Part 3: Seismic Evaluation and Retrofitting of Existing Reinforced Concrete Buildings
What is seismic evaluation?

Seismic evaluation may be understood like the diagnosis of a person with or without ailment on which the direction and nature of treatment depends. Seismic evaluation implies determining the capacity of the structures to resist earthquakes.
Why the seismic evaluation of a building is a must?

The aim of seismic evaluation is to judge the seismic capacity and vulnerability of buildings during earthquake so that the amount of retrofitting may be determined. There are many deficient buildings, not meeting the current seismic requirements that may suffer extensive damage or even collapse if shaken by an earthquake. This may cause injury to occupants or people living in the vicinity. So, it is necessary to identify weak buildings and to evaluate their capacity for future earthquakes. If required, the buildings must be retrofitted.
What are the procedures for seismic evaluation?

Numerous methods of seismic evaluation of a building are available depending upon the objective of evaluation and the skill of the evaluator ranging from the visual examination to detailed structural analysis. Each has its own advantage, disadvantage and limitations. The most commonly used methods for the seismic evaluation are:

- **Rapid Visual Screening Procedure (RVSP)** - This method is used for short term evaluation of buildings especially at a time when the frightened occupants refuse to re-enter their houses after an earthquake unless they have been assured that the building is safe for future earthquake.

- **Simplified Evaluation Procedure** - ATC-14 (A Handbook for Seismic Evaluation of Existing Buildings and Supporting Documentations) is a document in which a simplified method of seismic evaluation of different types of buildings is recommended. However it has been modified by a number of Indian conditions and requirements and is available in different ways. The purpose of evaluation is to identify the buildings or building components that are risky to human lives.

- **Visual Inspection Method** - It is generally used in earthquake damaged buildings. Based on the visual observation and modes of failure of building components, one estimates that the particular building may be used in future or not. Sometimes the help of Non Destructive Testing (NDT) may also be required.

- **Non-linear Static Pushover Procedure** - Non-linear Static Pushover Procedure is used by the design engineers to evaluate the seismic capacity of the building in terms of strength and ductility. It is very helpful to determine the amount of retrofitting required and to further re-evaluate the building after the retrofitting.

- **Non-linear Dynamic Time History Analysis** - This is a method to evaluate building considering dynamic behavior and non-linear material properties. But it requires huge computational effort and time with competent professional softwares. Therefore, most of the design engineers are generally not adopting this method of evaluation.
Why seismic retrofitting is required?

Past earthquakes have manifested that buildings with proper design and construction have borne the seismic shocks without collapse. But the structures either old or constructed without seismic design techniques have undergone serious damage or even collapse with an irreparable loss of innumerable lives. It has been seriously studied that if such buildings are modified to earthquake resistant structures by employing retrofitting techniques, they may be safely reused with no hazard to property and life safety. This also proves to be a better option catering to the economic considerations and immediate shelter problems rather than replacement of buildings. Moreover, retrofitting of buildings is generally more economical as compared to demolition and reconstruction even in the case of severe structural damage.

Global modification of the seismic deficient system

Local modification of the seismic deficient system
How the retrofitting is defined?

Seismic retrofitting includes concepts like system behavior improvement, components repair/strengthening up to expected performance i.e. minimum required strength and acceptable damage from an earthquake. Various terms like repair, strengthening, retrofitting, remolding, rehabilitation, reconstruction etc. are freely employed with a marginal difference;

Repairing

Repairing suggests reconstruction or renewal of any part of a damaged or deteriorated building providing the same level of strength and ductility as was prior to the damage. Sometimes, Repair is also related to the seismic resistance of the building to its pre-earthquake state.

Retrofitting

Retrofitting includes upgrading earthquake resistance of either an existing seismically deficient building or earthquake damaged building up to the level of the present day codes by appropriate techniques. Retrofitting also incorporates upgrading of certain building system, such as mechanical, electrical, or structural, to improve performance, function, or appearance.

