# Seismic Retrofitting of Structures – A Review

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**Abstract -** *The destruction of life and property due to earthquakes is an unpredictable hazard, which may reach gigantic proportions. It is vital then, to enhance the seismic performance of structures by incorporating appropriate building norms. This review paper has collected works on different retrofitting techniques to show the ways in which available retrofitting solutions may be judiciously used to improve load carrying capacity of the structures.*

***Key Words***: *Shear wall, reinforced concrete, Seismic Retrofitting, Retrofitted, Bonding and beam-column, STAAD. Pro v8i.*

## 1. INTRODUCTION

Seismic Retrofitting is the upgradation of existing structures to make them more resistant to seismic loading, ground motion, or failure of soils due to seismic activities such as earthquakes. This purpose is fulfilled by the implementation of various strategies like reduction in the seismic demands on members and structures as a whole, or by improving upon members' stiffness capacities, ductility, overall strength, etc. The decision of which strategy to implement in the end resides on the availability of the materials in immediate vicinities, cost considerations, technologies used, project deadline, and ultimately architectural, aesthetic, and functional limitations. Seismic Rehabilitation Schemes can be implemented on both global (Complete Structural Retrofitting Projects) and local (member wrappings) levels depending on the scope of the job. Global, also called Structural Level retrofit methods are diverse and include conventional methods (which improve the seismic resistance of existing structures) and novel methods (which reduce the seismic demand of the structure). Of all these, Jacketing is still the most prevalent method of retrofitting that is used via the following techniques:

- Jacketing by confining members with fiber-reinforced polymers (FRP) such as carbon fibers, aramid fibers, and glass fiber reinforced composites.
- Jacketing by confining with external steel cages and concrete.
- Jacketing with ferrocement.

In contrast to the aforementioned, rehabilitation via the introduction of shear walls has considerably expanded the horizons of effective structural retrofitting.

## 2. LITERATURE REVIEW

**Singh (2003)-** The number of poor seismic-resistant design Buildings and Structures in India is on the substantial rise recently which was evident in the past earthquakes. The solution to the as-built structures is Seismic Retrofitting. The complexity of seismic retrofitting of these R.C. Buildings is even greater due to the composite nature of R.C.C. as material and thus requires proper planning and strategies for implementation. The behavior of these structures depends on the placement and detail of the members just as much as the reinforcement and size of these members. In association with the aforementioned issues, the poor workmanship and execution quality of Indian Construction makes seismic retrofitting an even more challenging task. Thus, a procedure has been laid out for such works:

- Specifying Goals and required performance level of the Structure with accurate Seismic Hazard estimation.
- Systematic visual inspection with a proper understanding of available floor and structural plans and associated documents.
- In situ investigations regarding strength parameters and recreation of floor plans and structural plans as per built structure.
- Identification of deficiencies and their plans for further probing.
- Comprehensive evaluation of loss of strength, and ductility in the structure
- Detailed design of Seismic Retrofitting scheme which is based on evaluated deficiencies
- Analysis and evaluation of the retrofitted building.

**Jain (2002)-** Pushover Analysis – A modern element of Building Design and Seismic Analysis of as-built Buildings is utilized to develop effective strategies of seismic retrofitting has been discussed in this paper. It further accentuates how this tool is effective in determining efficient seismic retrofitting techniques.

**Lakshmanan D (2006)-** This paper conducts pushover analysis on Structures using SAP2000. It also evaluates the improvement in Seismic performance of these RCC Buildings as per the various retrofitting strategies.

Furthermore, it discusses the behaviors of Beam-Column Joints of these retrofitted beams. Although a considerable increase in performance is seen, the original redundancies of the detailing of these joints persisted. Two of these extensions also hint that repair would be ineffective in such cases.

