

Research Article

Advanced Retrofitting Techniques for RC Building: A State of an Art ReviewMinakshi V. Vaghani^{Å*}, Sandip A. Vasawala^Å and Atul K. Desai^Å^ÅApplied Mechanics Department,, Sardar Vallabhbhai National Institute of Technology, Surat, India - 395007.

Accepted 03 March 2014, Available online 01 April 2014, Vol.4, No.2 (April 2014)

Abstract

A higher degree of damage in a building is expected during an earthquake if the seismic resistance of the building is inadequate. The decision to strengthen it before an earthquake occurs depends on the building's seismic resistance. The structural system of deficient building should be adequately strengthened in order to attain the desired level of seismic resistance. Though considerable research was carried out on performance of existing- and retrofitted- 'GLD' and 'Ductile' structures, studies on the behaviour of 'Nonductile' one, which falls between these two prominent levels of design concept, are inadequate. Indian Standard is well accepted in the larger part of South-East Asia which is a prominent seismic zone. Since most of the structures in this region are commonly built without adhering to ductile provisions, usability of the damaged structure after any earthquake is of great importance. The existing building can be retrofitted using various techniques like Jacketing existing beams, columns, or joints, Use of Fibre Reinforced Cement, confinement of column by embedded composite grid, use of metal shear Panels (Steel and Aluminum), Use of steel fibre reinforced mortar, use of steel wire reinforced polymer, steel bracing, shape modification in column, external prestressing and post-tensioning existing beams, columns, or joints. So, in this paper, efforts are made to describe the different retrofitting techniques available and its suitability for particular conditions. Jacketing is excellent for column but it may not be too effective for beam or slab. Finally, selection criteria for retrofitting technique are briefly discussed.

Keywords: retrofitting, jacketing, ductile, confinement, prestressing**Introduction**

Rehabilitation is an all-encompassing term that includes concepts of repair, retrofitting, strengthening and weakening that may minimize the vulnerability of building structures to earthquake loading. Repair is defined as the reinstatement of the original characteristics of a damaged section or member and is confined to dealing with the as-built system. The term strengthening is defined as the number of interventions that may improve one or more seismic response parameters (stiffness, strength and ductility) as a function of the desired structural performance level. Furthermore, strengthening includes the addition of structural elements or the change of the structural system. Weakening is an alternative scheme to upgrade existing structures; it consists of reducing the seismic demand in critical regions, e.g., beam-to-column connections. 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. Rehabilitation denotes repairing buildings damaged during service or by earthquakes without upgrading the seismic resistance, while seismic retrofitting

denotes upgrading the safety of damaged or existing deficient buildings.

Necessity of Seismic Retrofitting

Buckling and bulging are the common phenomenon of RC column failure. For a flexural member like Beam bending and deflection are the common phenomenon of RC column failure. The joint has been always considered as weaker section of the structure. If sufficient care is not taken for the beam-column or slab-column connection at designing stage as well as at the construction stage, it may lead to the degradation of the building in early age. Factors responsible for the degradation of RC element are: Longitudinal reinforcement is insufficient, Sufficient cover is not provided, Lack of ductile detailing, Not designed for seismic loading, Unexpected overloading, Lateral ties or stirrups are not provided at the required spacing, Poor quality of material used, Quality of workmanship is inferior, Ignorance of vertical or diagonal cracks, spalling of concrete, corrosion in the reinforcement, dampness of surface, Unexpected impact loading, vibration etc., Lack of ductile detailing, Poor concreting at the connection, insufficient maintenance etc.

