):**

*The third* fundamental earthquake engineering concept that distinguishes this field is that the earthquake loading can be so severe that the materials must often be designed to behave inelastically. Within the domain of Hooke's Law, stress is proportional to strain, but beyond that point, behavior becomes complex. Most of the analytical and experimental work investigating inelastic behavior began approximately in the 1960s (Newmark & Veletsos, 1960).

**(Paulay & Priestley, 1992):**

Shear wall buildings are a popular choice for reinforced concrete buildings in many earthquake zone countries, like USA, Canada, Chile and New Zealand. Shear walls are easy to construct, because reinforcement detailing of walls is relatively straight-forward and therefore easily implemented at site. Shear walls are efficient, both in terms of construction cost and effectiveness in minimizing earthquake damage in structural and non-structural elements. Properly designed and detailed buildings with shear walls have shown very good performance in past earthquakes. In many cases the "failure" mode of adequately reinforced concrete walls in severe earthquakes has been the formation of horizontal or diagonal cracks which are easily repaired after the earthquake (Paulay & Priestley, 1992).

**(Symans, et al., 2002):**

The flow of forces in a timber and a steel braced frame of the same layout are essentially the same under earthquake loads in the elastic range. However, the mode of behavior and seismic design philosophy in timber and steel braced frame can be quite different in the inelastic range. Because wood does not have well defined yield points like steel has. The splitting, crushing, and breaking of a piece of wood in the range defined as inelastic does not conform to a classic definition of ductility (Symans, et al., 2002).

**(Moehle et al., 2012):**

Walls should be well distributed within the building plan providing resistance to story shears in each principal direction and also they should be positioned such that their center of resistance is close to the center of mass to avoid induced

torsion. Walls located near the perimeter may be preferred because they maximize torsional resistance. Furthermore, good connections between diaphragms and structural walls are essential to the seismic force path. Selection of special reinforced concrete shear walls as primary seismic force-resisting elements is influenced by considerations of seismic performance, functionality, constructability, and cost. For low-to mid-rise buildings, shear walls typically are more cost-effective than other systems such as concrete moment frames (Moehle et al., 2012).

### III. PROPOSED METHODOLOGY

#### 3.1 MATERIAL AND THEIR PROPERTIES

Cast-in-place ordinary concrete, fiber-reinforced concrete, shotcrete or gunite, self-consolidated concrete, and advanced mortars (polymeric or fiber enriched) comprise a class of materials widely used for the purpose of retrofit and strengthening of existing structures.

##### 1. Portland Cement:

Cement slurry injections with or without polymers to seal the gaps, pores or cracks, Mortar with or without plasticizers for replacement of concrete cover or surface coating, Microcrete: Guniting / shotcrete as replacement of concrete or cover concrete, and Concrete with or without plasticizers as replacement of existing concrete.

##### 2. Polymer modified concrete (PMC)

Polymer modified concrete or mortars with the help of polymer latex such as acrylates and SBR (Styrene Butadiene Rubber).

##### 3. Epoxy Resins

Epoxy resins with or without addition of filler materials such as quartz sand for injection or concrete repairs. Polymer resins with or without addition of filler materials for concrete repairs.

#### Diagnose Structural Damages and Their Repair-

##### 1. Retrofit Corroded Structural Member-

If corrosion has started, following process is adopted:

- Remove weak concrete and expose reinforcement all around.
- Clean the rust of steel by wire brushes or sandblasting.
- Apply rust removers and rust preventers.
- Provide reinforcement to supplement rusted steel if required with anchorage i.e. shear connectors.
- Apply tack coat (bonding coat to provide a bond between old concrete and new concrete) of polymer or epoxy based bonding material.
- Use one of the patching technique to restore concrete to the original surface level. Polymer modified mortars are very good. This can be used with or without guniting.
- Injection of cement slurry or polymer modified slurry or epoxy to fill up pores or internal cracks or honeycombing.
- Apply a suitable protective coating.

### Retrofit Severely Damaged Concrete-

In case the condition of original concrete is very bad and injection grouting is not able to rehabilitate the section to take the required loading, RCC Jacketing of concrete section is to be provided.

1. Provide the required supporting system to the structure.
2. Remove weak concrete.
3. Clean the surface and clean the rust of steel.
4. Apply rust removers and rust preventers.
5. Provide additional steel all around the section.
6. Provide required formwork.
7. Provide a polymer based bonding coat between old and new concrete.
8. Place the concrete of required thickness and grade and workability admixed with plasticizers.

