NSET EXPERIENCE ON SEISMIC RETROFITTING OF MASONRY AND RC FRAME BUILDINGS IN NEPAL

1. INTRODUCTION

National Society for Earthquake Technology Nepal (NSET) was established in June 1993 and started its first school retrofitting project in 1999. It was the pilot program of retrofitting one of the public schools in a rural area of Kathmandu Valley. The building was brick in mud type and Splint and Bandage method of retrofitting was employed to enhance the structural performance of the building in earthquake. Since then, NSET was involved in seismic retrofitting of about 300 school buildings all over Nepal. These include mostly masonry buildings and very few reinforced concrete frame buildings. NSET was also involved in seismic vulnerability assessment and retrofit design of residential buildings of many private house owners, diplomatic agencies, national and international organizations for masonry and RC frame buildings. However most of the construction for retrofitting is urban based or in the close vicinity of urban area where materials like cement and steel/galvanized iron mesh are available.

2. SEISMIC RETROFIT

Seismic retrofit of a structure is the correction of the major weakness in the structure relating to seismic performance. It refers to a process of enhancing the structural capacities such as strength, stiffness, ductility, stability and integrity of a building to mitigate the effect of future earthquakes. The need of seismic retrofitting of building arises under two circumstances: (i) earthquake damaged buildings and (ii) earthquake vulnerable buildings that have not yet experienced severe earthquakes. Due to the lack of standards and guidelines for retrofit design and construction specific to our building typologies, problems in designing and implementation of retrofitting works are faced by engineers.

Seismic behaviour of a structure can be enhanced by adopting different retrofitting strategies. The choice of the optimal retrofitting strategy depends on good understanding of the dynamic behavior of the building, cost of the chosen retrofit strategy and also on the future use of the building.

In structures where many of its members do not have adequate strength and ductility, an effective way to retrofit the structure would be to add new lateral load resisting elements. Additions of infill walls, shear walls and braces are examples of global retrofit strategies. Improving regularity and mass reduction can also be categorized under global retrofit strategy.

In structures where only few members lack adequate strength or ductility and the structure has got sufficient level of strength or ductility at the global level, local retrofit strategy is adopted. Strengthening of individual beams, columns, joints and walls are examples of local level retrofit strategy.

Seven strategies have been identified to retrofit building. They are: Improving regularity, Strengthening, Increasing ductility, Softening, Damping, Mass reduction and Change in use.

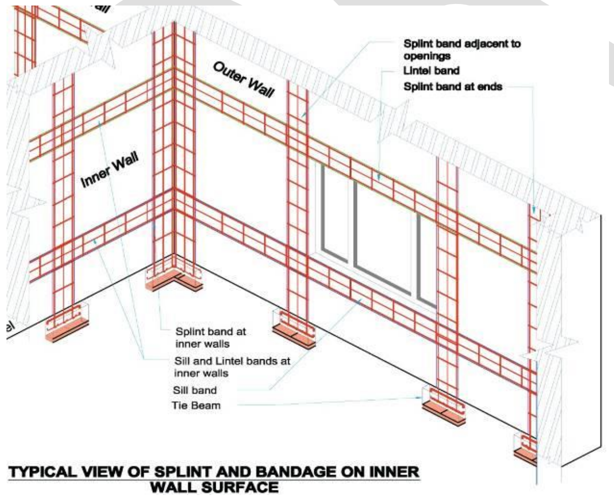
The most common retrofitting options that NSET is implementing is discussed here. These methods have been found suitable in Nepal based on the availability of materials, technicians and simple technology.

3. RETROFIT OF MASONRY BUILDINGS

i. Splint and Bandage

Unreinforced masonry buildings are brittle in nature. To ensure ductile structural behaviour of such buildings, reinforcement is provided with design details specific to each building. This reinforcement consists of galvanized welded wire mesh (WWM) or TOR/MS bars that are anchored to the wall and fully encased in cement plaster or micro-concrete. In this method, reinforcing bars are provided at most critical locations, wherever stress concentrations can develop. Splints are vertical elements provided at corners, wall junctions and jambs of openings in the external faces of the building. The objective is to enhance in plane flexural capacity as well as vertical out of plane capacity of wall. Also it provide integrity in vertical direction. The bandages are horizontal elements running around all the walls and building enhancing the in plane shear capacity and horizontal out of plane capacity of walls. Also they integrate various walls together. In addition, openings are also surrounded by splints and bandages to prevent initiation and widening of cracks from their corners.