**Oliveto and Marletta (2005)-** The paper discusses seismic retrofitting methods, both conventional and innovative, utilized in Buildings prone to seismic events. Stiffness reduction methods were discussed extensively more than all the other methods mentioned. It also was applied in practice using a series of springs, leading to the isolation of the base. With one spring representing the structure and the other representing the base isolation system, the improved system displayed considerable resistance of the building against a seismic event demonstrating the competency of the method. Furthermore, the system also helped the performance parameters of the building.

**Mukherjee and Kalyani (2004)-** The authors introduce a method of structural retrofitting using FRC and discuss the enhancements that FRC can potentially provide to R.C.C. elements. Furthermore, they discuss strategies for retrofitting R.C.C. frames and the use of the Capacity Spectrum Method in R.C.C. upgradation.

**Jain (2003)-** This paper discusses the implications of retrofitting work on the functioning of the building. Conventional retrofitting procedures often hinder the use of the building and sometimes require a complete shutdown of work in the building due to retrofitting work. The paper discusses the leading retrofitting methods that limit their effects on the daily use of buildings. Some of the techniques discusses are as follows

- Sheet Jacketing
- Strand Jacketing
- Panel Jacketing
- Dampers
- Wall Type Viscous Dampers

**Agarwal et. al (2003)-** Since conventional jacketing of members is implemented mainly as per experience. The author discusses an analysis procedure for effective jacketing. Codal provisions are implemented to suggest an efficient jacketing method using Column Design. Furthermore, a C++ program plotting interaction diagrams and calculating the final dimensions of the jacketed member is also developed.

**Jong-Wha Bai (2003)-** The author proposes an innovative performance-based method of design impacting seismic retrofitting. The concept approaches design objectives and performance levels from a new direction. Since performance-based design ideology is becoming more widely used for new Buildings, and structures; seismic retrofitting is also gets impacted by it. Consequently, the importance of the structure alongside desired structural performance is imperative during a seismic event with a particular recurrence interval and has become a mainstay for performance objectives.

**Abdullah and Takiguchi (2003)-** The author investigated the behavior of square columns subjected to both square and circular ferrocement jackets under compressive and cyclic loading simultaneously. Using 3 different columns as subjects, designated CJ-AL10-6L, CJ-AL15- 6L, and CJ-AL20-6L respectively. The subjects were tested under varying axial loads post strengthening from circular ferrocement jackets, each containing six layers of wire mesh. Each column's had 12 deformed D-6 bars distributed uniformly across the perimeter of the column with suitable cover. Smooth R-2 (diameter¼2mm) bars provided transverse reinforcement with the center-to-center spacing of 50mm. Two Columns, SJ-AL15-4L, and SJ-AL15-6L were used as a reference and were subjected to square ferrocement jackets, each with four and six layers of wire mesh, respectively. These reference columns were tested for failure and the results were studied for the effects of different shapes of Jacketing on the lateral load-displacement response. Similarly, specimen CJ-AL15-6L/3L was strengthened with a smaller number of wire mesh layers with a circular ferrocement jacket and was investigated for its behavior via different loadings.

**Agrawal and Chourasia (2003)** The author compares the strength parameters alongside the pushover curve of an R.C.C. Building before and after seismic retrofitting by performing a nonlinear static analysis. The stiffness of the Structure was found to have been identical till the linear stage while increasing substantially, both in capacity and the deformation at most points in the nonlinear stage, post retrofitting. Correlating building strength with base shear, the net increment in strength was also measured after retrofitting.

**M C Griffith and A V Pinto (2000)-** This paper investigates a 4-Story, 3-Bay reinforced concrete frame test structure with unreinforced brick masonry (URM) infill walls against seismic loading. With the setup of strong beams and weak columns, it forecasts poor hysteretic behavior after yielding. The author forecasts the building to have a maximum lateral deformation capacity of 2% in lateral drift based on a comprehensive literature review. Although, it is expected that the URM infill walls start cracking at considerably lower lateral drifts of 0.3%, and thus, will most likely lose their load carrying capacity fully by drifts of 1% and 2%.

