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RETROFITTING MANUAL FOR ENGINEERS ON CONSTRUCTION OF DISASTER RESILIENT SHELTER CONSTRUCTIONS

May 2019

Retrofitting Manual for Engineers on Flood and Landslide Resistant Shelter Construction Practices

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Contents

Executive Summary

This manual is a guideline for the retrofitting techniques adopted by engineers of different typologies of building in Kerala. As in Kerala is vulnerable for different types of disaster like earthquake, landslides, cyclone, floods etc. In any case building experience additional dynamic loading which can cause damage or collapse in structure that leads loss in property and human life. In India, there are several types of construction practices are used based on locally available material, climate and other but in several study, it is found that most of the building are deficient to the different hazards that make our society more vulnerable. To prevent damage and reduce risk it is recommended that vulnerable structures should be identified, assessed and retrofitting by using different techniques. Before understanding retrofitting techniques it is important that to understand following topics like vulnerability profile of state, existing building typology, site selection criteria, construction material selection criteria, quality construction material selection criteria, Indian standard code provision, different retrofitting measures and damage assessment techniques, general retrofitting method used for flood hazards, general retrofitting techniques used in landslides etc.

There are several severe disaster events occurred in Kerala, one of the most eye-opening flood event happened in 2018 i.e. because of Kerala received heavy monsoon rainfall which it was about 75% more than usual rainfall in Kerala, Because of the heavy rainfall the water level rapidly rise in the dams to avoid any damage in dams immediate water discharge was processed, it was the first time in the state's history 35 out of its 54 dams has been opened. Due to this, flood is induced in the state. There are several districts In Kerala was severely affected by flood over 3274 relief camps have been opened at various locations to accommodate the flood victims. it is estimated that 1,247,496 People have found shelter in such camps. The three most affected districts were Pathanamthitta, Wayanad and Idukki.

The different type of building structures presents in Kerala which can broadly divide building types in two ways first on the basis of architectural configuration and second on the basis of Building construction material. When these structures are exposed to the different hazards response behavior of the buildings will change accordingly. There is one the deciding factor for building response is material quality of built structure, that is why the quality material is needed to be selected for the construction. There are some general criteria are discussed further in the manual.

Site selection plays important role to reduce the risk that may cause due to any disaster. There are several factors which need to be considered while we are going to construct a building in flood or landslide prone area. Some of the most important factors are like Site drainage, Flooding, Soil erosion, Proximity of natural hazards and distance from nearest water body.

In India there are different IS code are available for the building construction, but IS codes for the retrofitting is one of the area where development of code are still going on till date there are some code with brief guild line about retrofitting are available which are discussed further but there is no code available for the retrofitting due to flood or landslide hazard damage. In that case it is recommended to refer other codes which states building structural information and build the building with different resilient features.

RVS is the most popular method of assessment which is worldwide adopted in this method. The screening is based on numerical hazard and vulnerability score. In case of earthquake scores are based on the expected ground shaking levels in the region as well as the seismic design and construction practices for the city or region. The scores use probability concepts and are consistent with the advanced assessment methods. The RVS procedure can be integrated with GIS-based city planning database.

In post disaster management process, it is most challenging part to recreate the damage infrastructure so that disaster victims can rehabilitate. Recreating all the infrastructure is a challenging process which includes three major steps i.e. repair, restoration/rehabilitation and retrofitting. In different disaster building are damage on the basis of the different factors like built quality, structural system, impact direction and intensity etc. there are different retrofitting techniques are present globally which can be adopted on the basis of damage assessment. There is different damage assessment method are available for different structural components, some of the common components are substructure and superstructure. In first step damage need to be assessed and mark on building component wise and then most suitable retrofitting technique will be adopted according to the damage type.

In case of flood hazard there are some common failures are observed after Kerala flood i.e. cracks in walls, settlement in foundation, partial damage in structure, uneven column settlements etc. Some structures are survived but needed special attention for the future. To minimized impact of flood water there are several construction principles which need to be followed like plinth protection, plinth raise, proper site selection, durable construction material etc. In landslide hazard there are very few techniques are available that may be used to retrofit building due to the scale of hazard. Landslide generally effect a huge land mass due to which mitigation and retrofitting is needed at larger scale to stabilize slope, but in case of individual buildings there are some common retrofitting techniques like repair for structural cracks, extension of foundation, installation of drill anchor in the slope etc. Retrofitting techniques will be adopted according to the damage assessment of the building.

Key idea to retrofit of a built structure is to make it durable and achieve factor of safety at the time of any disaster, for that there are some important recommendations like analysis the structure in different perspectives like site of building, material used for construction, damage appear, building configuration, maintained quality on the basis of above mention analysis retrofitting technique should be adopted which include several factors like expert executor available, quality of intervention needed to be quantified, supervision of site engineer is must etc. To build safer society it is very important to retrofit existing structures so that impact of any disaster would be minimized, and chance of economic and human loss can be reduced. In Kerala it is need of this hour to carry a detail survey of all flood effected area and create a common structure damage pattern inventory for the vulnerable structure which shows damage or vulnerable for the damage than a retrofitting program needed to be conducted with the practical session to selected masons. There should be a detail assessment standard proforma needed to be created for the public and private engineer to standardized assessment.

Chapter 1

Disaster Profile

Chapter 1

Introduction of various Disasters Profile in Kerala

1.1 Introduction:

A disaster is a serious disruption, occurring over a relatively short time, of the functioning of a community or a society involving widespread human, material, economic or environmental loss and impacts, which exceeds the ability of the affected community or society to cope using its own resources. Disaster are seen as the consequences of inappropriately managed risk. these risks are the product of combination of both hazards and vulnerability. hazards that strikes in the areas with low vulnerability will never become disasters, as in the case of uninhabited reasons. developing countries suffer the greatest cost when disaster hits- more than 95% of old debts caused by the hazards occur in developing countries and losses due to natural hazards are 50 times greater (as a percentage of GDP) in developing countries then industrialized countries.

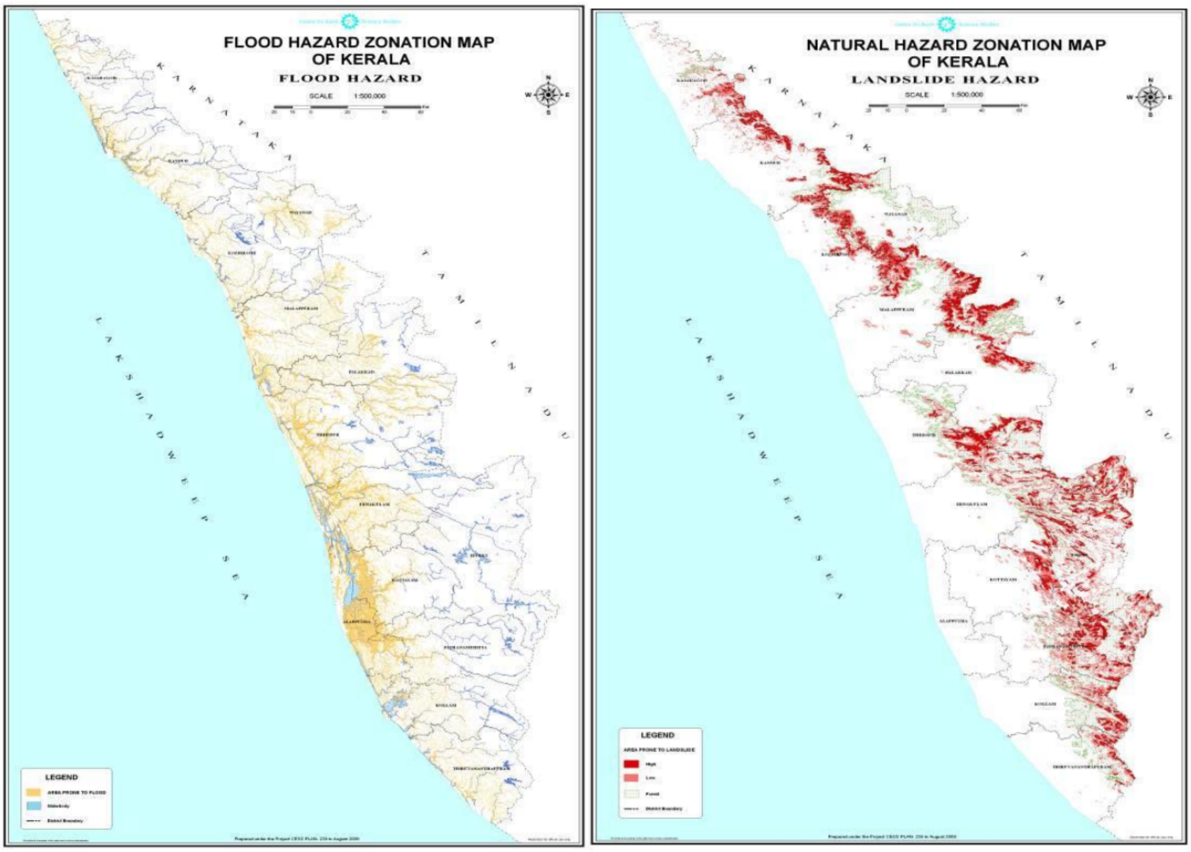


Figure 1: Maps of Flood hazard zonation *(left)* and Landslide hazard zonation *(right)*
(credit: Kerala State Disaster Management Plan Profile)

Kerala is prone for various types of disasters, some of the common disasters are cyclones, floods, earthquake, landslides and forest fires. some of the specific vulnerability of the state as follows:

- Kerala has a long coastline of 590 kms out of which, 322 km is prone to severe sea erosion the density of population is 819 persons per sq.km which is the second highest density in the country.
- About 96.9% of the total area in the state lies in the 140.4km/h wind zone which is classified as Moderate Damage Risk Zone by the BMTPC Atlas while the remaining area lies in 118.8km/h wind zone.
- The mean maximum storm surge height in the state is 3.5m and minimum is 2.3m. If the storm surge is during high tide, the maximum surge height in the state will be 4.2m and minimum storm height will reach up to 3m, as observed by the Meteorological Department, Thiruvananthapuram.
- The coastal belt of Kerala is one of the most densely populated regions in the country, which adds to its vulnerability.
- The Western flank of the Western Ghats covering the eastern part of Kerala is identified as one of the major landslide prone areas of the country.