RC Splints and bandages are provided on both the faces of the walls, which are connected with steel bar connectors that pass through the wall, or anchored with nails. The added concrete or plaster should be about 40 to 50 mm thick to protect the mesh from corrosion. For this wire mesh, 1:3 cement-coarse sand mortar is used and for steel bars, M20 micro-crete i.e. Concrete with small aggregates, is used. Concreting work is solely manual, without the use of shotcrete equipment, and is hence applied in two layers like plaster. Shotcreting equipment can also be used to accelerate the process. The general process in implementation of retrofitting work using steel wire mesh includes 1) Removal of plaster from walls in the proposed area for RC Bandage/Splint 2) Rake out mortar joints to 15-25 mm depth in case of mud mortar, clean surfaces and wet with water 3) Excavate the soil for tie beam and lay the reinforcement of tie beam and wall 4) Drill in the wall and provide anchor rod to tie inner and outer steel reinforcement 5) Cast tie beam and apply concrete/plaster in two layers on walls 6)Cure concrete. In case of low strength masonry, there is always a chance of local failure of material in between the bands. In such cases either closely spaced splints and bandages have to be used or the unreinforced wall panels need to be confined using some kind of elements such as PP band etc.



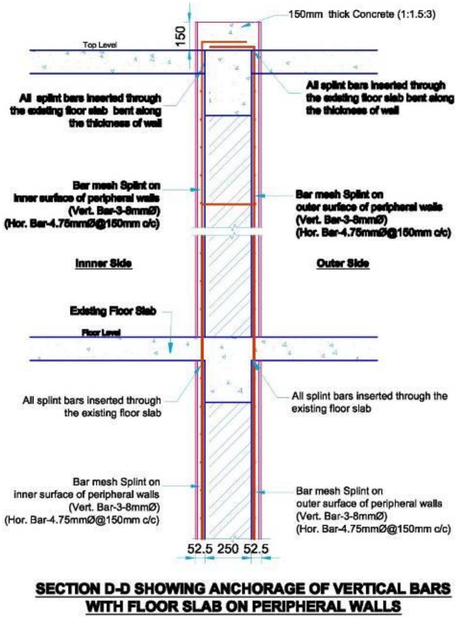


Fig 1: Details of RC splint and bandage

	
Fig 2: Construction of RC splint and Bandage	*Fig 3: Building retrofitted by RC splint and Bandage method*

ii. Jacketing

In case of low strength of masonry like masonry with mud mortar, full wall jacketing from both the sides is the more effective option rather than the splint and bandage system to minimize local disintegration of masonry material. Galvanized welded wire mesh (WWM) or TOR/MS bars mesh is provided on either side of the whole wall. The mesh is connected with steel bar connectors that pass through the wall, or anchored with nails. The added concrete or plaster should be about 40 to 50 mm thick to protect the mesh from corrosion. For this wire mesh, 1:3 cement-coarse sand mortar is used and for steel bars, M20 micro-crete i.e. Concrete with small aggregates, is used. Concreting work is solely manual, without the use of shotcrete equipment, and is hence applied in two layers like plaster. Jacketing helps to basket the wall, hence improve its shear strength and ductility. This method also improves integrity and deformability. This method is costlier than splint and bandage method.

The general process in implementation of retrofitting work using steel wire mesh includes 1) Removal of plaster from walls in the proposed area for RC jacketing 2) Rake out mortar joints to 15-25 mm depth, clean surfaces and wet with water 3) Excavate the soil for tie beam and lay the reinforcement of tie beam and wall 4) Drill in the wall and provide anchor rod to tie inner and outer steel reinforcement 5) Cast tie beam and apply concrete/plaster in two layers on walls 6)Cure concrete.

