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Promotion of Seismic Retrofitting For Existing Low Earthquake Resistant Structures

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ABSTARCT
The aftermath of an earthquake manifests great devastation due to unpredicted seismic motion striking extensive damage to innumerable buildings of varying degree i.e. either full or partial or slight. This damage to structures in its turn causes irreparable loss of life with a large number of casualties. As a result frightened occupants may refuse to enter the building unless assured of the safety of the building from future earthquake. It has been observed that majority of such earthquake damaged buildings may be safely reused, if they are converted into seismically resistant structures by employing a few retrofitting measures. This proves to be a better option catering to the economic considerations and immediate shelter problems rather than replacement of buildings. Seismic retrofitting of building structures is one of the most important aspects for mitigating seismic hazards especially in earthquake-prone countries. Various terms are associated to retrofitting with a marginal difference like repair, strengthening, retrofitting, remolding, rehabilitation, reconstruction etc. but there is no consensus on them.
The main objective of this thesis work is the measures to be adopted in case of inadequacy without making structural retrofitting.
Keywords: Earth quake, Retrofitting, Assessment.

I. INTRODUCTION

The need of seismic retrofitting of buildings arises under two circumstances:
(i) Earthquake damaged buildings and
(ii) Earthquake-vulnerable buildings that have not yet experienced severe earthquake.
The problems faced by a structural engineer in retrofitting earthquake damaged buildings are:
(a) lack of standards for methods of retrofitting;
(b) effectiveness of retrofitting techniques since there is a considerable dearth of experience and data on retrofitted structure;
(c) absence of consensus on appropriate methods for the wide range of parameters like type of structures, condition of materials, type of damage, amount of damage, location of damage, significance of damage, condition under which a damaged element can be retrofitted etc. Therefore, a catalogue of available options regarding feasible and practical retrofitting method is needed by the structural engineer due to great variability of retrofitting requirements differing from building to building.

II. CONSIDERATION IN RETROFITTING OF STRUCTURES

The method of retrofitting principally depends on the horizontal and vertical load resisting system of the structure and type of materials used for parent construction. It also relies on the technology that is feasible and economical. The understanding of mode of failure, structural behavior and weak and strong design aspects as derived from the earthquake damage surveys exercise considerable influence on selection of retrofitting methods of buildings. Usually the retrofitting method is aimed at increasing the lateral resistance of the structure. The lateral resistance includes the lateral strength or stiffness and lateral displacement or ductility of the structures. The lateral resistance is often provided through modification or addition of retrofitting elements of an existing structure in certain areas only.

III. NEED FOR SEISMIC RETROFITTING:

An existing structure may need seismic retrofitting, if the structure was initially not designed and constructed to resist an earthquake. Further, retrofitting would be essential if the structure was initially designed and constructed to resist an earthquake but
i) The loading/ load carrying parameters have changed since its construction due to:
- The present structural quality being bad due to poor maintenance or aging
- Loads have increased due to change of mode of use.
- Alterations / extensions are carried out or are contemplated.

ii) The design criteria have changed due to:
- Up gradation of the seismic zone, importance factor etc.

- Revisions in the methodology or specifications of structural design/detailing.

IV. CLASSIFICATION OF RETROFITTING TECHNIQUES

There are two ways to enhance the seismic capacity of existing structures. The first is a structural-level approach of retrofitting which involves global modifications to the structural system. The second is a member level approach of retrofitting or local retrofitting which deals with an increase of the ductility of components with adequate capacities to satisfy their specific limit states. Based on the above concept the available techniques of retrofitting of reinforced concrete buildings may be classified as in Figure 7.1.1

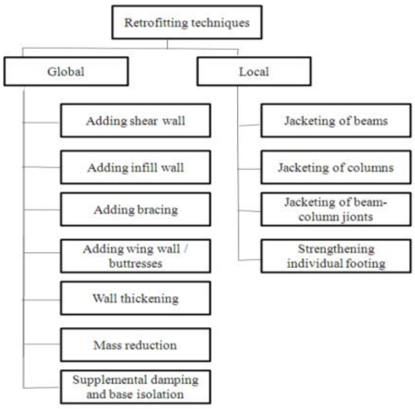

Fig.1 Retrofitting Techniques

V. SEISMIC ASSESSMENT

Seismic assessment is a natural prerequisite to seismic retrofitting. Ideally, the purpose of a comprehensive assessment should be to "assess the seismic resistance of the structure for the present criteria and to check the feasibility of one or more (alternative) practical schemes of retrofitting keeping in mind the aspects of economy and convenience to the owners". Hence, every task of assessment should pass through a set of well-defined steps, should refer to or create useful references and end with a well-structured report giving recommendations for the schemes of retrofitting along with their merits, demerits and limitations.

