Advances in Seismic Strengthening Materials and Techniques

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Abstract. Seismic strengthening of reinforced concrete (RC) members is a method of improving their existing capacity to withstand seismic forces. The process typically includes strengthening of RC structural members such as beams, columns, slabs, footings, beam-column junctions, etc. to improve the axial, flexure, and shear capacity. Experiences during the recent earthquakes and changes in Indian Standards made it essential to carry out structural audit of buildings. The buildings, which do not comply with the recent Code provisions have to be reconstructed or to be strengthened to achieve the desired capacity level. Reconstruction of such buildings will consume time and money. In addition, evacuation of such buildings for reconstruction is a difficult task. In this paper an attempt has been made to focus on the seismic strengthening of structural members of RC buildings which are designed to only gravity loads or the structures designed prior to release of new building Codes. This paper covers a brief introduction of conventional methods of strengthening followed by an introduction of advanced FRP composite materials and techniques of retrofitting for existing RC buildings. Finally, it is concluded that the advanced FRP composite materials and recent innovative methods can more advantageously used for seismic strengthening of RC buildings.

1. Introduction
Many buildings in India are vulnerable due to inadequacy in their strength due to some reason though they are coming under high intensity zone of earthquake as per study of Giuseppe Oliveto and Massimo Marletta [1]. In seismic strengthening seismic load resisting capacities of buildings are improved such that these become safe as per existing Codal provisions. Different factors affecting strength of structures are its dimensions, materials used for their construction and material properties, arrangement and percentage of reinforcement etc. Structures requires strengthening due to several reasons like weakening of structure due to accident, damage in earthquake or changes in standards due to change of Code of practice. Sometimes changes in structure are made due changes of uses of building or changes in environment. The main aim in strengthening of structure is to improve its strength, stiffness and sometimes ductility or durability. Rehabilitation is requires sometimes for old buildings which had lost their strength due to old edge. Retrofitting is essential to meet current Code requirement. Different conventional technics and some innovative technics available and are in practice for seismic strengthening. Use of composite has become popular in recent days due to their added properties and simplicity in applications. Work done by previous researchers on seismic strengthening of RC structure with conventional and innovative methods is reviewed and special
attention is made on use of FRP composite materials and other combinations used in seismic resistance of existing structure, strengthened structure, structure repaired after damage and review of research made by many researchers in regards to strength, stiffness and effectiveness. Use of FRP was studied by Asfa M et al. [2] for seismic strengthening of shear wall with openings using different configuration of FRP around opening and found that, FRP composite can be used effectively for improving behaviour of shear walls with openings. And it was also investigated that, there is remarkable enhancement in behaviour of shear wall having opening by making FRP strengthening. Different techniques of retrofit or strengthening are available but their choice depend on expected failure mode, consequences of wall retrofit, physical limitations, and budget available as investigated by Galall K. and El-Sokkary H [3]. Application of CFRP strips and its usefulness in applying as a of the externally bonded CFRP around structural member in improving the capacity of RC member compared to externally bonded CFRP sheets is made by Mofidi Amir and Chaallal Omer [4]. Use of FRP in RC structure was studied considering parameters like point of application of these strips, width of strip and location of strips with respect to shear reinforcement. It was observed that, use of FRP in the form of strips is more advantages than to use it as continuous sheets. Placing CRP strip between reinforcement found beneficial than that of placing them along same location. Use of jacket having high performance was tried for strengthening of existing shear wall by Marini A. and Meda A. [5]. Performance of shear wall found improved significantly in term of strength, as well as ductility and deformability. Use of cement composite with fiber reinforcement was tried by Parra-Montesinos and Gustavo J. [6] for seismic strengthening of structures like beam to column joint, shear wall having low height, coupling beam etc. It was observed that, use of this type of composite significantly improves behaviours like strength, deformation capacity and overall behaviour of structural element. Marini A. and Meda A. [5] had presented use of jacket made with steel mesh for retrofitting of shear wall and observed that, use of this jacket having very good performance in safeguarding structures from earthquake and in improving behaviours like strength, deformation capacity, ductilityetc. Layssi Hamed and Mitchell Denis [7] made tests on two walls repaired with jacket of steel fibers concrete having self-consolidation property and retrofitted with warp of CFRC and found that retrofitting of wall make it to behave with improved ductility. Repair with above jacket improved displacement behaviour of walls and flexural behaviour. Galall K. and El-Sokkary H [3] made use of carbon fiber polymer in rehabilitation of shear wall improving its behaviour and observed that, performance of shear wall improved remarkably in shear strength, flexure and ductility. Lee Kang Seok et al [8] in their investigation on column found that, use sprayed FRP in strengthening of column improved shear strength and deformation capacity markedly.

2. Conventional Strengthening Methods
IST Group (2004) presented conventional strengthening used in structure to improve performance of structural members. These methods consists of addition of structural member where required, placing a new shear wall, enlarging size of existing structural element or bracing of existing structural elements etc. Addition of shear wall and bracing system found most efficient and it has became more popular due to their ease in construction, lower in cost and having good effect compared to other methods. Shear wall helps to resist most of the probable lateral load acting on structure keeping structure safe [9, 10]. Following conventional methods are in present practices.