Remolding

Remolding means reconstruction or renewal of any part of an existing building owing to change of usage or occupancy.

Rehabilitation

Rehabilitation encompasses reconstruction or renewal of an earthquake damaged building to provide the level of function, prior to the damage. It also refers to increasing the seismic resistance of an existing seismically deficient building.

Restoration

Rehabilitation of buildings in a certain area may be described as restoration.

Strengthening

Reconstruction or renewal of any part of an existing building to provide better structural capacity i.e. higher strength and ductility than the original building, is taken as strengthening. Sometimes the term strengthening and retrofitting are used simultaneously.

Van diagram for various terms used in retrofitting

Van diagram for various terms used in retrofitting

Van diagram for various terms used in retrofitting
What are the causes that make a building seismically deficient?

For existing seismic deficient buildings

- The buildings have been designed according to a seismic code, but the code has been upgraded in the following years
- Changes in codes over the past 50 years show that the design force levels have increased with each revision and the detailing requirements have been made more stringent
- Buildings are designed to meet the modern seismic codes, but the deficiencies exist in the design and/or construction;
- Existing reinforced concrete (RC) frame buildings with non-ductile detailing
- Essential buildings must be strengthened like hospitals, school & colleges, historical monuments and architectural buildings;
- Important buildings whose service is assumed to be essential even just after an earthquake;
- Buildings, the use of which has changed through the years;
- Buildings those are expanded, renovated or rebuilt.

For earthquake damaged buildings

- Immediate and long terms safety of the occupants since all the damaged buildings can not be replaced or rebuilt
- Economic consideration since the retrofitting, in general, is more cost efficient than reconstruction of buildings
- Important, historical, heritage buildings should be preserved at any cost
What are the problems associated with retrofitting?

The problems faced by a structural or field engineer in case of earthquake vulnerable or earthquake damaged buildings are:

- Methods of seismic assessment or evaluation of existing buildings' capacity
- To obtain sufficient records of buildings such as architectural and structural drawings, structural design calculations, material properties, details of foundation and geotechnical reports, records of at least natural period of the buildings
- Retrofitting and issues of their structural safety
- Guidelines or Codes of Practice on retrofitting
- Issues related to costs, invasiveness and the requirement of specialist knowledge
- Socio-economic issues such as aesthetic and psychological assumptions
- Cost vs. importance of the structure, especially in the case that the building is of cultural and/or historical interest
- The available workmanship and the level of quality control
- The duration of work/disruption of use and the disruption to occupants
- The functional and aesthetic compatibility of the retrofitting scheme
- Selection of the type and level of intervention
- Repair materials and technology available
- Controlled damage to non-structural components
- Sufficient capacity of the foundation system is essential
- To counter the irregularities of stiffness, strength and ductility
What are the concepts of retrofitting?

Aim of retrofitting is to (i) upgrade of the lateral strength of the structure (ii) increase the ductility of structure (iii) increase in strength and ductility

![Graph showing concepts of retrofitting]

Aim of seismic strengthening or retrofitting

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What is the classification of retrofitting techniques?

Two alternative approaches are conceptually adopted and implemented in practice for seismic retrofitting: the first approach focuses on reduction of earthquake induced forces (i.e. modifying the demand) and the second focuses on upgrading the structure to resist earthquake induced forces (i.e. modifying the capacity). While applying the first approach, base isolation or damping devices are commonly applied to the structure. An upgraded structural capacity is achieved either by intervening on specific elements or by changing the load paths within the structure.

Structural Level (or Global) Retrofit Methods

Structural-level approach of retrofitting which involves global modifications to the structural system

Conventional Methods (modifying the capacity)
- Adding New Shear Walls into/onto the Existing Frames
- Adding Steel Bracing into/onto the Existing Frame
- Adding Infill Walls into/onto the Existing Frames

Non-Conventional Approach (modifying the demand)
- Seismic Base Isolation
- Supplemental Damping Devices

Member Level (or Local) Retrofit Methods

Member level approach of retrofitting or local retrofitting of components with adequate capacities to satisfy their specific limit states. It includes jacketing/confinement of Columns, Beam, Beam-Column Joint, Slab, Foundations etc.
What are the considerations in retrofitting of buildings?

