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Study on Various Methods and Techniques of Retrofitting

Komal Bedi
GNIET Nagpur

Abstract

The retrofit process is a general term that may consist of a variety of treatments, including: preservation, rehabilitation, restoration and reconstruction.

Selecting the appropriate treatment strategy is a great challenge involved in the retrofit process and must be determined individually for each project. Depending on project objectives, preservation and renovation of buildings may involve an array of diverse technical considerations, such as fire life safety, geotechnical hazards and remedies, weathering and water infiltration, structural performance under earthquake and wind loads.

1. Introduction

Preservation is defined as the process of applying measures to sustain the existing form, integrity, and materials of a historic property. Rehabilitation refers to the process of creating new application for a property through repair, alterations and additions while preserving those features which convey it's historical, cultural, or architectural values. Restoration is the process of accurately restoring a property as it existed at a particular period of time. Reconstruction is described as the act of replicating a property at a specific period of time.

Rehabilitation provisions require selecting the rehabilitation objectives and acquiring current building information prior to performing rehabilitation design. At the stage of selecting the retrofitting method, the current status of the existing structure and its performance are known, and the performance required for the structure after retrofitting. Factors that should be considered in selecting the method include the effectiveness of the various retrofitting methods with respect to the required performance improvements, the viability of execution of the retrofitting work, the impact of the retrofitting work on the surrounding environment, the ease of maintenance after retrofitting, economy and other factors.

2. 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.
- Repaving method: Replacing some or all of the existing concrete members with new members through the use of precast members or concreting on site to restore or improve load-carrying capacity.

3. 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 load-carrying 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 load-carrying 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 load-carrying 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.

4. Foundation Retrofitting

- Underground wall (beam) addition method: Connecting the foundations with cast-in-site diaphragm walls and underground connecting beams to distribute stress and ensure the stability of the entire system.
- Pile/footing addition construction method: When pile foundations are damaged or there is residual displacement, adding piles or footings to increase the load-carrying capacity of the foundation.
- Foundation improvement method: Improving the ground around the foundation with cement improvement materials to improve the ground bearing capacity and horizontal foundation resistance. Also prevents excessive pore water pressure and liquefaction.
- Steel sheet-pile coffering construction method: Placing sheet-piles around the periphery of the footings and bonding them to the footings to improve bearing capacity and horizontal resistance.
- Foundation compacting method: When insufficient foundation bearing capacity is a concern due to scouring or the like, using concrete or the like to compact the ground around the foundation in order to restore bearing capacity.
- Ground anchor method: When bridge abutments or the like move or tilt laterally as a result of an earthquake, etc., using ground anchors to stabilize the bridge abutments.

5. Repair of Cracks

- Crack fills method: Forcing low viscosity resin and ultra-fine cement into the cracks in existing concrete members to seal the cracks.
- Fill method: Filling cracks, rock pockets, cavities, peeling and other small-scale missing sections in existing concrete members with resin and mortar to repair sections.
- Section repair method: Removing deteriorated or damaged portions of existing concrete

6. Historical Building

Buildings with historic value are regional cultural assets worth preserving. Minimizing noise, disturbance, and damage to the surrounding buildings and providing temporary shoring and support are typical challenges involved in most retrofit projects. Depending on the extends of retrofitting, assessed risk, technical limitations, structural historic value, and economical constraints, the preferred retrofit strategies are studied to preserve the authenticity of historic fabrication and minimize removal of architectural material:

6.1. No penetration of Building Envelope

The process does not require any destructive procedure so the historic fabrication remains untouched. This approach is only applicable to very limited cases since structural components are mostly either embedded in or covered by the finishing.

6.2. Penetration without Breakage

The structural component subjected to retrofitting is accessible, and the retrofit process only requires drilling holes

6.3. Breakage with Repair

In many cases, some destructive procedures are required to access the structural component or to perform retrofit process.

6.4. Replace

In cases structural components cannot be improved to meet retrofitting objectives or the damage or deterioration could not be repaired, components are replaced.

6.5. Rebuild

In cases a feasible retrofitting solution cannot be found, the historic building is reconstructed, partially or as a whole.

7. Innovative Technologies for Historic Preservation

Modern materials and equipment provide many retrofit options to improve the behavior of structural system, global strength, and stiffness or mitigate the seismic hazards. Some of the commonly used techniques in retrofitting are listed below:

Figure 1

Figure 2

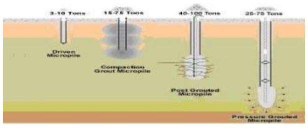

Figure 3

7.1. Post Tensioning

Post tensioning (fig1) is considered one of the potentially efficient retrofit options for reinforced concrete or masonry buildings. Masonry has a relatively large compressive strength but only a low tensile strength. Hence, it is most effective in carrying gravity loads. Commonly, induced tensile stresses exceed the compressive stresses and reinforcing must be added to provide the necessary strength and ductility.