Primarily, the process of assessment will consist of:

Fieldwork**:** This will entail collection of data by detailed inspection of the structure.

References**:** References should comprise original drawings, drawings of extensions, test results etc as compiled data.

Office work: This would mainly involve structural analysis to suggest feasible schemes of retrofitting.

6.5.1 STEPS OF ASSESSMENT:

The standard and comprehensive assessment should involve data collection, compilation of data and assessing the feasibility of retrofitting. The details are given below.

6.5.2 Data Collection:

Data collection is a primary process in assessment work. Following are the steps involved in the data collection for seismic assessment.

- Review of original architectural and structural drawings (if available) from the angles of structural design and detailing. This has to be done by checking whether the structure was originally designed for earthquake from:
  - The loading specifications and provisions for future extensions.
  - The materials specifications.
  - The soil properties.
  - The seismic design parameters (if the structure was designed for seismic loads).
  - The design methodology.

  Even if the original drawings are available, before using them, it is necessary to compare them with the existing building and to confirm that they indeed represent the actual building.
- If original drawings are not available or if they do not match the existing building, as in-built drawings may be prepared for future use in modeling for feasibility assessment. While it would be easy to prepare architectural drawings, preparation of structural drawings can be quite difficult and may call for a good amount of judgment and experience from the structural engineer. This process may involve the following:
  - Taking actual measurements of the dimensions of the structural frames and member sizes
  - Ascertaining the quality of concrete by using appropriate non-destructive tests. These tests should be carried out, if necessary. Effects of sulphates and chlorides should also be ascertained.
  - For columns below plinth (or ground), foundations and sometimes for plinth beams, it may be necessary to excavate up to the foundation level for inspection.
- Qualitative assessment of the structure (from the original drawings or from in expert inspection) should be undertaken with respect to a list of seismic sensitivity parameters such as:
  - Architectural**:** Planning, shape, dimensions, symmetry and soft storey etc.
  - Structural**:** Load-carrying system, frames, shear walls, floating columns and plinth beams etc.
  - Geo-technical**:** Foundation depth, supporting strata, type of foundation, etc.

6.5.3 Compilation of data:

While compiling the data collected, efforts should be made to establish rational correlation amongst:

- Original/ prepared architectural and structural drawings and specifications
- Seismic vulnerability report based on seismic sensitivity parameters
- Report on the visual inspection recording:
    - Observations about structural health of structural members
    - Deviations from original planning
    - Effects of earlier earthquakes
    - Earlier rehabilitation works.
  - Test reports
  - Record of past rehabilitation works, if any.

6.5.4 Feasibility of Retrofitting:

Based on the data Collected, the structural feasibility of various alternative schemes of retrofitting can be checked by modeling such schemes vis-a-vis the existing structure. If any addition/ extension is contemplated in the near future, the same should also be modeled in suggesting the schemes. Thereafter, alternative estimate of cost and time can be prepared. The practicality of each of the alternatives can then be evaluated with reference to the following criteria.

- Estimated cost.
- Estimated time required for retrofitting.
- Convenience of the implementation of the scheme from the point of views of the owners / complaints.
- Limitations of the scheme.

It is very important to note that the structurally best scheme may not necessarily be the most practical one. More ever the limitations of the each scheme should also be clearly understood. The comprehensive data collected can be very useful in quickly revising, a scheme to take care of the problems / apprehensions of the owners whenever possible.

VI. STEPS FOR RETROFITTING

Before undertaking any retrofit, it is imperative to carry out the following procedures:

- Compile all available information on the structure including existing drawings.
- An exhaustive photo-documentation of any distress patterns visible in the structure needs to be done if it has already been subjected to seismic loading.
- A thorough visual inspection of the structure with special attention to the vulnerable spots - beam-column junctions, frame members, re-entrant corners of shear walls, and water tanks at roof is required.
- Perform an analysis based on the above data and determine the inherent capacity of the structure to resist the code-specified design seismic forces with a reasonable degree of confidence.
- Review the detailing and design of the as-built structure and determine its inherent capacity.

