



Retrofitting Guidelines

for Developing Hazard Resilient Schools in Khyber Pakhtunkhwa



Education Department
Government of Khyber Pakhtunkhwa

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Disclaimer: The Guideline is based on the retrofit practices applied in twelve earthquake affected schools at two Districts Peshawar and Swat of Khyber Pakhtunkhwa Province (KP). The Guideline will serve as a guiding tool to undertake the retrofitting of other hazard affected buildings in various schools throughout KP Province, or elsewhere in Pakistan; and to also assist the Local Education Departments and School Administrations in constructing hazard resilient school buildings, in future. While every effort is made to ensure the accuracy and completeness of information and retrofit practices contained.

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A. Preface

The natural disasters don't kill most people, but the poorly built building structures do. The safety of buildings, both before and after a disaster, can be enhanced by incorporating the retrofit-standards in their design and construction, while complying with the local building code and regulations.

To support this initiative, the present guidelines is based on the retrofit practices applied in twelve earthquake affected schools at two Districts Peshawar and Swat of Khyber Pakhtunkhwa Province (KP). The Guidelines will serve as a guiding tool to undertake the retrofitting of other hazard affected buildings in various schools throughout KP Province, or elsewhere in Pakistan; and to also assist the Local Education Departments and School Administrations in constructing hazard resilient school buildings, in future.

This Guidelines is neither intended to replace any present Building Code or School Construction Standards; nor is a Building Construction Manual. It presents a summary of the retrofit construction techniques for use as a guide by the masons, artisans and work supervisors. As such, these should be adopted to the local context, and used as a guide for planning and implementing an appropriate response to build hazard resilient school buildings. The retrofit measures for the non-structural building components are also included, which can vary according to the type of hazard and building typology of each school, and the techniques as considered appropriate by the structural-engineer or work-supervisor.

An effort has been made to make the guidelines easy-to-understand for replication, and readily implementable as per the level of building's vulnerability to be indicated in the pre- and post-disaster vulnerability and technical assessments; besides, disseminating practical knowledge to make school buildings maximum possible safe for the children within the overall framework local Disaster Management Strategy.

B. Vocabulary

Affected: People can be affected directly or indirectly by a hazard. Affected people may experience short-term or long-term consequences to their lives, livelihoods or health and to their economic, physical, social, cultural and environmental assets. In addition, people who are missing or dead may be considered as directly affected.

Building Code: A set of regulations and associated standards intended to regulate aspects of the design, construction, materials, alteration and occupancy of structures, which are necessary to ensure human safety and welfare, including resistance to collapse and damage. It can include both technical and functional standards, based on international experience and tailored to national/local norms.

Infrastructure: Physical structures, facilities, networks and other assets which provide services essential to social and economic functioning of a community or society. Effect of disaster can be immediate and localized but is often widespread and could last for a long time.

Disaster: A “serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses/impacts, which exceeds the ability of affected community or society to cope using its own resources”. Disaster impact is an effect, including negative effects (losses) and positive effects (gains) of hazardous event/disaster. It may cause death, injuries, disease and other negative effects on human physical, mental and social well-being.

Disaster Risk Resistance Framework: It considers the following.

- **Small-scale disaster:** Affects local community-requires some assistance beyond community.
- **Large-scale disaster:** Affecting a society, requiring national/international assistance.
- **Frequent and infrequent disasters:** Depend on probability of occurrence and return period of hazard and its impacts; which can be cumulative or chronic for community or society.
- **Slow-onset disaster:** Emerges gradually over time, associated with drought, desertification, sea-level rise, epidemic disease.
- **Sudden-onset disaster:** Triggered by a hazardous event that emerges quickly or unexpectedly, and associated with earthquake, volcanic eruption, flash flood, chemical explosion, critical infrastructure failure, or transport accident.

Disaster Risk Reduction: A practice to reduce disaster risks through systematic efforts i.e. analyze and manage factors of disasters, including reduced exposure to hazards, lessened vulnerability of people and property, management of land and environment, and preparedness for adverse events. DRR strategies and goals are set out in UN endorsed Sendai Framework for DRR 2015-30, whose expected outcome in next 15 years is: “Substantial reduction of disaster risk and losses in lives, livelihoods and health and in economic, physical and environmental assets of persons, communities and countries”.

Hazard: A phenomenon or human activity that may cause loss of life, injury or health impacts, property damage, socio-economic disruption and environmental degradation. Natural hazards are predominantly associated with natural processes and phenomena. Anthropogenic or Human-induced hazards are caused by human activities and choices. Socio-natural hazards are associated with a combination of natural and anthropogenic factors (i.e. environmental degradation, climate change).

Hazard (or Disaster) Resilience: Ability of a system, community or society exposed to hazards to resist, absorb, accommodate and recover from the effects of a hazard in a timely and efficient

manner, including through the preservation and restoration of its essential basic structures and functions.

Mitigation: The process of lessening or limiting the adverse impacts of a hazards and related disasters, in particular natural hazards, which cannot be prevented fully, but their scale or severity can be substantially lessened by various strategies and actions. The “Mitigation Measures” include engineering techniques and hazard-resistant construction i.e. retrofitting and improved environmental and social policies and public awareness.

Non-Structural Measures: They do not involve physical construction and use knowledge or practice to reduce disaster risks and impacts, in particular through building codes, land-use planning laws, public awareness raising, training and education.

Preparedness: Knowledge and capacities developed by the Governments, professional response and recovery organizations, communities and individuals to effectively anticipate, respond to, and recover from, the impacts of likely, imminent or current hazard.

Prevention: Outright avoidance of adverse impacts of hazards and related disasters.

Reconstruction: Medium- and long-term rebuilding and sustainable restoration of resilient critical infrastructures, services, housing, facilities and livelihoods required for the full functioning of a community affected by a disaster, aligning with principles of sustainable development and “build back better”, to avoid future disaster risk.

Rehabilitation: The restoration of basic services and facilities for the functioning of a community or a society affected by a disaster.

Risk: A product of hazards over which we have no control and vulnerabilities and capacities over which we can exercise very good control.

Resilience: The ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management.

Responses: Provision of emergency services and public assistance during or immediately after a disaster in order to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people affected.

Retrofit: Reinforcement or upgrading of existing structures to become more resistant and resilient to the damaging effects of hazards. Retrofitting requires consideration of the design and function of structure, the stresses that the structure may be subject to from particular hazards or hazard scenarios and the practicality and costs of different retrofitting options. Examples of retrofitting include adding bracing to stiffen walls, reinforcing pillars, adding steel ties between walls and roofs, installing shutters on windows and improving the protection of important facilities and equipment.

Structural Measures: Any physical construction to reduce/avoid possible impacts of hazards, or application of engineering techniques/technology to achieve hazard resistance and resilience in structures or systems; including EQ-resistant construction, dams, flood dykes and evacuation shelters.

Vulnerability: The characteristics/circumstances of a community or system that make it susceptible to the damaging effects of a hazard. A school is said to be 'at-risk' or 'vulnerable', when it is exposed to known hazards and likely to be adversely affected by impact of those hazards when they occur.

Section - 1

Need of Guideline and Role of UN-Habitat

1.1 Introduction

The Northern Areas of Pakistan including Khyber Pakhtunkhwa Province (KP) are situated in an active seismic region. There, the safety of school buildings plays a critical role in protecting the children from the risks and vulnerabilities of a disaster. It is neither practical nor feasible to demolish all the existing buildings and construct new schools meeting seismic safety standard. A practical approach to increasing seismic safety of these buildings is to strengthen and upgrade their level of safety. All non-engineered or semi-engineered buildings (built of unconfined or confined masonry and simple reinforced concrete structures, using stone, brick and wood), which do not meet the hazards resilient and safety standards need to be inspected to determine their eligibility for reconstruction, or strengthening, or retrofitting.

Hazard resilient schools can provide safe spaces, normalize the daily activities of children, and assist in their life-saving and wellbeing, knowledge and skills. It is therefore, important that the Governments respond quickly to restore the provision of education, with the longer-term mission of “building back better”. A resilient school must be able to withstand the extreme disaster events without collapsing, and that whilst there may be extensive damage, the risk to loss of life is low as the children are able to exit safely. Considering that most schools are structurally unsafe, there is also an urgent need to raise an awareness of safe school construction through the implementation of hazard resilient design and construction practices.

In view of the continued use of existing school buildings, main effort to reduce hazard risk in future is to introduce EQ resistance features in their construction, i.e. retrofitting methods. Depending on the type and location of damages occurred in school buildings during 2005 Earthquake, there are a number of methods that can be applied for retrofitting the existing damaged structures.

1.2 Types of School Buildings in KP

Majority of the existing school structures in KP are one or two-storey high and built with “vernacular building system”, i.e. confined masonry in stone, bricks, or CC blocks, and roofed with wooden or pre-casted purlin and rafters topped with mud-layers, brick-tiles or both, or pitched corrugated galvanized iron roofs, or RCC slabs topped with tiles or mud layers.

- Stone Masonry: Where the stones are easily available, they are bonded together with mud mortar. Stone on cutting and dressing to a proper shape is an economical material for construction of walls, columns, footing, arch-lintels, etc. Most stone masonry is built without reinforcement to bear heavy load roof, and no through-stone at designed spaces; thus, causing severe damages in earthquakes.
- Brick Masonry: Brick masonry used in most KP schools is either mud mortar or cement sand mortar, but without reinforced columns or pillars to bear the heavy load of reinforced brick or tile roof. In case of difficulty to get bricks, the hollow or solid cement-concrete blocks are used.
- Reinforced Cement Concrete: In KP, the schools built in near past, are RCC buildings, designed with proper foundation, reinforced columns and footings for holding the live and dead loads. But they generally lack the “hazard-impact resilient structures”, which causes damages and casualties during earthquakes

Most buildings were built 15 to 20 years ago by local masons with poor detailing, using local materials, and traditional methods and without any consideration of the level of seismic damage.

The performance of these buildings varies greatly, depending on the quality of materials and construction methods, which makes the vulnerability assessment more difficult. Following “Major Weaknesses” were observed during the earthquakes in similar building typology.

- Absence of ties in beam column joints
- Inadequate confinement near beam column joint
- Inadequate lap length and anchorage and splice at inappropriate position
- Low concrete strength
- Improperly anchored ties (90o hooks)
- Inadequate lateral stiffness and strength
- Irregularities in plan and elevation
- Irregular distribution of loads and structural elements
- Structural deficiencies (strong beam and weak column connections, short columns)

1.3 Hazard Level Maps

After the 2005 Earthquake, to determine the level of ground-shaking which the school buildings may undergo, and the level of earthquake ground-motion to be expected at various locations, the seismic hazard maps were produced by Earthquake Rehabilitation and Reconstruction Authority. These maps are included in the Pakistan Seismic Building Code 1987. The maps inform about the maximum responses, expressed in the “earthquake zone-wise hazard assessment”, corresponding to 10% probability of occurrence in 50 years. However, there is no literature available to provide information on the assumptions made in producing these seismic maps.

The process recommended for retrofit works in 12 schools was based on Pakistan damaging magnitude 7.6 Earthquake in 2005. The fact that most schools in KP followed a standard design, provides a unique opportunity to assess the broad segments of school buildings uniformly and to develop uniform analysis and assessment plans for detailed evaluation and retrofit, as per the gradual enforcement of Pakistan Seismic Building Code 2007.

1.4 Seismic Performance of Schools

The KP-ED also conducted an evaluation of seismic performance of selected school buildings in order to ascertain the life safety of children. This evaluation revealed following potential deficiencies.

- Shear stresses in the frame columns exceed safe limits. This can lead to excessive lateral deformations, degradation of concrete within the columns, and possible loss of gravity capacity.
- Expansion/contraction joints between adjacent walls and between stairs and the building structure are not sized to function as seismic separation joints, so some pounding damage is expected, which may lead to loss of or block the emergency egress paths for children.
- There is an inadequate separation between infill walls and structural columns. The structural frame and the non-structural masonry wall are not properly inter-connected. This may lead to a captive column condition, in which the lateral deformation of roof or upper-storey is

concentrated over the reduced free height of concrete column. In the 2005 Earthquake, this has led to the columns' shear failure and partial structural collapses.

- ➔ The reinforcing detailing does not meet the design requirements for a ductile structure.

1.5 Retrofitted Schools Pictures

The Photo-log of retrofit works completed in 12 earthquake damaged school buildings is placed at ANNEX-A.

1.6 Major and Minor Vulnerabilities in Schools



GPS Pajjaggi - Peshawar

A bomb blast just behind the wall resulted in buckling of walls and columns in addition to sag in beam.



GBPS Hazara Khwani # 1 - Peshawar

Bond failure in RCC columns due to humidity caused by roof drain water and standing of water on street during rains.



GGPS Hazara Khwani Chena Dag – Peshawar

Steel exposed on both sides of staircase. Using substandard material loosened due to rain water flowing along sides. If retrofit works not done earlier, the stairs' slab may sag.



GHS Ghalegay - Swat

Plaster removed/fallen because of bonding failure with stone masonry. Also, limited quantity of cement was used in stone masonry, as may be seen in the voids.



GPS Kabal – Swat

Continuous seepage at particular point over beam resulted in CC falling and exposed steel bars.



GMS Lala Kalay – Peshawar & GPS Bara Bandai – Swat

Material failure on ceiling due to various reasons like improper concrete cover underneath the reinforcement, poor construction and seepage from roof.

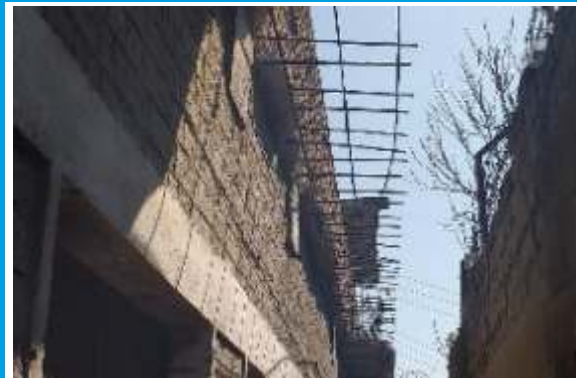


GGPS Hazara Khwani Chena Dag – Peshawar

Undulation of beams and slab caused due to negligence in the formwork during construction. It requires proper cutting and leveling prior to applying the chemical process and mortar.



Normal practice in construction of KP Government buildings is frame structure and using brick tiles over RCC slab, which becomes hazard due to improper pointing as in above pictures. Continuous stagnation of water during rains resulted in seepage from voids and hence bond failure occurs in slab and beams.



RCC Projection failure is also very common in Government school buildings. Main causes are bad design, faulty construction, seepage due to growth of weed-plants on them, no parapet walls, extra loads; or a combination of more than one cause.



Various minor and deep cracks in brick or stone masonry, concrete and staircase.

1.7 Role of UN-Habitat

In KP Province, most of the school buildings have been damaged by the earthquakes; mainly, due to the lack of impact-resistance of their structures built with old vernacular construction techniques, which are non-resilient to the both pre-hazard and post-hazard impacts.

The UN-Habitat initially undertook a rapid assessment of a long list of partially damaged schools as provided by Provincial Education Department, and 36 schools were short-listed based on the following site-visit reports.

- Schools of different types of construction
- Cracks in ceilings, corners and roof
- Damaged doors, windows and surfaces requiring plaster
- Connections of cracked walls at corners and junctions.
- Major Cracks (Crack width more than 5 millimeter)
- Connecting corners and walls at T-junction
- Weld-Mesh or other reinforcement
- Water proofing of roofs

Later, based on the following selection criteria, the 12 school buildings were finally selected in two districts Swat and Peshawar, and the UN-Habitat has completed a pilot project of retrofitting these schools, to serve as prototype model.

- Level of vulnerability and possibility of seismic retrofitting intervention,
- Visibility of retrofit technology so as to raise its awareness,
- Willingness and acceptance of the school-admin and the community,
- Potential of capacity building of local masons, and
- Not requiring future expansion of the building

Prior to the execution of project work, the technical trainings were arranged by the UN Habitat for the contractors' artisans/masons, the technical teams of Education Department, and School liaison committees; along with the distribution of introductory booklets on retrofitting techniques. Based on the experience of retrofitting process and methodology applied in 12 schools, the present Guidelines has been developed.

Section - 2

Building Categories, Hazard Risks and
Vulnerability Assessment, etc.

