1. **Background**

   Much of the loss of life in past earthquakes has occurred due to the collapse of buildings. Both modern and traditional buildings suffer damage if there are no earthquake resistant features associated with the structure. In general, the buildings constructed with traditional materials such as stone, brick, adobe and wood and which are not engineered to be earthquake resistant suffer high damage.

   The following chart shows factors that made the Kathmandu valley earthquake risk (Source: GESI). The large portion is due to building collapse and match with the scenario in most cities in developing countries.
2. Implementation Strategy for Achieving Seismic Safety

Three strategies should be taken together to achieve seismic safety of buildings

**A. New Construction: Stop Increasing Risk**, all new construction should be earthquake resistant so that there is no increase in risk.

**B. Existing Buildings: Decrease Unacceptable Risk**, existing structures should be either retrofitted or reconstructed to withstand reasonable shaking.

**C. Accept Inevitable Earthquake: Prepare for Consequences**, awareness level should be increased at all levels from policy makers to community to individuals.

3. Analysis of Existing Construction Mechanism

3.1 Type of building construction mechanism

There are two distinct types of construction mechanisms (definition from M3-02)

**Engineered constructions:**
These are the structures (e.g., buildings) that are designed and constructed as per standard engineered practices. In case of buildings, engineered construction are those that are supposed to have undergone the formal process of regular building permit by the municipal or other pertinent authority. The formal building permit process is supposed to require involvement of an architect/engineer in the design and construction for ensuring compliance to the existing building code and planning by-laws. In most developing countries, formal building permit process is observed only in urban areas. Building codes with earthquake safety consideration, either do not exist, or not implemented strictly. Therefore, consideration of seismicity on building design depends upon the individual initiative of the designers and the availability of funds. Where the client requests for such inputs, mostly the engineer resorts to the building code of the country where he was trained. This is in appropriate.
**Non-engineered constructions:**
These are physical structures (e.g., buildings) the construction of which usually has not been through the formal building permit process. It implies that the construction of non-engineered buildings have not been designed or supervised by an architect/engineer. Such buildings are obviously prevalent in the rural or non-urban areas including the periphery of municipalities. A large percentage of the buildings even in urban areas of many developing countries are non-engineered constructions. In the urban areas of Kathmandu, it is estimated that more than 90 percent of existing building stock are non-engineered (partly because there are many old historic buildings), and every year about 5000 more such non-engineered buildings are added.

**Owner-built buildings:**
These are buildings constructed by the owner at the guidance and with the involvement of a head-mason or a carpenter who lacks comprehensive knowledge on earthquake resistant construction. Traditional construction materials such as timber, stone rubble or brick (fired or un-burnt) and mud as mortar are used. There is usually no input from any engineer. These are usually rural constructions. However, such constructions are seen also in the poorer part of a city, or in the city suburbs.

### 3.2 Resources distribution comparison for construction mechanisms

The first triangle shows the ratio of buildings by different construction mechanisms and second one the existing resources allocation. For real implementation of earthquake resistant measures the scenario should be changed.

### 4. Improving Earthquake Resistance of New Construction

In the past, the seismic design criteria were to:
- Resist minor earthquake without damage
- Resist moderate earthquakes without structural damage, but with some non structural damage
• Resist major earthquakes, of severity equal to the strongest that could be experienced in the area, without collapse but with some structural as well as non-structural damage.

With the advent of the recent earthquakes in California, Japan, Turkey etc., the above philosophy has been questioned. The current practice now is that different design criteria for buildings in particular, and structures in general, can be met by competent structural designers.

Design levels are negotiable and need not be tacitly accepted as being those laid down in current design codes. These lay down minima not maxima. Differing performance levels are acceptable for different functions.

The new approach is the performance-based design, which is based on different level of damage for different type of building function at different levels of earthquake considered. The major level earthquake defined in NEHRP (1991) code has a recurrence interval of 475 years corresponding to a 10% probability of being exceeded in 50 years. The corresponding service level for a typical building would have a 10 years recurrence interval and a 99.3% probability of being exceeded in 50 years.