Techniques for Rehabilitation

The decision to strengthen it before an earthquake occurs

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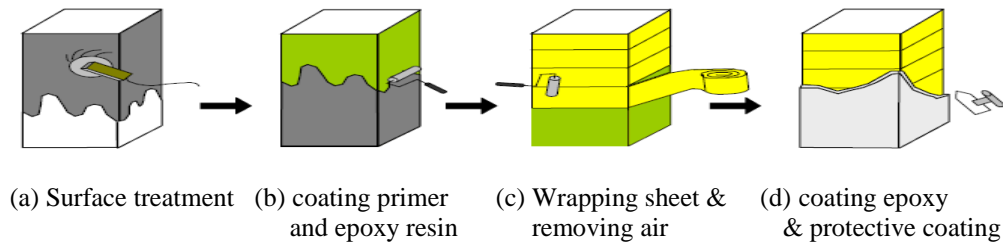


Figure 1 Process of application of AFRP sheets

depends on the building's seismic resistance. The structural system of deficient building should be adequately strengthened in order to attain the desired level of seismic resistance. The term strengthening comprises technical interventions in the structural system of a building that improves its seismic resistance by increasing the strength, stiffness and/or ductility. FEMA 273 – NEHRP Guidelines for the Seismic Rehabilitation of Buildings is referred to increase the seismic resistance of existing building.

The selection of the type of intervention is a complex process, and is governed by technical as well as financial and sociological considerations. The following are some factors affecting the choice of various intervention techniques: Cost versus importance of the structure, Available workmanship, Duration of work/disruption of use, Fulfilment of the performance goals of the owner, Functionally and aesthetically compatible and complementary to the existing building, Reversibility of the intervention, Level of quality control, Political and/or historical significance, Structural compatibility with the existing structural system, Irregularity of stiffness, strength and ductility, Adequacy of local stiffness, strength and ductility, Controlled damage to non-structural components, Sufficient capacity of foundation system, Repair materials and technology available. A strengthening scheme consists of one/many strengthening techniques to remedy structural deficiency. Such schemes are specific to structural system and material type. Following is a brief description of major techniques that are used for reinforced concrete buildings. (1) Local modification of components, (2) Removal or Lessening of Existing Irregularities and Discontinuities and (3) Global Structural Stiffening and Strengthening, (4) Base Isolation and (5) Supplemental Energy Dissipation

General Strengthening Techniques

There are many seismic retrofit techniques available, depending upon the various types and conditions of structures. Therefore, the selection of the type of intervention is a complex process, and is governed by technical as well as financial and sociological considerations.

Jacketing of existing beams, columns, or joints

Jacketing existing beams, columns, or joints with new reinforced concrete, steel, or fibre wrap overlays can be carried out. The new materials shall be designed and

constructed to act compositely with the existing concrete. Where reinforced concrete jackets are used, the design shall provide detailing to enhance ductility.

While retrofitting columns, FRP sheets can be wrapped on the column as mentioned in **Figure 1**. In sheet method columns are wrapped by FRP sheet of certain width and with a certain overlap. In tape method sheets are applied continuously without the need of any overlap. The second method is effective because it reduces the cost of construction by saving materials and also it is stronger because it does not have any joint. Advanced composite materials such as carbon fibre reinforced plastic (CFRP) is much stronger and lighter than steel. The inherent non-corrosive characteristic of CFRP makes CFRP reinforcement a very effective alternative to steel reinforcement for reinforced concrete structures, especially when reinforcement corrosion is a main concern for the performance and durability of the structure. Analytical and experimental results have shown that, wrapping structural components (such as columns, beams and walls) with CFRP sheets improve their strength and ductility without adding stiffness to the elements. Ease of installation, which is similar to putting up wall papers, makes the use of CFRP sheets a very cost-effective and efficient alternative in the seismic retrofit of existing buildings.

Friction Damper

Friction damper, consisting of specially coated steel plates being bolted together, is usually part of a steel brace system that is mounted within a column-beam frame. The commonly used friction damper systems are in the form of an X (friction damper being at the middle of the X) or a diagonal (friction damper being along the diagonal) inside a rectangular column-beam frame. Such a friction damper system is attached to the structural frame through connections at the column-beam joints. Friction damper system's function is similar to that of a shock-absorbing system in a car. Earthquakes release energy through ground shaking motions, which induce seismic loads to a building structure. Friction dampers absorb the earthquake-induced energy (or load) when the steel plates slide against each other at pre-determined slip load, i.e. dissipating the earthquake-induced energy through friction-generated heat energy. Adding friction dampers to an existing building increase the seismic load carrying capacity of the building structure by means of reducing the demand of seismic resistance capacity upon the building's existing load carrying elements. Friction damper system

has been used in a building (**Figure 2**) and is currently being installed in a second federal building (**Figure 3**) in British Columbia. Similar in function to that of friction dampers, fluid viscous damper is another type of passive device that can be used in the seismic retrofit of existing buildings.