2.1 Types of Buildings and Seismic Zones

For the school buildings in a high seismic zone and located on soft soil or on rock soil in KP region, the strict design rules need to be applied. The buildings' classification or category is related to a "basic seismic coefficient", which is a combination of seismic zonation, ground conditions and building use. Zoning data is derived from the "seismic zonation maps" in Seismic Building Code 2007, which tells expected seismic hazard levels based on frequency and intensity of expected earthquakes in an area. Also, the ground conditions can greatly influence the seismic behavior of a school building, and the strength and stiffness of soil relates to certain values of geotechnical engineering properties, such as the foundation-soil factor and the allowable bearing capacity.

For considering the seismic strength of load-bearing masonry school buildings in KP, the following three types of vernacular construction systems are to be considered. Whereas, in non-engineered buildings two types of structural systems are built i.e. Wall-bearing construction bearing vertical and lateral loads (unconfined masonry), and the Masonry walls with framing construction bear vertical and lateral loads (confined masonry).

- Confined masonry walls act as shear panels which serve as the lateral load-bearing system. These walls are built first, usually with a toothed pattern at the wall ends, and then tie beams and tie columns of reinforced concrete are cast around the panels, serving as confining members. Ashlar stone walls qualify for confined masonry, but at the high cost.
- Unreinforced masonry (i.e. non-engineered construction type): No reinforcements whatsoever incorporated in the walls. All seismic codes prohibit its use in earthquake zones, unless the strengthening for unreinforced masonry in place, such as concrete beams or steel ties.
- Reinforced masonry, being an engineered construction technique, has regular horizontal and/or vertical reinforcements throughout the wall. They are embedded to act together with the masonry units in resisting lateral forces in the both "In-plane" and "Out-of-plane" directions.

2.2 Common Construction Faults

The structures of vernacular buildings are generally non-engineered, designed without adequate detailing and reinforcement for hazards and seismic protection. The structures of existing school buildings built on vernacular confined masonry system are strong to resist gravity load only. However, because of their weak-resisting lateral load system, they are unstable to withstand the forces or impacts of hazards and consequent disasters. Witnessing that most of the forces of natural disasters apply laterally, it is imperative that the vulnerability of existing schools' buildings be reduced.

In some schools located at distance areas, the contractor's failure to build school buildings in accordance with approved drawings and specifications have also added to the failure of structures. Use of inferior or sub-standard building materials is another reason of buildings failure. Overloading during the life span of a building also critically weakens their structural reliability of it. Some buildings were damaged due to extra load because of unauthorized change of use, or additions/alterations to the structure, resulting in the eventual failure of under-designed building.

Additional factors for such failures were the inadequate supervision and control of site operations and quality control due to distant location of many schools; besides, the inappropriate work

sequencing, not-enough professional support or technical skill; unnecessary structure weight, untimely taking away of formwork; and non-conformance to specifications.

2.3 Factors Affecting Earthquake-induced Structural Damages

In KP, the ground shaking is the main cause of damage by earthquakes. There, the main priority for school buildings is to make them earthquake (EQ) resistant structures, keeping in view the following pre-requisites. Others hazards' failures (landslides, tsunami, fire, etc.) have been reckoned as secondary disasters, insofar the scope of present Guidelines is concerned.

· Site condition significantly affects building damage. Earthquake shaking characteristics is directly related to the type of soil layers supporting the building. Suggested earthquake resistant building configurations are the "Regularity" and "Symmetry" in the overall shape of a building.

- More openings in walls of a building tend to weaken the walls. Generally, the damage of walls with fewer openings is reduced. Rigidity of a building be distributed as uniform as possible in vertical as well as horizontal direction. Difference in rigidity from one floor to the other tends to damage the buildings, when shaken by earthquakes. The greater the distance between center of mass and center of rigidity, the greater the tendency of damage, when shaken.
- Strength of buildings' structure should have adequate strength to resist earthquake shaking and particularly the "Rocking" effect. Generally "rocking" occurs in rigid buildings i.e. all building components, foundation, column, beam, walls, roof trusses/slabs must be tied to each other, so that when shaken by earthquakes, the buildings will act as one integral unit.
- Ductility is an ability of a building to bend, sway and deform without collapse. Technically, ductility is the comparison between "deflections before a building collapse" with the "deflection when a building starts to damage". A building is earthquake resistance, if its overall structure has high ductility. For high-rise building, both strength and ductility are necessary. But, for 1 or 2 storey relatively rigid school buildings, the strength is more dominant compared to ductility.

2.4 Level of Safety

School buildings are considered as important facilities due to their vital roles in the communities. Considering the school children are more vulnerable to disasters, hence the provision of high "Level of Safety" must be the priority action(s) to ensure the survival of both human and physical assets. Level of "school safety standards" need to specify the mandatory requirements associated with the:

- basis of structural design,
- quality of construction materials,
- durability of structural members,
- workmanship during construction, and
- Safety against EQ; floods, fire, etc.

To achieve required "level of safety", it is necessary that separate Technical Standards be followed for the: (a) masonry and RC block construction, (b) RCC and steel reinforced concrete construction, and the (c) other construction. For retrofitting school buildings, following 3 levels of safety be kept in view.

- If safety level of school building is found adequate, the necessary repair and regular maintenance be undertaken, for ensuring the adequate performance of structure a future earthquake.
- If safety of building is considered inadequate, the retrofit is necessary; provided the proposed retrofit scheme is technically feasible and economically viable (Usually retrofitting is considered suitable if its cost is within 30% of the cost of new construction).
- If safety of a building is declared inadequate and building is in imminent danger of collapse in the event of an earthquake; any retrofit scheme is not economically viable or feasible. It is recommended to demolish and reconstruct it for better seismic performance.

2.5 Evaluating Risks in Existing Buildings

Earthquake damages in various buildings mostly depend on many parameters and evaluated against the following hazards.

- Earthquake shaking characteristics: Intensity, duration, and frequency content of ground motion
- Soil characteristics: Topography, geologic, and soil condition
- Building characteristics: Building's stiffness, strength, ductility, and integrity
- Sociologic factors causing earthquake casualties: Density of population, time of day of the earthquake occurrence, and community preparedness

2.5.1 Multi Hazard Risks

- Earthquakes, for all schools, based on appropriate hazard levels
- Normal winds and storms, for all buildings in all zones
- Hurricanes, tornadoes in special zones
- Landslides and avalanches for schools in hills and mountains, and known hazard zones.
- Floods in schools in plains, hills and other areas with established flooding hazard.
- Glacial Lake Outburst Floods (GLOFs), for specific areas
- Fire for all buildings in all zones

2.5.2 Seismic Risks

Unlike the above-listed hazards, which may affect some particular regions, the EQ seismic hazards are of high level and affect the large areas or entire country.

- Many of the natural disasters are either seasonal, or can be predicted, or early warning systems can be developed and implemented to take preventive or evacuative measures.
- Often many hazards can be avoided by temporary relocation (move to higher ground during floods etc.), but there is no such refuge or time to relocate due to the lack of warning and extremely short event time of earthquakes
- The consequence of a "rare" or "extremely strong" earthquake event is expected to be much more devastating, and longer lasting than other hazards.

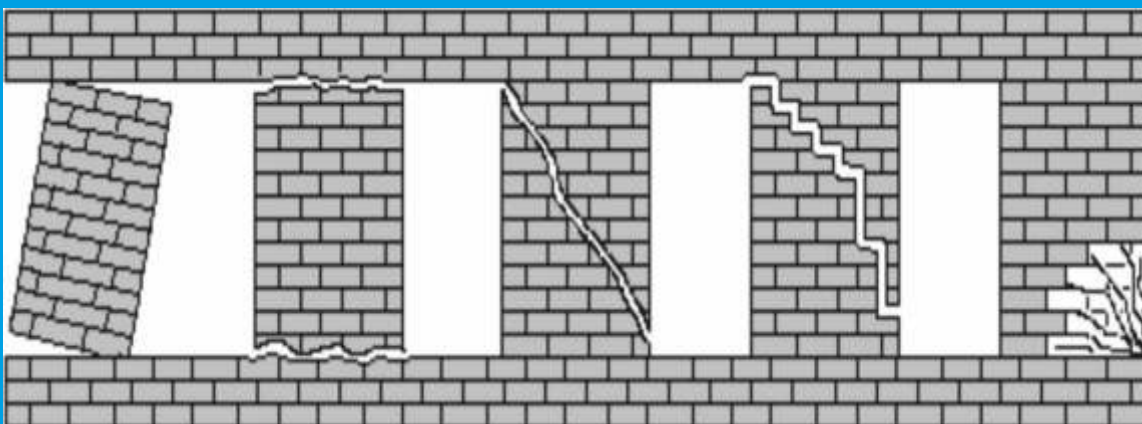
2.5.3 Hazard Damage Patterns

It is important to understand the relative vulnerabilities of the various types of damages as they relate to children life safety and the protection of school buildings. By doing so, the priorities for stabilization, repairs, and/or retrofits can be established for each type of damage.

- If a particular damaged area or component of a building is likely to degrade rapidly (if not repaired), then that damaged element assumes a higher priority than others that are not likely to deteriorate.
- If damage to a major structural element, such as a roof or an entire wall, increases the susceptibility to collapse, then a high priority is assigned to it because of the threat to life safety.
- If damage that could result in the loss of a major feature, such as a wall, compromises the integrity of entire structure, then it is more critical than damage that would result in partial failure, but no loss.

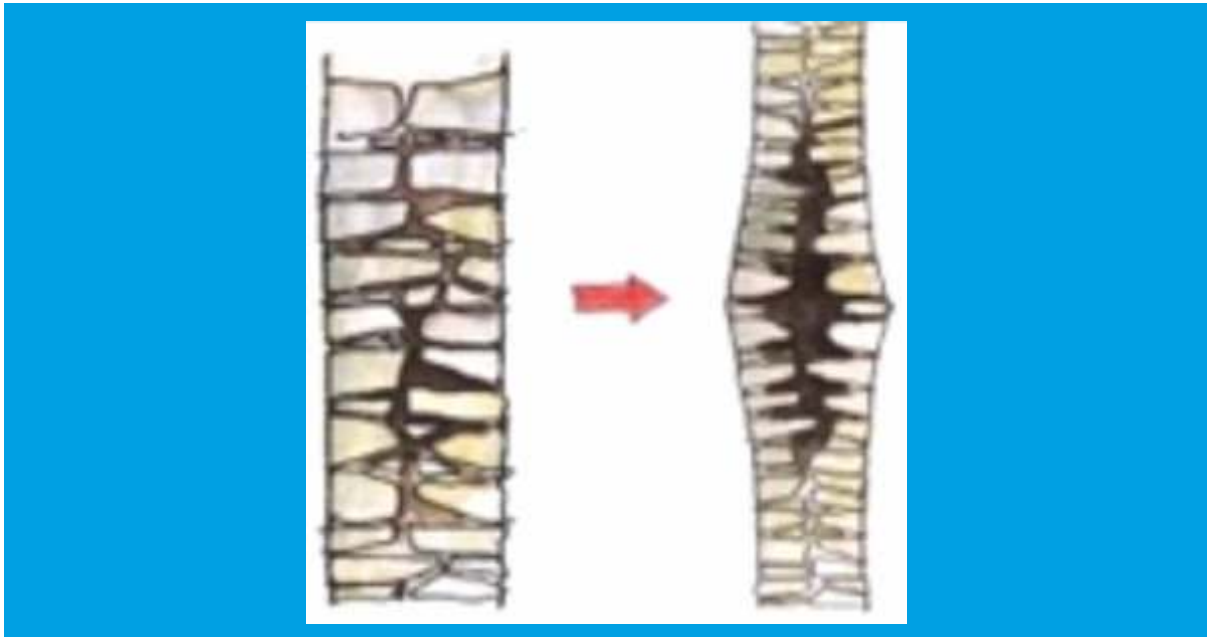
2.6 Hazard Damage Typologies

2.6.1 Shear or Diagonal Cracks are typical results of in-plane shear forces. These cracks are caused by horizontal forces in the plane of the wall that produce tensile stresses at an angle of approximately 45 degrees to the horizontal. Such X-shaped cracks occur when the sequence of ground motions generates shear forces that act first in one direction and then in opposite direction. These cracks often occur in walls or piers between window openings. The severity of in-plane cracks is judged by the extent of the permanent displacement (offset) that occurs between the adjacent wall sections or blocks after ground shaking ends. More severe damage to the structure may occur when an in-plane horizontal offset occurs in combination with a vertical displacement, that is, when the crack pattern follows a more direct diagonal line and does not “stair-step” along mortar joints. Diagonal shear cracks can cause extensive damage during prolonged ground motions because gravity is constantly working in combination with earthquake forces to exacerbate the damage. Whereas, in-plane shear cracking, the damage at wall and tie-rod anchorages, and horizontal cracks are relatively low-risk damage types.



Hazard Damages and Cracks in Masonry Walls

2.6.2 Vertical cracks often develop at corners during the interaction of perpendicular walls and caused by flexure and tension due to out-of-plane movements. Such damage can be particularly severe when vertical cracks occur on both faces, allowing collapse of the wall section at corner. In-plane shear forces cause diagonal cracks that start at the top of a wall and extend downward to the corner. These cracks result in a wall section that can sway up and downward during extended ground motions. Damage of this type is difficult to repair and may require reconstruction.



2.6.3 Out of Plane Bulging or Flexural Cracking is one of the first crack types to appear during a seismic event. Freestanding walls, such as garden walls, are overturned because there is usually no horizontal support along their provided by cross walls or roof or floor systems.

2.6.4 Bed Joint Sliding is caused by lateral load on the building structure. It results due to the inadequate bed joint bonding strength. When the lateral load on the building tends to overturn the building structure, it causes load concentration at the toe which crushes the local material at the toe.

2.7 Building Vulnerabilities

To determine the vulnerability of buildings, a number of their characteristics need to be assessed, including the structural capacity of key building elements; foundations, lateral and vertical load systems along with floors and roof, to ensure that they have capacity to withstand the relevant hazard. Also, the non-structural systems need to be checked, including the building envelope, internal walls, services and other internal/external building components that can have an impact on the building performance in the event of a disaster. Typically, this requires technical expertise but preliminary assessments can be made.

Schools that are vulnerable due to poor design, materials or workmanship may be able to be repaired or retrofitted. Likewise if schools are in poor condition due to lack of maintenance or because there is minor damage then they should be able to be repaired. The age of the building should always be considered in relation to its design life. The following conditions of school buildings exhibit vulnerabilities, which generally occur due to the natural hazards, like earthquake.

- **Absence or inadequacy of interlocking between** two faces of random rubble or stone walls, which collapsed the wall due to delamination.
- **Absence of seismic bands** at sill, lintel and gable top levels, which resulted in to vertical, horizontal and diagonal cracks in walls.
- **Absence of encasement of wall openings** for doors and windows, which caused diagonal cracking from opening corners.
- **Absence of vertical reinforcement embedded within masonry** at wall junction, which disjointd the walls at wall junctions
- **Absence of anchoring of principal supports of roof to walls,** caused deformation/cracks in walls.
- **Poor connections between the old and new construction,** which mostly damaged or caused major cracks in older walls.
- **Water leakage** problems caused due to invisible leakages, along with corrosion damages to RC elements in columns or beams.
- **Non-structural elements installed in the buildings** showed degradation and installation weaknesses due to long-term use.

2.8 Vulnerability Assessment & Analysis of Existing Schools in KP

Earthquake mitigation efforts for existing school buildings have become a priority due to the great number of such structures in KP; requiring the vulnerability assessment of their structures in resisting earthquake forces and design them as per Seismic Building Code. Based on the assessment, if the performance of a structure is found unsatisfactory, the retrofiting strategy be opted.

The first step in vulnerability assessment is to check the locations of EQ damaged school buildings. Then, the main building typologies for schools be divided into main categories, namely reinforced concrete (RC) and masonry buildings, along-with the following sub-types:

- Adobe & stone, stone & brick-in-mud
- Un-reinforced masonry made of brick in cement, well-built brick in mud, and stone in cement.
- Reinforced concrete ordinary-moment-resistant-frames.
- Reinforced concrete intermediate-moment-resistant-frames
- Reinforced concrete special-moment-resistant-frames

Within each typology, the existing condition assessment be done by checking the materials used, the building height, year of construction, the lateral force resisting system and floor diaphragm. For the school buildings to be retrofitted in KP, only generic structures, namely RC (low-rise, up to 2 storey) and masonry (reinforced or unreinforced) structures be listed. The performance of these buildings varies, depending on the quality of the materials, and the construction methods, which can make the vulnerability assessment more difficult. After the field investigations and vulnerability assessment, the structural engineering analyses needs to be carried out, in order to determine the level of risk associated with loss of serviceability and severe damage or collapse. With the possible risks decided, the rational decisions are to be made as to whether the buildings be retrofitted or

rebuilt. Other related aspects to be looked at during assessment may include the following, but not limited to these.