7.2. Composite Wraps

Composite wraps (fig2) or carbon fiber jackets are used to strengthen and add ductility to reinforced concrete and masonry components without requiring any penetration. Composite wraps are most effective on reinforced concrete columns by providing additional confinement.

7.3. Micro-piles

Micro-piles (fig3) are utilized in foundation rehabilitation and seismic retrofitting projects to enhance the foundation ultimate capacity and reduce foundation deflection.

7.4. Epoxy

Epoxy is one of the most versatile materials used in structural repair and retrofitting and it is used as a sealant, adhesive or mortar.

8. Seismic Retrofitting Technique

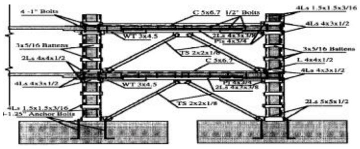

Figure 4

There are many seismic retrofit techniques available, depending upon the various types and conditions of structures.

8.1. Structure-Level Retrofit

Structure-level retrofits are commonly used to enhance the lateral resistance of existing structures. Such retrofits for RC buildings include steel braces, post-tensioned cables, infill walls, shear walls, masonry infill's, and base isolators.

8.2. Addition of RC Structural Walls

Adding structural walls is one of the most common structure-level retrofitting methods to strengthen existing structures. In order to reduce time and cost, shotcrete or precast panels can be used. The overturning effects and base shear are concentrated at the stiffer in fill locations.

8.3. Use of Steel Bracing

Concentric or eccentric bracing (fig4) schemes can be used in the selected bays of an RC frame to increase the lateral resistance of the structure. The advantage of this method is that an intervention of the foundation may not be required because steel bracings are usually installed between existing members.

8.4. Seismic Isolation

The objective of this type of retrofit is to isolate the structure from the ground motion during earthquake events. The bearings are installed between the superstructure and its foundations. Because most bearings have excellent energy dissipation characteristics, this technique is most effective for relatively stiff buildings with low-rises and heavy loads.

9. Member-Level Retrofit

The member-level retrofit approach can provide a more cost-effective strategy than structure-level retrofit because only those components needed to enhance the seismic performance of the existing structure are selected and upgraded. The member-level retrofit approaches include the addition of concrete, steel, or fiber reinforced polymer (FRP) jackets for use in confining RC columns and joints.

9.1. Column Jacketing

Column retrofitting is often critical to the seismic performance of a structure. To prevent the story mechanism during earthquakes, columns should never be the weakest components in the building structure. The response of a column in a building structure is controlled by its combined axial load, flexure, and shear. Therefore, column jacketing may be used to increase column shear and flexural strength so that columns are not damaged. Fiber reinforced polymer (FRC) material is used for jackets when retrofitting columns.

10. Surface Treatment

Surface treatment is a common method, which has largely developed through experience. Surface treatment incorporates different techniques such as ferrocement, reinforced plaster, and shotcrete. By nature this treatment covers the masonry exterior and affects the architectural or historical appearance of the structure.

10.1. Ferrocement

Ferrocement consists of closely spaced multiple layers of hardware mesh of fine rods with reinforcement ratio of 3-8% completely embedded in a high strength (15-30 MPa) cement mortar layer (10-50 mm thickness). The mortar is troweled on through the mesh with covering thickness of 1-5 mm. The mechanical properties of ferrocement depend on mesh properties. However, typical mortar mix consists of 1 part cement: 1.5-3 parts sand with approximately 0.4 w/c ratio. The behavior of the mortar can be improved by adding 0.5-1% of a low-cost fiber such as polypropylene. Ferrocement is ideal for low cost housing since it is cheap and can be done with unskilled workers. The mesh helps to confine the masonry units after cracking and thus improves in-plane inelastic deformation capacity.

Figure 5

10.2. Reinforced Plaster

A thin layer of cement plaster applied over high strength steel reinforcement can be used for retrofitting. The steel can be arranged as diagonal bars or as a vertical and horizontal mesh. The improvement

Its strength depends on the strengthening layer thickness, the cement mortar strength, the reinforcement quantity and the means of its bonding with the retrofitted wall.

10.3. Grout and Epoxy Injection

Grout injection is a popular strengthening technique, as it does not alter the aesthetic and architectural features of the existing buildings. The main purpose of injections is to restore the original integrity of the retrofitted wall and to fill the voids and cracks, which are present in the masonry due to of the slab can prevent punching shear failures.

10.5. FRP Strengthening

A Fibre Reinforced Polymer (FRP) typically consists of high tensile continuous fibres oriented in a desired direction in a speciality resin matrix. These continuous fibres are bonded to the external surface of the member to be strengthened in the direction of tensile force or as confining reinforcement normal to its axis. FRP can enhance shear, flexural, compression capacity and ductility of the deficient member. Glass fibers are the most common types of fibers used in the majority of commercially available FRPs. FRP systems, commonly used for structural applications.