**Sengupta et. al (2003)-** The purpose of this paper is to develop a method for assessing the seismic vulnerability of reinforced concrete in 3- ten-story residential and commercial buildings. The use of the local retrofitting strategy shown here is as follows:

- Steel Jacketing
- Steel Plating
- Use of FRP bars
- Addition of Concrete / Concrete Jacketing

It is necessary to conduct evaluations of a building against seismic loadings both prior to and post retrofitting.

**N.M.Bhandari and A.K. Dwivedi (2003)-** The authors describe the materials utilized in retrofitting like Epoxy, Steel, Mortar, Quick Setting Cement Mortar, and FRP Sheets. Furthermore, they also elucidate the variety of techniques of retrofitting such as Shotcrete Jacketing, Mechanical Anchorage, Insertion of new walls, Masonry arches, and strengthening of existing Unreinforced Masonry Infills.

**Kondraivendhan and Pradhan (2009)** The authors documented the effect of ferrocement confinement on concrete columns while keeping other parameters constant. The following Grades of Concrete were used, namely – M25 (Fck = 25N/mm2), M30 (Fck = 30N/mm2), M35 (Fck = 35N/mm2), M40 (Fck = 40N/mm2), M45 (Fck = 45N/mm2), M50 (Fck = 50N/mm2), M55 (Fck = 55N/mm2). 42 Plain cement concrete specimens, each cylindrical with a diameter of 150mm and 900mm of height were formed, half of which were controlled, and other, confined specimens were cast and tested for the effects of confinement by ferrocement. The results found that compressive strength improved significantly by up to 78% in the case of lower grade concrete, i.e., M25, while M55 grade concrete saw a compressive strength improvement of 45.3%.

**Turgay et. al. (2010)-** The research targets to –

1. Study the effects and subsequent failure mechanisms of large-scale square/rectangular columns wrapped in fiber-reinforced polymer (FRP) sheets.
2. Study of the effects and failure mechanisms of large-scale square columns wrapped in carbon fiber reinforced polymer (CFRP) sheets.
3. A comprehensive result on longitudinal and transverse reinforcement of FRP Jackets on concentrically loaded columns and their behavior.

20 specimens of large-scale reinforced concrete columns were tested for failure under axial loading. The specimen was categorized as –

1. Unwrapped (C1)
2. Partially Wrapped (C2)
3. Fully Wrapped (C3)
4. Partially Wrapped with two layers (C4)
5. Fully wrapped with two layers (C5)

The dimensions of all specimens were 200mm x 200mm for square columns with 1.0 m height and were subject to 2000KN of uniaxial compression load via the testing machine.

With monotonically increasing compression subjected to each specimen until fracture, it was observed that the standard cylinder specimen attains a compressive strength of 18.08 MPa in 28 days, and 19.36 MPa in 60 days. While fully wrapped specimens with the slenderness ratio of 5:1 were observed to fracture from the top or bottom quarters; the partially wrapped specimens failed at the ends of the confinement region. It was also observed that the CFRP partially wrapped with one-layer specimens resulted in a noticeable increase in ductility with this being more significant in columns with eight longitudinal bars. Furthermore, for all specimens that were fully wrapped with one layer of CFRP, the transverse reinforcement with a diameter of 12mm resulted in clear enhancements of the benefits of CFRP in ductility.

**Xiong et. al (2011)-** The authors compared the load-carrying capacity and ductility of two major retrofitting methods –

- Ferrocement confinement including steel bars (FS)
- Bar mat mortar with steel bars (BS), and
- Fiber-reinforced polymer (FRP) wrapping

The column specimens were tested under uniaxial compression. Reinforced concrete cylindrical columns of diameters 105mm and 150mm, and height of 450mm were tested. The samples were cured for 27 days in a curing room after wet curing for 24 hours.