In past years, There are several severe disaster events occurred in Kerala, one of the most eye-opening flood event happened in 2018 i.e. because of Kerala received heavy monsoon rainfall which it was about 75% more than usual rainfall in Kerala, Because of the heavy rainfall the water level rapidly rise in the dams to avoid any damage in dams immediate water discharge was processed, it was the first time in the state's history 35 out of its 54 dams has been opened. Due to this, flood is induced in the state. There are several districts In Kerala was severely affected by flood over 3274 relief camps have been opened at various locations to accommodate the flood victims. it is estimated that 1,247,496 People have found shelter in such camps. The three most affected districts were Pathanamthitta, Wayanad and Idukki. Due to flooding there are several multi-disaster scenarios generated in different districts. There are different landslides events induced by flood is also recorded in the different districts of Kerala.

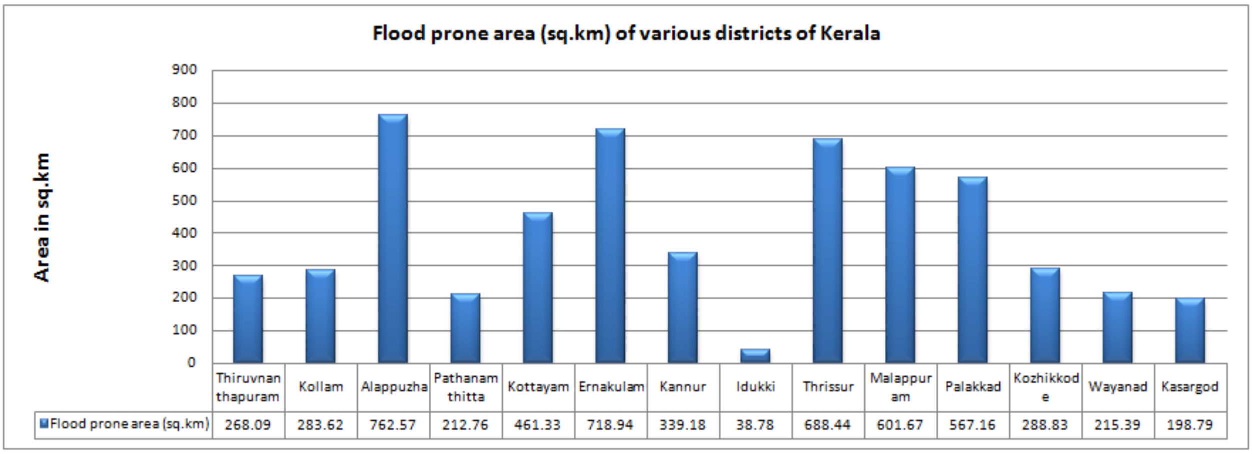
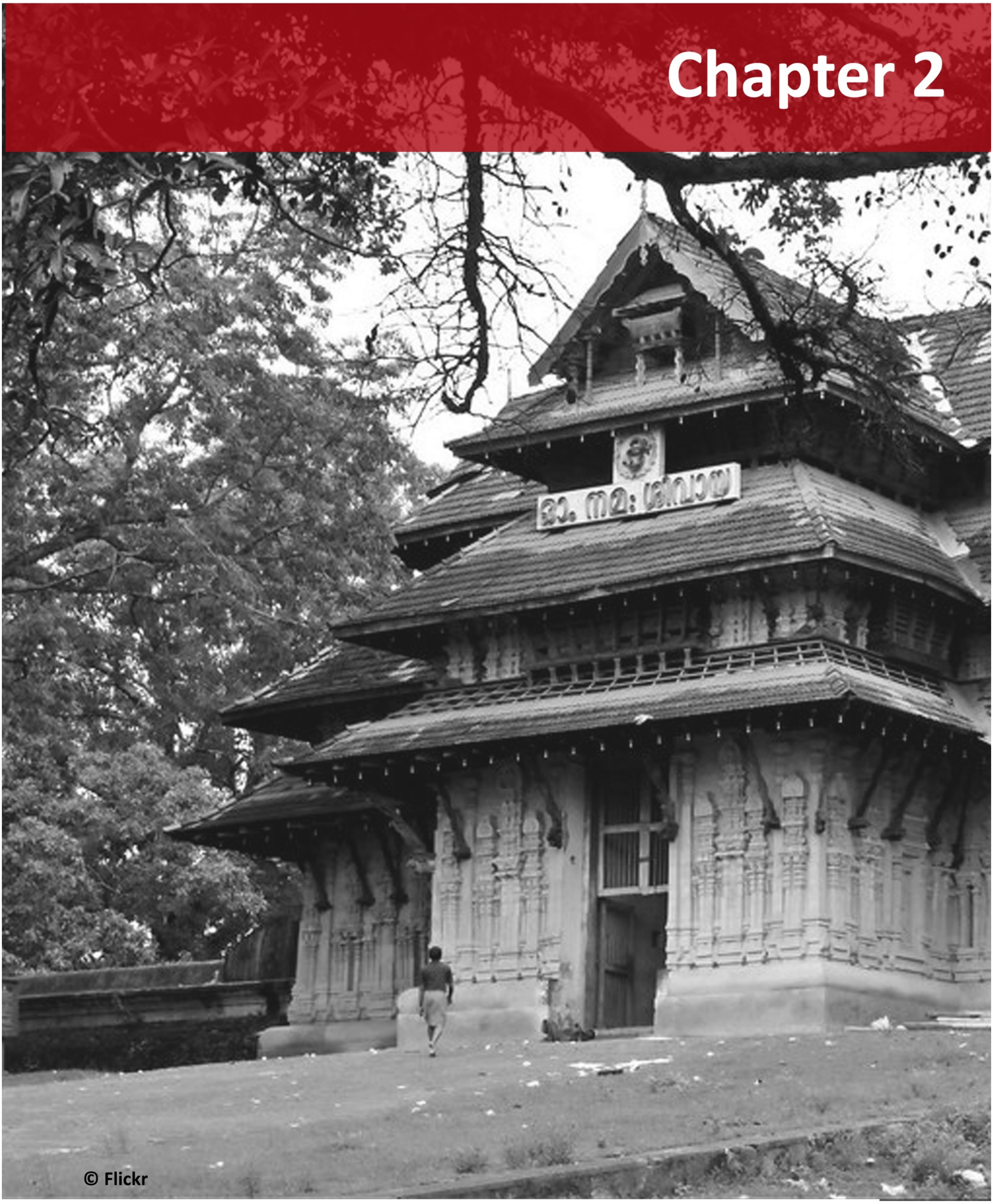


Figure 2: Chart showing Flood scenario in Kerala
(source: Consult CESS, 2010. Plan project 249 for taluk wise area)

Chapter 2



Construction Practices

Chapter 2

Traditional and Modern Construction Practices

2.1 Evolution of the present building process:

This section presents an overview of the evolution of the prevailing building processes in Kerala followed a quick insight into the history of present technology. Traditional Kerala architecture is based on the principles of Vastu-Shastra (science related habitation). It considers the astrological placement of the Sun, Earth, and other planets during the actual construction along with the location of the site, its shape, the proposed building's shape, the facing direction of the building, the location of gates, entry doors, doors to each room, windows, and the general design of the building. The basic theories of Vastu-Shastra are closely connected with astrological principles. Therefore, deviation from the accepted rules was believed to cause detrimental effects to those who use the building or the artisans who had constructed it. Thus, the technology demanded highly skilled craftsman and precision in the entire work. The whole process was under the control of a head craftsman. Also, the building process was based on caste-related social customs and traditions. It had a great influence on the overall building process, such as the type of buildings, materials used for construction, technologies employed, labor involved etc. Absence of wage labor relations and the supremacy of the caste system was a distinguishing characteristic (Harilal ct al., 2000; 2002). Houses belonging to each caste had a common name of identification revealing their appearance and technology used. The quality and size of houses diminish as we go down to the caste scale. The "Pulaya's" (lowest division of caste) hut was considered as the smallest unit of accommodation (Government of India, 1891). The caste system provided the framework for occupational division of labor. Only the upper class enjoyed the privilege of employing the services of artisans, and the poor people used to build their houses with self-help or mutual help using locally available materials. This situation continued till the early 1970s.

2.1.1 Modernization of the building process:

The social reform movements and the larger process of modernization of Kerala since independence and later the formation of Kerala state had effectively overcome many social and caste-based restrictions in all sectors of life including the building process. Following the 1973 hike in oil prices, the majority of youth from Kerala migrated to the gulf countries in search of better employment opportunities and there was a significant inflow of remittances to the state from the Middle East. Income windfalls and exposure to the outside world brought out greater changes in their aspirations. desires and preferences. A major part of the investment at that time was in the housing sector. Average prices of indigenous building materials (sand, clay) increased by about fifteen to twenty times during this period (1978-80). Free access to the natural materials was denied and traditional practice of community cooperation in house building became non-practicable. At the same period, the factory-produced materials (cement, steel) showed an increase of less than ten-fold (Gopikullan, 2002). The share of construction sector in the gross domestic fixed capital formation of Kerala for the last two years of 1970 was more than 90% (Gopikuttan, 1988). The number of new residential buildings has also showed a steady increase. This housing boom was the combined effect of economic, social, institutional and cultural changes occurring during those days. Land reforms conferred ownership on land to those who had earlier been landless laborer. Also, the popularity of One lakh housing scheme generated the importance of having own houses, even among the economically weaker sections. These social changes and subsequent investments in housing favored the excessive use of energy-intensive building materials like cement, steel and bricks, replacing the traditional materials.

2.2 Various existing buildings typology in Kerala:

In this chapter, we are going to discuss about the different type of building structures present in Kerala. we can broadly divide building types in two ways:

1. on the basis of architectural configuration.
2. on the basis of Building construction material.

2.2.1 Architectural configuration:

Kerala architecture can be broadly divided into 2 distinctive areas based on their functionality, each guided by different set of principles.

1. Religious Architecture
2. Domestic Architecture

Religious architecture primarily patronized by temples of Kerala as well as several old churches, mosque etc. Domestic architecture recognizes in most of the residential houses that have common architectural style and features.