### 3.2 Methodology

In the present study, Seismic Retrofitting can be done by adding shear wall, adding infill wall, base isolation etc. The technique of adding new shear walls is often taken as the best and simple solution for improving seismic performance. Therefore, it is frequently used for retrofitting of non-ductile reinforced concrete frame buildings. The added elements can be either cast-in-place or pre-cast concrete elements. It has been proposed to follow the following methodology.

- Structural planning
- Modeling and analysis in Staad Pro.

There are many relatively new technologies developed for seismic Retrofitting which are based on "Response control". These techniques includes providing additional damping using dampers (Elastoplastic dampers, friction dampers, tuned mass and tuned liquid dampers, etc.) and techniques such as base isolation which are introduced to take care of seismic control.

- (i) Concrete Jacketing,
- (ii) Steel Jacketing,
- (iii) FRP Wrapping

Retrofitting as a Structural Body -

Beam addition method: Adding beams between the main girders of the existing reinforced concrete deck to reduce the deck span and restore or improve the loadcarrying capacity of the reinforced concrete deck.

Seismic wall addition method: Placing new reinforced concrete walls between existing reinforced concrete rigid-frame bridge piers and bonding them to form a continuous unit in order to restore or improve the loadcarrying capacity as a structural body.

Support point addition method: Supporting the intermediate sections of the beams and other existing concrete members with new members to reduce the span of the members in order to restore or improve the loadcarrying capacity as a structure.

Seismic Isolation method-

Using seismic isolation bearings and the like to reduce the seismic energy applied to the structure in order to improve its various performance values during an earthquake.

### STRUCTURAL MODELLING AND DESIGN:

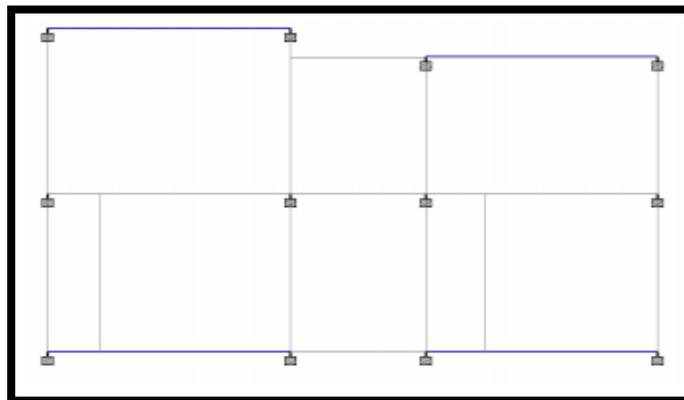
In this paper, the building is analyzed using STAAD PRO V8i software. Both the static and the dynamic analysis have been done for the existing building. Firstly, Dead and the live loads are found out separately. The unit weights of the material are taken from IS 875: Part 1. The live loads of residential building, accessible and inaccessible roof is taken from IS 875 Part 2. Then, the wind loads are calculated taking the wind speed of Jammu as 39 meter per second and the constants of wind proportionality as unity. Also, the seismic loads are taken out using IS 1893:2002. Analysis and the design of the concrete building are then carried out.

**RETROFITTING USING SHEAR WALL:**

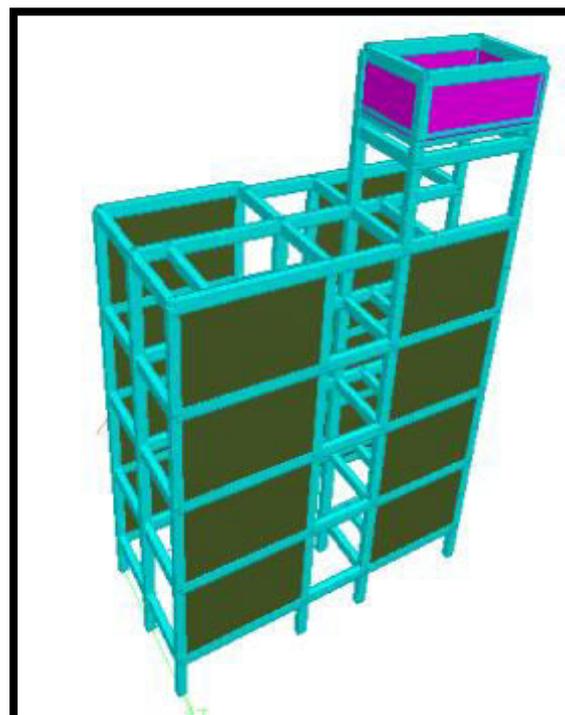
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**Best location of adding shear wall:**

Using STAAD Pro v8i, shear walls were added in the different bays of the building. For example, it was added in the 2.8m bay on both the sides of the building. However, it did not improve Earthquake resistance of the building. Then the shear wall was added in the 5m and 4.75m bay simultaneously in order to maintain symmetry and for uniform distribution of forces. Fig. 6 and 7 shows the location of shear wall in the building. The blue line highlighted in Fig. 6 shows the location of shear wall.