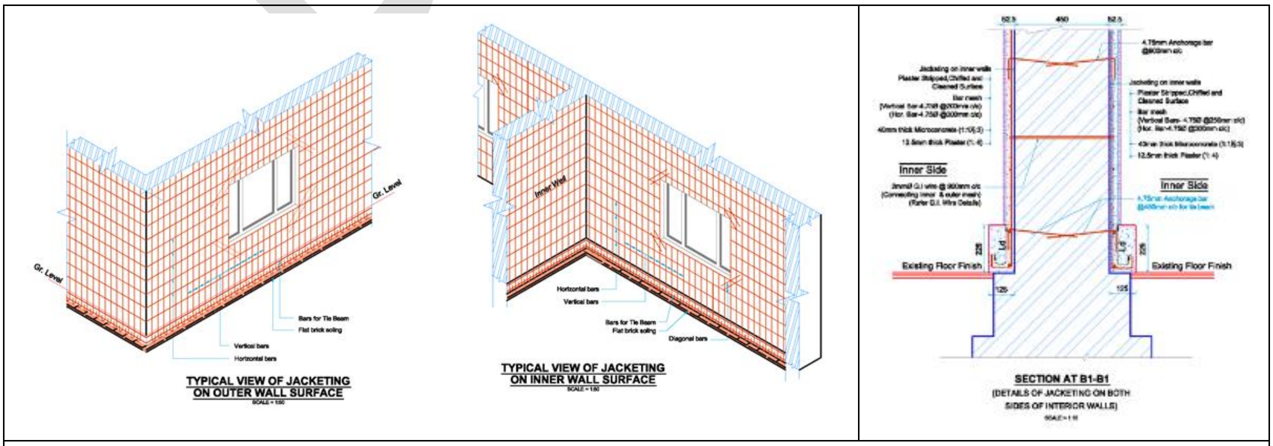


Fig 4: Details of RC splint and bandage

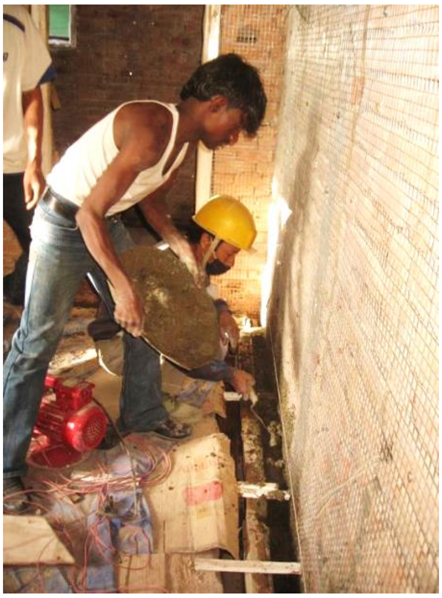
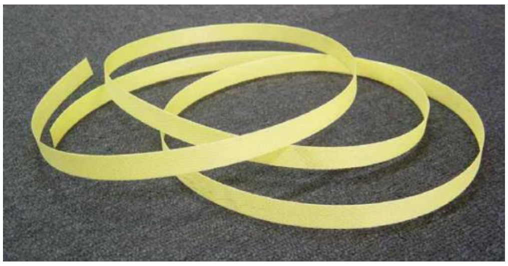