- Supporting with steel sections
- Addition of precast walls
- Strengthening with additional foundation
- Jacketing with suitable high performance material
- Addition of extra column
- Grouting weaker section
Use of steel section in the form of cross bracing and as a steel plate shear wall is common method since past many years. These are easy to apply and causing minimum disturbance to occupants while installations and have good strength. Some other methods are also in use like shotcreteing, grouting and epoxy injection, and prefabricated reinforced concrete thin walls panels or steel plate bracing fixed to one side of brick wall etc. are also work effectively in strengthening of structures. Results of conventional methods of repair and retrofitting are not up to mark of satisfaction. Existing practices of repair of buildings go little beyond cosmetic treatment of the structure. Such methods neither strengthen the structure nor extend its life as observed by Mukherjee Abhijit and Joshi Mangesh V. [11]. Recently new and innovative methods are come in practice, which includes use of composite materials, use of energy dissipaters and isolators in seismic resisting system.

3. Retrofit of Structures using Innovative Materials and Approaches

The innovative methods of seismic retrofitting may be grouped into the following classes as per Gustavo J. Parra-Montesinos et al. [9] had differentiated these methods in to following classes.

- Base isolation
- Energy Dissipation System
- Use of Composite
- Combination of above methods

3.1. Base isolation (Stiffness reduction)

The base isolation is effective method of stiffness reduction approach. Base isolation is separation of super structure of buildings from sub structure introducing base isolators in between for the purpose of reducing seismic effect on buildings. Though technology is still developing, it is being used in many structures in worldwide. Each structure has its own natural frequency of vibration depending on various factors like mass, stiffness and height. Whole building oscillates in earthquake violently with frequency of earthquake. Base isolators are available in different variety like roller bearing isolators, springs isolators, sliding Bearing, elastomeric bearings. Each type has its own advantages and dis advantages or limits to use. Figure 1 shows all these type of isolators.

3.2. Confinement (Ductility increase)

Confinement of weak or failed element can be done with FRP composites. It improves ductility of member. In this method, structural members are strengthened with application or warping of structural members where essential for improving seismic resisting capacity of them. These materials in new form are easy to apply and are more efficient.

3.3. Energy Dissipation System (damage controlled structures)

In this method of seismic retrofitting new elements called dissipaters are introduced with diagonal braces to damp seismic forces by absorbing seismic energy striking to structures at the time of occurrence of earthquake.
Dampers works like hydraulic shock absorbers in vehicles, which absorbs most of the jerks due to acceleration or rough roads. Commonly used seismic dampers are shown in Figure 2 and are explained below.

![Seismic Dampers](image)

**Figure 2.** Type of Seismic Dampers

- **Viscous Dampers:** In this system, energy of seismic wave is absorbed with fluid passing between piston and cylinder arrangements. Piston head utilizes specially shaped passages and damp the energy by altering the flow.
- **Friction Dampers:** In this system, seismic energy is absorbed with friction between rubbing surfaces. Use of friction between plates is made for controlling seismic waves.
- **Yielding dampers:** In this system, seismic energy is absorbed by yielding of secondary components inserted between two main components during shock or vibration.
- **Viscoelastic dampers:** In this system, seismic energy is absorbed by utilizing the controlled shearing of solids converting seismic energy to heat energy.

### 3.4. Use of Composite Materials

Composite materials are made with a addition of two or more materials for getting available a new material having required additional properties. Use of composite materials is familiar and aware to human being from ancient days for improving properties of materials to be used in homes or making articles as per study of Pandey P.C. [10]. Use of straw in mud bricks in old days is one of the best examples for this thing. CFRP, GFRP, AFRP are the mostly used polymers in construction industry for strengthening or retrofitting. These materials are superior in quality, easy to apply and reasonable in cost so had preferred for strengthening or retrofitting by most of the peoples from last few decades. Each ingredient of the composite material do not dissolve each other though they are working in same mixture and for same work. One material is material mix with other in the form of reinforcement. Reinforcing material is generally available in fibers, particles or sheets and they are mixed to matrix which is a bulk material in which reinforcing materials are dispersed as per nptel.ac.in [12]. As per study of Susana Cabral-Fonseca [13] four main fibers used in the construction industry are: (i)carbon fiber, (ii) glass fiber, (iii) basalt and (iv) aramid. Composite materials are used generally for local strengthening of structural elements either in compression, flexure or in shear.

These materials are applied generally for

- (a) Strengthening of RC members for flexural
- (b) Strengthening of RC members shear
- (c) Confinement of RC members

### 4. Flexural Strengthening of RC Members

Structural members can be strengthened using FRP in the region of their maximum tension, compression or shear stresses. FRP is applied in the form of strips or sheets as per requirement. Epoxy is used as adhesive generally [4]. For proper application of FRP standards are available. Flexural strengthening of beam is shown in Fig. 3.
5. Shear Strengthening of RC Members

Shear strengthening of structural member is done as shown in Figure 4. For shear strengthening FRP is applied on beam surface in inclined manner with beam axis to resist shear stresses in beam cross section[13]. Strengthening of column is usually done as shown in Figure 5.