- Technical aspects,
- Availability of adequate materials,
- Skilled masons to implement retrofit works,
- Needs to upgrades non-structural components,
- Cost and benefit,
- Continuation of normal functions of school, and duration of work

It will not be out of context to inform, that generally the both qualitative and quantitative assessments are done through visual inspection at the site, study of existing designs, drawings and non-destructive tests. Based on these analyses, the capacity of a building to resist probable disaster is carried out, to recommend the appropriate interventions for reducing the vulnerability for different potential hazards such as earthquake, landslide, rock fall, high wind and floods.

2.8.1 Steps for Vulnerability Assessment

- Determination of probable earthquake intensity at the building site
- Establish seismic performance target level
- Obtain As-built information
- Perform Non-destructive tests as needed: - In-situ Shear Test, Micro-Tremor Test, locate re-bars using Ferro Scan Detector
- Perform limited destructive test as required: - Foundation exploration, Mortar check, opening up concrete cover to verify reinforcement
- Building Typology Identification
- Determine the fragility of the identified building typology
- Identification of the vulnerability factors
- Reinterpretation of the building fragility based on observed vulnerability factors
- Conduct detailed structural analysis using standard engineering software (i.e. Linear and non-linear structural analysis methods, as per building details)
- Determine Probable performance of building at different intensities of earthquake

2.9 Vulnerability Reduction Assessment Measures

The KP Education Department (ED) is recommended to adopt the following approach and methodology for vulnerability reduction of various school buildings.

- Rapid Assessment of selected schools
- Detailed Vulnerability Reduction Assessment
- Retrofit Design as per technical-specifications of civil works for retrofitting
- Cost Estimation (based on approved item-rates)
- Retrofit Work Planning and Review

- Approval of Design, BOQ; Costs and Work Schedule at competent forum
- Tendering, work-award, material procurement and project initiation
- Selection and On-the-Job Training of Local Masons
- Monitoring and Supervision of Implementation

2.10 Minimum Performance Level of EQ Resistant / Retrofitted Structures

Main priority to plan an earthquake resistant building is to prevent loss of human life. Second priority is to prevent the property loss. Buildings should neither suffer partial or total collapse; nor suffer such damage that cannot be retrofitted. Buildings may suffer structural or non-structural damage but must not suffer heavily damaged to demolish and reconstruct them. Instead, they could be retrofitted quickly so that the utility buildings like schools continue functioning, and the cost of retrofitting is not greater than making a new building.

Performance-based features of the buildings are checked with reference to the definition and limits specified in local Seismic Building Code. Buildings are protected from collapse under an earthquake across-the-board application of “Capacity Design” to control the following Performance Levels.

- **“Near Collapse” or “Collapse Prevention”**: In this verification, a structural member is subjected to its ultimate force or deformation capacity during EQ. The verification of ductile structural members is based on full- deformation test; whereas, the verification of existing members focuses on their limit-deformations.
- **“Significant Damage”, or “Life Safety” or “Local-Collapse Prevention Level”,** for which the buildings are designed. This verification should provide a margin against the ultimate capacity of structural member to absorb EQ impacts.
- **“Limited Damage” or “Immediate Occupancy”**. Structural members should be verified to remain elastic in seismic hazard.

The evaluation of buildings performance is based on following response to the earthquake impacts.

- **Gravity Loads:** Maintenance of building serviceability under permanent loading conditions (dead and live loads)
- **Hazards Load:** Prevention of structural damage under frequent loading conditions in EQ events, corresponding to a return period of approximately 50 years
- **Protection of Occupants' Life,** under extraordinary loading conditions (wind, floods & EQ)

The minimum performance level of school buildings in KP should be **“Immediate Occupancy”**, with an earthquake hazard of 50% probability of occurrence in 50 years. Their building structure is expected to behave elastic under the applicable loads, with the target performance level of immediate occupancy. If the result from the structural analysis with reference to the following 4 levels reveals that the performance of buildings is inadequate in resisting lateral loads, then the retrofitting should be conducted.

Level-1: **Strong enough to bear gravity loads** (both dead and live) & wind load without causing damage to operational components (structural and non-structural).

Level-2: **Resist minor earthquake**, without any damage.

Level 3: **Resist moderate EQ** without structural damage, but with non-structural damage.

Level-4: **Resist major earthquake**

Logically, based on these performance levels, it should be decided that up-to what extent the retrofitting provisions be designed and structural elements provided in the school buildings? In this regard the "Performance Objective" be determined, based on the both building "performance level" and the "hazard level".

Section - 3

What is Retrofitting?
Steps of Retrofitting and Benefits

3.1 Repair, Restoration, Strengthening & Retrofitting

Before an anticipated earthquake, the strengthening of a building can be determined by undertaking “Physical and Instrumental Surveys” along with the “Vulnerability and Performance Analyses”. Immediately after a damaging earthquake, the installation of temporary supports and emergency repairs need to be carried out. Concurrently, actions are necessary to enable the public utility buildings continue functioning and do not collapse during aftershocks. When things start settling down, a decision is made that what “type of action(s)” be done for repair, restoration, strengthening or retrofitting of damaged structures.

There is no such thing as a hazard-proof structure, although its hazard resilient performance can be enhanced through proper initial design or subsequent modifications. Nearly all types of vulnerabilities in the school buildings can be reduced through one or more measures. With the better understanding of hazard impacts and corresponding resilient construction or improvement, the need of repairing, or restoration, strengthening and retrofitting is established.

Repair: It brings back the architectural shape of building so that all services start working and the functioning of building is resumed quickly, after following actions.

- Patching up of defects such as cracks, and fall of plaster
- Repairing doors, windows, replacement of glass panes
- Checking and repairing electric wiring, gas pipes, water pipes and plumbing
- Rebuilding non-structural boundary walls. and re-plastering of walls as required
- Repair Roof-cracks/rearranging disturbed roofing tiles

Restoration: It is done to carry out structural repairs to load-bearing components to restore their original strength, through following actions.

- Injecting “strong-in-tension epoxy material” into cracks in walls, columns, beams.
- Addition of reinforcing mesh on both faces of the cracked wall, holding it to the wall through spikes or bolts and then covering it suitably.
- Removal of portions of cracked masonry walls and piers and rebuilding them in richer mortar. Use of non-shrinking mortar will be preferable.
- Remove damage column or beam, fix/add reinforcing if needed, and re-concreting.

Strengthening: Main purpose is to make buildings stronger than before. Actions include the following:

- Demolish stress concentration in structure: i.e. un-symmetric columns and walls distribution; varying stiffness from one to another floors; excessive openings.
- Make the building as a unity by tying together all components of building
- Avoid brittle failure by re-arranging, adding reinforcing bars, and make the details in accordance with ductility requirement.
- Increasing the both load and lateral strength by adding walls, columns, etc.

Retrofitting: The retrofit process, in addition to the structural strengthening activities, also considers vulnerability level of damaged buildings and the urgency of interventions; besides following aspects:

- Age of the building, with respect to its expected service life
- Relative cost of the retrofit, as a percentage of the total cost of new construction.
- “Down-time” of the retrofit and rebuilt in comparison with the new construction.
- “Reuse” of existing building components/ material, in case building is demolished.
- Advantages of new building over retrofitted building, in terms of better land-use, planning, services and utilization; and future expansion plans for new facilities.
- Non-availability of resources for new rebuilding, then retrofit is the only option.

Retrofitting is an improvement over the original strength, when the evaluation of the building indicates that the strength available before the damage was insufficient and restoration alone will not be adequate in future hazards or earthquakes. The original structural inadequacies, material degradation due to time, and alterations carried out during use over the years such as making new openings, addition of new parts inducing dissymmetry in plan and elevation are responsible for affecting the seismic behavior of old existing buildings.

Before focusing on specific retrofit measures, undertake the full assessment of existing vulnerabilities. Adopt the performance-based design rather than following the prescriptive rules. This offers an opportunity to do a financial analysis and go beyond life safety, when it's economically beneficial. A performance-based modeling exercise can reveal when there might be extensive damage to the skin, interior elements, or building contents. If it is known how much we need to invest to meet seismic code versus to achieve more resilience, then it will be easier to decide how best to retrofit the building.

In educational institutions, the retrofitting assists to reduce hazard risks in order to provide safer learning places for children and the others. However, it is necessary to ensure the quality of construction and retrofit works to achieve higher safety standards for existing schools. A retrofitted building must satisfy the structural requirements i.e. the safety of a structure conforms to the allowable strength calculation or by the structural calculation, which safety level is equivalent to the allowable stress calculation, set forth in the Code, or by the Engineer.

3.2 Retrofitting Strategy

Retrofit is done to improve the seismic safety of existing buildings damaged during earthquakes, and must follow the local Seismic Building Code, for:

- Increasing stiffness and/or strength increase,
- Increasing ductility- no change in ductility or damping
- Increasing energy dissipation
- Modifying the character of the ground motion transmitted to the building
- Base-isolation to decrease earthquake force impact to buildings (utilities, hospitals, schools), to keep them functional after struck by earthquakes, and
- Reducing occupancy exposure. If retrofitting a damaged office building to its original function is high, it will be retrofitted at less-cost to be a warehouse which has lower performance criteria than office building.

For reliable seismic performance, a building must have a complete EQ lateral force resisting system, capable of limiting earthquake-induced lateral displacement of its mass, along with good

configuration and deformation capacity of its elements. Retrofit strategies need to explicitly, or implicitly consider above-listed factors. For further stiffening and strengthening of the building, additional factors to be considered follow.

- New vertical elements, such as columns and bearing walls
- Including shear walls, or adding in-fill walls
- External braced frames/Buttresses
- Adding or converting moment resisting frames
- Bucking Restrained Braces (BRB). Diaphragms may be added or strengthened
- Reduce deformation-induced failure - add confinement to structural elements with supplemental - supports (steel plates/WWM jackets, RCC annuluses)
- Aesthetics: Internal and external “fixed” elements - infill/new walls, braced frames, etc. present a negative impact on building appearance, and be properly finished.

To improve the seismic performance of building and reduce the existing risk to an acceptable level, both the “technical and management strategies” be employed.

- Technical strategies aim for increasing building strength, correcting critical deficiencies, altering stiffness, and reducing demand. These include consideration and approaches to modifying the basic demand and response parameters of a building for Design Earthquake, and include the System completion, integrations and correction; System strengthening and stiffening; Enhancing deformation and energy dissipation capacity; and reducing building demand.
- Management strategies focus on the change of occupancy, incremental improvement, and phased construction.

3.3 Retrofit Interventions Stages

- Firstly, the diagnosis of the structural integrity using in-situ or laboratory testing for damage identification is carried out.
- Then, the design or redesign, refers to an assessment of the current state based on measurable criteria set out by involved parties (Education Department, Engineers, etc.) and it requires the architectural layouts, the building material properties, the modeling and analysis (based on Local Code and specifications framework), and the conclusion of preferred intervention method(s).
- Accordingly, the implementation of decided method is carried out; ensuring the ability of masons to undertake retrofit works, the quality of materials and the effective site inspection.

Considering that the KP school buildings are mostly damaged by the earthquake hazards, their seismic retrofitting should aim at one or more of the following objectives.

- Increase lateral strength in one or both directions, by reinforcement or by increasing wall areas or the number of walls and columns in the buildings plan in a symmetrical and regular manner.
- Give unity to structure by providing a proper connection between its resisting elements, so that inertia forces generated by vibration of building transmit to members, who can resist them i.e. connections between roofs/floors and walls, intersecting walls, and walls and foundations.
- Eliminate features that are sources of weakness and produce stress-concentrations in members.

- Avoid the possibility of brittle modes of failure by proper reinforcement and connection of resisting members. It is costly, the justification of such strengthening be fully evaluated.

3.4 Hazard Damages & Retrofit Actions

Masonry Buildings (Also applicable to Stone Masonry)		
Damage	Nature of Damage	Suggested Actions
Negligible-slight damage (no structural, slight non-structural)	Fine cracks in plaster in walls at the base, and in partitions and infill	Architectural repairs needed.
Moderate damage (slight structural, moderate non-structural damage)	Cracks in columns & beams of frame and in structural walls, in partition & infill walls, fall of brittle plaster & mortar from wall joints	
Substantial heavy Damage (moderate Structural, heavy non-structural damage)	Cracks in column and beam at the base, splitting of concrete covers, buckling of steel bars, Large cracks in partitions and infill walls, failure of individual infill panels	Wall-cracks need grouting; columns need repair, with architectural finish.
Heavy damage (Heavy structural , very heavy non-structural damage)	Large cracks in structural elements with compression failure of concrete, bond failure of beam bars, tilting of columns, collapse of few columns or upper floor	Demolish and construct or extensive retrofitting with strengthening
Destruction (Very heavy structural damage)	Collapse of ground floor or parts of the building	Clear the site and reconstruction
RCC FRAME BUILDINGS		
Negligible-slight damage (no structural, slight non-structural)	Fine cracks in plaster over frame members or in walls at the base, in partitions and infill	Only architectural repairs needed. Seismic strengthening advised.
Moderate damage (slight structural, moderate non-structural damage)	Cracks in columns & beams of frame, in structural walls, in partition and infill walls, fall of brittle plaster, falling mortar from joints of wall panel	Architectural repairs needed, Seismic strengthening advised.
Substantial to heavy Damage (moderate Structural, heavy non-structural damage)	Cracks in column and beam at the base, spalling of concrete covers, buckling of steel bars, large cracks in partitions and infill walls, failure of individual infill panels	Cracks in wall need grouting, columns need repair with architectural finish and seismic strengthening.
Very heavy damage (Heavy structural , very heavy non-structural damage)	Large cracks in structural elements and compression failure of concrete, bond failure of beam bars, tilting of columns, collapse of few columns or upper floor	Demolish and construct or extensive retrofitting and strengthening
Destruction (Very heavy structural damage)	Collapse of ground floor or parts of the building	Clear the site and reconstruction

3.5 Retrofit Plan/Process

To implement retrofitting of school buildings, the “Retrofit Plan” (based on “Technical Assessment” aiming to bring the structures up to required level of hazard resilience), be implemented as under.

- Collect information regarding construction of school building (Year of construction: Engineering and geological data of site strength and deformation characteristics of underground and ground constructions; Sizes and condition of construction elements of a building, joint connections (focusing on defects and damages); and the Settlement resistance of soil and concrete to compression.
- Analysis of the damage and defects, locations and hazards prevalence.
- Vulnerability assessment of structural and non-structural components with respect to local hazards and the retrofit activity/ies to enhance buildings' hazard resistance.
- Review solutions according to local capacity and decide retrofit works for various damages, considering availability of required materials and skill level, and the cost.
- Accordingly, prepare construction document(s); specifications and structural compliance, complying with minimum performance objective of life safety and local building code/regulations.
- Decide the “Work Plan” in consultation with the school officials to minimize disruption to school operations and least exposure of students to construction hazards.

Any Retrofit Plan of existing school buildings, unlike the new schools, must also consider the existing physical and structural conditions of school building to be retrofitted, and include in Plan the provision of new components necessary to be integrated into the original structural system of building.

3.6 Steps of Retrofitting

- Determine as accurate as possible how a building behave when shaken by earthquake, by checking building condition; materials' quality; and list all damaged components of building.
- Perform a structural analysis for the building to get an idea of the causes of damage and determine the load paths when shaken by the earthquake.
- Determine damage-causes of components; caused by shear, compression, tension, flexure, etc.
- After identifying the type of damage, repair and restore the components separately, to ensure that the original strength of components can be restored.
- If results of analysis indicate that a building with restored components can withstand maximum expected earthquake for that area based on Seismic Code, then there is no need to strengthen.
- However, if a building with restored components was not designed for a lower than maximum expected earthquake specified by Seismic Code, then the building needs to be strengthened.
- For strengthening, the restored building must be re-analyzed to identify which components must be strengthened.
- After the strengthening works is completed, the building must be re-analyzed to ensure that the strengthened building is earthquake resistant.

- Besides increasing the strength of structural components, welded mesh, jacketing and external pre-stressing can be used to increase their ductility.
- Retrofitting of non-structural components is also necessary to ensure that the building is fully functional, and all services are operational after earthquake i.e. Architectural elements: partitions, in-fill walls, ceiling, windows, doors, etc. Building services: piping, electrical, water tanks, pumps, lighting system, etc. Building contents, like desks, chairs, electronic equipment, cabinets, etc.