Figure 3: Image showing typical house type in Kerala *(credit: pinterest.com)*

2.2.2 Building construction material:

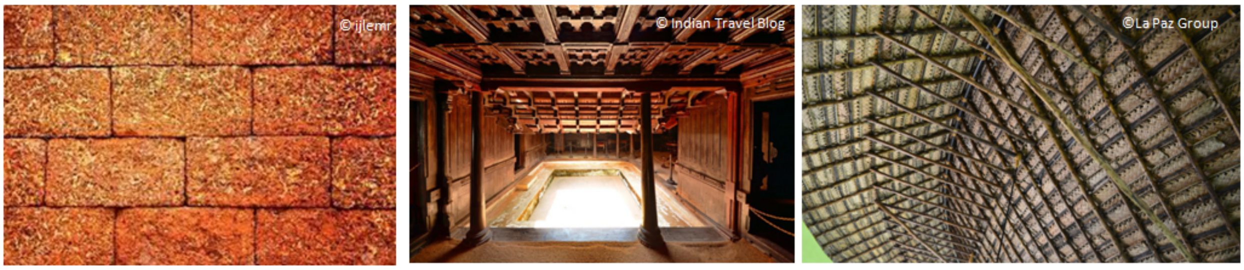
There are different typology of the building present in Kerala, some of the common building typologies are RCC structures, masonry structures (brick masonry structures and stone masonry structures), confined masonry structures, Adobe construction, mud houses, temporary structures, Steel or prefab structures etc. In most of the urban areas general topology of the structures are found of RCC and brick masonry while in rural areas, stone masonry buildings, confined masonry buildings, temporary structures and mud houses are present.

Figure 4: Image showing common residential building *(credit: pinterest.com)*

Figure 5: Image showing urban residential Building using laterite stone *(left)*, typical rural residential building *(right)*. *(credit: pinterest.com)*

2.2.3 Common building materials used in Kerala:

The natural building materials available for construction in Kerala are stones, timber, clay and palm leaves. Granite is a strong and durable building stone; however, its availability is restricted mostly to the highlands and only marginally to other zones. Owing to this, the skill in quarrying, dressing and sculpturing of stone is scarce in Kerala. Laterite on the other hand is the most abundant stone found as outcrops in most zones. Soft laterite available at shallow depth can be easily cut, dressed and used as building blocks. It is a rare local stone which gets stronger and durable with exposure at atmospheric air. Laterite blocks may be bonded in mortars of shell lime, which have been the classic binding material used in traditional buildings. Lime mortar can be improved in strength and performance by admixtures of vegetable juices. Such enriched mortars were used for plastering or for serving as the base for mural painting and low relief work. Timber is the prime structural material abundantly available in many varieties in Kerala – from bamboo to teak. Perhaps the skillful choice of timber, accurate joinery, artful assembly and delicate carving of wood work for columns, walls and roofs frames are the unique characteristics of Kerala architecture. Clay was used in many forms – for walling, in filling the timber floors and making bricks and tiles after pugging and tempering with admixtures. Palm leaves were used effectively for thatching the roofs and for making partition walls. From the limitations of the materials, a mixed mode of construction was evolved in Kerala architecture. The stone work was restricted to the plinth even in important buildings such as temples. Laterite was used for walls. The roof structure in timber was covered with palm leaf thatching for most buildings and rarely with tiles for palaces or temples. The exterior of the laterite walls were either left as such or plastered with lime mortar to serve as the base for mural painting. The sculpturing of the stone was mainly molding in horizontal bands in the plinth portion (adhistans) whereas the carving of timber covered all elements pillars, beams, ceiling, rafters and the supporting brackets. The Kerala murals are paintings with vegetable dyes on wet walls in subdued shades of brown. The indigenous adoption of the available raw materials and their transformation as enduring media for architectural expression thus became the dominant feature of the Kerala style.



Laterite blocks Timber Thatch Weaving

Figure 6: The images showing Construction Materials commonly used in Kerala

Chapter 3

Retrofitting Techniques

Chapter 3

Introduction of Retrofitting Techniques in India

India is very vulnerable of several disaster that cause damages to the built structures heavily. There are different level damages observed in post disaster time. As it is now need of this hour that a paradigm shift is need from post disaster management to the disaster mitigation. In this respect different concern authorities and citizens of India are working together to build a safer society. With respect of this, in mitigation re-strengthening of the existing structures are very important and there are several techniques are already evolved in the country for the retrofitting of old structures for different hazards like earthquake, Landslides, floods etc. This chapter is about some of the techniques of retrofitting which are commonly used in India.

Classification of retrofitting techniques:

1. Adding New Shear Walls.
2. Adding Steel Bracings.
3. Jacketing (Local Retrofitting Technique)
4. Base Isolation (or Seismic Isolation)
5. Mass Reduction Technique of Retrofitting
6. Wall Thickening Technique of Retrofitting

The retrofitting of building may be required in each of the components: superstructure, bearings, substructure and foundations. The extent of retrofitting will be based on detailed assessment following dynamic methods of analysis. The retrofitting techniques for various portions of buildings are described below:

3.1 Superstructure

Super structures of any buildings are containing different components like Wall, column, beam, slab etc. It depends on the quality of construction and structural composition that a building is needed retrofitting or not. According to different national level studies it is observed that most of existing buildings in our country are deficient in required structural strength and it needed retrofitting.

3.2 Substructure

Substructure of a building consist of different component like foundation, plinth beam etc. Retrofitting of different component is also required at substructure level. In present scenario, due to flood, earthquakes or any hazard that imposed dynamic load to the building structure, it is common observation that several cracks and damages appear which leads to the building collapse. To prevent this there are several methods are available for the mitigation by adopting retrofitting measures. In this chapter, I am further discussed about damage assessment and proposed retrofitting techniques on the basis of different building components.

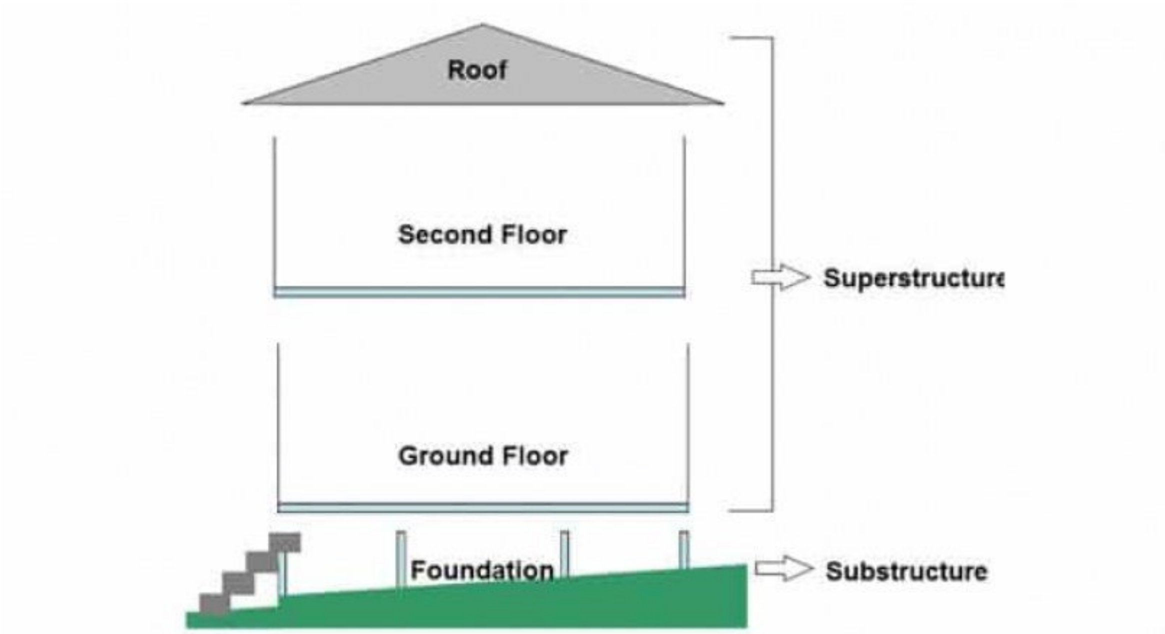


Figure 7: schematic diagram of building structure *(credit: theconstructor.org)*

3.2.1 Ferro-Cement Plating

It consists of a galvanized iron mesh fixed to the walls through nails or connector-links drilled through the wall thickness and the mesh is covered by rich mix of cement-sand mortar in the ratio of 1:3. To achieve good results, the following step-wise procedure is to be followed

1. Mark the height or width of the desired plating based on the weld mesh number of longitudinal wires and the mesh size
2. Cut the existing plaster at the edge by a mechanical cutter for neatness and remove the plaster (see figure below).
3. Rake the exposed joints to a depth of 20 mm. Clean the joints with water jet.
4. Apply neat cement slurry and plaster the wall with 1:3 cement – coarse sand 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.
5. 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 (see figure below).
6. Now apply the second layer of plaster with a thickness of 15 mm above the mesh. Good bonding will be achieved with the first layer of plaster and mesh if neat cement slurry is applied by a brush to the wall and the mesh just in advance of the second layer of plaster.
7. Cure the plaster by sprinkling water for a minimum period of 10 days.

Note - Where the RC belt is provided on both faces of the wall, the nails should be replaced by twisted wire links through drilled holes filled with mortar grout and tied to the meshes on both faces.