4.1 Engineered construction

Approaches in vulnerability reduction for engineered structures include the following:

**Adequate assessment of forces created by natural phenomena**
- Necessity for building codes, building acts, building bylaws
- Good earthquake engineering courses in academic institution
- Research on seismology etc.

**Good site planning**
- Analysis of probable landslides, rock-fall, liquefaction susceptibility etc.

**Adequate planning and analysis of structural measures to resist such forces**
- Choice of appropriate lateral force resisting system in building
- Detail analysis

**Adequate design and proper detailing of structural components**
- Design of each and every components in detail
- Consideration of ductility and detailing
Construction with suitable materials
- Choices of suitable materials
- Quality of materials

Good workmanship under adequate supervision
- Supervision by adequate engineer
- Good workmanship

4.2 Non-engineered construction

Improving seismic capability of non-engineered building construction mechanisms should take various considerations beside the development of technical expertise.

Preparation of necessary documents
- Mandatory rules of thumb
- Design Guidelines
- Mason manual
- Preparation of leaflets, posters and handbook

Raising awareness
People and house owners should be aware about the consequences of earthquake, necessary actions for mitigation and also the affordability of the technology.

Training and increasing capability of local institutions
Masons or craftsman should be trained through on-the-job training and the capability of municipalities should be increased in terms of manpower and resources.

Development and transfer of appropriate technology
Theoretically, if appropriate resources and building materials are made available, buildings can be constructed to withstand the effects of earthquake. Practically it is not feasible to do so due to very high costs involved.

The safety of human lives is the primary concern and the functioning of the buildings has lower priority except the buildings required for community activities such as schools, assembly halls, places of worship, and cinema halls, etc. and those required for emergency, such as, buildings for hospital, operation theatre, telephone and telegraph, fire fighting and the like. The safety aims would therefore be met, if a building is designed and constructed in such a way that even in the event of the probable maximum earthquake intensity in the region, it will remain functional.

- Building should not suffer total or partial collapse,
- It should not suffer such irreparable damage which would require demolishing and rebuilding
It may sustain such damage which could be repaired quickly and the building put back to its usual functioning; and
The functioning of the building should ensure that the activities during post-emergency period can continue unhindered and the community buildings may be used as temporary shelters for the adversely affected people.

The present state of research indicates that fortunately the above structural safety can be achieved by adopting appropriate design and construction details involving only small extra expenditure which should be within the economic means of people in most countries.

- Extra cost necessary to make earthquake resistance for masonry buildings is 4-6% of structural cost (from Experience of SESP NSET-Nepal)
- Extra cost necessary to make earthquake resistance RC buildings is 5-10% of structural cost

4.2.1 Present trend of construction of different building types

Recent trend of building construction in urban areas shows that there is significant increase in use of cement. Even though the new construction material is adopted, there is lack of knowledge for proper use of these materials in society.
From the above chart it is seen that, a significant growth in brick-in-cement and RC frame constructions started only 20 and ten years ago respectively. During these years, the proportions of adobe and brick-in-mud buildings are on a significant decrease (Source: Building Inventory Report, THE STUDY ON EARTHQUAKE DISASTER MITIGATION IN THE KATHMANDU VALLEY)

### 4.2.2 Improving earthquake resistance of masonry buildings in cement mortar

The integrity between different components of a building is the most crucial aspect for survival of a masonry building during an earthquake. For improved integrity, the buildings need to have following reinforcing features:

- **Stitching of walls:** To strengthen wall junctions by stitching as these are potentially weak point;
- **Bands:** To avoid out of plane collapse of walls, these should be reinforced with RC bands at different levels;
- **Gable ends:** Reinforcement around gables with gable band and connection to purloins;
- **Floor or roof band:** Reinforcement element on top of the wall capable of transferring the inertia force of the floor/roof structure to the walls, unless floor or roof is constructed of RC slab;
- **Vertical bars:** In–plane bending and shearing resistance of masonry walls and ductility can be improved by using vertical reinforcement and control on opening sizes thus preventing crack propagation from corners of openings;
- **Floor/roof structure:** Can be improved by nailing and tie-up with straps between different components;
- **Connection between wall and floor/roof structure:** Proper integrity between floor/roof structure and wall can be enhanced by adequate holding down bolts, etc;
- **Bracing of floor and roof structure:** Floor and roof structures should be stiffened in horizontal plane by bracing elements or RC topping to act as rigid diaphragm in the case of wooden or steel floor/roof structure.
- **Openings:** The size and the position of the openings have a substantial affect on the resistance of masonry building to earthquake loading. Large size openings weaken the masonry walls against vertical as well as earthquake load. A control on their size and location is desirable, consistent of course, with functional requirements. Therefore, in order to improve behavior of masonry building openings must be reinforced. Where openings do not comply with the above geometrical requirements they should be strengthened or the vertical bars can be started from damp proof course.
4.2.3 Improving earthquake resistance of reinforced concrete buildings

For improvement of earthquake resistance of RC buildings many things should be considered. The major deficiency of low raised RC buildings is associated with strength and ductility of the RC elements. So the ductile detailing is a major part for improving seismic resistance. In this section seismic detailing are described.

**Foundation**

If isolated footing is used as foundation, it is advised to connect them at foundation level or ground level or just below plinth level. When a column terminates into a footing or a mat, special confining reinforcement shall extend at least 300 mm into the footing or mat. The spacing of confining reinforcement shall not be more than 100 mm.

**Beam Dimensions**

- Beams shall preferably have a width to depth ratio of more than 0.3.
- The width of the beam shall not be less than 200 mm.
- The depth of the beam shall preferably be not more than 1/4 of the clear span.
**Longitudinal Reinforcement**

- Top as well as bottom reinforcement shall consist of at least two bars, of not less than 12 mm, throughout the member length.
- The tension steel in any face, at any section, shall not be less than 0.3% (for concrete grade M15 or mix 1:2:4 and steel yield strength 415 MPa).
- The positive steel at a joint must be at least equal to half the negative steel at that section, subject to minimum of 0.2%.
- The maximum steel percentage on any face at any section shall not exceed 2.5%.
- The steel provided at each of the top and bottom face of the member at any section along its length shall at least equal to 1/4 of the maximum negative moment steel provided at the face of either joint.
- In an external joint, both the top and bottom bars of the beam shall be provided with anchorage length, beyond the inner face of the column, equal to the development length in tension plus 10 times bar diameter minus allowance for 90 degree band (58xdiameter of bar for concrete grade M15 or mix 1:2:4).
- Splicing of bars by overlapping should be done using full development length (i.e. 56 x diameter of bar for concrete grade M15).
- Spliced length shall be enclosed in stirrups spaced not more than 150 mm apart.
- Not more than 50% of the bars shall be spliced at any section. If the spacing between centres of splicing is more than 1.3 x lap length, staggered splicing shall be considered.
- Splice position for bottom bars shall be restricted to a region at least 2d (2x depth of beam) away from face of column but excluding the middle quarter length of effective span.
- Top bars shall be spliced in middle 1/3 of effective span.
- All longitudinal bars of beam shall pass through longitudinal bars of the column.

**Web Reinforcement**

- Web reinforcement shall consist of vertical stirrups. The closed stirrup should have a 135° hook. The ends of the stirrup should be embedded in confined core. In compelling situation, it may also be made up of two pieces of reinforcement; a U- stirrup with a 135° hook and a 10 diameter extension at each end, embedded into confined core and a cross tie. Across-tie is a bar having a 135° hook with a 10 diameter extension (but not<75 mm) at each ends. The hooks shall engage peripheral longitudinal bars.
- The minimum diameter of stirrups shall be 6mm. However, in beams with clear span exceeding 5m, the minimum bar diameter shall be 8mm.
- The spacing of stirrups over a length of 2d at either end of a beam shall not exceed (a) d/4, and (b) 8 times diameter of smallest longitudinal bar. However, it need not be less than 100mm as shown in Fig. 54. In rest of the length, stirrups shall be provided at spacing not exceeding d/2.