Fig 5: GI wire mesh jacketing	*Fig 6: Steel bar jacketing*

iii. Polypropylene Meshing

Polypropylene meshing uses common polypropylene packaging straps (pp-bands) to form a mesh which is used to encase masonry walls, preventing both collapse and the escape of debris during earthquakes. PP-bands are used for packaging all over the world and are therefore cheap and readily available while the retrofitting technique itself is simple enough to be suitable for local builders. PP meshing has been applied in Nepal, Pakistan and more recently in China. This method is most readily applicable in terms of low-cost upgrading of traditional structures to limit damage caused by normal earthquakes and give occupants a good chance of escape in a once-in a- lifetime large earthquake. Non-engineered masonry is widespread throughout the developing world and replacement of all such dwellings is both unfeasible and undesirable, given that they are often the embodiment of local culture and tradition. It is therefore often more feasible to consider low-cost retrofitting of such buildings. Experiments and advanced numerical simulations have shown that PP band mesh can dramatically increase the seismic capacity of adobe/masonry houses [P. Mayorka and K Meguro, 2008]. This is mainly achieved by increasing the structural ductility and energy dissipation capacities. Under moderate ground motions, PP-band meshes provide enough seismic resistance to guaranty limited and controlled cracking of the retrofitted structures. Under extremely strong ground motions, they are expected to prevent or delay the collapse, thus, increasing the rates of survival. This method is good for one storey buildings and a combination of PP band and other materials can be used if more than one story. To protect the Polypropylene from ultra-violate rays, mud plaster is used on the outside, providing adequate cover to ensure the durability of the material.

	
Fig 7: Retrofitting using PP band	*Fig 8: PP band*

4. RETROFIT DESIGN OF RC FRAME BUILDINGS

i. RC Jacketing of Columns and Beams

RC Jacketing involves placement of new reinforcement and concrete overlay around the existing beam and column member. It increases the flexural strength, shear strength as well as ductility of the column. Size of columns, size of beams, quantity of longitudinal reinforcement, transverse reinforcement can be increased in deficient columns and beams as per design requirement.

The general process in implementation of retrofitting work includes 1) Excavation of foundation 2) Dismantling of infill walls adjacent to columns/beams 3) Removal of plaster from columns/ beams 4) Addition of new steel in foundations/ columns/ beams as per requirement 5) Inserting dowel bars in foundations/ columns/ beams to connect new concrete with the old concrete 6) Concreting of foundations/ columns/ beams 6) Curing concrete.

After RC jacketing of beams and columns, their size increase, minimum 100mm from all faces. Hence this retrofitting technique is suitable only for medium rise school buildings and commercial buildings. It is not feasible for low rise residential building where there is space limitation. Such size increased columns and beams also reduces the aesthetic value of the residential buildings. Since the column and beam sizes increase a lot, stiffness also increases, hence stiffness balance in the building also need to be considered while designing by this method and most likely all columns need strengthening.

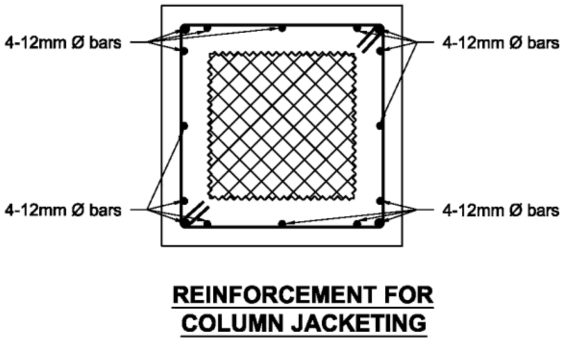


Fig 9: Retrofitting of columns by RC jacketing

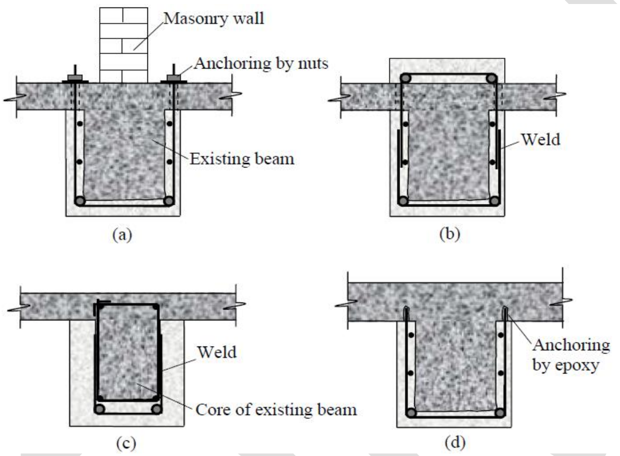


Fig10: Different options of retrofitting of beam by RC jacketing

ii. Steel Profile Jacketing of beams and columns

Steel profile jacketing of beams and columns is the process of encasing these members with steel plates. It is basically used for remedy of inadequate shear strength and also to provide passive confinement to frame members. It can also be used to increase the flexural capacity of beams and columns. But in cases where the columns and beams are of the same size, the steel plates cannot be made continuous through the floor slab and frame members, hence it cannot be used for enhancement of flexural strength.

