Study of Seismic Retrofitting Techniques

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Abstract - *Many parts of the country have suffered earthquake in last three decades. Seismic protection of buildings is a need-based concept aimed to improve the performance of any structure under future earthquakes. Earthquakes of varying magnitude have occurred in the recent past in India, causing extensive damage to life and property. Some recently developed materials and techniques can play vital role in structural repairs, seismic strengthening and retrofitting of existing buildings, whether damaged or undamaged. The primary concern of a structural engineer is to successfully restore the structures as quickly as possible. Selection of right materials, techniques and procedures to be employed for the repair of a given structures have been a major challenges. Innovative techniques of the structural repairs have many advantages over the conventional techniques. The benefits of retrofitting include the reduction in the loss of lives and damage of the essential facilities, and functional continuity of the life line structures. For an existing structure of good condition, the cost of retrofitting tends to be smaller than the replacement cost. Thus, the retrofitting of structures is an essential component of long term disaster mitigation. In present study, global and local retrofitting techniques are discussed. Conventional techniques (Local and global) of retrofitting are compared with modern technique (Fiber Reinforced Polymers).*

Key Words*: *Retrofitting, seismic, FRP ,inertia force,

1. INTRODUCTION

Damages caused by recent earthquakes have exposed the vulnerability of buildings in India. Many of the non-engineered and semi-engineered constructions lack the basic features required for seismic resistance. Many of the so-called 'engineered' constructions, such as multi-storeyed apartments, are not adequately designed, detailed and constructed to provide the desired resistance against seismic forces. This may be attributed largely to a lack of awareness of seismic resistant design and code requirements. In recent years, particularly after the devastating Gujarat earthquake in 2001, there has been a concerted effort nation-wide to provide for increased awareness, in education and practice, with regard to seismic resistant design of buildings. There is now a greater awareness and insistence on adherence to design code requirements, with regard to new buildings, especially those constructed by major organizations in the public and private sectors. It is hoped that this healthy practice becomes mandatory and adopted by all builders. Mechanisms need to be evolved by local approving bodies (corporations, municipalities, development authorities) to ensure that the buildings conform to the National Building Code. In particular, the structural design has to be proof-checked by a competent third party for code compliance. Ordinary people, investing their life savings in buildings such as apartment complexes, should also insist on this, in their own interest. All this is possible with buildings to be built in the future. But, what is to be done about existing buildings? Many of these will be found to lack compliance with the current codes of practice, especially in terms of earthquake resistance. This is partly attributable to the increased seismic demand and up-gradation of some seismic zones in the country, as reflected in the recently revised code of practice for seismic analysis (IS 1893 Part 1: 2016. Even 'engineered' buildings built in the past are likely to lack the seismic strength and detailing requirements of the current design codes, such as IS 1893: 2016 and IS 13920: 2016, because they were built prior to the implementation of these codes.

2. SEISMIC EFFECTS ON STRUCTURES

2.1 Inertia forces in Structure

Earthquake causes shaking of the ground. So a building resting on it will experience motion at its base. From Newton's First Law of Motion, even though the base of the building moves with the ground, the roof has a tendency to stay in its original position. But since the walls and columns are connected to it, they drag the roof along with them. This is much like the situation that you are faced with when the bus you are standing in suddenly starts; your feet move with the bus, but your upper body tends to stay back making you fall backwards!! This tendency to continue to remain in the previous position is known as inertia. In the building, since the walls or columns are flexible, the motion of the roof is different from that of the ground. (Fig.1)