**Column Dimensions**
- The minimum dimension of the column shall not be less than 200mm. However, in frames which have beams with centre to centre span exceeding 5m or columns of unsupported length exceeding 4m, the shortest dimension of the column shall not be less than 300mm.
- The ratio of shortest cross sectional dimension to perpendicular dimension shall preferably be not less than 0.4.
- Width of column shall preferably be 75mm larger than the supported beam.

**Longitudinal Reinforcement**
- Lap splices shall be provided only in the central half of the unsupported member length as shown in Fig. 56. It should be proportioned as a tension splice. (i.e. lap length shall be 56ϕ for concrete mix 1:2:4 and steel grade fe 415).
- Steel at any section shall not be less than 0.8%.
- Bars less than 12 mm in diameter shall not be used in column as longitudinal reinforcement.
- Closed hoops shall be provided over the entire splice length at spacing not exceeding 150 mm or d/2, preferably 100 mm.
- Not more than 50% of bars be spliced at any one section.

**Web Reinforcement**
- The stirrups should be closed type having a 135 ° hook with a 10-diameter extension (but not less than 75mm) at each end.
- The parallel legs of rectangular hoops should not be more than 300mm apart. If the length of any side of hoop exceeds 300mm, a cross-tie shall be added.
- Alternatively, a pair of overlapping stirrups may be provided within the column.
- Stirrups shall be provided at the spacing of 100 mm ord/4 (but not less than 75 mm) in the ends of column (a) 1/6 of clear span of column (b) larger lateral dimension of the column; or (c) 450 mm whichever is more.
- In the rest of the length, the spacing of stirrups shall not exceed half the shortest lateral dimension of the column.
- Where column is confined by low walls height (as columns abutting walls on opposite sides), stirrups shall be provided at the spacing of 100 mm or d/4 (but not less than 75 mm) throughout the free length of the column.
Beam Column Joint
Transverse Reinforcement

- In exterior columns stirrups as provided at the ends of column shall also be provided through the beam-column joint.
- In interior beam-column joint which has beams framing into all vertical faces of it and where each beam width is at least 3/4 of the column width, stirrups may be provided at the spacing of 200 mm or d/2 whichever is less.
- Stirrups in the joint area may be provided.

5. Improving Seismic Resistance of Existing Buildings

5.1 Choices of Option

For decreasing existing risk of structures to earthquake there are two options for choice. Either pull down the structure and reconstruct it or retrofit it. From the comparison of cost it is seen that retrofitting is quite a promising option unless the building has lost its structural value and cannot be saved or the modern day’s functional requirements of the building have changed.

The following chart and table (From SESP report NSET-Nepal) describe the retrofit option is better if the retrofitting option for the building is technically feasible.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Demolition &amp; Reconstruction</th>
<th>Retrofitting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Involved Costs</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Time for Construction</td>
<td>&gt; 1 year</td>
<td>3-4 months</td>
</tr>
<tr>
<td>Disturbance to School Function</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Disposal of Scrapped Materials</td>
<td>Big Problem</td>
<td>No Problem</td>
</tr>
<tr>
<td>Technology (adaptability)</td>
<td>Usual, so no excitement</td>
<td>New, so high excitement, need Training.</td>
</tr>
<tr>
<td>Potential Impact (Replicability)</td>
<td>Low/Medium</td>
<td>High</td>
</tr>
</tbody>
</table>
5.2 Retrofitting

The analysis, design and construction of any necessary retrofitting must be carried out bearing in mind the following aspects:

1. **Physical and functional aspects.** The retrofitting should not affect the day-to-day operations.
2. **Aspects of structural safety.** It is essential to reduce vulnerability to acceptable levels, so that the building can continue to function after an earthquake.
3. **Construction techniques.** Retrofitting should be carried out using construction techniques that have the least impact on normal functions. For instance it would be difficult to shut down a hospital for repairs.
4. **Cost of the intervention.** The cost of retrofitting cannot be ascertained unless a detailed design of the structural solution and of its implications for the nonstructural elements is carried out.