Figure 2 X – braced Friction Damper used in Building



Figure 3 Installation of Friction Damper used in Pump House

Use of Fibre Reinforced Cement

Past and recent earthquakes have exposed the vulnerability of un-reinforced masonry (URM) and the consequence of URM's failure. Common practice of retrofitting URM walls is either by replacing the URM walls with lighter construction or by adding a structural overlay onto the URM walls. The latter method often increases the stiffness of the wall elements, which in turn attract higher loads in the event of an earthquake. Fibre reinforced cement, or FRC, comprises of a high strength fibreglass grid or mesh and a thin layer of fibre reinforced cement. Adding a FRC overlay onto an URM wall enhances its strength and ductility performance without increasing its stiffness. FRC can transform an URM into a reinforced masonry wall with improved structural performance under an earthquake.

Confinement of Column by embedded composite grid

The pathological study of vulnerability of concrete structures led towards the use of composite materials as reinforcement ensuring a restoration of stiffness and strength. Considering the high mechanical performance of composite materials combined with their lightness, it becomes judicious to associate them in the composition of the concrete members, to better resist external loading. This concept has emerged as a novel alternative for

rebuilding as well as for repairs of damaged structures. The composite material is made of resin impregnated E-glass fibers with thickness of 2 mm. The yield strength and the Young's modulus of elasticity of the E-glass fiber provided by the manufacturer are respectively 560 MPa and 4.1 GPa. This construction technology aims to increase the member rigidity and strength, to allow for ductile failure and to prevent sudden failure under excessive loading. It avoids also the problems due to interface between concrete and composite materials.

Use of Metal Shear Panels (Steel and Aluminum)

The evolution of the metal plate shear walls behaviour has led to a different classification of these devices within two main typologies, namely compact shear panels, realised with either stiffened plates or plates made of low-yield strength metals (LYS steel or pure aluminium), and slender shear panels, made of thin steel plates connected to the members of a surrounding steel frame by means of either welded or bolted connections. Compact shear panels have a good energy dissipation capability, they being characterised by stable and large hysteretic cycles due to the occurrence of buckling phenomena in the plastic field only (**Figure. 5**). On the contrary, slender shear panels have a poor hysteretic behaviour with pronounced pinching effects due to buckling phenomena occurring in the elastic field (**Figure 6**). Nevertheless, the fabrication simplicity of slender metal plates suggests their employment as passive control devices of structures. In this framework, while compact shear panels have been strongly used in USA and Japan within new and existing buildings, slender shear panels have been widely studied and applied in Canada, but they have been hardly ever employed for seismic retrofitting purposes. Steel shear panels can be considered as effective strengthening and stiffening devices, whereas the pure aluminium ones are also able to increase significantly the energy dissipation capacity of existing RC framed structures.

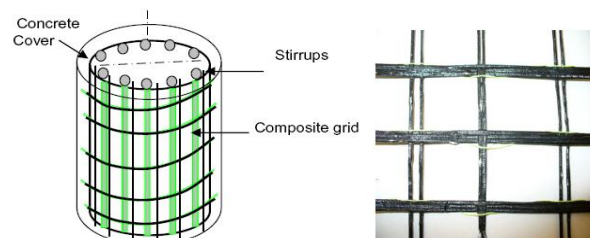


Figure 4 Confined specimens and composite grids

Use of Steel Fibre Reinforced Mortar

Steel fibres are added to the mortar mixture at ratios of 1%, 2%, and 4% by volume and sticking ability of the mortar mixtures on the brick wall can be observed. Besides, compressive strength tests on cubic specimen, flexural strength tests on prismatic specimens, and adhesion strength tests are conducted. Additional compressive strength tests may also be carried out on cubical pieces obtained from flexural strength test specimens. All the tests are carried out for two types of

SFRM prepared using either plasticizer or bonding agent. It is a cold drawn wire fiber, with hooked ends, and glued in bundles. The fibers are filaments of wire, deformed, and cut to lengths, for reinforcement of concrete, mortar, and other composite materials. There is no coating on the fiber. Applications of the fiber are shotcrete, screeds, and compression layers. Minimum tensile strength of the fiber can be 1100 MPa. A commercial water resistant bonding agent was used in the mortar mixes of the second series. It is a synthetic rubber emulsion added to cement mortars where good adhesion and water resistance are required. A commercial normal setting plasticizer was used in all mortar mixes.