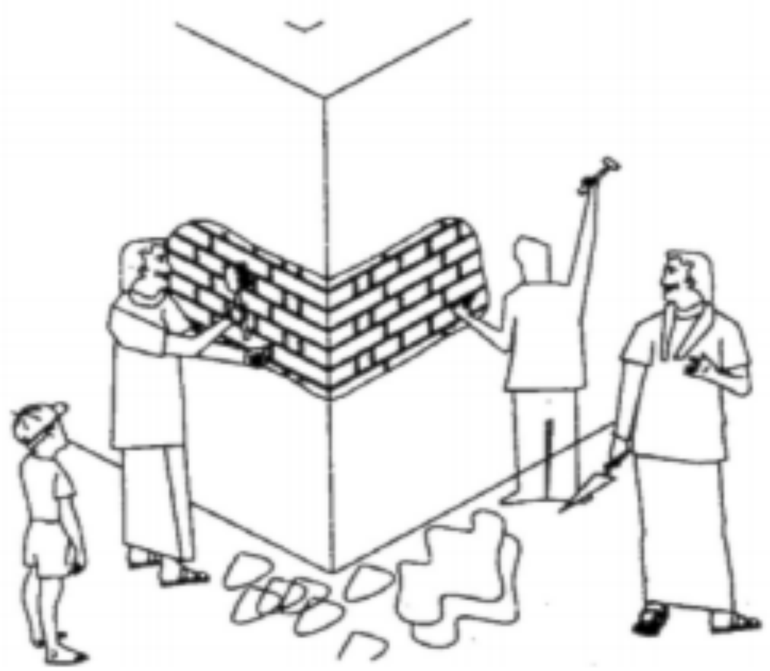


Figure 8: Removal of plaster and raking of joints process

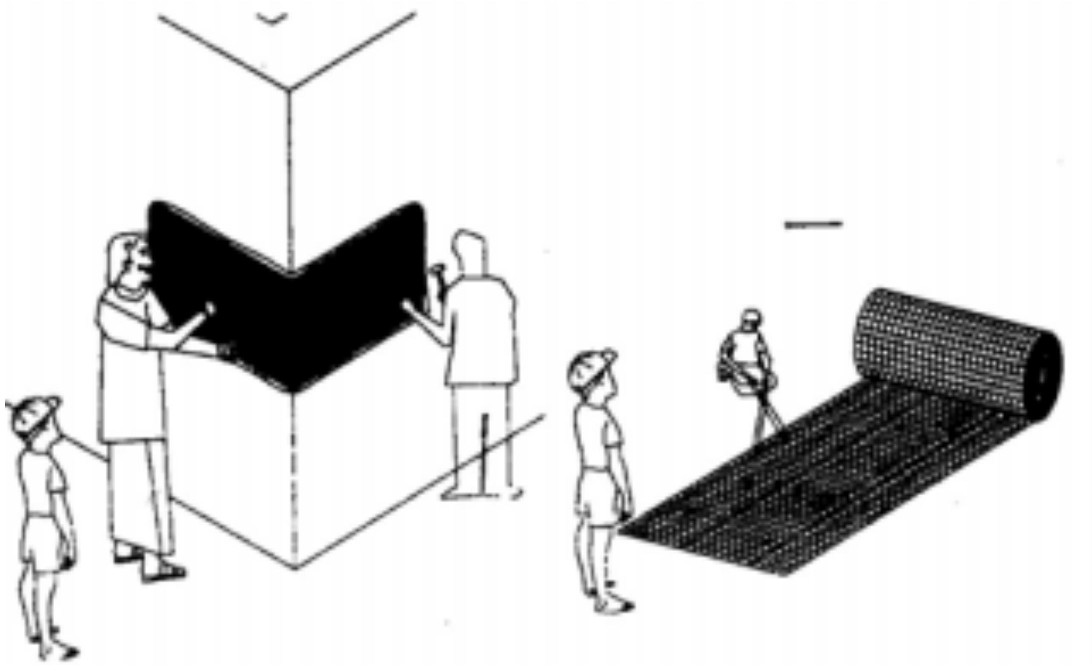


Figure 9: Galvanized steel wire mesh

3.2.2 Galvanized Steel Wire Mesh

Galvanizing of the steel mesh is necessary to prevent corrosion. The gauge of wires and mesh size will depend upon the functional purpose:

1. To strengthen a half brick thick load bearing wall the welded wire mesh may be of 14-gauge wires @ 35 to 40 mm 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, ferrocement plating be provided on both faces.
2. To provide horizontal seismic belts the welded mesh size and the height of the belt will depend on the length of wall between the cross walls.

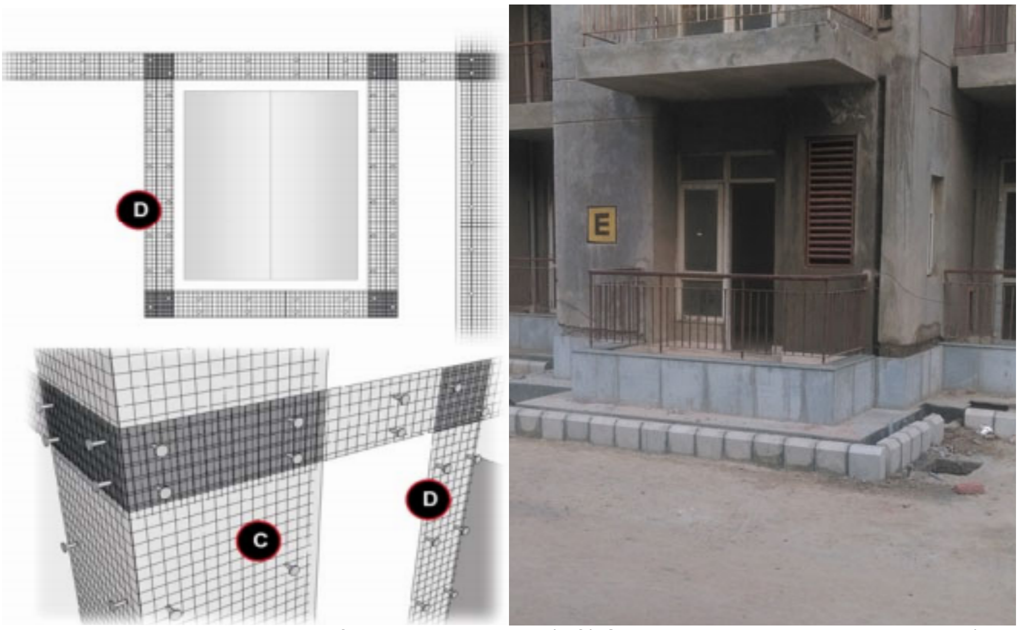


Figure 10: wire mesh installation for plinth protection (left) Stone plinth protection installation (right)
(Credit: www.bptp.com)

Chapter 4

IS Code Provision

Chapter 4

IS code Provision for Retrofitting in India

4.1 Introduction:

In India there are different IS code are available for the building construction, but IS codes for the retrofitting is one of the area where development of code are still going on till date there are some code with brief guild line about retrofitting are available which are discussed further but there is no code available for the retrofitting due to flood or landslide hazard damage. In that case it is recommended to refer other codes which states building structural information and build the building with different resilient features.

Retrofit strategy refers to options of increasing the strength, stiffness and ductility of the elements or the building as a whole. Several retrofit strategies may be selected under a retrofit scheme of a building. The goals of seismic retrofitting can be summarized as follows (IS 13935:1993:

1. Increasing the lateral strength and stiffness of the building.
2. Increasing the ductility and enhancing the energy dissipation capacity.
3. Giving unity to the structure.
4. Eliminating sources of weakness or those that produce concentration of stresses.
5. Enhancement of redundancy in the number of lateral load resisting elements.
6. The retrofit scheme should be cost effective.
7. Each retrofit strategy should consistently achieve the performance objective. To decide the retrofit scheme, a performance-based approach can be adopted. The performance-based approach identifies a target building performance level under an anticipated earthquake level. For retrofit of the buildings covered in this project, the basic safety objective can be selected. Under this objective, the dual requirement of life safety under design basis earthquake (DBE) and structural stability under maximum considered earthquake is aimed at.

4.2 Indian Standard Codes for Earthquake Design of Structures:

- IS: 1893-2002 Criteria for Earthquake Resistant Design of Structures (General Provision and Buildings) – Code of Practice
- IS: 4326-1993 Earthquake Resistant Design and Construction of Buildings – Code of Practice
- IS: 13920-1993 Ductile Detailing of Reinforced Concrete Structures subjected to Seismic Forces – Code of Practice
- IS: 13935-1993 Repair and Seismic Strengthening of Buildings – Guidelines
- IS: 13828-1993 Improving Earthquake Resistance of Low Strength Masonry Buildings – Guidelines
- IS: 13827-1993 Improving Earthquake Resistance of Earthen Buildings – Guidelines.

In the flood and landslide hazard, it is important to assess damage in detail and then the code provision can be adopted accordingly. There are some NDMA guidelines are available on Flood management and Landslides but that does not contain any detail information about retrofitting for the damaged building due to any natural hazard.

There is a scientific procedure is available in India for the assessment of building structures, in further chapter it is discuss in detail.

Chapter 5

Rapid Visual Screening (RVS)

Chapter 5

Guidelines for Identification of Damage Through RVS

5.1 Introduction:

5.1.1 RVS Procedure, Objectives and Scope:

The rapid visual screening method is designed to be implemented without performing any structural calculations. The procedure utilizes a scoring system that requires the evaluator to

1. identify the primary structural lateral load-resisting system, and
2. identify building attributes that modify the building performance expected for this lateral load resisting system.

The inspection, data collection and decision-making process typically occurs at the building site and is expected to take around 30 minutes for each building.

The screening is based on numerical hazard and vulnerability score. In case of earthquake scores are based on the expected ground shaking levels in the region as well as the seismic design and construction practices for the city or region. The scores use probability concepts and are consistent with the advanced assessment methods. The RVS procedure can be integrated with GIS-based city planning database and can also be used with advanced risk analysis software. The methodology also permits easy and rapid reassessment of risk of buildings already surveyed based on availability of new knowledge that may become available in future due to scientific or technological advancements.

The RVS methodology can be implemented in both rural and urban areas. However, the variation in construction practice is more easily quantifiable for urban areas and the reliability of the RVS results for rural areas may be very low. It is therefore preferable that the RVS methodology be used for non-standard (or non-government) constructions in rural areas only with adequate caution. The RVS methodology is also not intended for structures other than buildings. For important structures such as bridges and lifeline facilities, the use of detailed evaluation methods is recommended. Even in urban areas, some very weak forms of non-engineered buildings are well-known for their low seismic vulnerability and do not require RVS to estimate their vulnerability. These building types are also not included in the RVS procedure.

5.1.2 Uses of RVS Results:

The results from rapid visual screening can be used for a variety of applications that are an integral part of the earthquake disaster risk management program of a city or a region. The main uses of this procedure are:

1. To identify if a particular building requires further evaluation for assessment of its vulnerability.
2. To rank a city's or community's (or organization's) hazard rehabilitation needs.
3. To design disaster risk management program for a city or a community.
4. To plan post disaster building safety evaluation efforts.
5. To develop building-specific hazard vulnerability information for purposes such as regional rating, prioritization for redevelopment etc.

6. To identify simplified retrofitting requirements for a particular building (to collapse prevention level) where further evaluations are not feasible.
7. To increase awareness among city residents regarding vulnerability of buildings.

5.1.3 Building Types Considered in RVS Procedure:

A wide variety of construction types and building materials are used in urban areas of India. These include local materials such as mud and straw, semi-engineered materials such as burnt brick and stone masonry and engineered materials such as concrete and steel. The vulnerability of the different building types depends on the choice of building materials. The building vulnerability is generally highest with the use of local materials without engineering inputs and lowest with the use of engineered materials. The basic vulnerability class of a building type is based on the average expected performance for that building type.

The RVS procedure has considered 10 different building types, based on the building materials and construction types that are most commonly found in urban areas. These included both engineered constructions (designed and constructed by following the specifications) and non-engineered constructions (designed or constructed without following the specifications). Some masonry building types constructed using local materials are prevalent in urban areas but are not included in this methodology since their vulnerability is known to be very high (vulnerability class A and B) and do not require visual screening to provide any additional information regarding their expected structural performance. These include all constructions using random rubble masonry in mud mortar, earthen walls, adobe and tin sheet constructions.
The likely damage to structures have been categorized in different grades depending on their impact on the strength of the building.