Retrofitting costs are usually relatively high, especially when done in a short period of time. However, if the work is done in stages, resources can be used within the range of expenditures for maintenance. In accordance with the above, the intervention of the structure should seek to reduce the existing vulnerability by responding to existing performance problems. The structural retrofitting should:
- Increase resistance;
- Increase stiffness and therefore decrease deformation; Increase ductility;
- Attain an adequate distribution of the stresses between the different resistant elements, as much in the ground plan as in the vertical configuration. The usual systems of structural reinforcement tend to incorporate the following additional elements

**RETOFITTING OF MASONRY BUILDING**

Retrofitting of existing school buildings to improve their seismic resistance seems the most feasible solutions for their protection.

Retrofitting an existing building to improve its seismic resistance involves four main issues. First is the engineering method employed, it includes technical problem of code requirements, design approach, materials and construction techniques. Second is the cost of the project, such as cost of construction, design and testing, and the cost of permits and approvals. Third is the indirect cost of retrofitting such as relocation cost. Fourth is the question of the effectiveness of the retrofitting in reducing the likely damage.

**Philosophy and Approach**

The philosophy adopted for retrofitting the school buildings is to: achieve fail-safe damage: delayed collapse-allowing pupils to escape during an earthquake, ii) achieve reduction in the likely damage allowing post-earthquake repair and re-strengthening at nominal costs.

Retrofitting schemes are generally considered acceptable for those building for which the retrofitting cost does not go beyond 25% of the present value of the building, and which will have, after retrofitting, an economic loss of less than 60% under an earthquake shaking equivalent to MSK intensity IX. Following additional requirements are also considered:

- Compatibility of the solution with the functional requirements of the structure
- Feasibility of the construction, including availability of materials, construction equipment and personnel
- Sociological consideration
- Aesthetic
Lessons Learnt from Past Earthquakes

Masonry Buildings
The following appear to be the major problems faced during earthquake shaking in the different types of school buildings and their component elements:

- Non-integrity of wall, floor and roof and their units
- Out of plane collapse of upper parts of the wall of the flexible roof buildings due to lack of anchoring elements.
- Separation of orthogonal walls at “L” and “T” junctions
- Buildings with rigid floor and roof (RC/RBC floor, roof) suffer diagonal cracking of piers in lower story.
- Delamination of wythes in rubble masonry walls buildings
- Dislocation of stone units from wall (mechanism failure) due to their irregular shape
- Collapse of gable wall as it behaves as free cantilever.

General Retrofitting Techniques
Commonly, seismic retrofitting should aim at one or more of the following objectives:

- Eliminating features that are source of weakness or that produce concentrations of stresses in some members, abrupt change of stiffness from floor to floor, concentration of large masses, large opening in walls without proper peripheral reinforcement
- Increasing the lateral strength in one or both directions, by reinforcing or by increasing wall plan areas or the number of walls
- Giving unity to the structure by providing a proper connection between its resisting elements, in such a way that inertia forces generated by the vibration of the building can be transmitted to the members that have ability to resist them. Typical important aspects are the connection between components of floors and roof, between roof or floors and walls, between intersecting walls, walls and foundation.
- Avoiding the possibility of brittle mode of failure by proper reinforcement and connection of resisting members.

Configuration Improvement

Modification of Plan
Majority of school buildings have simple design, most of them are rectangular with length to width ratio less than three. The next preferred shapes are elongated rectangle or L-shape. Other shapes also exist. The design of the buildings can be improved by separating wings and/or dividing it in parts.

To balance the stiffness of the building design, some existing openings may require elimination, reduction in size or even
construction of new openings. Similarly, as in new building construction, there should be limitation on openings.

_Elevation Improvement_

School building in general is simple in construction though there remains some problem of stiffness distribution, in vertical direction. As the construction process has been incremental, upper storey could have less covered area than lower one making building look like terrace that may lead to rotational effects. The problem can be solved, through not necessary, either by demolition of upper part or construction of the uncovered areas.