Seismic retrofitting is constrained to certain areas of an existing building. In such cases, the retrofitted structure is a "behavioral hybrid" system consisting of strong/ductile components (added elements) and of weak/brittle components (elements that are not strengthened). In the event of an earthquake, all components at each floor, retrofitted or not, will undergo the same lateral displacements. While modified or added elements can be designed to sustain these lateral deformations, the remaining non-strengthened elements could still suffer substantial damage. Therefore, it is suggested that the design of retrofitted schemes should be based on drift control rather than on strength consideration alone and should be able to predict initial and final stiffness of the retrofitted structure.

Idealized storey of a building and load-displacement relationship of elements\textsuperscript{30,31}
What are considerations for retrofitting of a building using shear walls into/onto the existing frames?

Addition of new RC walls is the most common method for strengthening of existing structures. Special consideration is needed to the distribution of the walls in plan and elevation (to achieve a regular building configuration), transfer of inertial forces to the walls through floor diaphragms, integration and connection of the wall into the existing frame buildings and transfer of loads to the foundations. Added walls are typically designed and detailed as in new structures which are designed to carry all or most of the lateral force. These systems simply bypass the existing inadequate system and the need to correct all or most of the deficiencies in the old structure. The main difficulty with this retrofitting scheme is that the lateral forces are concentrated in certain areas where shear walls are added and these walls impose large forces on the foundation. Therefore, new foundations or strengthening of the existing foundations may be required to resist the increased overturning moment and the increased dead load of the structure. Foundation intervention is usually costly and quite disruptive, thus rendering the application of this technique unsuitable for buildings without an existing adequate foundation system. This could be inconvenient in cases where the strengthening project, or when there is not enough or no information on the original foundation design.

Limitations

- Increase in lateral resistance but it is concentrated at a few places
- Increased overturning moment at foundation causes very high uplifting that needs either new foundations or strengthening of the existing foundations
- Increased dead load of the structure
- Excessive destruction at each floor level results in functional disability of the buildings
- Possibilities of adequate attachment between the new walls and the existing structure
- Closing of formerly open spaces can have major negative impact on the interior of the building uses or exterior appearance

Details for addition of a shear wall\[1\]
How far steel bracing is effective as retrofitted technique?

Steel bracing is commonly used in RC framed buildings if heavy reinforced concrete shear walls cannot be supported by existing foundation. Steel bracing can be a very effective method for global strengthening of buildings. Some of the advantages of steel bracing over the shear wall are the ability to accommodate openings, construction work can be performed externally to the building to minimize disruption of the occupants and increase speed of work; small increase in mass, as a result foundation and construction costs may be minimized. But care must be taken to produce a final design that is structurally well balanced i.e. no stiffness irregularity in plan or along the height. Coordination between building owner, engineer and architect is essential to satisfy architectural and functional requirements.

Limitations

- Lack of information on the seismic behavior of the added bracing
- The connection between an existing framing system and added elements should be carefully detailed because forces must be transferred between the existing and added structural system.
- A moderate to high level skilled labor is necessary for construction, due to the need for member fit-up adjustment and welding.
- Close quality control particularly with respect to welding is essential.

Flow chart for retrofitting with bracing system

Detail of the X-bracing system and its connection to the RC frame
How far steel bracing is effective as retrofitted technique?