Which leads to provide guidance regarding likely performance of the building in disaster. This information can be used to decide the necessity of further evaluation of the building using higher level procedures. It can also be used to identify need for retrofitting, and to recommend simple retrofitting techniques for ordinary buildings where more detailed evaluation is not feasible.

5.1.4 Vulnerability classification for different structural types:

All buildings can be divided into the following primary categories:

1. masonry buildings,
2. RCC buildings,
3. steel buildings, and
4. timber buildings. These can be further divided into various sub-categories. Based on their seismic resistance the following vulnerability classification has been proposed based on the European Macro seismic Scale (EMS-98) and modified during development of World Housing Encyclopedia.

Material	Type of Load-Bearing Structure	Sub-Types	Vulnerability Class					
			A	B	C	D	E	F
Masonry	Stone Masonry Walls	Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)	O					
		Massive stone masonry (in lime/cement mortar)	|-	-	O	-|		
	Earthen/Mud/ Adobe/Rammed Earthen Walls	Mud walls	O					
		Mud walls with horizontal wood elements	|-	O	-|			
		Adobe block walls	O	-|				
		Rammed earth/Pise construction	O	-|				
	Burnt clay brick/block masonry walls	Unreinforced brick masonry in mud mortar	|-	O	-|			
		Unreinforced brick masonry in mud mortar with vertical posts	|-	O	-	-|		
		Unreinforced brick masonry in lime mortar	|-	O	-	-|		
		Unreinforced brick masonry in cement mortar with reinforced concrete floor/roof slabs		|-	O	-|		
		Unreinforced brick masonry in cement mortar with lintel bands (various floor/roof systems)		|-	O	-|		
		Confined brick/block masonry with concrete posts/tie columns and beams			|-	O	-|	
	Concrete block masonry	Unreinforced, in lime/cement mortar (various floor/roof systems)		|-	O	-|		
		Reinforced, in cement mortar (various floor/roof systems)			|-	O	-|	
Structural concrete	Moment resisting frame	Designed for gravity loads only (predating seismic codes i.e. no seismic features)	|-	-	O	-|		
		Designed with seismic features (various ages)			|-	-	O	-|
		Frame with unreinforced masonry infill walls		|-	O	-	-|	
		Flat slab structure		|-	O	-	-|	
		Precast frame structure		|-	O	-|		
		Frame with concrete shear walls (dual system)			|-	-	O	-|
	Shear wall structure	Walls cast in-situ				|-	O	-|
		Precast wall panel structure		|-	O	-|		
Steel	Moment-resisting frame	With brick masonry partitions			|-	O	-	-|
		With cast in-situ concrete walls			|-	-	O	-|
		With lightweight partitions				|-	O	-|
	Braced frame	With various floor/roof systems				|-	O	-|
	Light metal frame	Single storey LM frame structure			|-	-	O	-|
Wooden structures	Load-bearing timber frame	Thatch roof	|-	-	O	-|		
		Post and beam frame			|-	O	-|	
		Walls with bamboo/reed mesh and post (Wattle and Daub)		|-	O	-|		
		Frame with (stone/brick) masonry infill	|-	-	O	-|		
		Frame with plywood/gypsum board sheathing		|-	O	-|		
		Frame with stud walls				|-	O	-|

O Most likely vulnerability class
Most likely lower range
Most likely upper rang

5.1.5 Table 2. Classification of damage to buildings:

The damage classifications based on the European Macro seismic Scale (EMS-98) define building damage to be in Grade 1 to Grade 5. The damage classifications help in evaluation of earthquake intensity following an earthquake. They are used in RVS to predict potential damage of a building during code-level earthquake.

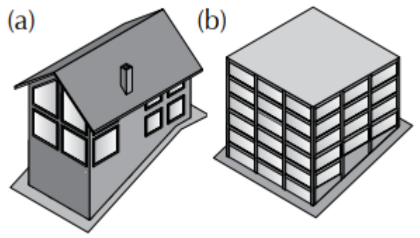
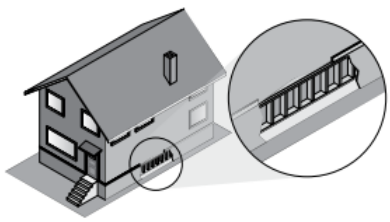
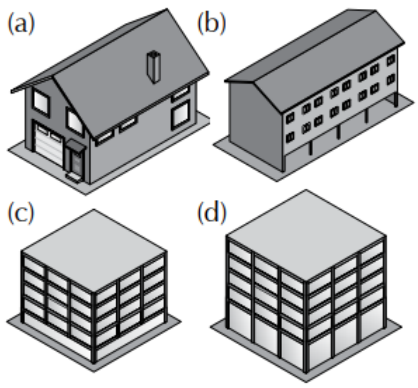
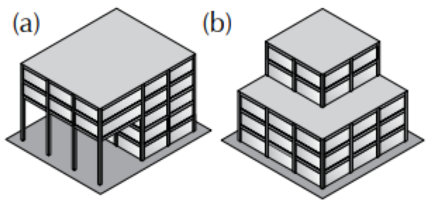
Classification of damage to masonry buildings	Classification of damage to reinforced concrete buildings
Grade 1: Negligible to slight damage **(No structural damage, slight non-structural damage)** Hair-line cracks in very few walls. Fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few cases.	**Grade 1: Negligible to slight damage** **(No structural damage, slight non-structural damage)** Fine cracks in plaster over frame members or in walls at the base. Fine cracks in partitions and infills.
Grade 2: Moderate damage **(Slight structural damage, moderate non-structural damage)** Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys and mumptys.	**Grade 2: Moderate damage** **(Slight structural damage, moderate non-structural damage)** Cracks in columns and beams of frames and in structural walls. Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from the joints of wall panels.
Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage) Large and extensive cracks in most walls. Roof tiles detach. Chimneys fracture at the roof line; failure of individual non-structural elements (partitions, gable walls etc.).	**Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage)** Cracks in columns and beam-column joints of frames at the base and at joints of coupled walls. Spalling of concrete cover, buckling of reinforced bars. Large cracks in partition and infill walls, failure of individual infill panels.
Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage) Serious failure of walls (gaps in walls); partial structural failure of roofs and floors.	**Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage)** Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforcing bars; tilting of columns. Collapse of a few columns or of a single upper floor.
Grade 5: Destruction (very heavy structural damage) Total or near total collapse of the building.	**Grade 5: Destruction (very heavy structural damage)** Collapse of ground floor parts (e.g. wings) of the building.

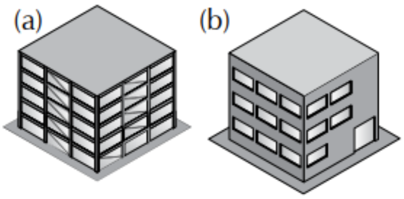
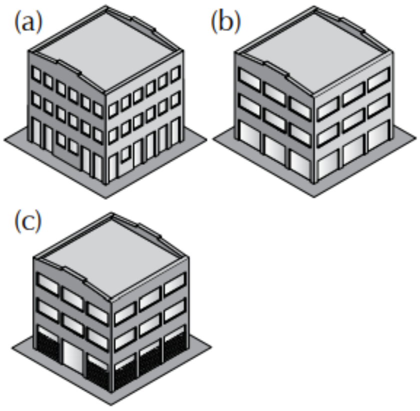
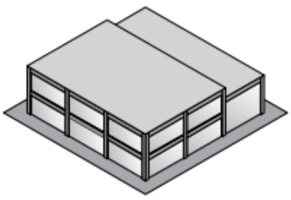
5.1.6 Table 3. Expected damage level as function of RVS score:

The probable damage can be estimated based on the RVS score and is given below. However, it should be realized that the actual damage will depend on a number of factors that are not included in the RVS procedure. As a result, this table should only be used as indicative to determine the necessity of carrying out simplified vulnerability assessment of the buildings. These results can also be used to determine the necessity of retrofitting buildings where more comprehensive vulnerability assessment may not be feasible.

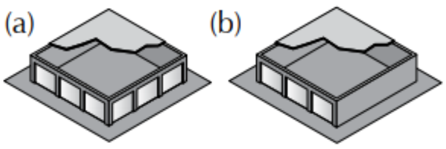
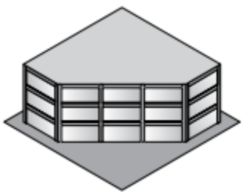
RVS Score	Damage Potential
S < 0.3	High probability of Grade 5 damage; Very high probability of Grade 4 damage
0.3 < S < 0.7	High probability of Grade 4 damage; Very high probability of Grade 3 damage
0.7 < S < 2.0	High probability of Grade 3 damage; Very high probability of Grade 2 damage
2.0 < S < 3.0	High probability of Grade 2 damage; Very high probability of Grade 1 damage
S > 3.0	Probability of Grade 1 damage

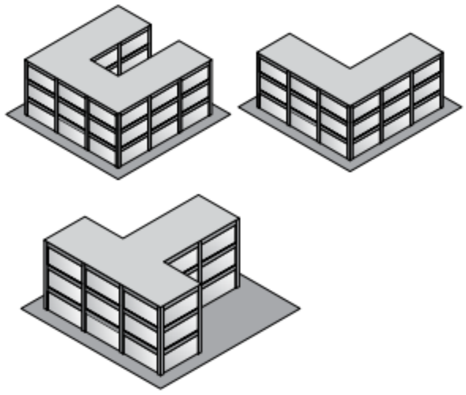
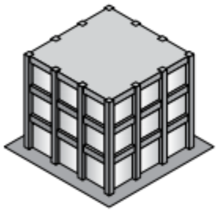
5.1.7 Vertical Irregularity Guide:

Vertical Irregularity		**Severity**	**Level 1 Instructions**
Sloping Site		Varies	Apply if there is more than a one-story slope from one side of the building to the other. Evaluate as Severe for W1 buildings as shown in Figure A; evaluate as Moderate for all other building types as shown in Figure B.
Unbraced Cripple Wall		Moderate	Apply if unbraced cripple walls are observed in the crawlspace of the building. This applies to W1 and W1A building types. If the basement is occupied, consider this condition as a soft story.
Weak and/or Soft Story		Severe	Apply: a) For a W1 house with occupied space over a garage with limited or short wall lengths on both sides of the garage opening. b) For a W1A building with an open front at the ground story (such as for parking). c) When one of the stories has less wall or fewer columns than the others (usually the bottom story). d) When one of the stories is taller than the others (usually the bottom story).
Out-of-Plane Setback		Severe	Apply if the walls of the building do not stack vertically in plan. This irregularity is most severe when the vertical elements of the lateral system at the upper levels are outboard of those at the lower levels as shown in Figure A. The condition in Figure B also triggers this irregularity. If nonstacking walls are known to be nonstructural, this irregularity does not apply. Apply the setback if greater than or equal to 2 feet.