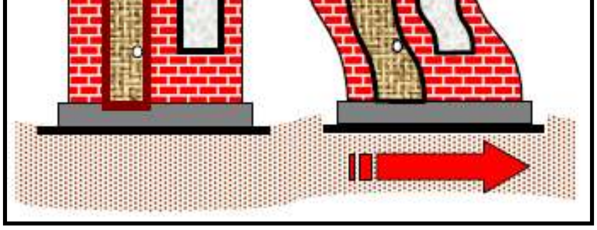

Fig. 1 Effect of Inertia in a building when shaken at its base

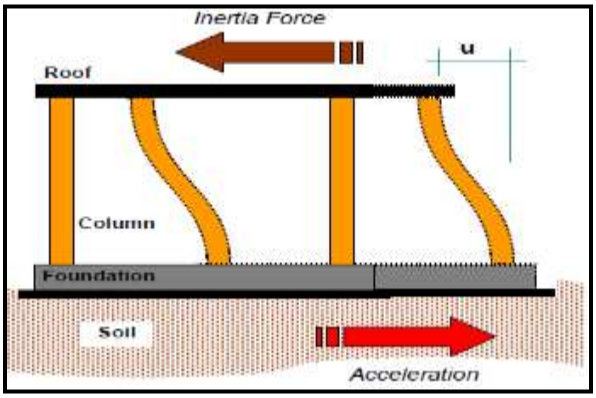

Fig. 2 Inertia force and relative motion within a building

Consider a building whose roof is supported on columns (Fig. 2). Coming back to the analogy of yourself on the bus, when the bus suddenly starts, you are thrown backwards as if someone has applied a force on the upper body. Similarly, when the ground moves, even the building is thrown backwards, and the roof experiences a force, called inertia force. If the roof has a mass M and experiences an acceleration a, then from Newton's Second Law of Motion, the inertia force F_I is mass M times acceleration a, and its direction is opposite to that of the acceleration. Clearly, more mass means higher inertia force. Therefore, lighter buildings sustain the earthquake shaking better.

3. SEISMIC RETROFITTING

3.1 Earthquake Risk of Housing in India

The projected aggregate effect of expected number of lives likely to be lost, persons injured, property damaged and economic activity disrupted due to an expected strong earthquake in an area, is the earthquake risk of that area.

India has experienced several major earthquakes in the past few decades and according to IS 1893 (Part I:2016), around 56% (12% in Zone V, 18% in Zone IV, 26% in Zone III) and 44% in Zone II of its landmass is prone to moderate to severe earthquake shaking intensity. Especially, in the last 25 years, several large to moderate earthquakes have occurred in the country (Table 1) (Bihar-Nepal border (M6.4) in 1988, Uttarkashi (M6.6) in 1991, Killari (M6.3) in 1993, Jabalpur (M6.0) in 1997, Chamoli (M6.8) in 1999, Bhuj (M6.9) in 2001, and Kashmir (M7.6) in 2005, which have caused more than 25,000 fatalities due to collapse of buildings.

3.2 Need for Seismic Evaluation of Existing Buildings

On a priority basis, seismic evaluation and retrofit are undertaken for the life-line buildings, such as hospitals, police stations, fire stations, telephone exchanges, broad casting stations, television stations, railway stations, bus stations, airports (including control towers), major administrative buildings, relief co-ordination centres and other buildings for emergency operations. The next set of important buildings includes schools, educational institutions, places of worship, stadia, auditoria, shopping complexes and any other place of mass congregation. High rise multistoreyed buildings, major industrial and commercial buildings, historical and heritage buildings are also among the important buildings.

Seismic vulnerability of an existing building is indicated under the following situations:

i. The building may not have been designed and detailed to resist seismic forces.
ii. The building may have been designed for seismic forces, but before the publication of the current seismic codes. The lateral strength of the building does not satisfy the seismic forces as per the revised seismic zones or the increased design base shear. The detailing does not satisfy the requirements of the current codes to ensure ductility and integral action of the components.
iii. The construction is apparently of poor quality.
iv. The condition of the building has visibly deteriorated with time.
v. There have been additions or modifications or change of use of the building, which has increased the vulnerability. For example, additional storeys have been built.
vi. The soil has a high liquefaction potential.

3.3 Goals of Seismic Retrofit

The goals of seismic retrofit refer to the actions to be taken with reference to the attributes for seismic design, in qualitative terms. They can be summarized as follows:

i. To increase the lateral strength and stiffness of the building
ii. To increase the ductility in the behaviour of the building, this aims to avoid the brittle modes of failure.
iii. To increase the integral action and continuity of the members in a building
iv. To eliminate or reduce the effects of irregularities

v. To enhance redundancy in the lateral load resisting system, this aims to eliminate the possibility of progressive collapse.
vi. To ensure adequate stability against overturning and sliding

3.4 Objectives of Seismic Retrofit

The objectives of seismic retrofit are quantitative expressions to achieve the goals of retrofit. Of course for a non-engineered building, the objective may not be quantifiable. The implicit objective is to provide adequate lateral strength by strategies that have been tested or proved to be effective in past earthquakes. The retrofitted building should not collapse during a severe earthquake.