Considering the space limitation in residential building, this method is more feasible than RC column jacketing as there is no much increase in column and beam sizes and their stiffness.

The implementation procedure is simple: removal of plaster from columns/ beams, steel profile jacketing and re-plastering columns/ beams. A proper care is required to ensure tight connection between the existing concrete and added steel elements.

Fig11: Retrofitting of columns by steel profile jacketing

iii. Addition of Wing Wall

The lateral strength of existing columns can also be increased by adding wall segments on each side of the column and reinforcing them or reinforcing the existing walls surrounding the column. GI wire mesh or steel bars can be used as reinforcing elements. These walls are called wing walls. Wing walls generally have thickness considerably less than the width of adjacent column. While designing wing walls, adequate connection to existing structure needs to be ensured. Wing walls should be anchored to all beams and at foundation level also. The wing wall will shorten the clear span of the beam creating large reversal moment in the beam at the face of the wing wall. If the beam is not detailed for the reversible moment at that location, strengthening of the beam or make other provision is required to ensure that beam does not fail. The construction process is similar to RC jacketing of masonry walls.

In RC and Steel profile jacketing of columns, walls surrounding the columns needs to be demolished to carry out the retrofitting work. But this method includes less interventions compared to RC and Steel profile jacketing of columns since walls need not to be demolished to carry out retrofitting work. This is the most suitable retrofitting method NSET is implementing for low rise residential buildings up to three storey. Retrofitting work is not even noticed after completion of the work with plaster and paint, hence the house owners are not hesitant to implement this method as the appearance of the building is not badly affected.