_Floor or Flat Roof Improvement_

Where the roof or floor consists of wooden poles or joists carrying brick, tiles and earth, their integration is necessary. Simultaneously, floor structure should be stiffened in horizontal plane as well. Some of the methods of improvements are listed below:

_Insertion of a New Slab_

Seismic behavior of a masonry building can be improved by replacing an existing timber floor with a rigid slab inserted into existing wall. The slab has to be properly connected to the walls through appropriate keys.

_Existing Wooden Floor or Flat Roof_

If the existing wooden floor or flat roof is not replaced by new RC slab, the following actions have to be undertaken to improve behavior of floor structure:

_Nailing/ Strapping_

The different components of timber floor or flat roof should be well integrated using nails, steel straps to make them one unit.

_Seismic Band_

Either insert a timber belt just below the floor or flat roof or construct a RC seismic bandage on the wall faces just below the floor or roof and anchor the floor or roof structure with the belt.

_Stiffening the floor structure_

This can be achieved either by:

- Nailing a layer of new planks: New layer of plank could be nailed perpendicularly or diagonally to the existing structure or
- Placing a thin RC slab topping over the existing floor: RC cast-in-place topping, with a minimum thickness of 40 mm must be provided which is reinforced by 4.75mm diameter bars placed at 200 mm intervals in both the directions or
- Alternatively a steel wire mesh is nailed to existing wooden floor, topped with concrete and connected to the walls by a number of distributed steel anchors. These can be hammered into the wall and a local hand cement grout has to be applied
- Bracing the wooden floor structure: Floor structure can be stiffened by nailing wooden planks or steel straps in the under
side of the floor structure and anchoring these new members with wall structure.

Connection of the existing floor structure with the walls
If the existing floor structure is not well integrated with wall structure, a proper connection can be achieved. It consists of flat steel bars nailed to the wooden supporting beams and to the wooden floor. Holes drilled in the walls to anchor them have to be filled with cement-sand grout. If a steel mesh has been used, the connection can be made.

Roof Improvement
Integrity between different elements of timber roof structure, lack of anchorage between roof rafters and wall, and lack of diaphragm action are general problems with timber floor. Following are the identified problems and some remedial measures:

- Slates and roofing tiles are brittle and easily dislodged. Where possible, they should be replaced with corrugated sheet or asbestos sheet.
- False ceiling of brittle material is dangerous. Non-brittle materials, such as Hessian cloth, bamboo matting or light ones of foam substance, could be used.
- Different components of timber roof should be well integrated using nails, steel straps.
- Anchorage of roof trusses to supporting walls should be improved. A roof level band of RC or timber should be constructed on top of existing wall and the rafters be well anchored into the band with help of rebars, long nails.
- The roof thrust on walls should be eliminated. Fig. 67 illustrates a method in which the rafters are connected with each other at the ridge and horizontal planks are added to take horizontal tension. Where longitudinal wall goes up to the ridge level, the wall top should be dismantled in parts starting from one end, the horizontal plank fixed into position and then rebuilt.

Improving Earthquake Resistance of Wall Structure
Earthquake resistance of a masonry building can be improved by increasing the strength and stiffness, reducing the length of existing walls, addition of new walls, reducing the existing opening, changing the location of opening and in some cases even constructing new opening if the openings in opposite face are unbalanced. The measures are discussed below.

Internal cross wall
Long barrack type halls may be subdivided by building cross walls at intermediate points to enhance their stability. The wall should be at least 200 mm thick and should be properly bonded with existing walls by keying masonry units into them and stitching old and new walls. Appropriate foundation must be provided for the new walls. Door and window openings and lintel bands may be introduced into
new walls bonded with the external walls by passing bars through and grouting them.

**Buttressing**

Where subdivision of the space by internal cross walls is not acceptable due to functional or other reasons (for breaking the longitudinal walls of long barrack type buildings), masonry buttress may be added externally or RC column may be introduced into walls.