Objectives of seismic retrofit can be summarized as follows:

i. Public safety only: The goal is to protect human life, ensuring that the structure will not collapse upon its occupants or passersby, and that the structure can be safely exited. Under severe seismic conditions the structure may be a total economic write- off, requiring tear-down and replacement.
ii. Structure survivability: The goal is that the structure, while remaining safe for exit, may require extensive repair (but not replacement) before it is generally useful or considered safe for occupation. This is typically the lowest level of retrofit applied to bridges.
iii. Structure functionality: Primary structure undamaged and the structure is undiminished in utility for its primary application.
iv. Structure unaffected: This level of retrofit is preferred for historic structures of high cultural significance.

3.5 Steps of Seismic Retrofit

A retrofit steps for a building refers to the complete process of retrofitting. For a systematic approach, it is necessary to be aware of the steps of a retrofitting before undertaking the retrofit project. The implementation of each step requires a certain time schedule and finance. All the listed steps may not be applicable for all projects. Similarly, there may be detailed sub-divisions of one step for a particular project.

The steps of a retrofit are shown as a flow chart in Fig. 3

4. SEISMIC RETROFIT STRATEGIES/TECHNIQUES

This section presents an overview of the process used to develop a retrofit strategy once deficiencies of the existing buildings have been detected and performance objectives have been apparently determined. The retrofit strategies can be grouped under global and local strategies. A global retrofit strategy targets the seismic resistance of the building. A local retrofit strategy targets the seismic resistance of a member, without significantly affecting the overall resistance of the building. It may be necessary to combine both local and global retrofit strategies under a feasible and economical retrofit scheme.