VII. RETROFITTING FOR VARIOUS PARTS OF THE BUILDING

6.7.1 Foundations:

In rare cases, when there is net uplift in a column, column footings may tend to fail before the supported column can develop a plastic hinge. This is usually due to the absence of a top layer of reinforcement and vertical ties in footing which need the capability to resist uplift forces. During an earthquake, this can result in flexural cracking of the footing concrete or de-lamination of the concrete footing and may also result in a loss of anchorage for the column longitudinal reinforcement.

This deficiency could be rectified by thickening the existing foundation and by providing additional steel in it. Dowels between the new and old concrete should be capable of transferring the shear stress on the interface. Alternately, tested chemicals may be considered for this purpose. Increasing the depth of the footing will also increase the positive moment capacity as a result of increased section depth. If this is still inadequate, widening of the footing will be needed, with additional bottom steel. However, rebars should be placed within a distance equal to the depth of the footing on either side of the column for these rebars to be effective. Strengthening of Foundation by Widening

6.7.2 Column Strengthening:

The philosophy behind seismic column strengthening is that the axial load strength of a column after concrete has spalled off should be at least equal to the axial load strength before spalling and should plastic hinges occur at column ends, ductility must be ensured by confining the concrete with special confining steel. The conventional retrofitting technique for columns is described below.

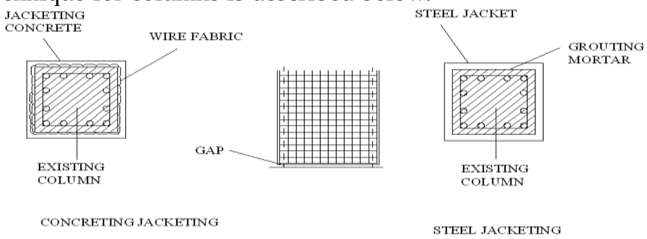

Fig 2 STRAP JACKETING

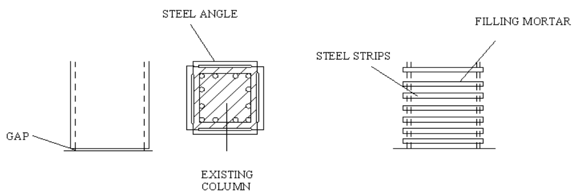

Fig 3 STRAP JACKETING

6.7.3 Concrete jacketing:

This method of column retrofit is very popular and is used when the columns are deficient in strength. It involves addition of a comparatively thick layer of reinforced concrete in the form of a jacket around an existing column. Adequate confinement of rectangular columns by a rectangular jacket requires extensive doweling to connect the jacket to the existing column (which also act as lateral ties for the newly introduced column vertical reinforcement) and/or use of suitable bonding chemicals at the interface of the old and new concrete shown in Concrete Jacket for Column.

6.7.4 Beam-Column Joint:

Doweling vertically through the existing beams is required to ensure continuity in strength enhancement at the beam-column junctions shown in. If this is not done, only local strength enhancement is achieved and the beam column junctions may continue to remind vulnerable.

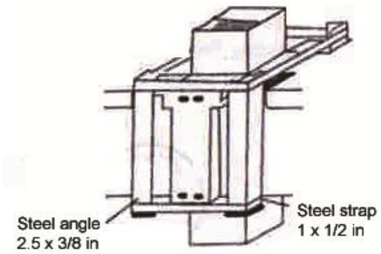

Fig 4

The advantage of this retrofit method is that it enhances both ductility and overall flexural strength. This method of retrofit is carried out by many agencies and information is easily available. There are no additional fire and corrosion protection required.

6.7.5 Beam Retrofit:

Deficiency in seismic behaviour of beams may be in shear, flexure or joint shear. Enhancing flexural capacity of integral beams is difficult because of the constraints placed by the existing superstructure on the sides. To augment the positive moment capacity (which usually is not a critical issue except it, the end supports under seismic loading), additional bottom reinforcement may be provided by introducing additional beams on either side of the existing beam, or by alternatively providing additional steel on the bottom by enhancing the depth of the beam by means of polymer concrete, a resin concrete or micro concrete depending on the suitability for the beam under consideration.