3.7 Schedule of Retrofit Works

As retrofitting and reconstruction can potentially disturb normal school operations and expose students to construction hazards, a work plan should be developed with school officials to minimize disruption. Various strategies include the Scheduling retrofit work outside of operating hours, such as during evenings, weekends and school breaks; or Rescheduling school operations to accommodate work; or Transferring students to neighboring schools; or Erecting transitional school structures. If extensive work is required to retrofit a larger school, an incremental approach can be taken. However, prioritize more vulnerable elements for initial treatment.

3.8 Advantages of Retrofitting

Retrofitting enhances the capacity of an existing structure in a scientific manner to resist the forces of natural or man-induced hazard or disaster, including earthquake, flash-floods, wind-storms, blasts and fire; which may occur in future. It undertakes remedial measures to remove the weaknesses as identified in construction of building. As against rebuilding or reconstruction of building, its retrofitting provides following advantages.

- The expense of demolition and debris removal followed by reconstruction is completely eliminated.
- The cost of retrofitting is generally no more than 15 to 20% of the construction cost of a new building. It is an economical option to reduce building vulnerability, and provide safety to the occupants.
- If the funds available are in-adequate, then retrofitting can be done in phases over a period. This permits the school to continue functioning with temporary adjustments, within its premises. Also, the need for temporary structure or classrooms is eliminated. However, the retrofitting of whole building in one-go should always be preferable, to avoid damage from any untoward EQ in near future, as well as to avoid putting delay-work responsibility on someone.
- Since the retrofit measures are applied only on small portions/parts, the building finishes and functioning of facilities such as laboratories, etc. more or less remain undisturbed. This saves the cost of redoing all that in a new building.



Section - 4

Retrofitting Guideline for School Buildings in KP

4.1 Technical Aspects of Retrofitting

Masonry structures gain stability from the support offered by cross walls, floors, roof and other elements such as piers and buttresses. Load bearing walls are structurally more efficient, when the load is uniformly distributed and the structure is so planned, that eccentricity of loading on the members is as small as possible. A continuous load path is must for masonry structures, like all other types of structures, subjected to earthquake loading. Discontinuity in load path in masonry structures arises due to Lack of Redundancy; Vertical Irregularities; and Plan Irregularities. Also, the height of wall should be taken as unsupported height (can be taken as center to center height for slabs) of the wall between floor slabs. The band beams (sill/lintel) are assumed to provide necessary lateral support for the masonry wall in out-of-plane direction if the beams are anchored into the return walls. Similarly, the floor system must provide lateral as well as rotational restraint (that is, full restraint) to the wall at the floor level.

Retrofitting must cater for the both hazards and structure of buildings, and ensure that the structures become resistant to all anticipated hazards. Diagnosis is the first step of retrofitting, requiring a systematic documentation and understanding of the behavior of following building's components during hazards.

- ☞ **Foundation:** Foundation is essential part of a building where all forces from building structure transfer to the underlying ground. Check that the foundation structure is well placed on firm ground, and is strong enough to resist or withstand the ground shaking due to earthquake; the lateral forces due to earthquake, wind and flood; and uplifting or tilting due to ground movement and damaging the structure
- ☞ **Walls:** The supporting-walls and columns along with beams constitute the skeleton of a building. Loads from the elements of a building like roofs, internal or external walls and floors are transferred to the foundation along the load-path. Most schools' buildings in KP are built of stone- or brick-masonry with wooden-truss and G.I. sheet gable roof; or flat-tile with purlins, or RBC/RCC roof; and can resist vertical gravity load only. Their retrofit needs to also resist the disaster induced lateral forces; besides the vertical load. The walls can be made strong enough to resist lateral forces by providing "Corner-, or T-, or Diagonal-Bracings" to strengthen the lateral load-lines. Openings in the walls - doors and windows be also reinforced to avoid cracks deformation.
- ☞ **Bearing Walls:** Distribution of lateral loads determines to what extent each wall received force. So it is important that the arrangement and specification of walls be considered for determining the retrofitting level.
- ☞ **Infill Walls:** It should be ascertained if infills are part of lateral resisting system or no! Therefore, first real behavior of infills should be recognized then appropriate strategy should be considered for retrofitting.
- ☞ **Floor:** Floor receives gravity loads and transfers the load through the foundation directly to the ground; thus, needs to be strong and properly laid on and connected with foundation.
- ☞ **Roof:** Loads from the roof transfer to the walls or columns and/or beam i.e. structure of building to the foundation. Roof structure must be braced both horizontally and vertically. Loads on the roof can be either pushing or pulling. Preventive measures to make roof system resilient against disaster include "inter-connecting roofing-materials to underlying roof-support system along with load-bearing structure to prevent bulging or buckling, or tilting, or cracking, or shifting ahead, or blowing away in the event of earthquake-jolts, thunder-storms.

In case of gable-roof, its slope be kept within safe-limits i.e. angles. Roof projections and cantilevers be structurally designed to ensure their hazard-free hanging. .

- **Upper Storey:** For schools with more than one storey, the capacity for the structure to resist lateral forces should be the same for each floor. A common cause of damage to multi-storied buildings is “soft-storey” collapse. This occurs because the lateral stiffness or shear strength of one story, typically the ground level, is less than that of the upper stories.
- **Connections:** Connections between all walls, floors and roofs are crucial stress points and must be designed to be stronger than the connecting elements. This is particularly important where the floor(s) and roof are connected to shear walls and beams to columns. Each element of the box relies on the other elements and therefore they must be securely fastened to each other. It is equally essential that the structural system is firmly fastened to the foundation. If the building is not sufficiently secured to the foundation, it may shift or slide off.

4.2 Retrofitting of School Buildings in KP

In KP, majority of the existing schools' buildings damaged during 2005 Earthquake are one or two storey structures, built with load-bearing masonry and having RC floors/slabs. Almost, all the buildings are typically single bay and elongated in shape. At some places, the school buildings are of mixed type i.e. one floor with brick in mud and another floor brick in cement; one floor RCC and the other floor or roof of flexible material.

To make these school buildings resilient to hazard and disaster impacts, ensure that all structural elements are securely connected together. The connections between all walls, floors and roofs being crucial stress points, are stronger than the connecting elements. The structural system is firmly fastened to the foundation, to resist shifting or slide-off of the buildings. The retrofitting of school buildings in KP be based on the following considerations.

- **Retrofit to resist lateral loads from all directions:** In bearing wall buildings, the walls, floors and roofs are the structural components, and be configured to form a rigid box. In framed buildings, the columns, beams, and other frame members are configured to form a box.
- **Bearing-wall construction:** All walls be designed to resist lateral loads. Retrofit the side walls with strong mortar to act as a stiff and integrated whole to resist lateral forces, as a shear wall to sustain damage and building collapse. Face-loaded walls perpendicular to a load, be securely braced from side to side and top to bottom, to avoid their overturning. Also, the corners, where the shear walls meet the face-loaded walls, be reinforced. The long face-loaded walls require additional internal-shear walls to resist overturning or bending and eventual collapse.
- **Horizontal Reinforcement of Walls:** In wall-bearing buildings, a rigid ring that encircles the building can act to resist deformation and damage to a wall caused by uplift, downward and lateral forces. Any system providing this reinforcement must form a continuous ring around the building and securely fastened to all vertical structural elements (columns and reinforced corners).
- **Openings:** Necessary openings in the wall, such as doors and windows, reduce shear wall's resistive capacity (particularly in the proximity of corners). Minimize openings in load bearing wall construction. Reinforcement of door and window frames will strengthen these weak points.
- **Expansion between structural columns and infill walls:** Expansion joints allow movement of frames under stress without inducing damage. In frame construction, the curtain/infill walls

do not bear any loads. Where columns and beams are designed to resist seismic loads, the movement joints must exist between infill walls and frame to allow two elements to move independently and prevent wall from cracking. However, solid infill such as brick walls must be tied back to the structure to avoid a collapse.

- **Gable walls braced to their full height:** Gables are the portion on the sides of a building which rise from the bottom edges of the roof up-to the ridge. In wall bearing construction, the gable walls or gable ends require additional bracing to the full height of the wall by fixing diagonal bracing between the gable wall and roof beams in order to resist overturning.
- **Retrofit to resist uplift loads:** If sub-soils are soft, the soil-liquefaction may cause the ground-elevation or level to drop. If the foundation does not rest on solid sub-soil, a part or all of the building may drop. Therefore, the stiffness/rigidity in shear walls or in a structural frame be made to resist the uplift loads along with downward loads.
- **Staircases to resist earthquake loads:** In more than single-storey school buildings, to reduce the harm to children and the loss of life of those evacuating a building, the staircases should be carefully designed to withstand the earthquake loads and jolts. Arrange the stairs along with escape routes and isolated safe assembly points.
- **Building extension in future:** If future extension or development of the existing school buildings is anticipated, sufficient space, or gap, or separation be provided between the already retrofitted buildings and those buildings planned to be extended, or newly constructed.
- **Firmly attach non-structural elements to structural elements:** A dangerous hazard induced by an earthquake is falling objects. All heavy furnishings or equipment be securely fixed to structural elements or installed independently. Exterior components which cover the building (windows/door frames, roof and wall coverings) be firmly attached to structural elements to minimize detachment and damage. Interior non-structural elements be braced or secured to structural elements. Architectural features ceilings, wall covering, non-load-bearing walls) be affixed securely to structure to prevent from falling. Electrical, gas, water supply networks and fixtures inside the school buildings be properly affixed.

4.3 Retrofitting of Building Elements

4.3.1 Strengthening of Foundations

The strengthening of foundation must be an integral part of retrofitting existing buildings. The ground soil type, condition of existing foundation and its connectivity to superstructure should be investigated to ensure that foundation is able to transfer the load safely to the ground. Foundation retrofitting plan be evaluated along with any rehabilitation of superstructure and according to the Local Code to assure that the complete rehabilitation achieves the selected building performance level resilient to selected earthquake hazard level. Improvement in existing soil materials may be effective to rehabilitate foundations by achieving (a) improvement in vertical bearing capacity of footing foundations, (b) increase in the lateral frictional resistance at the base of footings, and (c) increase in the passive resistance of the soils adjacent to foundations or grade beams. For the retrofitting of hazard affected foundations, the following measures be taken:

- New isolated or spread footings may be added to existing structures to support new structural elements such as shear walls or frames.
- Existing isolated or spread footings may be enlarged to increase bearing or uplift capacity, by shoring and/or jacking.

- Existing isolated or spread footings may be underpinned to increase bearing or uplift capacity. Uplift capacity may be improved by increasing resisting soil mass above footing.
 - Different lateral displacement of various portions of a building be carried out by interconnecting the foundation with grade beams, reinforced grade slab or ties.
- #### 4.3.2 Retrofitting of Damaged Walls

Damaged Stone Masonry Walls (both rubble and ashlar): Retrofitting of stone walls requires the reconstruction of the faulted part and strengthening of the connection using Tie-Stones. The procedure involves the following:

- The reconstruction must incorporate new stones of a similar type, size and proportion as those of the original wall, in order to achieve a homogeneous construction between the new and the old. If possible, the original stones from the ruined section should be used
- Careful cleaning of masonry using low abrasive tools and water. It is recommended that a brush and sand paper be used, while high pressure sand blasting and extreme mechanical cleaning should be avoided in order to prevent damage to the stone
- Stones should be bedded horizontally
- Laying of stones should be done in such a way as to maintain a horizontal line approximately every three courses
- Continuous vertical joints must be avoided
- Pointing should be recessed at about 0.5-1.0cm from exterior face of stones and be placed neither deeper than the exterior surface nor protruding from the wall
- PC mortar should be used both for pointing. Care be taken to keep, as much as possible, the exterior surface of the masonry stones clean
- The two sides masonry wall be connected with Tie-stones, placed at intervals of approximately 1.00m along the total length and height of the wall
- After completion of construction the wall should be brushed down and cleaned with water.

4.3.2.1 Retrofitting of Damaged Wall:

- Remove the inner as well as outer plaster of the wall \pm 40cm in the vertical as well as horizontal directions where the wire mesh will be installed.
- The inner as well as outer plaster of walls junction must also be removed.
- The cracks are sealed with cement and sand mortar.
- Walls be strengthened by anchoring/fixing with nails the wire mesh along with a spray or injecting of cement mortar in cracks, starting from lower part of wall.
- To support for the wire mesh, several thin beds of mortar, 1cm thick, 2cm width, and with spacing \pm 10 cm be made.
- Wire mesh on each side of the wall be tied. For this, holes are drilled on the thin beds of mortar every \pm 15-20cm.

4.3.2.2 Retrofitting Collapsed Wall and Addition of Support Columns

- In case of totally collapsed walls, a new wall be constructed, and it is recommended to provide confinement consisting of foundation beam, ring beam and columns. Wall anchoring must also be provided min 10mm length > 40 cm, for every 6 layers of bricks.

- If the vulnerability analysis shows that the column and beam reinforcement is not adequate, additional reinforcement be placed and their dimensions can be increased (jacketing). But, the joint detailing of reinforcement must comply with earthquake resistant requirements.
- Beams and columns that can be chipped easily is an indication of low concrete quality. All low concrete quality must be replaced.
- Beam and column stirrups must be added if the spacing is > 150mm or no stirrups.
- Top and bottom of damaged column be retrofitted by placing more stirrups in beams and columns.

4.3.2.3 Wall Cracks & Retrofit

Cracks Observed	Action for Retrofit
Different types of cracks seen in masonry walls grout or mortar, both Vertical cracks and Inclined cracks	Cracks be fully filled using appropriate grout or mortar.
Cracks at the corners or T-junctions, and separation of the cross-walls	Cracks be filled as above but before that the walls at right angles to be connected using Ferro-cement corner plates.
At some places, occurrence of many cracks close together in the walls, or tilting of some wall portions out of plumb after separation, or bulging of stone wall after delamination, or falling of some wall portions.	This type of cracked, fallen, tilted or bulged wall portion to be reconstructed using mortar, richer than originally used, after partial demolition of wall as required.
Wall having medium or minor crack	Repair as in masonry building and tie walls with frame
Walls severe cracked	Demolish and reconstruct the wall
Thin cracks in many walls, falling of plaster in little bits over large area, damage to non-structural parts like chimney, projecting cornices; but the load carrying capacity is not reduced appreciably	Architecture repairs needed and seismic strengthening advised

4.3.2.4 Increase Out-of-Plane Bending Resistance:

Lateral load resistance of individual masonry walls can be increased against out-of-plane bending by providing both horizontal as well as vertical metal strips (50 x 6 mm). These strips are fixed on the both internal and external faces of the walls and well-connected with each other using pins.



Installation of vertical and horizontal metal strips

4.3.2.5 Wall Connection by Metal Connectors (Tie-Rods)

In seismic zones, the tie-rods be installed to strengthen masonry built structures against partial or total collapse and prevent lateral instability of the walls caused by the action of the horizontal structural members. Usually, the connectors are placed symmetrically on both sides of the wall in horizontal grooves of width about 4-5cm that are created on the plaster connections just below the level of the floor to the wall surface. In addition to the tie-stones, the steel tie-rods can be used to tie the courses together by following procedure:

- The crack is carefully widened from loose stones and mortar, and the opening is cleaned using low abrasive tools and water. The crack is widened at a depth of 0.15m on both sides of the wall.
- Mortar is removed from both sides of the crack at 0.75m on each side at a depth of 0.15m. The opening be cleaned and then tie-rods (1.50m) are installed on both sides of the wall at intervals of 1.00m in height. The tie-rods must be rustproof.
- The crack must be filled in with stones & re-pointed with PC mortar to complete the wall.

4.3.2.6 Cast-in-Situ RC Bond in Existing Masonry Walls

For random rubble walls, install the cast in situ reinforced concrete bond elements, to prevent delamination of walls. This belt binds all walls together (like a string tied to a box) and helps reduce cracking in corners. The bond also binds both sides of a wall together, thus preventing walls from going out of plumb. It reduces bending of wall due to forces perpendicular to the plane of wall, and thus helps prevent vertical cracks in the middle of the wall. Further, the seismic band resists tension caused by earthquake forces parallel to the wall and thus helps prevent diagonal cracks, especially those emanating from corners of doors and windows.