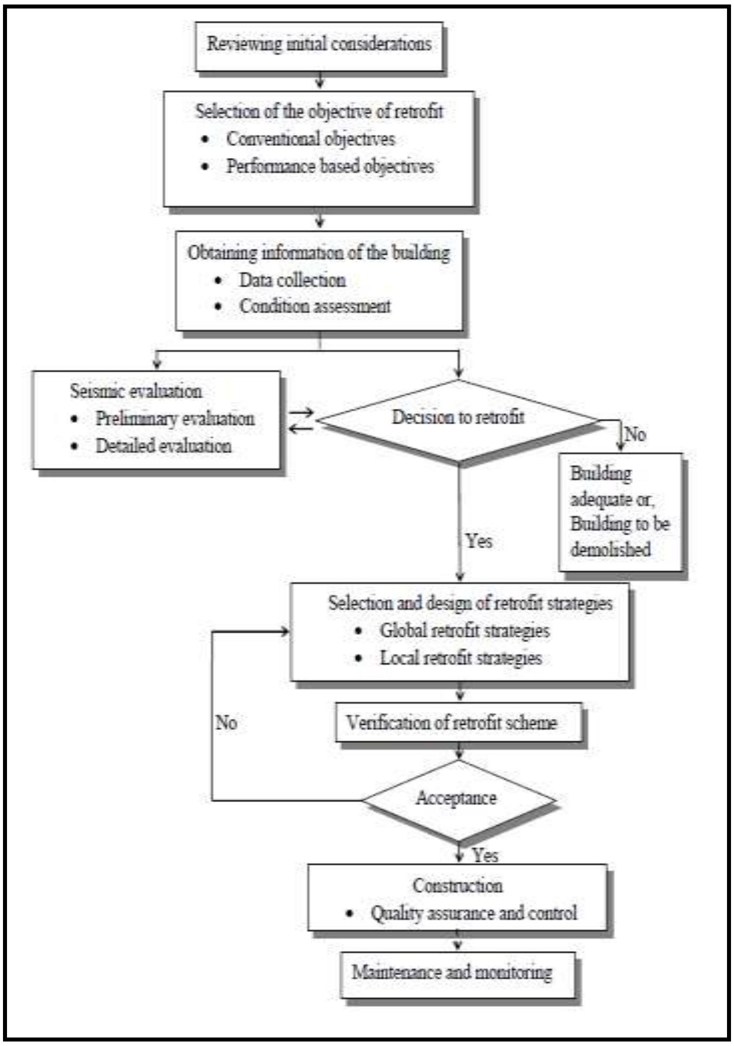

Fig. 3 Flow chart showing Steps of Seismic Retrofit

4.1 Global Retrofit Strategies

4.1.1 Adding Shear Wall

Shear walls can be introduced in buildings with frames or in buildings with flat slabs or flat plates. In the latter type of buildings, since there are no conventional frames, the lateral strength and stiffness can be substantially inadequate. A new shear wall should be provided with an adequate foundation. The reinforcing bars of the wall should be properly anchored to the bounding frame (Fig.4).

Shear walls resist two types of forces: shear forces and uplift forces. Connections to the structure above transfer horizontal forces to the shear wall. This transfer creates shear forces throughout the height of the wall between the top and bottom shear wall connections. The strength of the lumber, sheathing and fasteners must resist these shear forces or the wall will tear or "shear" apart.

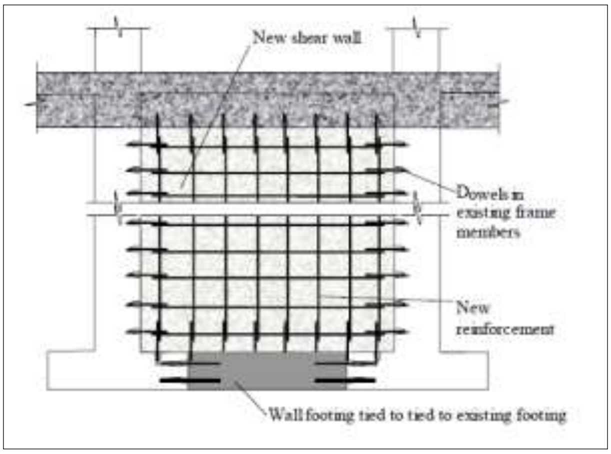

Fig. 4 Addition of a shear wall

4.1.2 Adding Infill Wall

Addition of infill walls in the ground storey is a viable option to retrofit buildings with open ground storeys. In absence of plinth beam, the new foundation of the infill wall should be tied to the existing footings of the adjacent columns (Fig. 5). Else, a plinth beam can be introduced to support the wall. The lateral load resistance and the energy dissipation capability of a frame increase with infill. This is a viable option for the building (with open ground storey) addressed. Infill walls with reinforced concrete masonry units can act as shear walls.

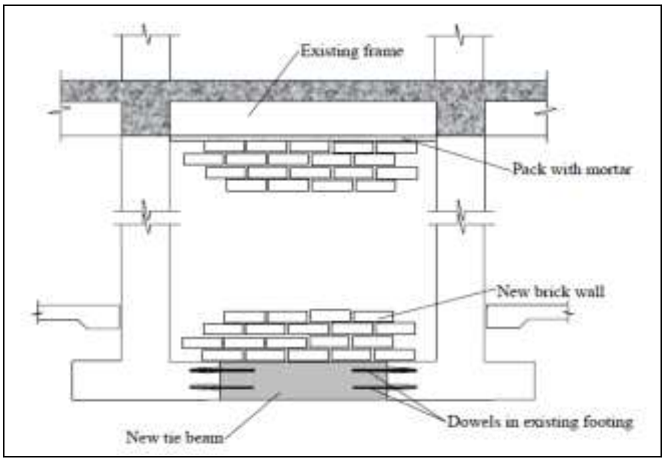

Fig. 5 Addition of a masonry infill wall

4.1.3 Adding Bracing

Steel braces can be inserted in a frame to provide lateral stiffness, strength, ductility, energy dissipation, or any combination of these (Fig.6). The braces can be added at the exterior frames with least disruption of the building use. For an open ground storey, the braces can be placed in appropriate bays to retain the functional use. The connection between the braces and the existing frame is an important consideration. One technique of installing braces is to provide a steel frame within the designated bay. Else, the braces can be connected directly to the frame with plates and bolts.