Vertical Irregularity		Severity	Level 1 Instructions
In-plane Setback	(a) (b) 	Moderate	Apply if there is an in-plane offset of the lateral system. Usually, this is observable in braced frame (Figure A) and shear wall buildings (Figure B).
Short Column/Pier	(a) (b) (c) 	Severe	Apply if: a) Some columns/piers are much shorter than the typical columns/piers in the same line. b) The columns/piers are narrow compared to the depth of the beams. c) There are infill walls that shorten the clear height of the column. Note this deficiency is typically seen in older concrete and steel building types.
Split Levels		Moderate	Apply if the floors of the building do not align or if there is a step in the roof level.

5.1.8 Plan Irregularity Reference Guide:

Plan Irregularity		Severity	Level 1 Instructions
Torsion	(a) (b) 	Severe	Apply if there is good lateral resistance in one direction, but not the other, or if there is eccentric stiffness in plan (as shown in Figures A and B; solid walls on two or three sides with walls with lots of openings on the remaining sides).
Non-Parallel Systems		Severe	Apply if the sides of the building do not form ninety-degree angles.

Re-entrant Corner		Severe	Apply if there is a reentrant corner, i.e., the building is L, U, T, or + shaped, with projections of more than 10 feet. Where possible, check to see if there are seismic separations where the wings meet. If so, evaluate for pounding.
Diaphragm Openings		Severe	Apply if there is a opening that has a width of over 50% of the width of the diaphragm at any level.
Beams do not align with columns		Severe	Apply if the exterior beams do not align with the columns in plan. Typically, this applies to concrete buildings, where the perimeter columns are outboard of the perimeter beams.

5.1.9 Steps of Building Screening:

Across the world, there are several methodologies for conducting seismic safety evaluation of buildings. Most of these methods follow a three level assessment procedure involving:

1. Rapid Visual Screening (RVS) of Buildings (or Tier 1 Evaluation)
2. Preliminary Assessment (or Tier 2 Evaluation)
3. Detailed Evaluation (or Tier 3 Evaluation)

RVS methods range from activities requiring about 20 minutes to more detailed ones involving basic calculations.

RVS is a basic methodology to assess a large stock of buildings in a town or city only by observing the building and walking around it and recording features that determine how the building will likely behave during an disaster. RVS does not require detailed analysis and is suitable for very large samples of building stock as it involves sidewalk survey either without entering the building or doing so for a short duration only (20-25 minutes).

RVS can be very valuable to prioritize the buildings to be further studied so that technical and other resources could be most effectively utilized. While it sounds like a fairly simple exercise, it should be done only by trained personnel with a background in civil engineering or architecture. This is so because the method requires use of technical judgment that can be acquired only through formal training. RVS should not be done by lay persons as this could lead to misleading conclusions.

Figure 11: RVS is for assessing large sets of buildings in a locality

Figure 12: Engineer carrying out RVS of a building

Chapter 6

Retrofitting Techniques as per Damage Assessment

Chapter 6

Retrofitting Techniques as per Damage Assessment

In post disaster management process, it is most challenging part to recreate the damage infrastructure so that disaster victims can rehabilitate. Recreating all the infrastructure is a challenging process which includes three major steps i.e. repair, restoration/rehabilitation and retrofitting. Most of the people confused with these three terminologies some of the major difference are as follows:

6.1.1 Repair:

1. The repairs are performed on damaged buildings to restore the strength after disaster.
2. The repair services include:
    a. Reconstruction of non-structural walls, chimneys , boundary walls etc.
    b. Checking and repairing electrical connections, plumbing , ventilation etc.
    c. Repairing of cracks

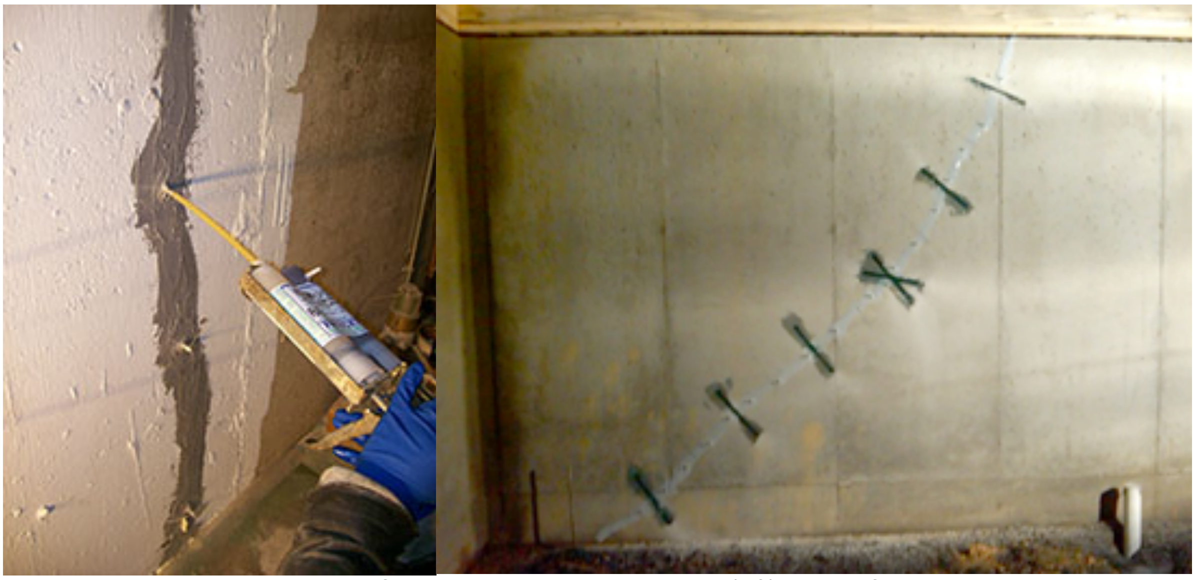


Figure 13:Image showing repair of crack using injection technique *(left)*, repair of crack using diagonal bracing *(right)*. *(credit: www.a1crackrepair.com)*

6.1.2 Restoration/ Rehabilitation:

1. The restoration is performed to retain the strength of existing building to the original strength.
2. The restoration enables to get at least the original strength of piers, Columns, beams and walls.
3. The following are the actions involved in restoration:
    a. By grouting
    b. Strengthening using wire mesh
    c. Rebuilding the cracked portions using rich non-shrinkable mortar after removal of cracked portion.

Figure 14:Image showing re-plastering and restoration of slab *(left)*, Restoration process of front facade of building*(right).*   *(credit: RMS civil repair works)*

6.1.3 Retrofitting:

1. Assessing the existing condition of the structure and deciding which component of the structure should be repaired or restored based on all the future requirements of structure.
2. The retrofit enables to increase the original strength of the building.
3. The actions of Retrofitting include:
    a. Addition of shear wall of diagonal braces
    b. Modification of roofs
    c. Strengthening of foundation
    d. Modification of building plan etc.

Figure 15: Images showing example of Retrofitting of basement *(credit: urbansolutionsbd.blogspot.com)*

Most of the post disaster scenarios buildings get damage due hazards like earthquake, flood, landslide etc. It is important in rehabilitation process standard procedure must be followed. Before executing rehabilitation, process detailed structural assessment is required. On the basis of assessment result most suitable repair, rehabilitation or retrofitting techniques should be adopted. Further in the chapter process of damage assessment has been discussed.

6.2 Retrofitting measures:

Before discussing about the retrofitting measures, I would like to discuss about several structural building components, which define building structural integrity. if the building is exposed to any hazard these components are key deciding factor for building response. In a building, structure is generally divided into two categories that is substructure and superstructure. Substructure is defined as the part of structure system which is is underground like foundation and plinth beam whereas superstructure is defined as all the structure part above the ground that is beam, column, wall, slab etc.

Structural element wise damage effect and general retrofitting measures:

1. Foundation
2. Load bearing walls
3. Columns
4. Beams
5. Slabs
6. Openings
7. Non-structural element

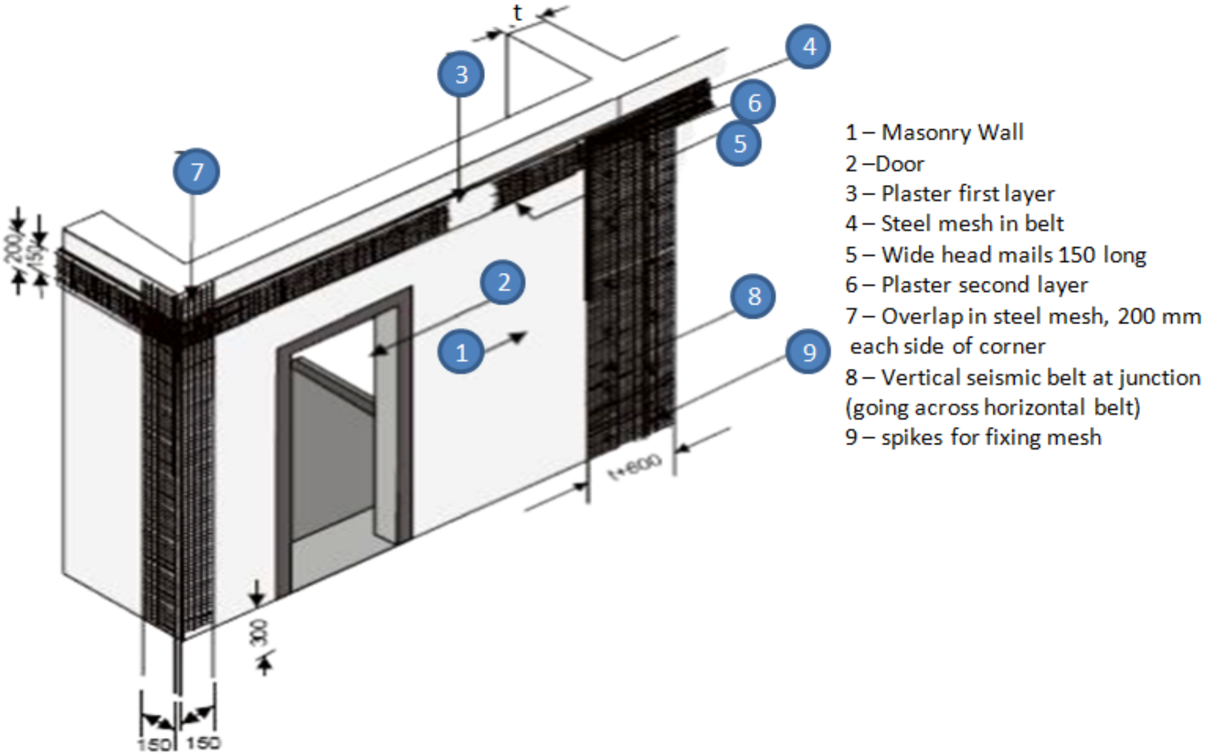


Figure 16: Image showing example of Retrofitting of using wire mesh installation
(credit: urbansolutionsbd.blogspot.com)