4.3.2.7 How to Install Cast-in-situ RC Bond Elements in Stone Walls

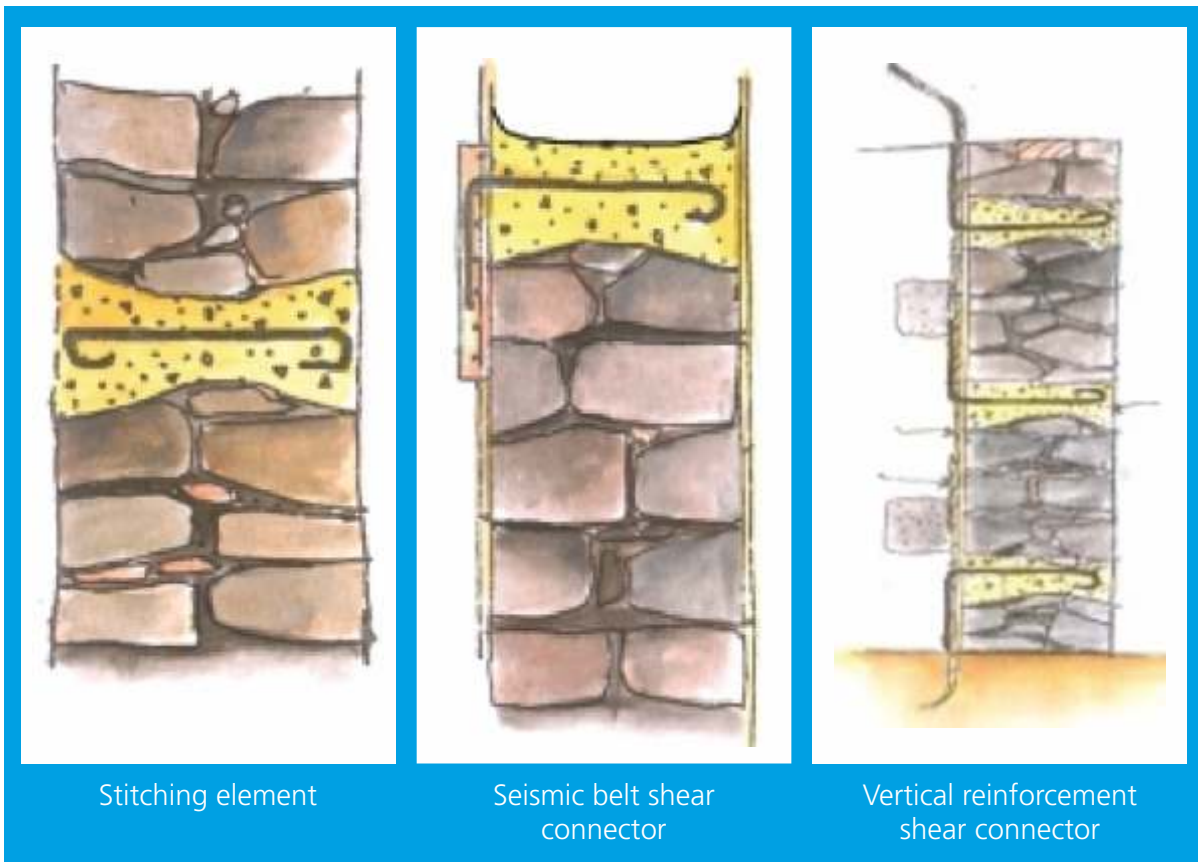
- Mark points on wall spaced horizontally and vertically 1 m apart, with a horizontal stagger of 500 mm, thus having one point per 1 Sq. Mt. (10 Sift.) of the wall area.
- Remove a patch of surface plaster of approximately 220 mm x 220 mm (9" x 9") at each point and expose the stones. Gently remove the mortar around the stone to a enough depth to expose the sides of the stone to loosen it from the wall.
- Loosen the stone, gently yanking it from side to side and up and down by means of a small rod with tapered end, being careful not to disturb the stones around it. The rod should be 12 mm in diameter and 750 mm (2'6") in length, with one end flattened and one end pointed.
- Pull out the stone slowly, holding it with both hands.
- Remove the material behind the stone gradually to make a hole of 75 mm (3") diameter through the wall until the stone on the other face is reached.
- Tap that stone to identify it from the far side. Remove this slowly from the other side by the same careful process.
- The hole should be bigger in size at both faces and narrower in the wall core, resembling a dumb-bell. It does not matter if the hole is inclined instead of level.
- Splash water in holes to clean off loose material from the surface of the stones.
- Place concrete of 1:2:4 mix to fill half the height of the hole from both sides. Place an 8mm diameter TOR bar hooked at both ends in the hole. Fill the hole completely with concrete to fully encase the bar. Suitable polymer additive should be used to make non-shrink concrete.
- Make sure the entire length of the bar is covered with concrete. The hooked bar must be 50 mm shorter than the thickness of the wall to ensure full encasing.
- Cure for minimum 10 days by sprinkling water on exposed surfaces on both sides. Finish the wall to match the existing wall. Making a bell-shaped hole through wall and placing concrete and bar in the hole.



Hooked bar must be 50 mm less than wall thickness



Water curing for 10 days



4.3.2.8 Shear Walls for RCC Frame Buildings

The concrete shear walls are used to add significant strength and stiffness to masonry structures. Its disadvantages include considerable increase in the mass of structure with new footings and expensive. The location of shear walls be chosen such that they (a) align with the full height of building, (b) minimize torsion, and (c) can be easily incorporated into the existing frame. Further, the shear walls should be able to maximize the dead weight to resist overturning uplift.

4.3.2.9 Steel Wire Mesh Planting in Masonry

Unreinforced masonry buildings are brittle in nature. To ensure ductile structural behavior of such buildings, reinforcement is provided with design details specific to each building. Wire meshing consists of a galvanized iron mesh fixed to the walls through nails or connector-links drilled through wall thickness and the mesh is covered by rich mix of cement-sand mortar. To achieve good results, the following procedure be followed:

- Mark height or width of desired planting based on weld mesh number of longitudinal wires & mesh size. Cut the existing plaster at edge by a cutter for neatness, and remove plaster.
- Rake the exposed joints to a depth of 20 mm. Clean the joints with water jet.
- Apply neat cement slurry and plaster the wall with 1:3 cement-coarse and mix by filling all raked joints fully and covering the wall with a thickness of 15 mm. Make the surface rough for better bond with the second layer of plaster. Fix the mesh to the plastered surface through 15 cm long nails driven into the wall at a spacing of 45 cm tying the mesh to the nails by binding wire.
- Now apply 2nd layer of 15mm plaster above mesh. Good bonding be achieved with the first layer of plaster and mesh, when next cement slurry is applied.

To install the mesh on either side of the wall 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 purpose, either 1:3 cement-coarse sand mortar, or concrete with small aggregates is applied in two layers like plaster. If MS bars are used, adequate lap lengths must be provided.

The wire mesh application method is low-cost upgrading of traditional school building structures to limit the damage caused by normal earthquakes and give the children a chance of escape in earthquakes. Under moderate ground motions, the wire mesh provide enough seismic resistance to limit and control cracking of the retrofitted structures. Under extremely strong ground motions, they are expected to prevent or delay the collapse, thus, increasing the rate of survival of children. However, the wire mesh method is good for one or two-storey buildings.

4.3.2.10 Strengthening Weak Brick Masonry Walls by Installing WWM Bond/Belt

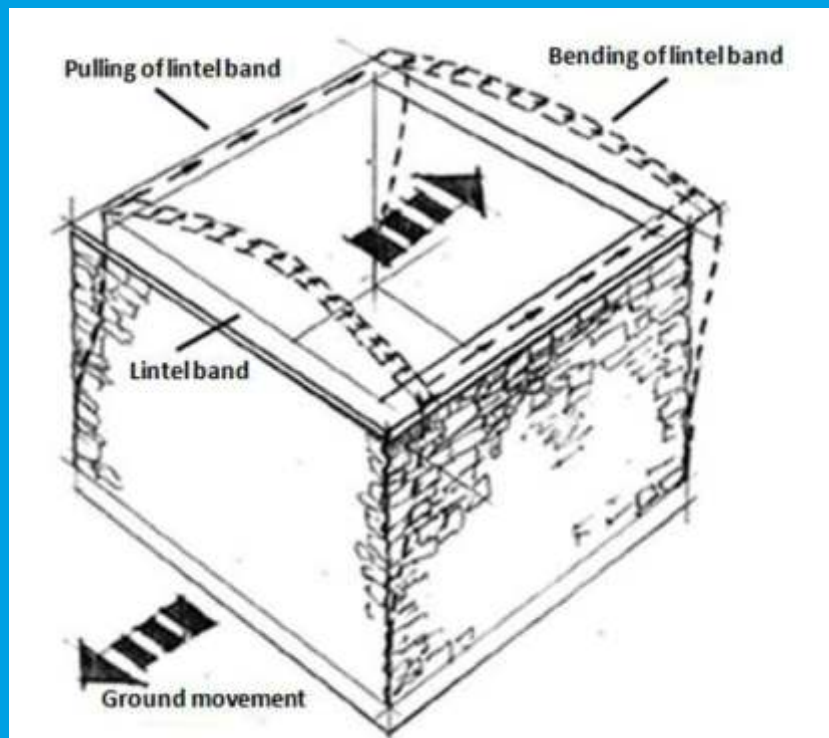
- Mark points spaced horizontally and vertically 1 m, with a stagger of 500 mm, thus having one point per 1 sq. m (10 sq. ft.) of the wall area.
- In a wall built with cement mortar, use a 350 mm long piece of 35 mm diameter GI pipe with a slit end as a punch to make a through hole.
- In a wall built with mud mortar, mark the header to be removed and rake off mud from the joint all around it. Loosen the brick slowly and remove it.
- Splash water in the hole to clean off loose material from the surface of the bricks.
- Fill bottom half of hole from both sides using non-shrink concrete of 1:1 1/2:3 proportions. Place an 8 mm diameter bar in the hole and fill the remaining void completely. Suitable polymer additive be used to make non-shrink water-proof grout compound.
- Make sure the entire length of the bar is covered with mortar. The bar must be 50 mm shorter than the thickness of the wall to ensure full encasing.
- Cure for minimum 10 days by sprinkling water on exposed surfaces on both sides. Finish the wall to match the existing wall. Follow same procedure to make all bond elements in walls.

4.3.2.11 Strengthening of Half Brick Thick Load Bearing Wall

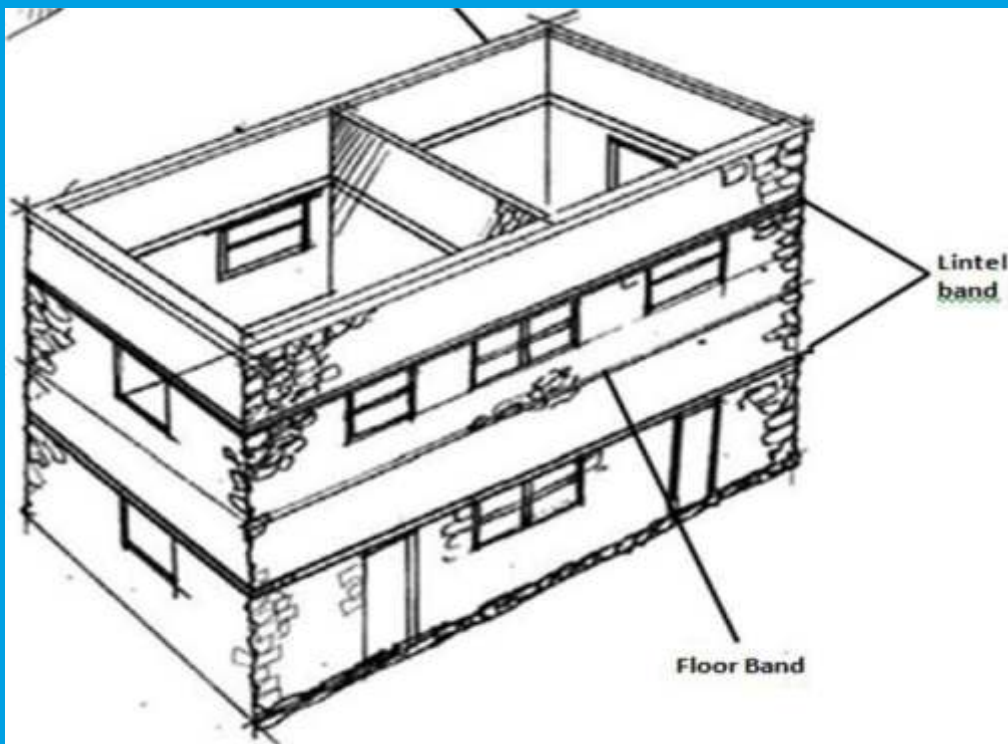
The welded wire mesh of 14 gauge wires @ 35 to 40 mm be fixed, apart both ways. Provision of mesh on external or internal faces with an overlap of 30 cm at the corners will suffice for up to 3 m long walls. For longer walls, Ferro-cement planting be provided on both faces.

4.4 Seismic Band (Ring Beams) or WWM Belt

A seismic band or WWM (welded wire mesh) belt is the most critical earthquake-resistant provision in a weak stone masonry building. Usually, it is provided at lintel, floor, and/or roof level in a building, the band acts like a ring or belt. Seismic bands are constructed using mostly reinforced concrete. Proper placement and continuity of bands and proper use of materials and workmanship are essential for their effectiveness. Seismic bands hold the walls together and ensure integral box action of an entire building. Also, a lintel band reduces the effective wall height. As a result, bending stresses in the walls due to out-of-plane earthquake effects are reduced and the chances of wall delamination are diminished. During earthquake shaking, a band undergoes bending and pulling actions. A portion of the band perpendicular to the direction of earthquake shaking is subjected to bending, while the remaining portion is in tension.



Merging RC floor and lintel bands. A seismic band acts like a belt

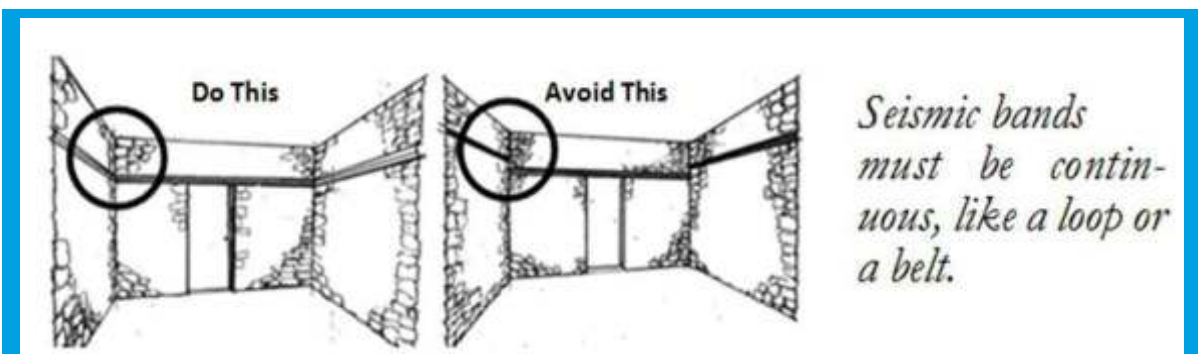


Location of seismic bands in a stone masonry building

Seismic bands can be provided at plinth, lintel, floor, and roof levels. In some cases, a lintel band is combined with a floor or roof band. An RC plinth band should be provided a top the foundation when strip footings are made of unreinforced masonry and the soil is either soft or uneven in its properties. In buildings with common masonry, uninterrupted belts be provided on all walls. Also, ensure the belt continuity when a belt is installed around the walls. In case of RC floor, the floor level belt is not required. If the wall is 12 feet or less long, install a tie rod at mid-length.

Seismic bands are required at lintel and floor level when the floor and roof structures are flexible, the vertical distance between lintel and floor level is more than 400 mm, or when the total story height exceeds 2.5 m (same is true of roof bands as well). Otherwise, provision of a lintel band is sufficient. A floor/roof band is not required in buildings with RC floor/roof structures, where the slab itself ties walls together. Seismic band must be continuous (like a loop or belt), otherwise it is inefficient.

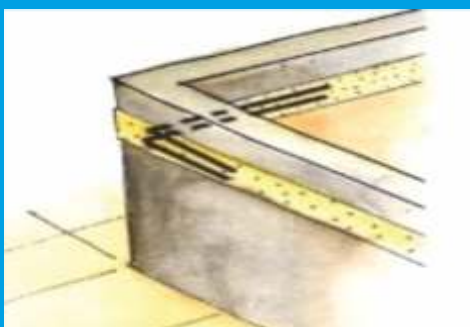
Lintel beams (commonly known as lintels) are required at the top of all the openings in a wall. However, if a band is provided at the lintel level, a lintel beam can be cast as an integral part of the lintel band to minimize construction costs. Details for combining a lintel and floor/roof band are shown hereunder. The band must be continuously reinforced at the wall intersections.