The steel bracing may be applied either externally or internally. In the external bracing system, steel bracing systems are attached to the exterior frames which create minimum disruption to the function of the building and its occupants and also provide better feeling of security. In case of internal bracing, the buildings are retrofitted by incorporating a bracing system inside the individual bays of the RC frames. The bracing may be attached to the RC frame either indirectly or directly. Different forms of steel bracing such as X, V and K may be used. Cable braces may also be used on a low-rise structure. The cables could be added quickly and with minimal disruption to the occupants. In addition, the cable braces required minimal modification to existing structure. End blocks are provided to hold the cable anchorages at the foundation level and at the roof.

The bracing system should be designed for elastic response, but detailed for ductile behavior. It is desirable to limit the effective slenderness ratio of the braces to 100, and preferably to 80 to limit inelastic buckling therefore it is effective in compression as well as tension. Such bracing members have been shown to exhibit better- absorbing characteristics than braces with higher effective slenderness ratios. Therefore the designer must control the slenderness ratio by selecting the bracing layout and the brace section. Inelastic buckling of the braces is the main problem in achieving good hysteretic ductility.

Bracing patterns
What are considerations for retrofitting a building by infill walls into/onto the existing frames?

A convenient way to introduce infill walls may be by partial or full infilling of strategically selected bays of the existing frame. The infill wall may be provided in a bay consisting of beams and the two columns and the latter acting as its boundary elements. In case of increasing the capacity of existing infill shotcrete is normally used. Pre-cast panels may also be a good alternative in place of cast - in -place infill walls. These walls, well anchored into the surrounding frame with various types of connections (e.g., shear keys, dowels, chemical anchors etc.), not only increase the lateral stiffness of the building significantly, but also relieve the existing non-ductile frames from being subjected to large lateral force demands.

\[\text{(a) Precast concrete block wall}\]

\[\text{(b) Light weight precast wall}\]

Addition of precast infill wall and its connection details\(^{31}\)
How far external buttresses help to reduce the seismic vulnerability of an RC building?

External buttresses increase the lateral resistance of the structure as a whole. It requires a new foundation system. There are two most intricate problems in retrofitting: (i) the buttress stability (ii) the connections between the buttresses and of the building. The buttress should be connected to the floors and columns at all levels to ensure full interaction and resisting the lateral loads. The connection area will be subjected to unusual levels of stresses that require special attention.

![Diagram of external buttresses and connections](image-url)

External buttresses to increase the lateral strength of frame

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How can seismic capacity of a foundation system be increased?

An existing foundation is strengthened for certain justified reasons (i) seismic upgrading of the super-structure; (ii) structural requirements; (iii) capacity design principles; (iv) parameters such as soil conditions and soil-structure interaction.

Retrofitting strategies aim at strengthening the existing foundation system and/or adding supplemental foundation elements (footings or piles). Larger spread footings can distribute the load and additional reinforcement can increase their shear and bending resistance. The incorporation of existing footings into grade beams or mats is another option.

The addition of grade beams or increased size of spread footings usually requires excavation and there are difficulties in pinning or attaching the existing footings to the new elements. Piles may be added to improve the overturning resistance. Adding piles along the perimeter of the building can be an easier task from an economical and constructional point of view. The cost varies depending on the type and the level of intervention. In cases where piles have to be installed in the existing system the cost may dominate the total seismic retrofitting project.

Strengthening of existing foundation system
What is seismic base isolation technique and how can it be used in retrofitting of buildings?

Seismic base isolation is recommended for retrofitting of critical or essential facilities, buildings with expensive and valuable contents and structures. It significantly reduces the seismic impact on the building and assemblies. Seismic isolation involves the insertion of flexible or sliding bearings at one level of a building. The isolation devices are inserted at the bottom or at the top of the first floor columns. Seismic isolation is more appropriate for buildings of historic significance because it may be applied without much disturbance to the historical architectural features. However, inserting an isolator within an existing column is not so simple because of the necessity of cutting the element, temporarily supporting the weight of the above structure, putting in place the isolators and then giving back the load to the column, without causing damages to persons and to structural and non-structural elements.