6.2.1 Foundation:

Damage assessment: Foundation is the most important part of the structure; it transfers superstructure load to the ground. If the structure exposed to the dynamic loading, there are several types of damage observed in foundation some of the general observations are as follows:

1. Sinking in foundation.
2. Structural crack in foundation.

Before finalizing retrofitting measures for the foundation, it is suggested process detailed documentation of following elements:

1. Type of foundation
2. Type of soil base
3. Basic construction material of foundation
4. Type of mortar used in Foundation

5. Cause of sinking
6. Plinth beam availability status

Figure 17: Image showing example of foundation sinking
(credit: www.clarkebasementsystems.com)

General retrofitting technique:
On the basis of damage assessment, the result should be quantified, and Different retrofitting techniques should be adopted to rehabilitate the structure. In case of sinking is very important to identify the cause of sinking, if the sinking is due to water penetration, then before retrofitting proper plinth protection is needed to be installed, otherwise different retrofitting measures like repair of structural cracks using wire mesh, extension of foundation, grouting of concrete under the foundation etc. should be adopted. For the detailed installation process of retrofitting measures refer section 10.1.

Figure 18: Image showing example of Retrofitting foundation using Jacks and extra reinforcement
(credit: www.renotahoefoundationrepair.com)

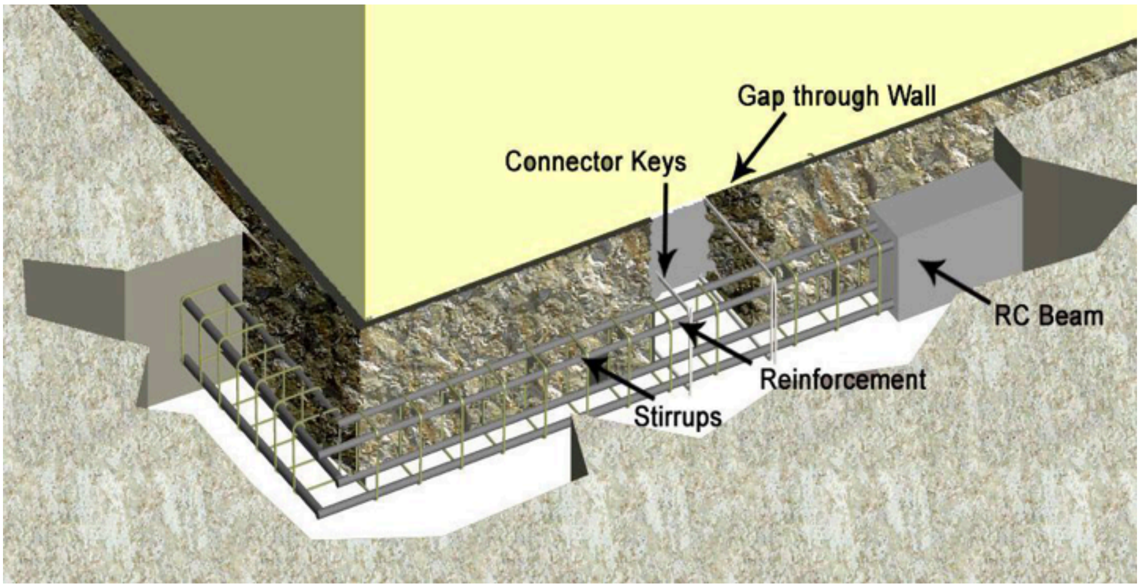


Figure 19: Strengthening of Foundation using RCC frame

6.2.2 Load bearing walls:

Damage assessment: In masonry buildings load bearing walls are the meals major structural component which carries all the load in vertical direction and transfer it to the foundation. according to Indian Standard code minimum width of load bearing walls is not less than 9 inches, there are other several components need to be documented for the detailed assessment. Some of the major components are as follows:

1. Type of wall like brick wall, stonewall, confined masonry wall, RCC wall etc.
2. Material used in wall construction
3. Type of mortar used in wall construction
4. Thickness of exterior wall
5. Thickness of interior wall
6. Any failure observed in wall like bulging, delamination, tilting, dampness etc.
7. Maximum height of the wall: 4 M Maximum
8. Maximum length of the wall: 7M maximum

Figure 20:Image showing example of structural cracks in wall due to flood
(credit: www.iitk.ac.in)

Figure 21: Image showing example of structural cracks in wall due to landslides
(credit: ascelibrary.org)

General retrofitting technique: On the basis of above observations, appropriate retrofitting technique for the load bearing wall is needed to be adopted. there are several retrofitting techniques are available tourist length load bearing wall some of the common techniques are:

1. Application of wire mesh on both side of the wall
2. Introduction of buttresses to support the wall
3. Repair of structural cracks using iron bars and wire mesh
4. Grouting of nonstructural cracks
5. Introduction of corner reinforcement
6. Introduction of horizontal bands at different level etc.

For the detailed installation process of retrofitting measures refer section 10.1.

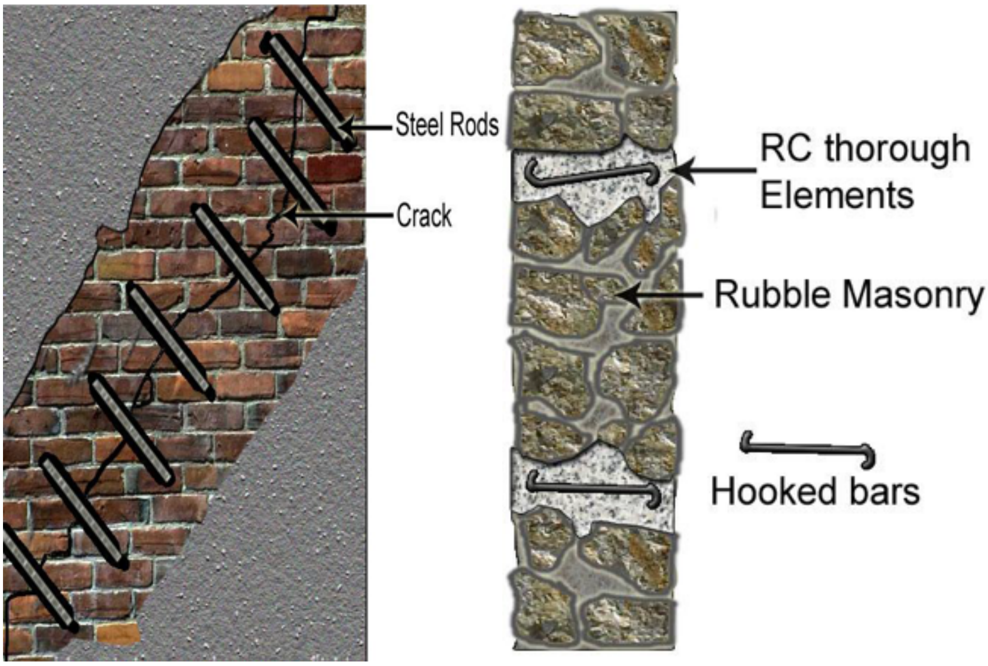


Figure 22: crack repair using 6 mm iron bars (left) and Hook bars in stone masonry wall (right)

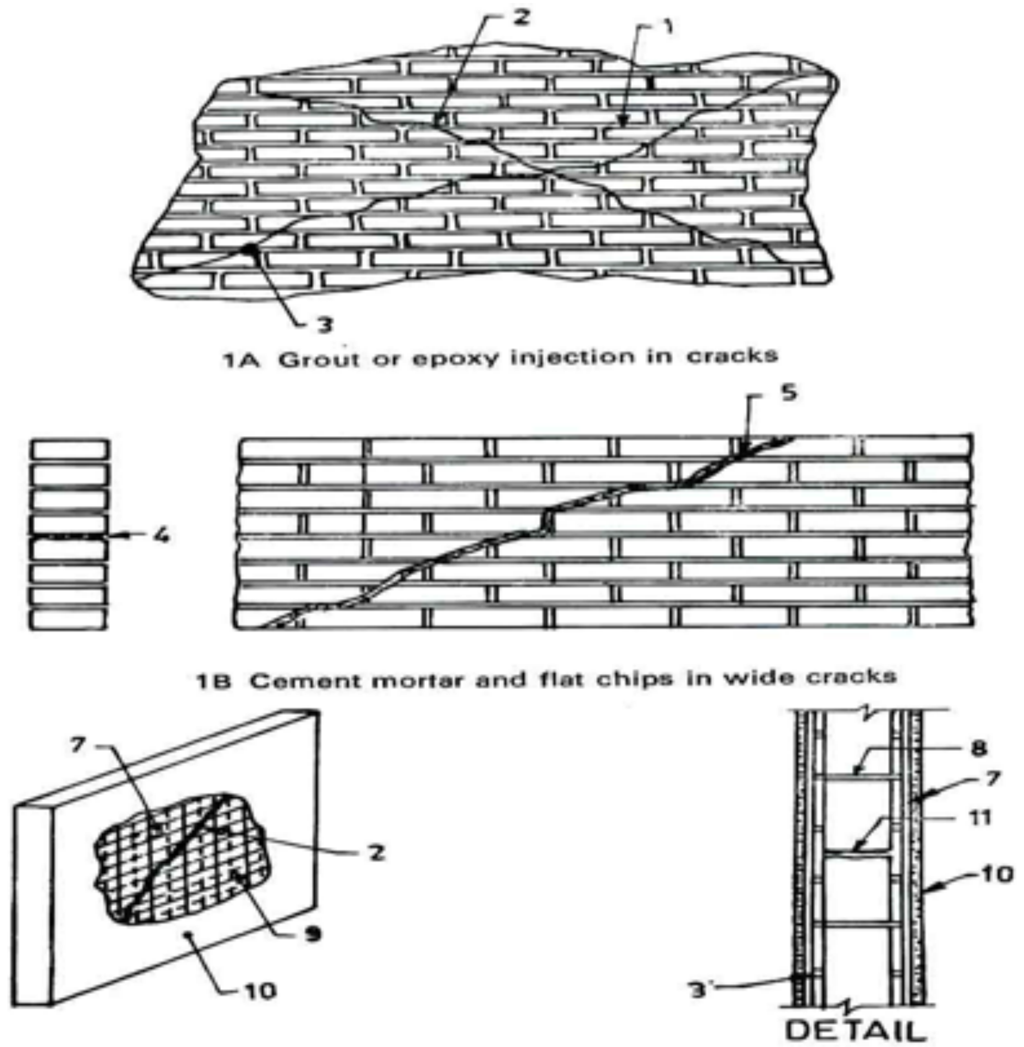


Figure 23: Step wise retrofitting procedure for load bearing wall
(credit: IS code: 19395:2009)