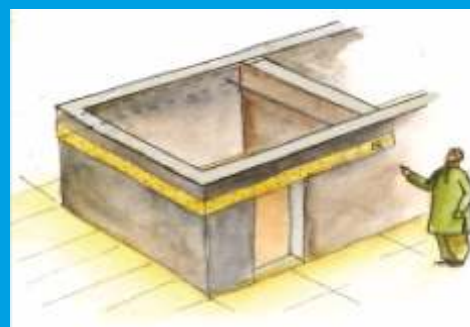
Seismic bands should always be continuous; an offset in elevation is not acceptable
RC seismic bands should always remain level without any dips or changes in height.

4.4.1 Belt Ending on One Face of Wall be connected to Belt on Other Face

Make hole through the wall connecting the two belts. Prepare two bars, either 'L' shaped or straight, as the situation requires. Length of the bars should permit 450 mm overlap with the WWM on both faces. Insert the rods through the hole and connect them to the WWM of concerned belts, tying binding wire at a minimum of two locations at both faces.



Using dowels for belt continuity through wall



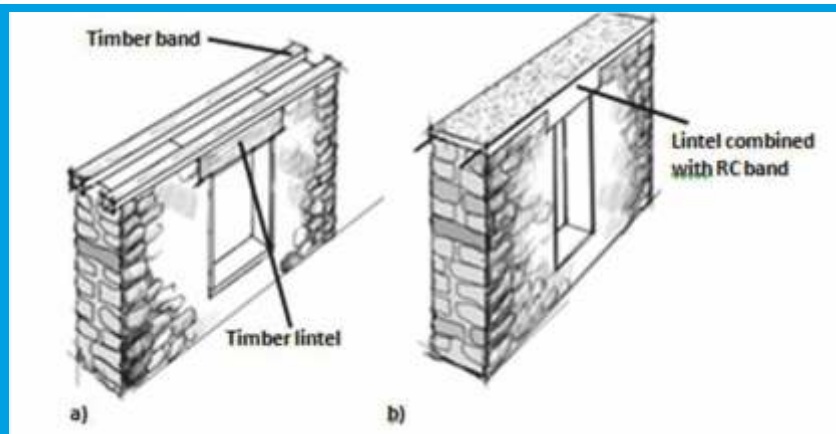
Ensuring continuity with tie rod on 4th wall

4.4.2 How to Install Encasement Belt around Openings

Demarcate 280 mm wide belt around the openings. Since the lintel belt is installed just above the openings, the encasement belt is required only underneath and on the sides of the openings and under the openings like windows and ventilators. Procedure is exactly same as that used for horizontal and vertical seismic belt. Belts on all sides of encasement must overlap at the corners. The belts on topsides must overlap with the lintel belt. If spacing between two openings is less than 560 mm (22"), vertical portions of encasement transverse wires and longitudinal wires for both openings will merge with each other.

4.4.3 How to install cast-in-situ Reinforced Concrete Bond Elements in Stone Walls

- Mark points spaced horizontally & vertically 1 meter apart, with a horizontal stagger of 500 mm, to have one point per 1 sq. meter (10 Sq. Feet) of wall area. Remove a patch of surface plaster of approximately 220 mm x 220 mm (9" x 9") at each point and expose the stones. Gently remove the mortar around the stone to a sufficient depth to expose the sides of the stone to loosen it from the wall. Loosen the stone, gently yanking it from side to side & up & down by a small rod with tapered end, & do not disturb the stones around it. Pull out the stone slowly, & remove the material behind it to make a hole through wall until the stone on other face is reached. Tap that stone to identify it from far side. Remove it from the other side by the same careful process.
- The hole should be bigger in size at both faces and narrower in the wall core, resembling a dumb-bell. It does not matter if the hole is inclined instead of level. Splash water in hole to clean off loose material from the surface of the stones.
- Place concrete of 1:2:4 mix to fill half the height of the hole from both sides. Place an 8mm diameter TOR bar hooked at both ends in the hole. Fill the hole completely with concrete to fully encase the bar. Suitable polymer additive should be used to make non-shrink concrete. Make sure the entire length of the bar is covered with concrete. The hooked bar must be 50 mm shorter than the thickness of the wall to ensure full encasing. Cure for a minimum of 10 days by sprinkling water on exposed surfaces on both sides. Finish the wall to match existing wall. Follow same procedure to make all bond elements in walls.
- Stitching wall witches: Both ends of the bar must be hooked. Length of the bar after bending must be 50 mm (2") shorter than the thickness of the wall.



Combining floor/roof and lintel band: a) timber band, b) RC band

4.5 Reinforcement of Openings in Walls

There should be reinforcement around the all openings greater than 50% of the building width. The walls should be strengthened for in-plane and out-of-plane loading in order to avoid complete or partial collapse of the walls. Masonry walls can be reinforced by any of the following measures.

- Steel wire mesh with plaster on both faces of the wall
- WWM Band with cement or mud plaster on both faces of the wall
- Gabion wire net with or without plaster on both faces of the wall

The retrofitted walls must be safe against worst combination of lateral forces and the Structural/Building Engineer should check it before starting the construction.

4.5.1 Large Openings in Walls

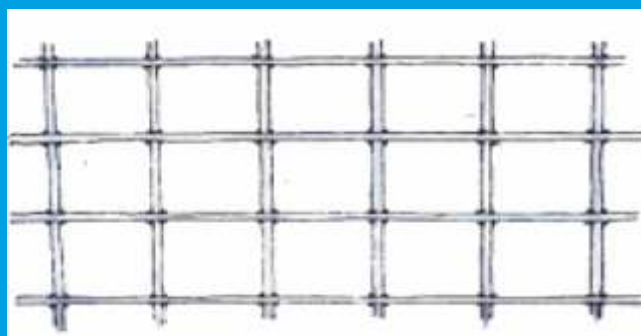
Wall panels with large openings cause the solid wall panels to behave more as frames than as shear walls. Large openings for store fronts and garages, when present, should be framed by post and beam framing. Lateral force resistance around opening can be provided by steel rigid frames or diagonal bracing. The openings should be reinforced by providing a lintel band and vertical reinforcement.

4.5.2 Seismic Belts around Door/Window Opening

A simple method to strengthen a shear wall in-plane is to infill unnecessary window and door openings. This prevents stress concentrations from forming at the corners of openings that initiate cracks. But, important thing to do is that when infilling an opening, interlace the new units with the existing or to provide some shear connection between the two; in order to enable the existing wall work compositely with new infill wall. The jambs and piers between window and door openings require vertical reinforcement for covering the jamb area on both sides of an opening or for covering the pier between the openings.

4.5.3 Encase Openings with Seismic Belt to Prevent Diagonal Cracks

Encasement of openings strengthens the boundary around door/window opening, especially at corners where concentration of tensile stresses occurs. It helps resist the tearing action that occurs at opening corners. It is similar to stitching extra strips of cloth continuously around the edge of an opening. When the gap between two openings is very small, the wall in that gap behaves like a pier. This pier has very weak resistance to shearing and bending but wrapping the pier in a seismic belt greatly strengthens it against these forces. Galvanized mesh with 10 wires spaced at 25 mm with WWM width of 250 mm and plastered belt width of 280 mm, be used. Alternately, use reinforcing bars along with chicken wire mesh (CWM) spaced at 50 mm and 2-6 mm diameter rods.



Seismic Belt- Chicken WWM



Application of iron wire-mesh in column position

4.6 Retrofitting of Bulked-in Beams & Tilted Columns

- Support the beams around column to be retrofitted with steel/wood posts at suitable intervals, adjusted as per load to be supported. Slanted beam must be supported and jacked-up to restore the desired level.
- Strip concrete-cover of inclined columns/beams to know number of reinforcement and stirrups. If jacking is difficult, the deformed column reinforcement be cut first.
- After the structure is horizontal at desired level, the jacks be replaced with posts or concrete blocks. Install new column reinforcement and splice with the existing one. The length of splice between the existing and new reinforcement be as per seismic analysis.
- If analysis shows that the number of column and beam reinforcement and stirrups is not sufficient, additional reinforcement must be placed. If necessary, re-arrange and add the column stirrups.
- Concreting formwork be shaped like a cone. If there is not enough space, concreting be done by drilling a hole in the slab. After 24 hours, the formwork can be removed and the protruding concrete part (due to the cone shape) can be chipped.
- If damaged or inclined column cannot be pulled-back or jacked-up to vertical position, it must be removed. Prepare foundations for new columns and must be integrated with the existing one, along with placing reinforcing bars and formworks for new columns. Pour with concrete minimum 1 cement: 2 sand: 3 gravel and adequate water. The scaffolding be removed minimum 14 days after a column is concreted.
- If the detail of column-beam joint reinforcing is not in accordance with the seismic resistant requirements, additional anchoring from column to beam must be placed. In this case, part of the beam concrete must be removed for anchoring.
- If no additional reinforcement for column is necessary, but its joints to be rectified, the beam concrete be removed 2m and install necessary anchoring.

4.7 Vertical Reinforcement Retrofitting

The vertical reinforcement within masonry should be installed if assessment results recommend it, at all junctions of walls and at 'T' junctions, on one side of the junction only. Installation of vertical bands within masonry wall to help prevent structural failures, improves the bending strength of wall to control horizontal cracks, and reduce the possibility of walls going out of plumb or collapsing. It helps in bonding the roof to the walls, providing support to the wall and controlling its shaking in an earthquake. It helps improve the bond between adjacent stores, which also strengthens the walls. Vertical reinforcement within masonry be installed at all junctions of walls; at the 'T' junctions, on one side of the junction only; and in upper-storey. Single vertical bar must be installed at the inside corner of a wall-to-wall 'L' type junction.

4.7.1 How to Install Vertical Bar in a Corner

- Identify the inside corner for installation of vertical bar. Select appropriate location to maintain vertical continuity between storeys in case of a more than one-storey structure
- Mark the area where the bar is to be installed. Using plumb-bob, demarcate a 100 mm (4") wide patch at the corner on both walls as the limits of concreting for encasing the rod. Cut the plaster along vertical boundary of both the patches to restrict the removal of plaster.

- Remove the plaster from marked area and expose the walling material. Rake all the mortar joints to the depth of 12 mm (½"). Clean the surface with a wire brush.
- Remove flooring within 300mmx300mm patch at corner & excavate to 450 mm depth.
- Make holes for installing shear connectors in both walls, starting on one wall at 150 (6") from the floor, with successive holes at approximately every 600 mm (2') but in alternate walls, and the last hole 150 mm below the ceiling level or 150 mm below eave level. Clean all the holes with wire brush to remove loose material.
- Place appropriate dia bars in the floor excavation with the lower 150 mm (6") bent in 'L' shape. In a structure with CGI roof, the top end can be connected to one of the principal elements of the attic floor or roof. In case of an RC slab roof, the top end can be bent into 'L' shape for connecting to the slab reinforcement. Rod will pass through the floor. Place 8 mm bar in the holes made for shear connectors and connect them to vertical bar making sure that vertical bar is 35 to 50 mm (½" to 2") from each wall.
- With vertical bar plumb and at right distance from the walls, pour concrete in 1:2:4 proportions in the hole excavated in floor, with continuous rodding, to completely encase the bottom of steel rod in concrete. Clean all the shear connector holes by splashing water and wetting the surface of the holes thoroughly. Fill up the holes with non-shrink cement cum polymer grout. Make sure that the grout completely encases the shear connector bar.
- Once all shear connectors are grouted, clean exposed wall surfaces with wire brush and water. Install centering for concreting around vertical bars. Concreting be done in stages with height of each new stage not exceeding 900 mm. Pour concrete in the form work, with continuous rodding to prevent honeycombing. Once the concrete is set, move the formwork upwards and continue concreting, up-to the entire length of vertical bar. The bar must have minimum concrete cover of 15 mm. Connect top bent end of vertical rod to slab reinforcement
- Where a roof is of RC slab, in the vicinity of the vertical bar, break the bottom concrete cover to expose the slab reinforcing bars. Connect the top bent portion of the vertical bar to the exposed bars of the slab using binding wires providing a minimum of 300 mm (12") overlap.
- Wet exposed surface of slab & then apply neat cement slurry. Finally apply cement mortar in 1:4 proportions & finish joint to match surrounding area. Cure all concrete work for 15 days.

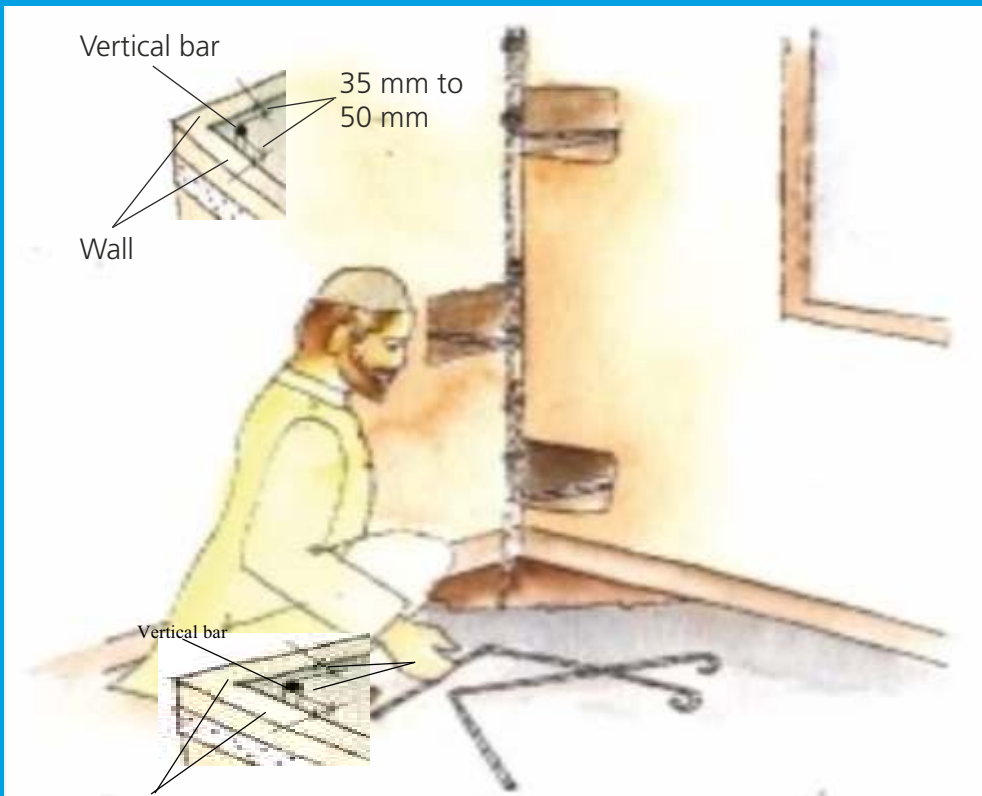
How to Install Vertical bar in a Corner



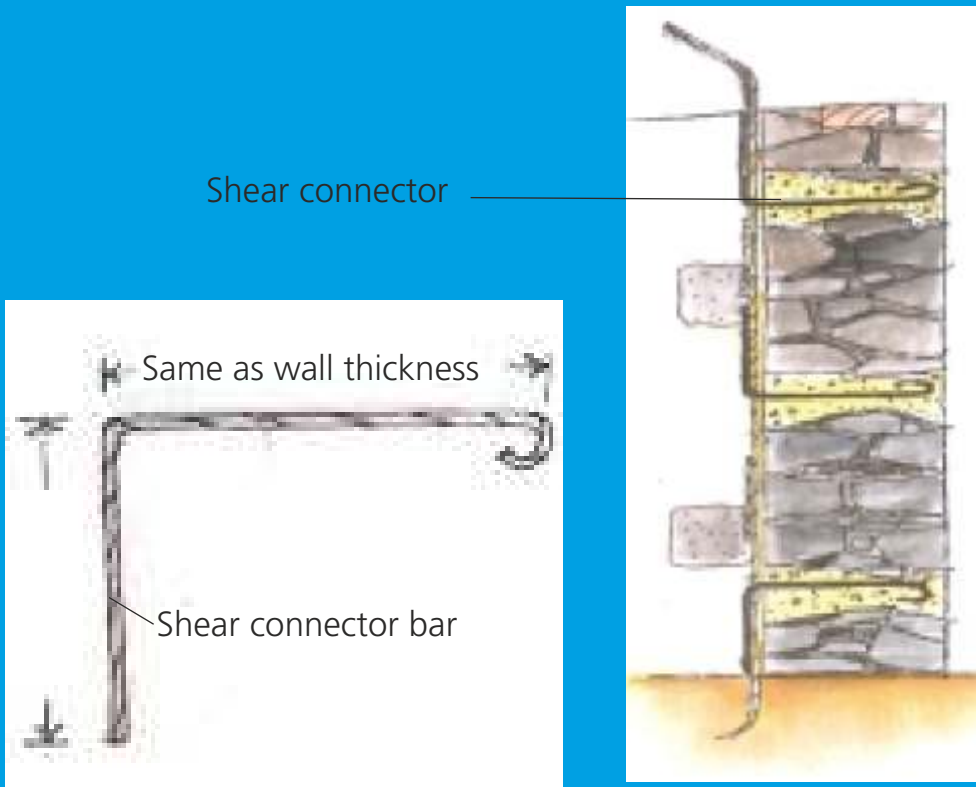
Marking boundaries of vertical rod concreting