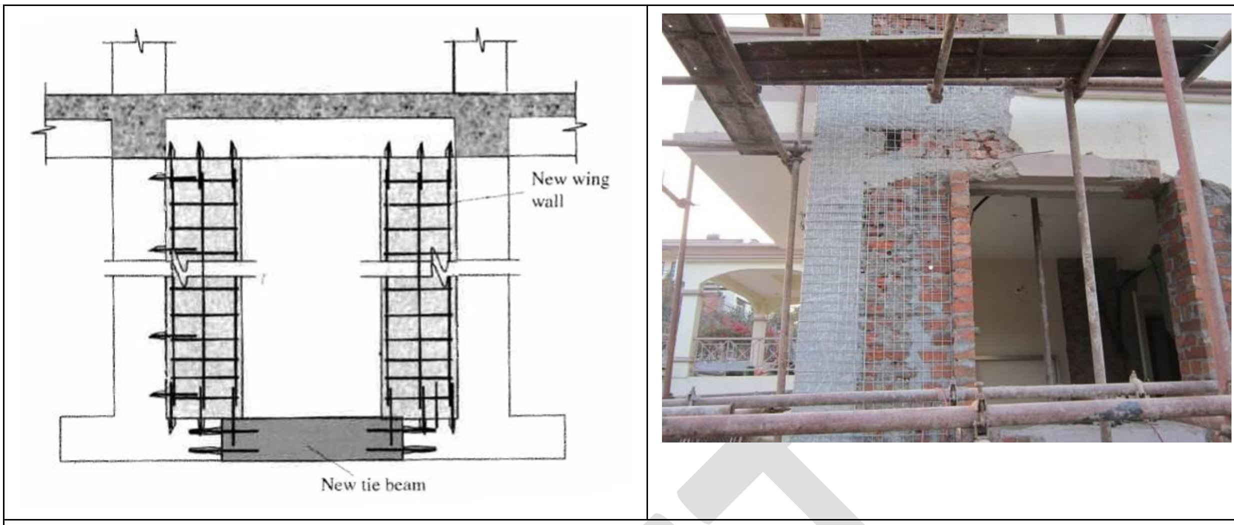


Fig12: Strengthening of wing wall in RC Frame Building

iv. Strengthening of infill masonry walls

In RC building, specially non-engineered residential buildings built 10-15 years ago, columns are very lean and non-ductile. Longitudinal reinforcements provided are highly insufficient and stirrups are provided are large spacing about 600mm- 800mm c/c. In such condition, the contribution of RC Frame is very less. But 230mm infill masonry are provided around most of the columns. Such buildings can be retrofitted using the contribution of infill masonry. The existing RC columns and beams will act as masonry wall confining elements. Reinforcing the unreinforced masonry walls through Splint and Bandage method or Full Jacketing method as per requirement are the better options for such types of buildings. Another advantage of this retrofitting technique is that it not only strengthen the RC Frame, but also ties all the masonry walls to RC frame, hence preventing it’s out of plane failure as well.
Either RC Splint and Bandage or RC Jacketing of infill walls can be done depending upon the retrofit design of the building. Construction procedure is similar to that of the masonry building.

Fig13: Strengthening of infill masonry wall of RC frame building through RC Splint and Bandage method

Fig 14: Strengthening of infill masonry wall of RC frame building through RC jacketing method

5. OTHER COMMON METHODS OF RETROFITTING

i. Improving Plan configuration:

If the building is irregular and unsymmetrical, torsional force will be induced in the building during earthquake. If the building is found irregular and unsymmetrical in plan shape, the plan shape of the building should be improved from earthquake point of view by separating wings and dividing into more regular, uniform and symmetrical shapes.
Similarly due to unbalanced position of openings, the building become unsymmetrical such as many openings in front wall and no openings in the back wall. This can be solved by removal of the openings or addition of the openings as per requirement.
In fact, such irregularities should be checked and balanced in any buildings before retrofit. A regular and symmetric building is far easier to design and also the cost of retrofitting becomes economical.

Fig 15: Removal of openings to improve the configuration

ii. Load Path improvement:

A complete load path is a basic requirement for all buildings. If there is discontinuity in load path, the building is unable to resist seismic forces regardless of the strength of the existing elements. Buildings may suffer from the problem of discontinuous load path. Such as when there are walls/columns in the upper stories at the places where there are no walls/columns in lower floor. It needs more intelligent solutions, re-planning of space to create new and more direct load paths.

iii. Modification of Roofs or Floors:

Heavy and brittle roof tiles that can easily dislodge should be replaced with light and corrugated iron and asbestos sheeting. Undesired heavy floor mass, that only induce increased seismic force, need to be removed. False ceiling and heavy ceiling plasters that create a condition of potential hazard of falling during a shaking should either be anchored properly or replaced with light material. Roof truss should be braced by welding or clamping suitable diagonal bracing members in vertical as well as in horizontal planes. Anchors of roof trusses to supporting walls should be improved and the roof thrust on walls should be eliminated.

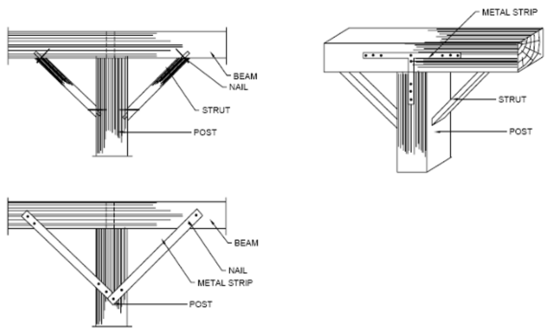


Fig 16: Improvement of roof connections

Fig 17: Addition of bracings to flexible floors

iv. Reduction in Building Mass:

A reduction in mass of the building results in reduction in lateral forces. This can be achieved by removing unaccountable upper stories, replacing heavy cladding, floor and ceiling, removing heavy storage or change in occupancy use.