FRP strengthening is a quick, neat, effective, and aesthetically pleasing technique to rehabilitate reinforced and pre-stressed concrete structures. Unlike steel plates, FRP systems possess high

physical and chemical deterioration or mechanical actions. For injection, epoxy resin is used for relatively small cracks (less than 2 mm wide); while, cement-based grout is considered more appropriate for filling of larger cracks, voids, and empty collar joints in multi-Wythe masonry walls. Walls retrofitted with epoxy injection tend to be stiffer than the unretrofitted, but the increase in stiffness (10 - 20%) is much less dramatic than the increase in strength. The increment in lateral resistance ranged from 2-4 times the unretrofitted resistance. The use of epoxy resins can be advisable when a thorough study of the structural consequences of such an increment in strength in selected portions of the building shows that there is no danger of potential damage to other portions.

10.4. Slab-Column Connection Retrofits

In slab-column connections, punching shear failure due to the transfer of unbalanced moments is the most critical type of structural damage. The retrofitting of slab-column connections is beneficial for the prevention of punching shear failures and much research into retrofitting slab-column connections has been conducted and reported that adding concrete capitals or steel plates on both sides

strength to self-weight ratio and do not corrode. But, it is imperative to be aware of the performance characteristics of various FRP systems under different circumstances to select a durable and suitable system for a particular application. It should be ensured that the FRP system selected for structural strengthening has undergone durability testing consistent with the application environment and structural testing in accordance with the anticipated service conditions. Suitably designed protective coatings may also be applied on an FRP system to protect it from exposure to adverse environmental conditions

10.6. Shotcrete

Shotcrete (fig5) overlays are sprayed onto the surface of a masonry wall over a mesh of reinforcing bars. The thickness of the shotcrete can be adapted to the seismic demand. In general, the overlay thickness is at least 60 mm. In order to transfer the shear stress across shotcrete-masonry interface, shear dowels (6-13 mm diameter @ 25-120 mm) are fixed using epoxy or cement grout into holes drilled into the masonry wall. Retrofitting using shotcrete significantly increases the ultimate load of the retrofitted walls. This retrofitting technique dissipates high-energy due to successive elongation and yield of reinforcement in tension.

11. Recent Retrofitting Methods

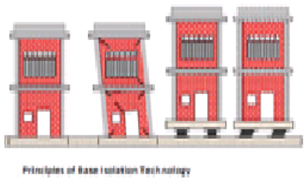

Figure 6

There are many relatively new technologies developed for seismic Retrofitting which are based on "Response control". These techniques includes providing additional damping using dampers (Elasto-plastic 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

Reduce the demand/forces on the system (Seismic Response Control Design)
(a)Elasto-Plastic Dampers,
(b)Base Isolators,
(c) Lead Extrusion Dampers,
(d)Tuned Liquid Dampers,
(e) Friction dampers

11.1. Elasto-Plastic Dampers

The proposed retrofitting method achieves a high level of structural safety through dampers installed in an existing seismically vulnerable building more efficiently than conventional retrofitting methods. There are many ways of installing dampers in an existing building, including (1) installing steel-framed braces that incorporate dampers into an existing open frame and (2) installing damper-embedded studs into existing frame so that existing openings are maintained. The latter method can be used in cases where the building is to be strengthened internally. Dampers used in this retrofitting method are elasto-plastic steel dampers that have honeycomb openings. External cable method, bonding and jacketing method and overlaying and jacketing method has most often been limited to beams, columns, slabs and so on.

11.2. Liquid Dampers (TLDs)

TLDs are rigid walled containers filled with liquid up to certain height, to match the sloshing frequency and are placed at the rooftop of the structure.

11.3. Base Isolators

Base isolation (fig6) 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 seismicity of the region and the underlying soil conditions should also be considered in the feasibility studies and design process. Constraint in the application of base isolation is the large relative displacements between the superstructure and the supporting ground at the isolation level. A clearance around the building must be provided and maintained through the life of the structure to accommodate the expected large displacements. Such displacements may be reduced with the incorporation of additional stiffness and energy dissipation mechanisms in the isolation system. Isolators have low horizontal stiffness and they are placed between the structure and foundation.

11.4. Non-Metallic Fiber Composites/Fiber Reinforced Composites (FRC)

Commonly used forms of FRC viz. Pre cured CFRC (Carbon Fiber Reinforced Composite), Glass Fiber Reinforced polymer Composites (GFRC) rebar, glass fibre roll, etc. Fiber Reinforced Polymer (FRP) composites comprise fibers of high tensile strength within a polymer matrix such as vinyl ester or epoxy. FRP composites have emerged from being exotic materials used only in niche applications following the Second World War, to common engineering materials used in a diverse range of applications such as aircraft, helicopters, space-craft, satellites, ships, submarines, automobiles, chemical processing equipment, sporting goods and civil infrastructure. The role of FRP for strengthening of existing or new reinforced concrete structures is growing at an extremely rapid pace owing mainly to the ease and speed of construction, and the possibility of application without disturbing the existing functionality of the structure. FRP composites have proved to be extremely useful for strengthening of RCC structures against both normal and seismic loads.

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