Samples of diameter 105mm were confined in FS, or BS while the samples of 150mm diameter were wrapped in FRP. Results showed that the compressive strength of FS columns was 30% more than that of BS Columns with increased ductility and energy absorption than both BS and FRP as well.

**Mourad and Shannag (2012)-** The author tested the ultimate load capacity and stresses of samples of column specimens confined in Ferrocement reinforced with welded wire mesh material as displayed.

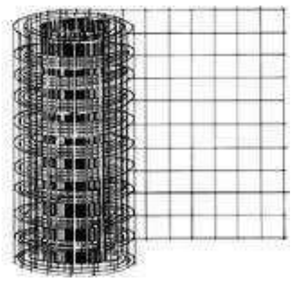

Fig -1: Welded wire mesh.

The results showed an increase of about 33% in the load-carrying capacity of pre-stressed specimens while also improving the ductility of the sample.

Moreover, for samples stressed at 80% and 60% of their ultimate load capacity, results showed that the confinement improved their ultimate load capacity by 15% and 28% respectively. Also, the column specimens failed in ductility as opposed to brittle failures of their controlled specimen counterparts.

**Matsagar and Jangid (2008)-** The system response of the rebuilt structure is obtained numerically by resolving the control parameters of the movement under different earthquakes and compared to the conventional corresponding structure without any restorative measures, in order to investigate the effectiveness of the foundation division in the relocation of buildings. It is noteworthy that the earthquake response of the reconstructed structures is significantly reduced compared to conventional structures that reflect the efficiency of the remodeling process carried out by the basic partitioning strategy. This paper also describes in detail the construction methods in rehabilitation activities that include the foundation division.

**Trapani et.al (2020)-** This paper presents a development framework aimed at reducing the costs associated with seismic retrofitting with better placement (topological development) and the amount of reinforcement of the steel jacket. In the proposed framework 3D RC frame-fiber-section Open Sees is hosted with a genetic algorithm system that duplicates to strengthen the preparation to match the correct solution. The feasibility of each solution is determined by the results of the static push analysis of the N2 road framework. The results will provide a tailored area and a value for steel-jacketing consolidation, showing how effective and sustainable reductions in reimbursement costs can be achieved to maintain a specified security level.

**Falcone et.al (2019)** The author develops a rational approach, based on applications of Genetic Algorithms (GA), which aims to select the "most feasible" solution among the technological possibilities. The paper shows that the important GA operators (that is, selection, intersection, and mutation) apply to candidates for recovery solutions that, legally, can include the combination of strategies at the member and building. Detailed information on the utility of the proposed approach is reported, along with a summary of specific applications within the RC framework thereby introducing utility in a wide range of existing buildings in countries like Greece and Italy, alongside other South European countries.

## 3. CONCLUSIONS

In conclusion, a thorough review of available literature on the topic of seismic retrofitting has been conducted providing considerably important takeaways on key issues relevant to the topic of Seismic Retrofit of Reinforced Concrete Framed Buildings. While some authors proposed novel seismic rehabilitation and strengthening methods for these structures; most researchers discussed the following methods –

- Concrete Jacketing of Columns
- Reinforced Brick Masonry Infill
- X and V Bracings
- Introduction of Shear Walls in the system
- Fibre Reinforced Polymer Wrapping of Columns and Beam Members

Although, these topics need further research as it is important for efficient seismic retrofitting of these buildings; it is achievable using modern software and analytical tools to achieve greater results.

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**BIOGRAPHIES**

Sarfaraz Alamgeer Kamal Yezdani is a Chartered Structural Engineer working in the field for the past 5 years. He received his Bachelor of Engineering degree in Civil Engineering from Rajiv Gandhi Technical University, Bhopal. He has completed more than 70 Government projects as well as many private projects. He has considerable expertise and knowledge in the field of Structural Engineering and Design, and he specializes in Advanced Foundation Design and Design of Earthquake Resistant Structures.

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