Possible locations of isolations in a building

Isolation bearing and lateral force - displacement relationship

Insertion of isolation at the intermediate storey
What are energy dissipating devices and how they can be used in retrofitting of buildings?

Energy dissipation devices can be inserted in an existing structure to reduce seismic demand through damping. Visco-elastic fluid dampers, Visco-elastic solid dampers, hysteretic energy dissipating dampers and friction dampers are various types of energy dissipating devices. These devices are also called Added Damping and Stiffness (ADAS) structural elements. They are mechanical devices, practically installed in structures in order to (i) substantially increase the overall damping in a structure, and (ii) to increase the overall stiffness of a structure. ADAS elements are ideally installed in flexible moment-frame structural system to economically achieve a moderately stiff and highly damped building system. It should be noted that most energy dissipating devices become effective with deformation in the devices.

Types of dampers and idealized load displacement relationships

Supplemental damping system used for seismic retrofitting

Column jacketing and a damper added frame
What are the member level (or local) retrofit methods?

To strengthen individual components, structural members and their connections can be retrofitted and/or strengthened by reinforced concrete or steel jacketing, or by fiber reinforced plastic (FRP) or carbon fiber wrapping called local retrofitting. The local modification of isolated components of the structural and non-structural system aims to increase the deformation capacity of deficient components. Local intervention techniques are applied to a group of members that suffer from structural deficiencies and a combination of these techniques may be used in order to obtain the desired behavior for a seismically designed structure.

Topics in global behaviour of frames

Member (or Local) retrofitting aims to improve the seismic deficiency of a member or connection of frame building.37
What is jacketing and how it is effective to increase the strength and ductility of structural members?

Jacketing is most often used and one of the most popular methods for strengthening of a deficient structural member. The most common types of jacketing are reinforced concrete (rc) jacketing, steel jacketing, fiber reinforced polymer (FRP) composite jacketing, jacketing with high tensile materials like carbon fiber, glass fiber etc. The main purposes of jacketing are: 
(i) to increase concrete confinement by transverse fiber/reinforcement, especially for circular cross-sectional member (ii) to increase shear strength by transverse fiber/reinforcement. Transverse fiber should be wrapped all around the entire circumference of the members possessing close loops sufficiently overlapped or welded in order to increase concrete confinement and shear strength. Jacketing of circular cross-section is more effective as compared to rectangular cross-section. Where square or rectangular cross-sections are to be jacketed, circular/oval/elliptical jacketing are most often used and the space between the jacket and column is filled with concrete. Such types of multi-shaped jackets provide a high degree of confinement by virtue of their shape to the splice region proving to be more effective. However, circular and oval jackets may be less desirable due to (i) need of large space, (ii) where an oval or elliptical jacket has sufficient stiffness to confine the concrete along the long dimension of the cross-section, is open to question.

Jacketing techniques

Notes: Shading shows areas of reduced confinement effectiveness

Various shapes of retrofitting jackets
What are types of reinforced concrete (RC) jacketing of columns?

RC jacketing is applied for the rehabilitation of concrete members. If the longitudinal reinforcement placed in the jacket passes through holes drilled in the slab and new concrete is placed in the beam-column joint, it is categorized as global intervention which improves flexural strength of the column but strength of the beam-column joints remains the same. If the longitudinal reinforcement stops at the floor level then RC jacketing is considered as a member intervention technique which improves the axial and shear strength of the column. It has several advantages like avoiding the concentrations of lateral load resistance; no major changes in the original geometry of building; the original function of the building can be maintained. However there are some disadvantages. The presence of beams may require most of the new longitudinal bars in the jacket to be bundled into the corners of the jacket; it is difficult to provide cross ties for the new longitudinal bars which are not at the corners of the jacket; lack of guidelines.
What are the constructional details of one sided reinforced concrete (RC) jacketing of existing columns?