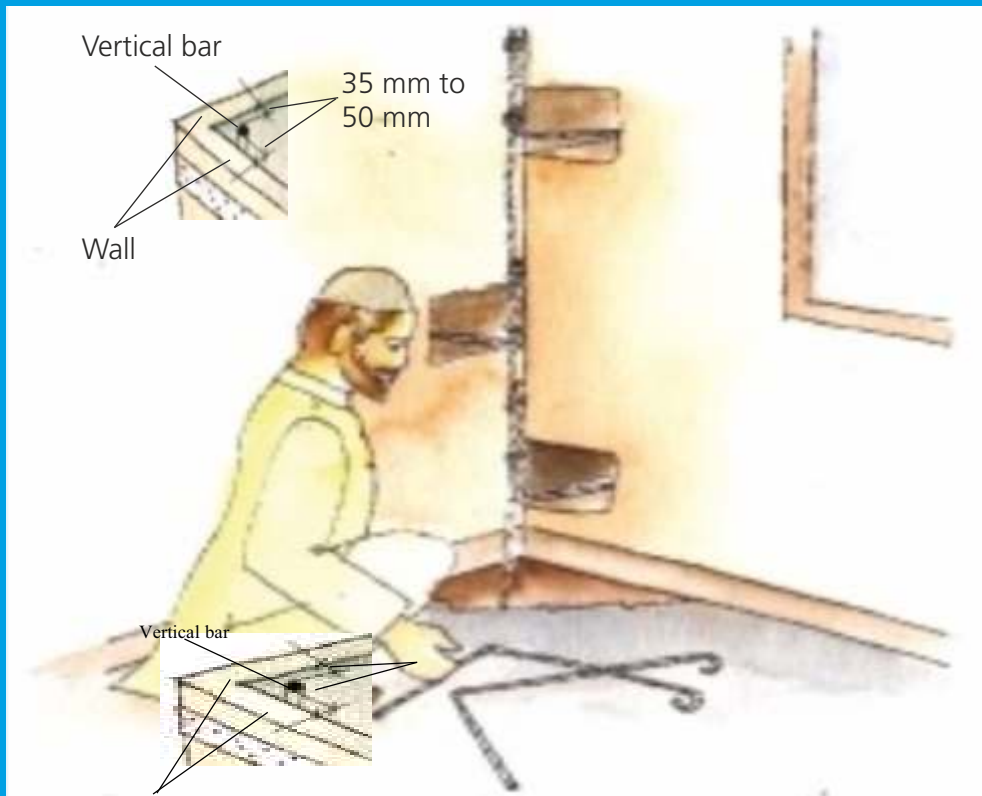
Breaking flooring and digging hole for vertical bar



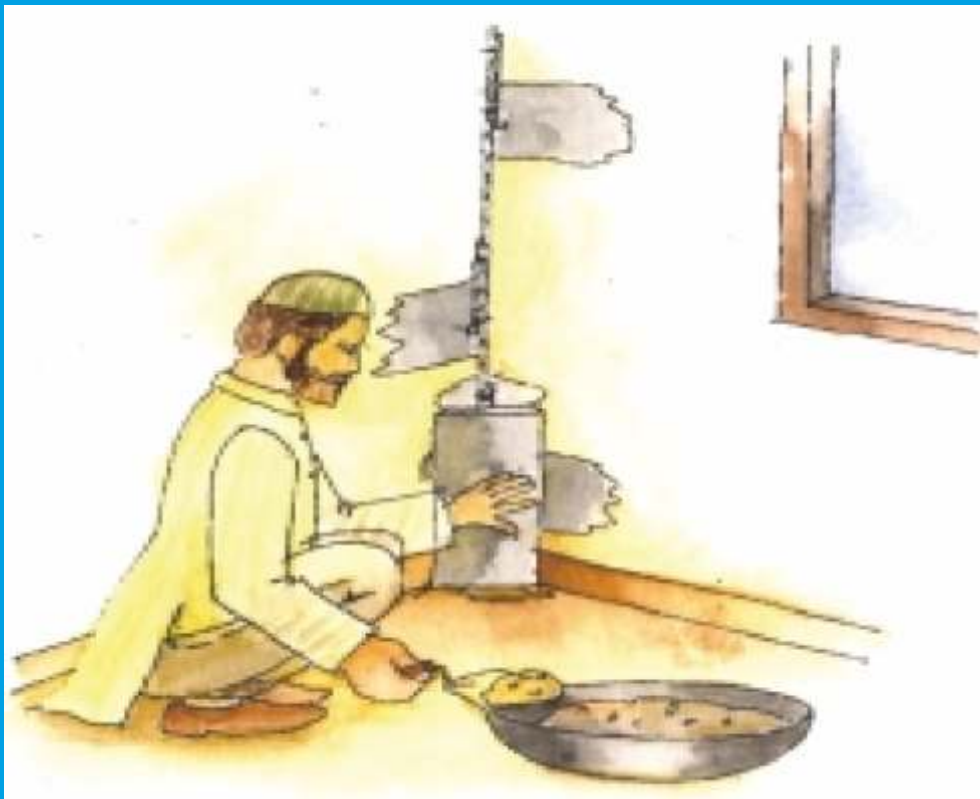
Placing of vertical bar in the corner along with shear



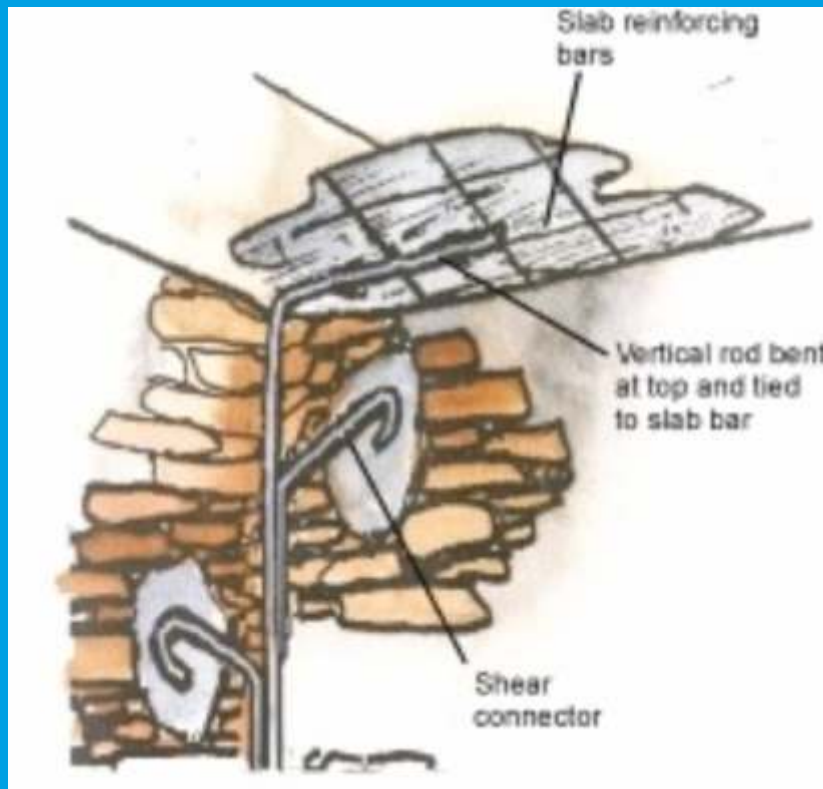
Shear connector & vertical rod details



Placing of vertical bar in the corner along with shear



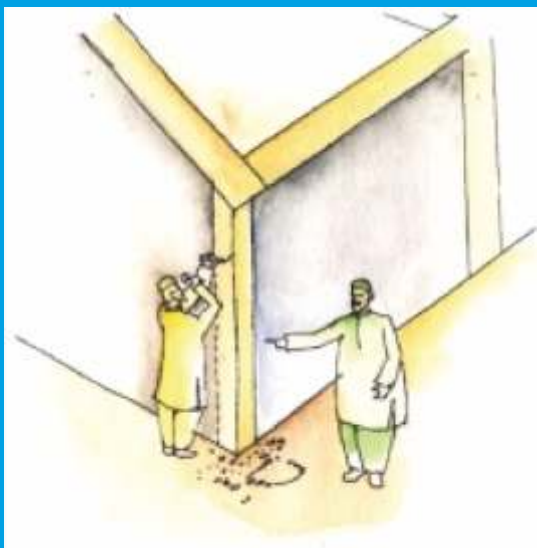
Encasing vertical rod in concrete



Connecting top bent end of vertical rod to slab

4.7.2 How to Install Vertical Belt with Welded Wire Mesh at Wall Junctions

- Identify the corners where flat configuration belts are to be installed and where 'L' configuration belts are to be installed. Mark the belt alignment on the wall using string and plumb-bob.
- Using electric grinder if available cut the plaster along the limits of the belt to restrict the plaster removal.
- Remove the plaster from the marked area and expose the walling material.
- Belt will start from 300mm below plinth level & continue up to top of wall at roof level. Rake all the mortar joints to the depth of 12mm (1/2") by hand or by electric grinder. Clean the surface with a wire brush.
- Prepare the mesh as per required length and attach it with binding wires to the pre-cut 6 mm bars that have been bent as required.
- Install WWM where the area of the wall should clean.
- Use wire nails 100 mm - 150 mm (4"-6") in length, spaced in staggered fashion at intervals of about 300 mm (12"), in two lines to fix the mesh to the wall. Nails must be driven into the mortar joints.
- Provide spacers 15 mm (5/8") thick of suitable material between wall surface and mesh.
- Splash exposed wall surface with water to remove all dust and to wet it properly. While still wet, apply neat cement slurry followed by a first coat of cement-sand (1:3) plaster of 12 mm (1/2") thickness.
- After 1 to 2 hours, apply second layer of plaster with same mix and with enough thickness to provide 16 mm (5/8") cover over the reinforcement.
- Cure the plaster for 15 days.



Removing plaster for vertical belt installation



Anchoring vertical belt 300 mm below plinth level

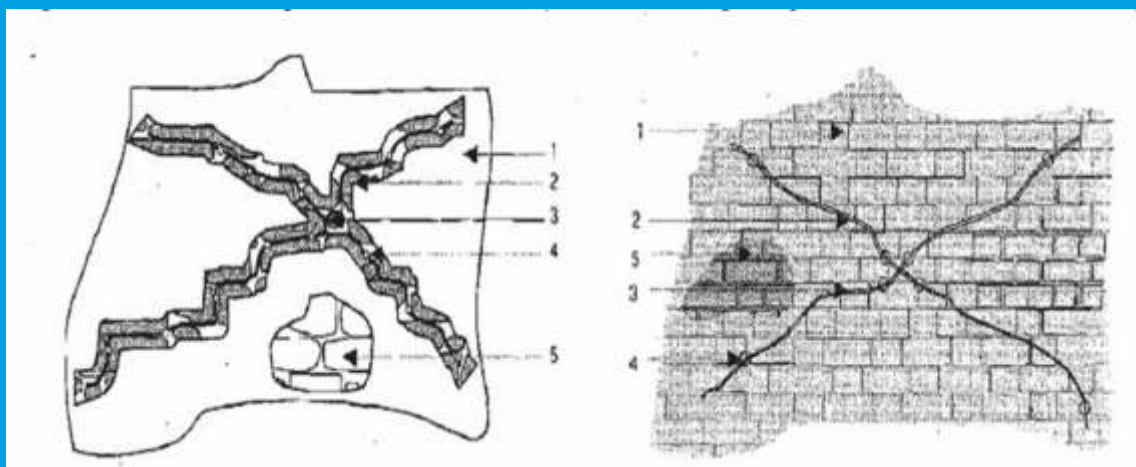
4.8 Grouting for Retrofitting of Masonry

Grouting is a process of injecting grout in the cavities of wall and it consists of cement and water. The technique is applicable where the extent of the cracks of the wall does not exceed One Centimeter. Knowledge of the internal structure of the wall and the percentage of gaps is an element of concern for choosing the most appropriate grout mix.

- Prepare sample tests for various grout mixes depending on the nature of the works. The water is placed in a can and $\frac{2}{3}$ of the cement is added. Then, a specified admixture or epoxy is added and finally the rest of the cement. The mixture needs four minutes in a mixer with a frequency of at least 1000 rpm. It is recommended that the cement based grout passes through a sieve No. 16 to remove any lumps
- Holes are then cleaned from loose material & dust and the edges are smoothed. The grout is filled-in using pressure and passing through the gaps, filling the vacuum by squeezing the air out of the gaps of masonry.

4.8.1 Grouting Minor and Medium Cracks (width 0.5 mm to 5.0mm)

- Remove the plaster in vicinity of crack exposing the cracked bare masonry. Make the shape of crack in the V-shape by chiseling out.
- Fix grouting nipples in V-groove on faces of wall at spacing 150-200 mm c/c.
- Clean the crack with compressed air through nipples to ensure that the fine and loose material inside the cracked masonry has been removed.
- Seal crack on both faces of wall with cement mortar 1:3 & allowed to gain strength.
- Inject water starting with nipple fixed at higher level and moving down so that the dust inside the cracks is removed and masonry saturated with water.
- Make cement slurry with 1:1 (1-non shrink cement:1-water) & start injecting from lower most nipple till slurry comes out from the next higher nipple and then move to next higher nipple.
- After injection grouting through all nipples is completed, re-plaster the finish the same.