**Stitching the walls**

The weak connection between transverse walls at corners, T-junctions can be improved by stitching these walls with reinforced concrete or inserting timber pieces. It can be done by opening the wall in parts and introducing RC stitch if wall is constructed in mud mortar as shown in Fig. 81. Alternatively the stitching can be done by drilling walls first, filling the drill hole with cement grout and forcefully inserting steel bar. It should be provided at the spacing of 500-700 mm.

**Pre-stressing**

A horizontal compression state induced by horizontal tendons can be used to increase the shear strength of walls. Moreover this will also improve considerably the connection of orthogonal walls. The easiest way of affecting the pre-compression is to place two steel rods on the two sides of the wall and tightened. In general two number 16mm diameter bars meet the requirement. Further more, good effects can be obtained by slight horizontal pre-stressing (about 0.1 MPa) on the vertical section of the wall. Pre-stressing is also useful to strengthen spandrel beam between two rows of openings in case no rigid slab exists.

**Jacketing of walls**

Steel mesh (welded wire fabric with mesh size approximately 150 x 150mm) is placed on both the sides of the walls, and interconnected by passing steel (each 500 to 750 mm apart), through the wall or held to the wall by driving spikes. A 40mm thick cement mortar or micro-concrete layers is then applied on the both faces of the wall thus giving rise to two interconnected vertical plates. These plates basically “basket” the wall, hence improve its shear strength, ductility. This system also improves the connection between transverse walls.

**Splint and Bandage**

This system is basically extension of “jacketing of wall”. In this system the mesh is provided in only critical zones to cut the cost. Splints and bandage are vertical and horizontal belts respectively to tie up walls together. The bandage is provided in the both faces of the wall and interconnected by passing steel (750-900 mm apart). A 40-50mm thick cement mortar or micro-concrete layers is then applied on the steel mesh thus giving rise to a horizontal beam. The main function of bandage is to hold horizontally the various walls together at corners and across the building and thereby prevent out of plane collapse of walls.
Splints are vertical elements, provided at corners, wall junctions, and jambs of openings in external face of the building so as to provide integrity in vertical direction.

Reinforced Concrete Column and Beams technique
In this scheme, RC columns are added at ends of cross and longitudinal walls and horizontal RC beams are added monolithic to the added columns. The beams run all around outside the building just below the ceiling level of roof and floor. Cross ties are used to connect opposite columns.

Stitching of Wythes
In stone walls constructed without "through" stones, these can be substituted with reinforcement and cement concrete. These can be installed by removing stones from the walls thereby making holes (75mm size) in them. Then an 8mm-diameter bar can be placed in the hole filled with 1:2:4 mix concrete.

**Associated Problems**
Retrofitting an existing building is a cumbersome task because of associated complications that may pose serious problems during retrofitting. Some of these could be:

- The buildings in the core area are so congested that there remains very little working space for implementing the retrofitting works.
- Courtyard with buildings all around may pose severe configuration problems.
- As the buildings are constructed over long periods of time, a sudden change in the walling, flooring and roofing materials is common in very small space. This fact generally cannot be visualized/verified until the walls are opened. There remains very high possibility of overlooking them.
- Such “surprises” during the implementation of the retrofit works will necessitate changes in the retrofitting design leading to time and cost overruns. This factor should be well considered before the commencement of retrofit works.
- The possibility of future vertical expansion should always be considered especially in core areas, prior to designing the retrofit works.
- Shifting of structural walls in upper stories is common (load path not defined) and it would be difficult to clearly define the load path because of space requirements.
- As the quality control measures are non-existent, there remains no assurance of quality of used material and the detailing. Shifting of columns, beams, cosmetic filling of honeycombing, non-existence of mortar between bricks are the common problems to be considered in the design of retrofit works.
- Frequently a part of timber floor and roof are rotten, insect eaten, sagging excessively needing replacement. It could pose some extra cost.
In old buildings, use of damp proof course is non-existent leading to decay of bricks up to first 1-1.2m from ground level. These bricks may need replacement.

References


3. PAHO, 1992, Disaster Mitigation Guidelines for Hospitals and Other Health Care Facilities in the Caribbean, Pan American Health Organization (PAHO).