In case of one sided jacketing of existing column, an adequate connection of new added reinforcement with the existing reinforcement of the column is necessary by providing good detailing and closely spaced, well anchored, additional transverse reinforcement. A number of options are as follows:

Details of options in case of one, two or three sided jacketing

1 - existing column; 2 - jacket; 3 - existing reinforcement;
4 - added longitudinal reinforcement; 5 - added ties;
6 - welding; 7 - bent bars
What are the constructional details of four sided reinforced concrete (RC) jacketing of columns?

The details of four sided RC jacketing of an existing column may be provided as follows. However, there are other options may also be possible on the similar fashion.

Diagram with labels:

1 - existing column; 2 - jacket; 3 - key; 4 - bent bars; 5 - added reinforcement; 6 - ties; 7 - welding; 8 - alternative corners

Details of options in case of four sided jacketing
What are the constructional details in reinforced concrete (RC) jacketing of circular columns without beams?

The jacketing of circular columns in case of flat slab (beamless) or has relatively narrow beam, can be achieved by adding longitudinal reinforcement through drilled hole in the slab if possible. Special attention must be paid to the adequate anchorage and splicing of the column ties or hoops.

1 - existing column; 2 - jacket; 3 - added reinforcement; 4 - hoop; 5 - drilled holes

Jacketing of column in case of flat slab or relatively narrow beams
What are the constructional details in steel or strap jacketing of columns?

The steel jacketing involves the encasement of the column with thin steel plates placed at a small distance from the column surface, ensuring gap filled with non-shrink grout. An alternative to a complete jacket is the steel cage or steel angles, placed at the corners of the existing cross-section. Space between the steel cage and the existing concrete are usually filled with non-shrink grout. When corrosion or fire protection is required, a grout concrete or shotcrete cover may be provided. The steel jacket is terminated 1.5" from the top of the footing to avoid possible bearing of the steel jacket against the footing.

Steel profile jacketing for shear only

1 - existing column; 2 - steel angle profile; 3 - steel plate; 4 - supporting plate; 5 - angle profile
What are the constructional details in steel or strap jacketing of columns?

The different options for steel jacketing are as follows:

1 - existing column; 2 - new concrete or grout; 3 - steel incasement; 4 - steel angle profiles; 5 - steel plate; 6 - welding

Steel casements retrofit for shear only.
What are the possible ways to carry out beam jacketing?

Jacketing of beams is recommended because it gives continuity to the columns and increases the strength and stiffness of the structure. In the retrofitted structure, flexural resistance must be carefully computed to avoid strong beam-weak column system since there is a strong possibility of change of mode of failure and redistribution of forces. Beam jacketing may be carried out by one-sided jackets or 3 and 4-sided jackets. At several occasions, the slab has been perforated. The beam should be jacketed through its whole length. The reinforcement has also been added to increase beam flexural capacity moderately.

Steel plate adhesion is also used to retrofit beams. It is advisable to use several thin layers instead of one thick plate, to minimize interfacial shear stresses. The execution of the bonding work helps to achieve a composite action between the adherents. Prevention of premature de-bonding or peeling of externally bonded plates is a most critical aspect of designs.

One sided jacketing or adding strength only to beam soffit
How to carry out four sided RC jacketing of beam?

Four sided jacketing of beam is useful to increase its flexural and shear strength of existing beam. The details for the jacketing are as follows:

1 - existing reinforcement; 2 - added longitudinal reinforcement; 3 - added stirrups; 4 - welded connecting bar; 5 - concrete jacket; 6 - welding

Four sided jacketing or adding strength to beam in flexure and shear.
How to increase the gravity load capacity of existing beam?

Steel rods can be used to improving the shear resistance of damaged or undamaged beams. It can be performed by vertical external clamps or by diagonal ones as shown below:

1 - existing beam; 2 - steel clamp; 3 - steel plate; 4 - nut; 5 - angle profile; 6 - welding

Four sided jacketing or adding strength to beam in flexure and shear\textsuperscript{26}
What are the possible ways to carry out jacketing of staircase slab?