Negative moment capacity can be increased by removing top concrete and providing additional reinforcement. This is not so difficult in a country such as India where there is a total flooring cover of about 50 mm. Most often, both moment and shear capacity need to be enhanced for ductile behaviour and in such cases a beam jacket, on similar lines to column jacketing complete with additional stirrups may be provided. This may require propping of the adjacent slabs.

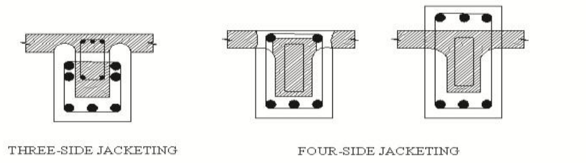

Fig 5 Beam Strengthening

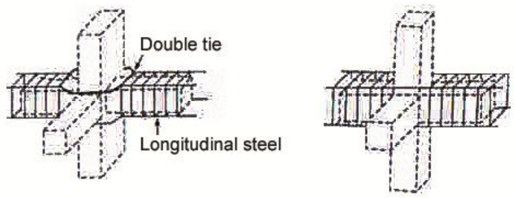

Fig 6 Beam Strengthening

6.7.6 Retrofit of Shear Wall Building:

The existing shear walls may be strengthened by increasing the stiffness of these walls; this can be achieved by providing additional thickness to the wall. The additional wall thickness may be provided by means of shotcreting (gunting). The new thickness of wall must be connected to the existing wall by means of doweling, designed to transfer the interface shear forces, or by suitable tested chemicals.

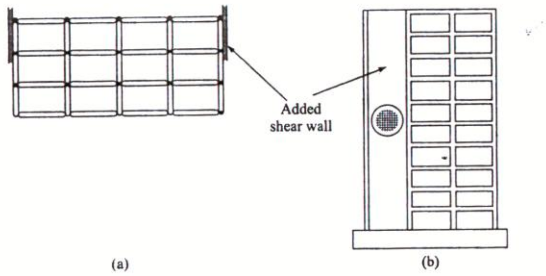

Fig 7 Strengthening of Existing Shear Wall

Alternately, end bolster columns may be added and connected sufficiently well with the existing wall. This may, however, also need enhancement of the foundations,

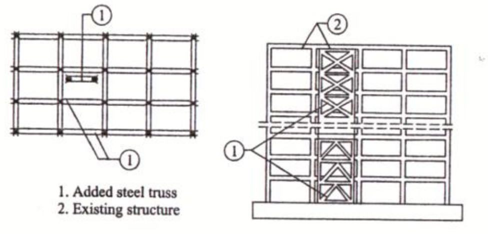

Fig 8 Building Retrofitted with steel bracing

VIII. RETROFIT SCHEMES

The various retrofit schemes adopted in Ahmadabad and other areas of the State of Gujarat include

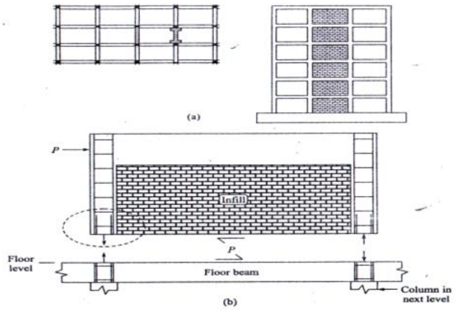

Fig 9 Infill walls and columns

- Pointing and re-plaster of cracked infill walls and columns
- Replace all the infill walls in the RC frame panels Jacket RC columns in the open ground story .In many cases of column jacketing, the new reinforcement was not anchored into the foundations or the building frame, and the plaster on the old concrete column surface was not removed.
- Prop beams with masonry pillars, or steel joists or built-up sections
- Provide steel braces in open bays

6.8.1 FRP jacketing

Several researches have investigated the possibility and feasibility of fibre reinforced polymer composite jackets for seismic strengthening of columns winding them with high strength carbon fibres around column surface to add spiral hoops. The merits of this method are: (i) carbon fiber is flexible and can be made to contact the surface tightly for a high degree of confinement; (ii) confinement is of high degree because carbon fibers of high strength and high modules of elasticity are used; (iii) the carbon fiber has light weight and rusting does not occur.