Necessary strength and lateral rigidity were provided to the structure by this newly developed strengthening method. Seismic behavior of the frame specimens was improved. The use of SFRM is advantageous from economy point of view, since it involves the use of traditional and cheap materials. Practical applicability makes SFRM application an advantageous strengthening technique. The production and application of similar to ordinary mortar.

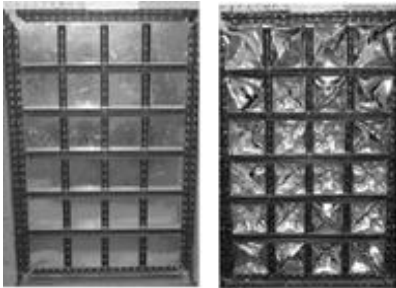


Figure 5 Aluminum Shear Panel

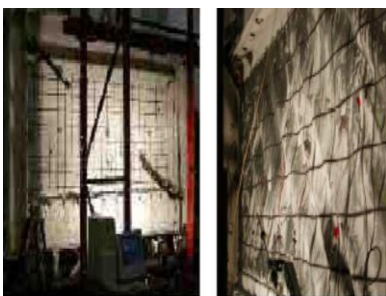


Figure 6 Steel Slender Shear Panel

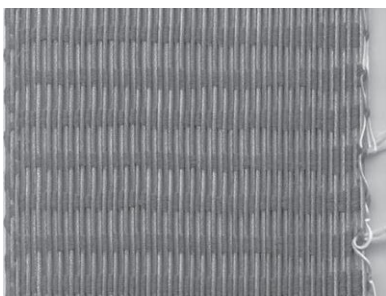


Figure 7 Top View of SWRP

Use of Steel Wire Reinforced Polymer

Steel plates have a low material cost and can easily be applied in larger sections. Therefore, deformation problems are often tackled with steel plates. As steel plates have no fibrous structure, bolts can be used to reduce the anchorage length.

Disadvantages are the high density of steel which hampers the application, and steel plates need a special treatment against corrosion. CFRP is a lightweight flexible composite. This makes it easier to apply. It has an E-modulus comparable to steel. The tensile strength is 5 to 10 times higher than standard steel. CFRP is used for strengthening of concrete plates, because their strength can be better exploited. As the flexible sheets can easily be wrapped, CFRP is also often applied as external shear reinforcement. But, as carbon can not take shear stresses, beams have to be rounded with a radius of 3 cm. Disadvantages are the high material cost and its brittleness. Therefore, large safety factors are required. Steel wire reinforced polymer (SWRP) is a new material that can be used as external reinforcement. It consists of thin high-strength steel fibres which are bundled into cords as shown in **Figure 7**. SWRP combines the advantages of steel and CFRP: the composite has the same strength as CFRP but is ductile. Shear strengthening of complex shapes, wrapping of rectangular beams, and improved uses of pre-stressing.

Steel Bracing

The main advantage of these methods is that they can be easily designed and applied using conventional construction techniques. The method is very effective in reducing the detrimental effects of earthquakes on buildings (**Figure 8**). They usually do not require heavy demolition or construction work when used for seismic retrofitting. Nevertheless, such methods are generally costly to implement (Cengizhan Duruca et al. 2010). This makes them unsuitable for ordinary buildings. Most applications of RMMs are therefore found in important government or historical buildings, museums or hospitals steel link-brace retrofitting system is configured to upgrade the performance of seismically vulnerable RC buildings by combining the advantages and eliminating most of the disadvantages of conventional and modern response modification retrofitting techniques for RC buildings.