The possible ways to repair the floor slab/staircase slab are as shown below:

1 - added reinforcement; 2 - welding; 3 - added concrete; 4 - existing slab

Possible ways to repair the floor slab/staircase slab\(^\text{26}\)
What are the possible ways to increase the thickness of an existing slab?

Possible ways to increase the flexural strength of existing slab by increasing its thickness. Two details may be possible (i) adding of reinforcement from top (ii) adding of reinforcement from bottom. First option is more preferred.

Details for adding of reinforcement in case of existing slab

Option for the compatibility of the existing slab and the newly added reinforced concrete
Is beam - column joint jacketing also possible?

Various configurations of steel jackets, plates, or shapes have been used to increase the strength and ductility of deficient beam-column joints. Steel jackets consist of flat or corrugated steel plates, or rectangular or circular steel tubes prefabricated in parts and welded in place. The jacket is expected to provide lateral confinement and shear resistance to the joint area, thereby adding strength and ductility to the joint. The corrugated steel jackets are constructed in two halves for easy installation. The vertical seams are welded in situ. The gap between the concrete and the steel jacket is then filled with grout to provide continuity between the jacket and the concrete. The corrugated shape is needed to provide confining pressure by passive restraint in the joint region. However, due to lack of space in the joint region it is difficult enough to provide an adequate confinement.

Another alternative to strengthen the beam-column joint with a steel cage is welded around the joint after casting the column jacket as shown. This type of jacketing is effective in rehabilitating the joint, with improving the strength, stiffness and energy dissipation characteristics of the existing joint.
How to retrofit the existing footing of a retrofitted column?

Retrofitting of existing footing depends upon the objective of retrofitting of columns. In first case, when the existing column is retrofitted with the objective to increase the axial, flexural and shear strength, the capacity of the existing footing is also increased so that the plastic hinges may form in retrofitted column. In second case, the existing column is retrofitted with the objective to increase only shear and axial capacity without increasing flexural strength; footing is retrofitted only for the additional load imposed on it. Retrofitting of footing under both the cases is shown below.

Strengthening of footing of a retrofitted column to increase its (a) flexural, shear and axial strength (b) only shear and axial strength
How to retrofit the existing footing of an un-strengthened column?

In the case of an un-strengthened column, the details of reinforcement are as follows:

1 - existing column; 2 - existing foundation; 3 - added concrete; 4 - added reinforcement; 5 - steel profile

Strengthening or jacketing of foundation in case of un-strengthened column
What is the procedure for retrofitting of a reinforced concrete building?

The complete procedure for retrofitting of an RC building illustrated in the flow diagram is shown below. The collection of information for the as-built structure is the first step of retrofitting. The configuration of the structural system, reinforcement detailing, material strengths, information relevant to the non-structural elements (e.g. infill walls), foundation system and the level of damage are recorded. Sources for the above information can be obtained from the site visits, construction drawings, engineering analyses and interviews with the original contractor. The retrofitting objective is selected from various pairs of performance targets and earthquake hazard levels. The performance target depends on acceptable damage level in a predefined seismic event on the basis of safety of occupants during and after the seismic event, the cost and feasibility of restoring the building to pre-earthquake condition, the length of time the building is removed from service to effect repairs, and the economic, architectural or historic impacts on the larger community.

In the next phase, the retrofitting method is selected starting with the selection of an analysis procedure. The development of a preliminary retrofitting scheme follows (using one or more retrofitting strategies) the analysis of the building (including retrofitting measures), and the evaluation of the analysis results. Further, the performance and verification of the retrofitting design are conducted. The retrofitting design is verified to meet the requirements through an analysis of the building, including retrofitting measures. A separate analytical evaluation is performed for each combination of building performance and seismic hazard specified in the selected retrofitting objective. If the retrofitting design fails to comply with the acceptance criteria for the selected objective, the interventions must be redesigned or an alternative strategy be considered.

Seismic evaluation and retrofitting procedure for a RC building