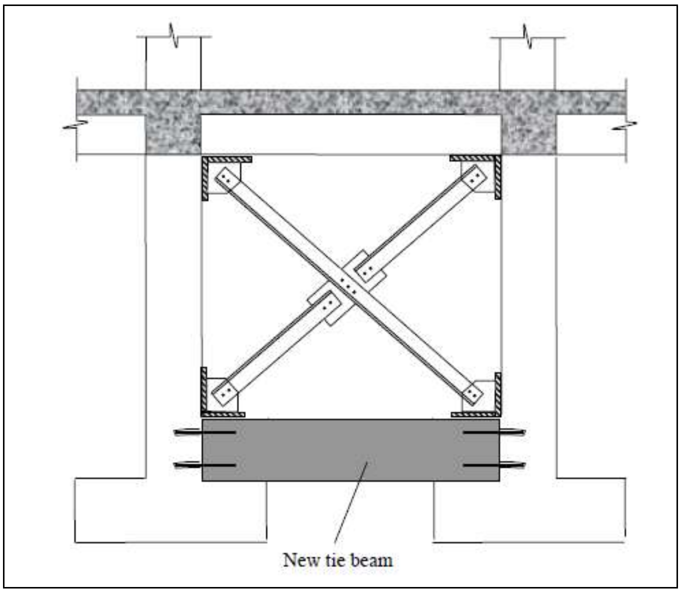

Fig. 6 Addition of a Steel braces

4.1.4 Base Isolation

Base isolation is a collection structural elements of building that should substantially decouple the buildings‟ structure from the shaking ground thus protecting the buildings integrity and enhancing its seismic performance. The base isolation tends to restrict the transmission of the ground motion to the building; it also keeps the building positioned properly over the foundation.

Base isolation systems have become a significant element to enhance reliability during an earthquake. Seismic isolation can be an effective tool for the earthquake resistant design of structures that can be used in both new construction and retrofit. One type of base isolation system is Friction Pendulum Bearing in which the superstructure is isolated from the foundation using specially designed concave surfaces and bearings to allow sway under its own natural period during the seismic events. Friction Pendulum Bearings are seismic isolation systems that have been as a kind of bridge, and building retrofit in numerous cases around the world. To assess their impact on structure performance, models are needed to capture the behavior of these highly nonlinear elements.

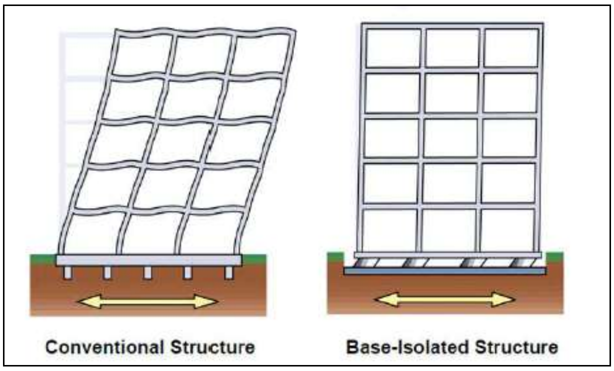

Fig. 7 Behavior of building structure with base isolation system

Base isolation is generally suitable for low to medium rise buildings, usually up to 10- 12 stories high, which have their fundamental frequencies in the range of expected dominant frequencies of earthquakes. Superstructure characteristics such as height, width, aspect ratio, and stiffness are important in determining the applicability and effectiveness of seismic isolation. The seismic base isolation technology involves placing flexible isolation systems between the foundation and the superstructure.

A comparative evaluation of the different global retrofit strategies is provided in Table 1

Table 1 Comparative evaluation of the global retrofit strategies

Global Retrofit strategy	Merits	Demerits	Comments
Addition of infill walls	(i) Increases lateral stiffness of a storey (ii) Can support vertical load if adjacent column fails	(i) May have premature failure due to crushing of corners or dislodging (ii) Does not increase ductility (iii) Increases weight	(i) Low cost (ii) Low disruption (iii) Easy to implement
Addition of shear walls	(i) Increases lateral strength and stiffness of the building substantially (ii) May increase ductility	(i) May increase design base shear (ii) Increase in lateral resistance is concentrated near the walls (iii) Needs adequate foundation	(i) Needs integration of the walls to the building (ii) High disruption based on location, involves drilling of holes in the existing members
Addition of braces	(i) Increases lateral strength and stiffness of a storey substantially (ii) Increases ductility	(i) Connection of braces to an existing frame can be difficult	(i) Passive energy dissipation devices can be incorporated to increase damping / stiffness or both

5. LOCAL RETROFIT STRATEGIES

Local retrofit strategies refer to retrofitting of columns, beams, joints, slabs, walls and foundations. The local retrofit strategies fall under three types: concrete jacketing, steel jacketing (or use of steel plates) and fibre-reinforced polymer (FRP) sheet wrapping.