(Fig. 6: Plan of the building showing location of shear wall)



(Fig. 7: Location of Shear Wall in the Building)



**Shear Wall Design:**

Shear wall is added to the building as a surface plate. It is added on all the four sides of the building. The provided reinforcements of the existing columns came out to be more than the required reinforcements. Hence, now the design is safe for all the columns and beams of the building. Table 4 shows the required and provided reinforcements of the building columns from foundation to ground level. Table 5 shows the required and provided reinforcements of the building from Ground to first level. Thus, all the beams and columns were checked after applying shear wall. The building was now found to be safe. The shear wall is designed with the help of Indian Standard Codes, IS 1893(Part 1): 2002 Indian Standard Criteria For Earthquake Resistant Design Of Structures, IS 13920:1993 Indian Standard Ductile Detailing Of Reinforced Concrete Structures Subjected To Seismic Forces, IS 15988:2013, Seismic Evaluation And Strengthening Of Existing Reinforced Concrete Buildings –Guidelines.

**Table 4: Comparison of Ast required and provided from foundation to ground level after adding shear wall**

Foundation to ground level Reinforcements			
Col. No	Column size	Area of reinforcement	
		Required	Provided
1007	250.0X400.0	1418.90	1608
1008	250.0X350.0	1471.49	1608
1011	250.0X350.0	1400.00	1608
1012	250.0X350.0	1606.00	1608

**Table 5: Comparison of Ast required and provided from ground to first level after adding shear wall.**

Ground to first level Reinforcements			
S. NO	Column size	Area of reinforcement	
		Required (mm2)	Provided (mm2)
2007	250.0X400.0	1600	1608
2008	250.0X350.0	1150.92/1349.65	1608
2011	250.0X350.0	440.48	1608
2012	250.0X350.0	767.29/310.58	1608

**IV. CONCLUSION**

The need of seismic retrofitting of buildings arises under two circumstances (i) earthquake damaged buildings and (ii) earthquake vulnerable buildings that have not yet experienced severe earthquakes. The problems faced by a structural engineer in retrofitting earthquake damaged buildings are (a) lack of standards for methods of retrofitting (b) effectiveness of retrofitting techniques since there is a considerable dearth of experience and data on retrofitted structures (c) absence of consensus on appropriate methods for the wide range of parameters like type of structures, condition of materials, type of damage, amount of damage, location of damage, significance of damage, condition under which a damaged element can be retrofitted etc. Therefore, a catalogue of available options regarding feasible and practical retrofitting methods is needed for the structural engineer due to great variability of retrofitting requirements differing from building to building. In addition experimental and analytical research is urgently needed to strengthen different techniques of retrofitting.

Adding shear wall significantly increases the lateral load carrying capacity of the building as well as the ductility. The building before adding shear wall was not designed as earthquake resistant. But after adding shear wall, significant improvement is seen in seismic performance of the building. The columns which were failing before addition of shear wall became safe after addition of shear wall. Also, the problem of soft present was solved. As addition of shear wall imposes very less disturbance to the existing structure so it is still very viable option in improving the earthquake resistance of the existing buildings. Foundations for newly added shear wall need significant attention of structural engineers.

## V. FUTURE SCOPE

### *Retrofitting of Concrete Members -*

- Continuous fiber reinforced plate bonding construction method: Bonding continuous fiber reinforced plates to the surface of the existing structure to restore or improve load-carrying capacity
- Continuous fiber reinforced plate jacketing construction method: Jacketing with continuous fiber reinforced plates around the periphery of the existing structure to restore or improve load-carrying capacity and deformation characteristics
- Prestressed concrete jacketing construction method: Placing prestressing wires and prestressing stranded steel wires in place of lateral ties around the periphery of existing member sections and using mortar and concrete to bond them in order to reinforce the structure.
- Prestressing introduction construction method: Using internal cables for the existing concrete members to provide prestressing and restore or improve the load carrying capacity of the members.

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