Shape Modification in Column

Externally bonded Fibre Reinforced Polymer (FRP) composite jackets can provide effective confinement for circular concrete columns. FRP confinement is much less effective in increasing the axial compressive strength of square and rectangular columns compared to circular columns. FRP composite jackets are more effective for confinement of circular cross-sections as opposed to square or rectangular cross-sections. The flat sides of square and rectangular columns remain largely unconfined and the FRP jacket is effective only along the two diagonals of the cross-section. The presence of internal steel ties limits the ability for rounding off the corner

radius in existing square or rectangular columns (**Figure 9**).

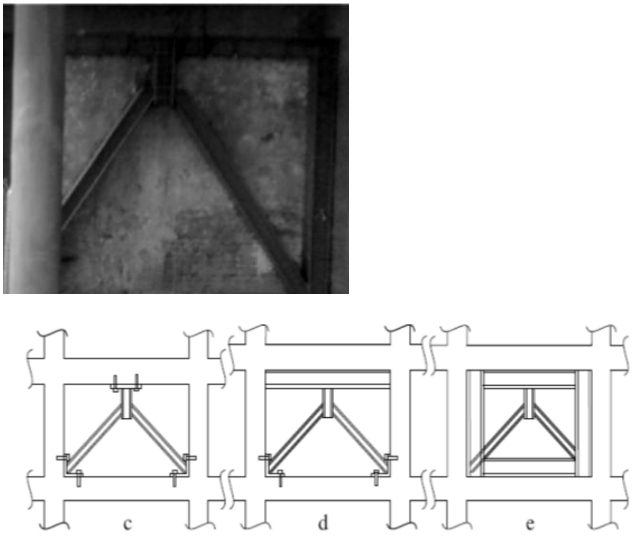


Figure 8 Configuration of Steel Bracing

Lower confinement effectiveness in square and rectangular columns results in softening behavior and premature FRP composite rupture; therefore, the inherent high tensile strength of FRP composite materials cannot be fully utilized. Shape modification of square and rectangular columns to circular and elliptical columns is implemented. One approach for improving the effectiveness of FRP jackets for rectangular or square columns is to perform shape modification of the cross-section into an elliptical, oval, or circular section. Another method for performing shape modification is to use prefabricated (non-bonded) FRP composite shells with expansive cement concrete. The mechanism of expansive cement concrete can be used with FRP composite shells for confinement. A significant benefit of shape-modified specimens with FRP shells and expansive cement concrete is that while cracking of the expansive cement concrete is extensive at failure, the original concrete column cross-section is protected.

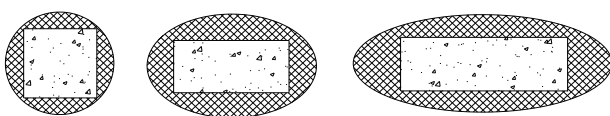


Figure 9 Cross-section of Shape-modified Specimens

A significant benefit of shape-modified specimens with FRP shells and expansive cement concrete is that while cracking of the expansive cement concrete is extensive at failure, the original concrete column cross-section is protected. Consequently, an additional benefit of the technique would likely include better performance in terms of preventing buckling of the vertical column steel bars that are within the original column cross-section and a higher residual axial load capacity for increasing ductility demand.

Conclusion

A number of experimental and analytical studies focused on seismic retrofitting techniques and extensive seismic damage control activities in practice have contributed to the present state of development. Further research should be conducted to improve the selection of appropriate retrofit techniques using criteria based on performance, economy and constructability. There are many seismic retrofit techniques available, depending upon the various types and conditions of structures. Therefore, the selection of the type of intervention is a complex process, and is governed by technical as well as financial and sociological considerations. The following factors should be considered while selecting the seismic retrofitting technique.

- Cost versus importance of the structure
- Available workmanship
- Duration of work/disruption of use
- Fulfillment of the performance goals of the owner
- Functionally and aesthetically compatible and complementary to the existing building
- Level of quality control
- Political and/or historical significance
- Structural compatibility with the existing structural system
- Irregularity of stiffness, strength and ductility
- Adequacy of local stiffness, strength and ductility
- Controlled damage to non-structural components
- Sufficient capacity of foundation system
- Repair materials and technology available.

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