Table 2 Comparative evaluation of the local retrofit strategies

Local Retrofit strategy	Merits	Demerits	Comments
Concrete jacketing	•Increases flexural and shear strengths and ductility of the member • Easy to analyse •Compatible with original substrate	•Size of member increases • Anchoring of bars for flexural strength; involves drilling of holes in the existing concrete •Needs preparation	• Low cost •High disruption •Experience of traditional RC construction is adequate

		of the surface of existing member	
Steel jacketing of columns	• Increases shear strength and ductility •Minimal increase in size	•Cannot be used for increasing the flexural strength •Needs protection against corrosion and fire	•Can be used as a temporary measure after an earthquake • Cost can be high •Low disruption • Needs skilled labour
Bonding steel plates to beams	•Increases either flexural or shear strengths •Minimal increase in size	• Use of bolts involves drilling in the existing concrete •Needs protection against corrosion and fire	•More suitable for strengthening against gravity loads • Cost can be high •Low disruption • Needs skilled labour
Fibre Reinforced Polymer wrapping	•Increases ductility • May increase flexural or shear strengths •Minimal increase in size •Rapid installation	•Needs protection against fire	• Cost can be high •Low disruption • Needs skilled labour

5.1 Retrofit Using Fibre Reinforced Polymer Composites (FRP)

A comparative evaluation of the conventional techniques with FRP is provided in Table 3

Table 3 Comparison of FRP system with Conventional Technique

Description	Concrete Jacketing	Steel Jacketing	FRP Wrapping	Remarks
Mode of strengthening	Increase in concrete and steel area	Confinement	Confinement	
Preparation of column for strengthening	Significant dismantling of cover concrete. At least 40 mm cover concrete to be removed. Epoxy primer to be applied on exposed surface.	Not major dismantling work involved. Mainly plaster to be removed and epoxy primer to be applied on exposed surface	Only plaster to be removed and epoxy primer to be applied on exposed surface. For rectangular columns, corners to be rounded off.	FRP involves minimum surface preparation.
Drilling of holes	Large amount of drilling is required	Large amount of drilling is required	Large amount of Drilling is required	FRP involves minimum work since no drilling is required.
Additional weight	Extremely high	Very high	Negligible. No increase in weight at all.	FRP does not increase the dead weight of the structure.

6. CONCLUSIONS

Conventional techniques (Local and global) of retrofitting are compared with modern technique (Fiber Reinforced Polymers). Following observations are concluded from the study:

1. Seismic resistant design of new buildings and seismic retrofit of existing buildings are essential to reduce the vulnerability of the buildings during an earthquake.

2. Before undertaking seismic retrofit, it is essential to determine the condition and diagnose the deficiencies in a building.
3. Seismic evaluation helps to identify the deficiencies of the building with respect to resistance to seismic forces.
4. Based on the condition and deficiencies, repair and retrofit strategies are selected.
5. When a building is severely deficient for the design seismic forces, it is preferred to select a global retrofit strategy to strengthen and stiffen the structure.
6. If deficiencies still exist in the members, local retrofit strategies are to be selected.
7. A retrofit strategy is to be selected after careful considerations of the cost and constructability. Proper design of a retrofit strategy is essential.
8. The failure mode in a member after retrofitting should not become brittle.
9. A global retrofit strategy that involves a shift in either of the centre of mass or centre of rigidity should be checked for torsional irregularity.
10. FRP involves minimum surface preparation, minimum work since no drilling is required.
11. FRP does not increase the dead weight of the structure.

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BIOGRAPHIES

Chetan J. Chitte obtained his M.Tech. in Structural Dynamics & Earthquake Engineering from VNIT, Nagpur and B.E. Civil from Sardar Patel College of Engineering, Mumbai. He has 4.5 Years experience in Structural Designing and 9 Years experience in area of teaching.