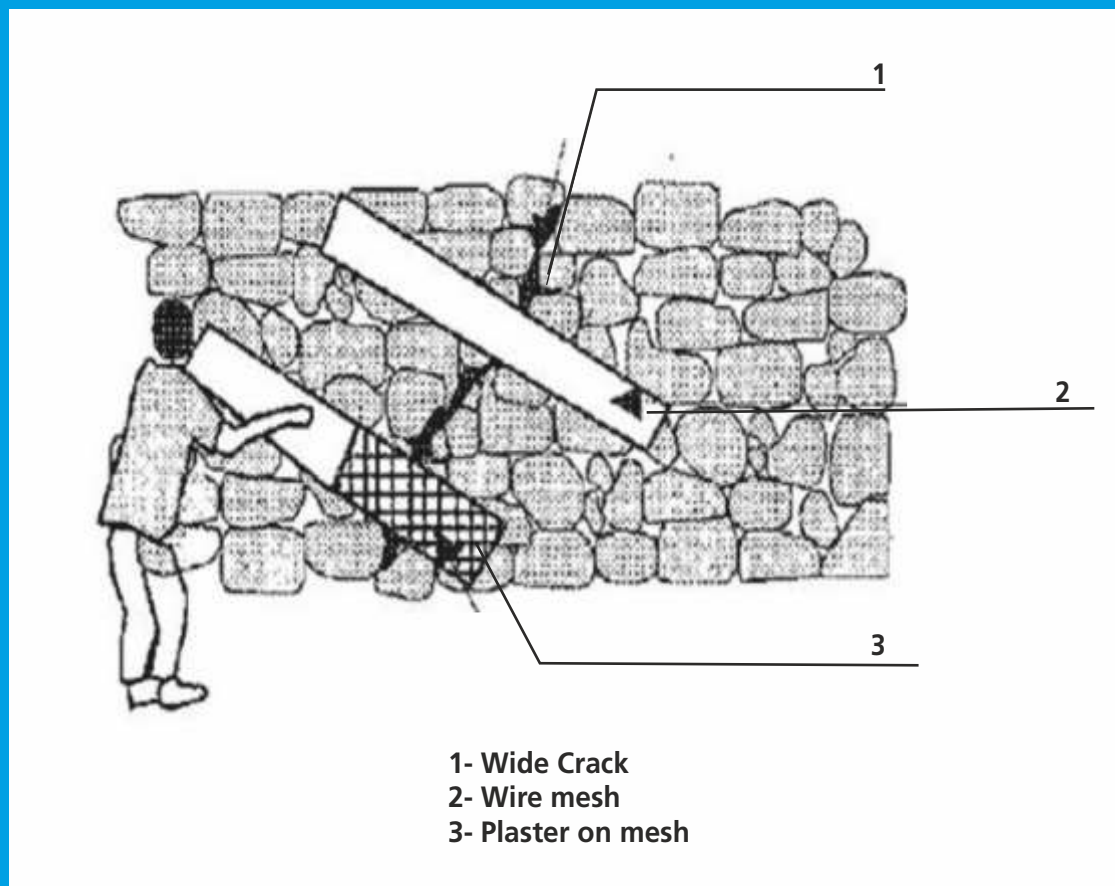


Stone wall

Brick wall

4.8.2 Grouting Major Crack (Crack width more than 5.0mm)

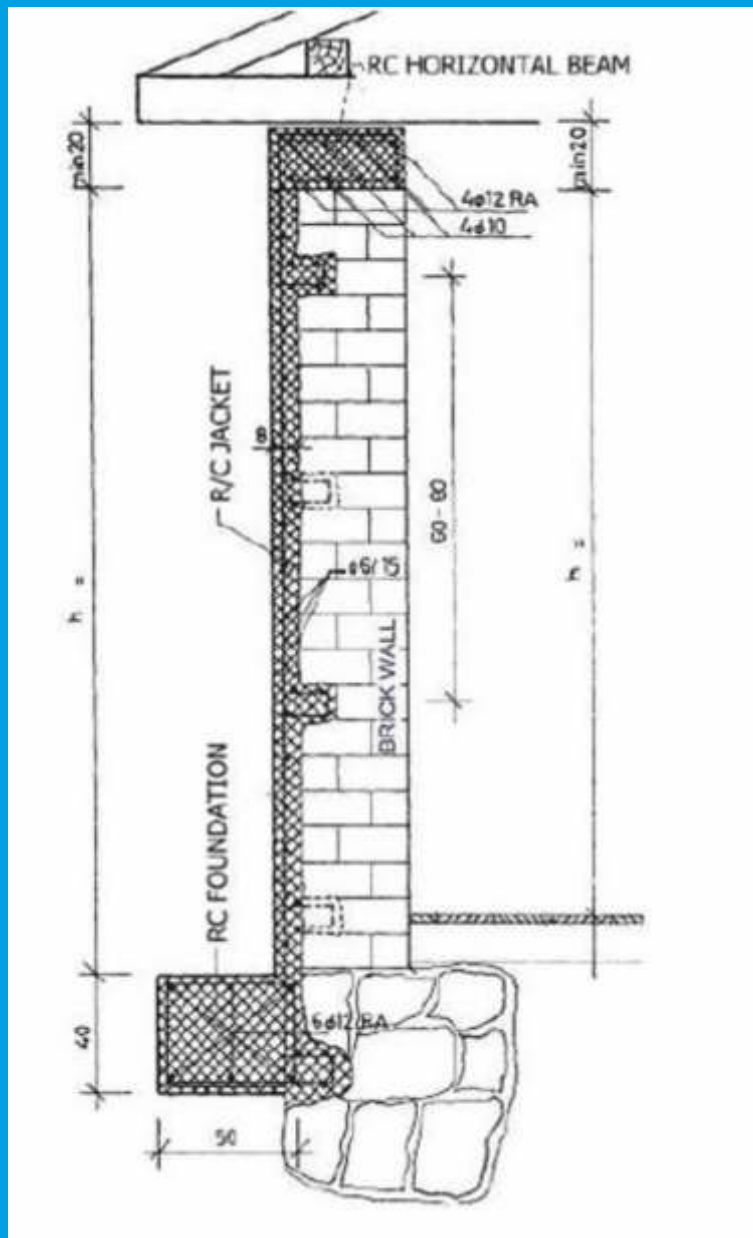
Remove plaster in the vicinity of crack exposing the cracked bare masonry. Make the shape of crack in the V-Shape by chiseling out. Clean the crack with compressed air, to make in V-groove. Fix grouting nipples in V-groove on both-sides of wall at 150-200mm c/c spacing. Clean the crack with the compressed air through nipples to ensure that the fine and loose material inside the cracked masonry has been removed. Seal the crack on both the faces of the wall with polyester putty or cement mortar and allowed to gain strength. Inject water starting with nipples fixed at higher level and moving down so that dust inside crack is removed & masonry is saturated with water. Make cement slurry with 1:2:W (1-non shrink cement: 2- fine sand: just enough water) and start injecting from lower most nipple till the slurry comes out from next higher nipple & then move to next higher nipple. After injection grouting through all nipples is completed, re-plaster surface & finish the same.



Fixing mesh across wide cracks

4.8.3 Jacketing

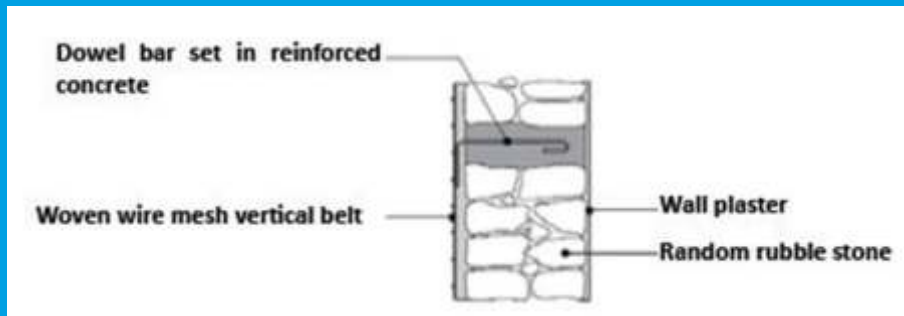
Jacketing is done to cover a wall surface with thin layer of reinforced concrete mortar or short-crete overlays, interconnected through-wall anchors. This technique is used for strengthening existing masonry buildings, by improving their lateral resistance and energy dissipation capacity of the structure. It is application of reinforced-cement coating (jacket) on one or both sides of the walls.



Jacketing on Outside of Wall

4.8.4 Application of RC Coating/Jacketing

Except for securing the coating reinforcement to existing masonry with steel anchors, the connection can be achieved by inserting shear connectors from cage reinforcement. Total thickness of jacket must not exceed 30 mm. Jacketing should be applied to both interior & exterior wall surfaces, because a single-sided jacket cannot confine a wall. In case of single-surface application, steel dowels & spacing be provided to ensure that existing stone wall & the new jacket act in unison.

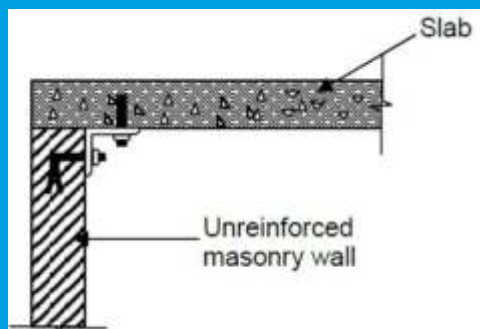


Single-sided jacketing showing steel

4.9 Retrofitting of Floor / Roof

Load bearing masonry structures be strengthened such that whole building performs as one unit in a box system. The in-plane rigidity provided by floor and roof (diaphragm) ensures box-system of structure. Floor and roof system in a building are horizontal elements that transfer hazard-impact forces to vertical elements of lateral-force-resisting system i.e. walls. The connections of floor/roof to vertical elements providing lateral support should comply as follow.

Masonry walls should be connected using reinforcement or anchors to the roof and all floors with a connection capable of resisting a seismic lateral force induced by the wall. Walls should be designed to resist bending between connections where the spacing exceeds 1.2 m. The slabs should consist of cast-in-place concrete systems that, in addition to supporting gravity loads, transmit inertial loads developed within the structure from one vertical lateral-force-resisting element to another, and provide out-of-plane bracing to other portions of the building. If masonry walls are constructed with vertical reinforcement, vertical bars at corners and junctions of walls be taken into floor slab, roof slab or roof band. RCC slabs not connected with masonry walls by continuation of vertical reinforcement be anchored with wall with suitable connection.



Anchorage of RCC slab with masonry wall

4.10 Retrofitting of Non-Structure Building Elements

The on-site field inspection of school buildings is an effective mean for obtaining EQ damages information of a building. The damage or collapse of buildings is caused by the both “Out-of-Plane loading” and “In-Plane Loading” of walls. The damages are also caused by poor materials quality, poor workmanship, and lack of maintenance. Typical damages in non-engineered buildings are:

- Cracks in roof, parapet, overhang, projection
- Roof tiles dislodge (in sloped roofs)
- Walls tear apart and Failure at corners of walls or at corners of openings
- Diagonal cracks in walls or walls collapse
- Bending/tilting of column and beam, or Failure of column and beam
- Floor and foundation cracks or sinking

There must be proper connection between structural and non-structural elements. All non-structural elements should be restrained properly. Ensure that the quality of non-structural elements in existing school should meet higher safety standards and must satisfy the approved structural requirements. These elements should neither suffer partial or total collapse; nor suffer such damage that cannot be retrofitted.

The methods to avoid the collapse of non-engineered masonry must be simple and inexpensive, working with the available resources and skill. Due consideration is to be given for uniform distribution of furniture and fixtures, equipment and other non-structural elements, so that the load distribution is even. The non-structural elements (partitions, furniture, equipment etc.) should be fixed properly for restricting their movement to prevent overturning, sliding and impacting during an earthquake. Masonry walls are recommended to be braced with reinforced concrete mess or any other means to prevent non-structural damage during large intensity earthquake.

Section - 5

Annexure

Annex-A

Retrofitting works completed in damaged buildings of 12 existing schools in Swat and Peshawar Districts of KP

1: Government Primary School Amankot – Swat KP,





Ceiling bond failure, rebar exposed Apply SBR prior to c/s mortar Finish c/s mortar surface



Opening of deep cracks for proper apply fresh prick masonry using bonding 1:3 c/s mortar



Chiseling of crack widely fixing of mesh for proper bonding Apply 1:3 c/s mortar of mortar



Finished surface



Before



After Retrofit Works



Finishing stage after retrofitting

2. Government Primary School # 2 Manglor Swat

Repairing of windows and cracks in progress, Repairing the Corner Cracks. Weld-Mesh or other reinforcement

Connection of cracked walls at corners and junctions. Major Cracks (Crack width > 5 mm)

Crack filling, connecting corners, connecting walls at T-junction repairing the Corner Cracks, Weld-Mesh or other reinforcement.



Before



After Retrofit Works



Before



After Retrofit Works



After completion



Addition of RCC columns on both ends along with RCC foundations



2" thick Roof screening using 1:2:4 concrete to prevent seepage



Retrofitting of cracks by filling epoxy and mortar; Repairing of windows

3. Government High School Ghalegay Swat.

At some places, occurrence of many cracks close together in the walls, or tilting of some wall portions out of plumb after Separation, or bulging of stone wall after delamination, or falling of some wall portions.

Major Cracks (Crack width > 5 mm) 2 walls 20 ft. x 16 ft. required new construction Rebuilding the Collapsed Portion of wall, repairing the RC Damaged Column.



Before



After Retrofit Works



Removal of loose stones and fill mortar along with epoxy

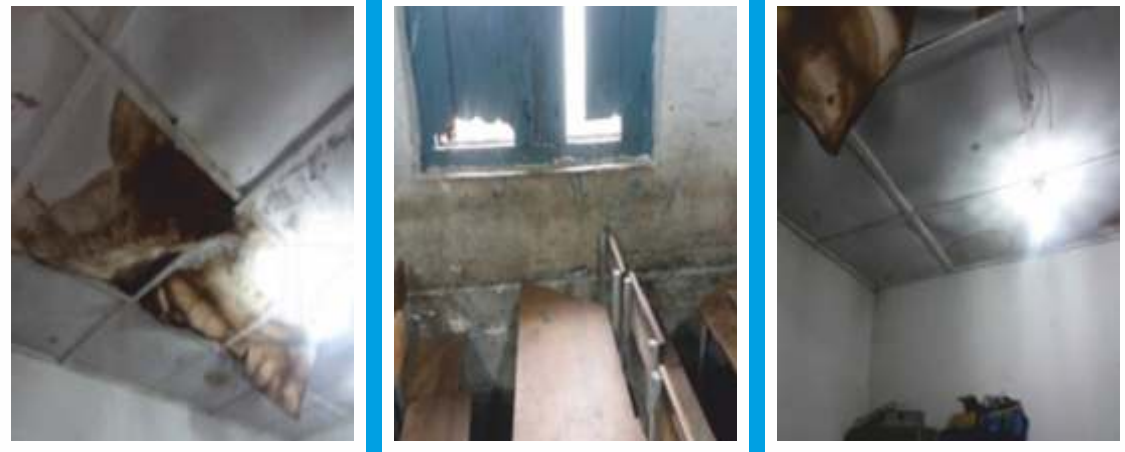


Dismantle existing loose plaster and fill epoxy on gaps/voids



Apply mortar over epoxy

4. Government Primary School Sherpalam – Swat



Before retrofitting



After retrofitting



Open classroom with damaged walls



Covered with CGI shed and repair



Replacement of damaged false ceiling



Fixing of new CGI sheets over whole roof by in order to avoid leakage during rain

5. Government Primary School Kabal – Swat



Filling epoxy on deep crack



Steel exposed due to bond failure and seepage



Apply SBR and then 1:3 c/s mortar



Removal of existing sub-standard plaster mortar



Fill voids with epoxy and apply fresh 1:3 c/s

6: Government Primary School Bara Bandai – Swat KPK

Cracks at the corners or T-junctions to be filled mortar. Back side wall windows shade need repairing. Some wall is medium/ minor crack, Improving the wall-floor& roof, Waterproofing on the roof top.



Fixing of mesh on joint



Apply mortar over bonding agent



Filling of cement bond along with adhesive chemical at girder joints



Retrofitting of ceiling through chemical process



Cracks retrofitted by filling epoxy

7: Government Girls Primary School Hazara Khwani Chena Dag – Peshawar KPK



Steel left outside the beam due to previous poor construction reinforcement



Cutting of existing oxidized steel of beam to reduce the rust impact on inner



Apply anti corrosive agent and then apply mortar



Apply white cement to strengthen plaster and avoid gradual erosion



Existing poor construction mortar and improper concrete cover exposed



Apply SBR and then plaster using 1:3 c/s



Brick flooring causes seepage and weaken the slab of ground floor



2" thick 1:2:4 PCC flooring in 5'x5' boxes using marble strips

8. Government Primary School No1, Hazar Khwani Chena Dag – Peshawar



Dismantling of weak/damaged parts of RCC columns and cleaning of rust from steel



Prepare chemical combination of crush Anti-corrosion (liquid) and binding Agent (powder)



Apply chemical over column



Pour 1:2:4 concrete using pan



2" thick 1:2:4 PCC flooring in 5'x5' boxes using marble strips



Repairing of windows by apply new mesh using gas welding for heavy-duty joints

9. Government Primary School Nazirabad Mera Kachori – Peshawar KPK



Mixing of waterproofing chemical (Liquid + Powder) application Through mechanical process



Curing of slab prior to water shield



Apply two coats of water shield and allow drying



Repairing of windows by apply new mesh using gas welding for heavy-duty joints

10. Government Model Middle School Tarnab Farm Sercial Chughelpura



Retrofitting of boundary wall next to river can be a hazard in flood



Retrofit of deep crack by filling epoxy and mortar



11: Government Primary School Tarai Payan Pajaggi – Peshawar KPK



Buckling of walls and column, sag in beam



Demolish existing walls



Eradicate existing buckle column excluding steel



Provide fresh masonry using 1:3 c/s



Pour 1:1.5:3 concrete in column and beam then provide plaster and pointing



After

12: Government Girls Primary School Lala Kalay – Peshawar KPK



Prepare SBR mixing with cement



Retrofitting of RCC projections using SBR and concrete



Chiseling of hollow plaster



Apply first rough coat of mortar over binding agent

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