Peoples are familiar to use of composite materials from ancient days for improvement of quality of material and for innovative works as per study of Pandey P.C. [10]. Advanced composite materials are more durable, easy to apply and having good strength. Strengthening of structural members has become easier due to introduction of FRP in strengthening application. Commonly CFRP, GFRP, and AFRP are used in most of situations like flexural, shear or compression strengthening. Columns are generally strengthened for compression with confinement. For beams, bonding of FRP is made on externally for flexure or shear at specific locations.
6. Summary

Retrofitting of structures can be made with different way according to suitability of use for particular type of failures. Table 1 gives information of different types of retrofitting.

**Table 1. Summary of retrofitting methods**

| Method of retrofit            | Arrangement used                  | Applications, use and nature                                                                 |
|-------------------------------|-----------------------------------|---------------------------------------------------------------------------------------------|
| Conventional methods          | Steel bracing or steel plate, jacketing, grout etc. | Applied for existing as well as failed structures                                              |
| Base isolation                | Base isolators                    | Generally applied to heavy structures. Separates sub and super structures. Reduce seismic energy by stiffness reduction using isolating pads or bearings. |
| Energy Dissipation System     | Dampers                           | Suitable for short as well as tall building. Applied as cross bracing. Damps seismic energy to safeguard structure. |

7. Conclusion

Different innovative methods are now available for strengthening and retrofitting technique for improving behaviour of structures and make them safe for use as per standards. These different techniques consists of strengthening of existing structures by addition of member, application of shotcreting, ferrocement filling, use of advanced composite materials and different techniques for seismic retrofitting. RC structures can successfully be strengthen or retrofitted with advanced composite materials and by using different techniques. FRP composites are most efficient easier in application material for retrofitting of structural element. Composites can be used effectively for retrofitting. Addition of new shear walls and steel bracing elements can be suitably done as per requirement. Retrofitting can be done successfully by strengthening applications mainly due to the relative ease of installation. It is essential to retrofit the buildings, which are seismically unsafe using suitable materials and techniques. The retrofitted structural members are able to develop their nominal axial, flexural, shear capacities and ductility. Finally, it can be concluded that the advanced composites materials can be used for seismic strengthening of structures with better performance than conventional methods. Innovative methods like base isolation, energy dissipation or use of composite materials are new, easier, economic and effective techniques over conventional strengthening methods.

References

[1] Oliveto G and Marletta M 2005 Seismic retrofitting of reinforced concrete buildings using traditional and innovative techniques ISET Journal of earthquake technology 42 21-46
[2] Asfa M, Mostofinejad D and Abdoli N 2011 Advances in FRP Composites in Civil Engineering: Springer) pp 837-40
[3] Galal K and El-Sokkary H 2008 Recent advancements in retrofit of RC shear walls. In: Proceedings of the Fourteenth World Conference on Earthquake Engineering. Beijing, China,
[4] Mofidi A and Chaallal O 2011 Shear strengthening of RC beams with externally bonded FRP composites: Effect of strip-width-to-strip-spacing ratio Journal of Composites for Construction 15 732-42
[5] Marini A and Meda A 2008 Seismic retrofitting of existing shear walls by means of high performance RC jacket. In: Proc. of the 14th World Conference on Earthquake Engineering, Beijing,
[6] Parra-Montesinos G J 2005 High-performance fiber-reinforced cement composites: an alternative for seismic design of structures ACI Structural Journal 102 668
[7] Layssi H and Mitchell D 2012 Experiments on seismic retrofit and repair of reinforced concrete shear walls. In: Proceedings of the 6th International Conference on FRP Composites in Civil Engineering (CICE), pp 13-5

[8] Lee K S, Lee B Y and Seo S Y 2016 A seismic strengthening technique for reinforced concrete columns using sprayed FRP Polymers 8 107

[9] Parra-Montesinos G J, Canbolat B A and Jeyaraman G 2006 Relaxation of confinement reinforcement requirements in structural walls through the use of fiber reinforced cement composites. In: 8th National Conference on Earthquake Engineering,

[10] 2004 Methods for Seismic Retrofitting of Structures-technical IST Group

[11] Mukherjee A and Joshi M V 2002 Seismic retrofitting technique using fibre composites Indian concrete journal 76 496-502

[12] https://nptel.ac.in/courses/105/108/105108124/

[13] Custódio J and Cabral-Fonseca S 2013 Advanced Fibre-Reinforced Polymer (FRP) Composites for Structural Applications: Elsevier) pp 814-82

[14] Motavalli M and Czaderski C 2007 FRP composites for retrofitting of existing civil structures in Europe: State-of-the-art review. In: International Conference of Composites & Polycon: American Composites Manufacturers Association Tampa, FL, USA) pp 17-9