The most critical type of structural damage is the slab column connection which results in the punching shear failure due to the transfer of unbalanced moments. The retrofitting of slab column connection is beneficial for the prevention of punching shear failures.

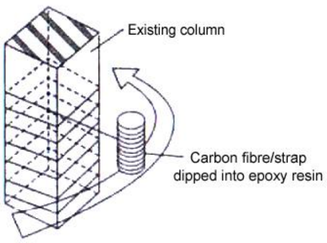

Fig 10 FRP JACKETING

6.8.2 JACKETING COLUMNS:

Jacketing of RC columns in the ground story is the most common measure being adopted. In most cases, the additional concrete and reinforcement is just added around the old column and in some cases, the old column is snugly strapped with steel angles and flats and then the concreting is done. There was at least one building in Ahmadabad, where immediately after the earthquake, the columns in the ground story were jacketed to an unusually large size. In many cases, the jacketing has been done without removing the plaster, if any, or roughening the surface of the old column. Jacketing often starts from the finished ground floor level as against the foundation. In some cases, the jacketing has been started from the foundation. Furthermore, the longitudinal bars added in the additional concrete portion are often left projecting out without any connection to the older RC beam and column members.

The some of the other retrofitting methods adopted are as follows:

- Numerous buildings in the affected area sustained only frame-infills separation. In most of the cases the separations were cleaned and filled with rich cement mortar.
- Large block sand stone masonry infills in cement mortar at two-story school building in Ahmadabad were completely replaced with burnt-clay brick masonry infill in cement mortar.
- Jacketing of a rectangular column of the ground storey of a seven-storey old age home in Gandhidham, was performed from the floor level to a level well below the beams at the top of that column. The column bars are seen curtailed by the side of the beam.
- RC columns of the three-story residential RC frame building in Gandhidham are adjoined with brick masonry columns from the floor level to the beam soffit. The beam is propped at intermediate locations with hot-rolled steel I-sections.
- Instances where column jacketing was started at the footing level were few. Even in this case, the column reinforcement may not have been anchored into the footing.

IX. RECOMMENDATIONS

The measures to be adopted in case of inadequacy without making structural retrofitting are adequately discussed in this study. A the structural retrofitting is costlier, time consuming and inconvenience for the occupants, the study has been taken up to evolve a scientific approach for retrofitting.

The following are the some of the recommendations:

- If the strength of the column in the building found to be deficit, they are strengthened / retrofitted .Beams and foundations are adequately safe.
- To perform well in an earthquake, a building should possess four main attributes, namely simple and regular configuration, adequate lateral strength, stiffness and ductility.
- The cantilever overhang should be minimized and the efforts should be made to ensure direct vertical transfer of the gravity loads.
- All of the frames continue to the building base.

- Shear failure being brittle, it must be avoided in the design of RC beams.
- Steel reinforcement up to grade Fe415 shall be used.
- Limitation on flexural reinforcement ratio is recommended so as to ensure tension failure in the beams.
- All longitudinal column steel is should be dowelled into the foundation.
- The top as well as bottom reinforcement shall consist of at least two bars throughout the member length.
- The positive steel at a joint face must be at least equal to half the negative steel at that face.

The following recommendations on detailing of the structure should be avoided in construction:

- Large spacing of lateral ties in columns can lead to lack of confinement for the concrete core and/or shear failures.
- Insufficient column lap lengths can cause concrete to spall.
- Location of inadequate splices for all column bars at the same section can lead to column failure.
- If the column shear strength is insufficient to develop the full moment hinge capacity, the column can exhibit a brittle shear failure.
- Insufficient anchorage of shear tie reinforcing in column cores can prevent the column from developing its full shear capacity.
- Lack of continuous beam reinforcement can cause hinge formation during load reversals.
- Inadequate reinforcing of beam-column joints or location of beam bar splices at columns can lead to joint failures.
- Foundation dowels that are insufficient to develop the capacity of the column steel above can lead to local column distress, the pedestals the above the footing mitigates such failure.
- Use of bent-up longitudinal reinforcing in beams as shear reinforcement can result in shear failure during load reversal.
- The relatively low stiffness of the frames can lead to excessive inter storey drifts. These large drifts can cause damage to non-structural items such as partitions, window, etc.

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