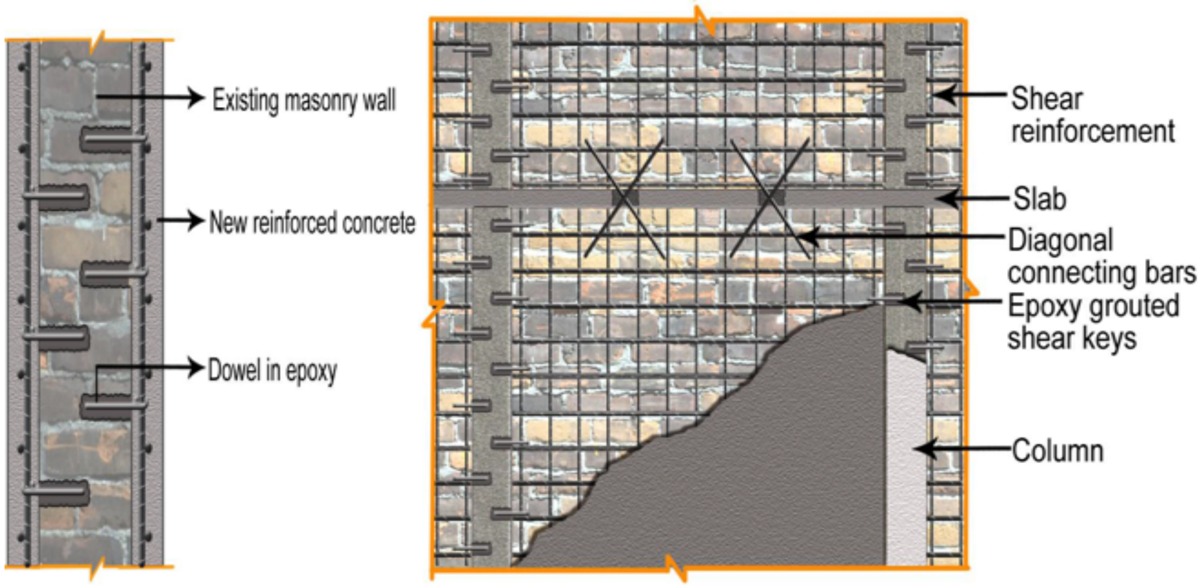


Figure 24: detail of retrofitting procedure for Stone wall *(credit: TESRA ppt)*

Figure 25: Retrofitting procedure of masonry building using iron bars *(credit: www.intechopen.com)*

6.2.3 Columns:

Damage assessment: In RCC framed structures columns are the structural element which carries load to the foundation, RCC building when any dynamic force is applied it is observed that there are different type of damage happened in columns, some of the common damages are buckling, bending and twisting of the columns. The detailed assessment of the columns There are several structural components which needs to be documented as follows:

1. Type of column
2. Continuation of load path diagram
3. Physical damage mapping of column
4. Consistency of construction material
5. Material of column
6. Column beam joineries

Figure 26: image showing damage in columns due to dynamic loading
(credit: TESRA ppt)

Figure 27: Collapse pattern due to soft story failure due to column failure *(credit: TESRA ppt)*

General retrofitting technique: On the basis of damage assessment the result should be quantified, and Different retrofitting techniques should be adopted to rehabilitate the structure. if column is failing due to lack of concrete, then jacketing of column should be done. There are other several techniques are available for the retrofitting of columns as follows:

1. Jacketing of column using RCC
2. Jacketing of column using FRP
3. Retrofitting of column beam joints using Steel plates
4. Introduction of bracings between columns
5. Introduction of load bearing walls between columns etc.

For the detailed installation process of retrofitting measures refer section 10.1.

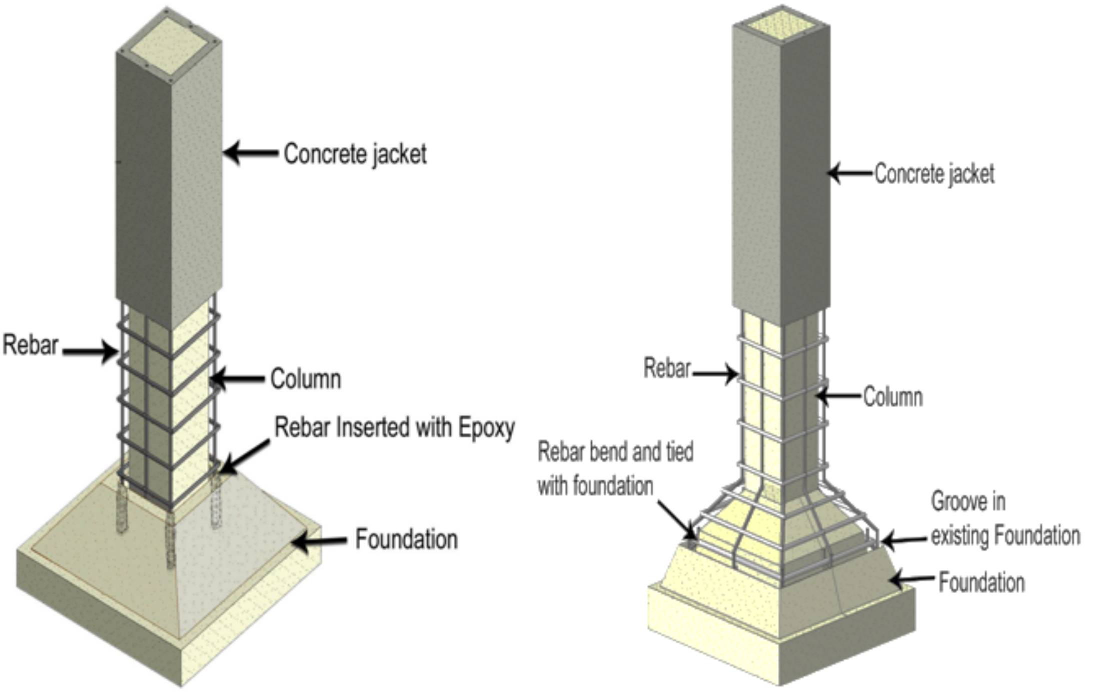


Figure 28: Jacketing of column and foundation *(credit: TESRA ppt)*

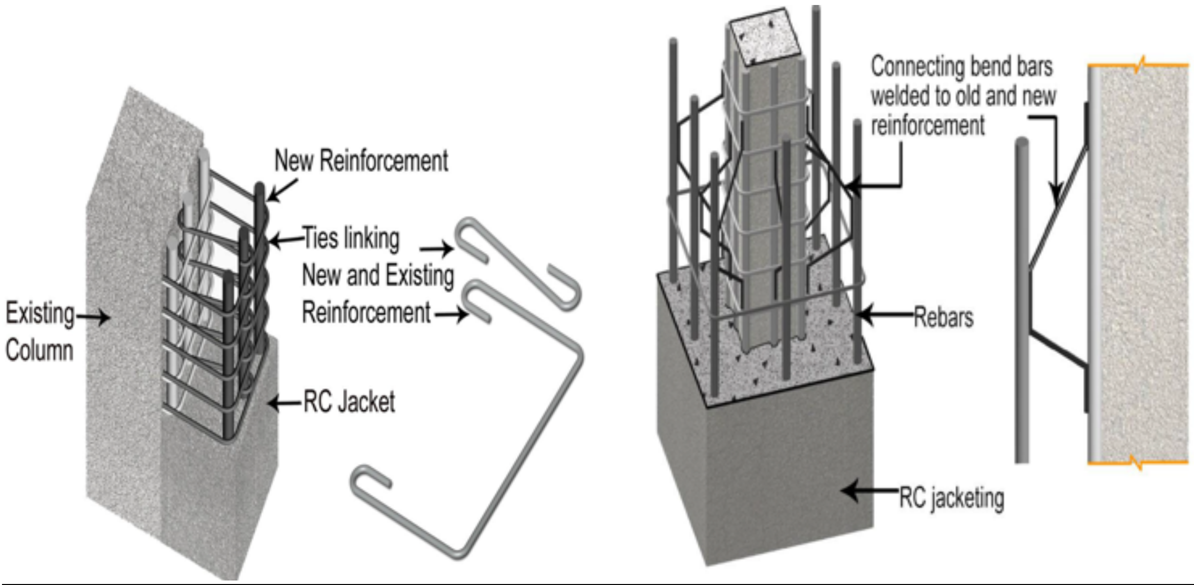


Figure 29: RCC jacketing of existing column *(credit: TESRA ppt)*

6.2.4 Beams:

Damage assessment: Beams are the horizontal load carrier in any building structure, beams are widely used in RCC frame structures and confined masonry structures, at the time of dynamic loading if the beam failed or damaged there is a severe chance of a structural collapse. While carrying out any structural assessment either pre-disaster or post-disaster There are several components need to be assessed are as follows:

2. Status of beam column connection
3. Status of beam to beam connection
4. Availability of infill wall under Beam
5. Ratio of beam depth to the span


Figure 30: damage due to sagging *(credit: daily civil)*


Figure 31: damage in wall and slab due to sagging *(credit: daily civil)*

General retrofitting technique: On the basis of damage assessment appropriate retrofitting methodology is needed to be adopted to retrofit beams. There are several techniques available for retrofitting of beams as follows:

1. Jacketing of beam using RCC
2. Jacketing of beam using FRP
3. Retrofitting of beam to beam connection using Steel plates
4. Introduction of bracings to support the beam

Figure 32: Jacketing of Beam using FRP *(credit: TESRA ppt)*

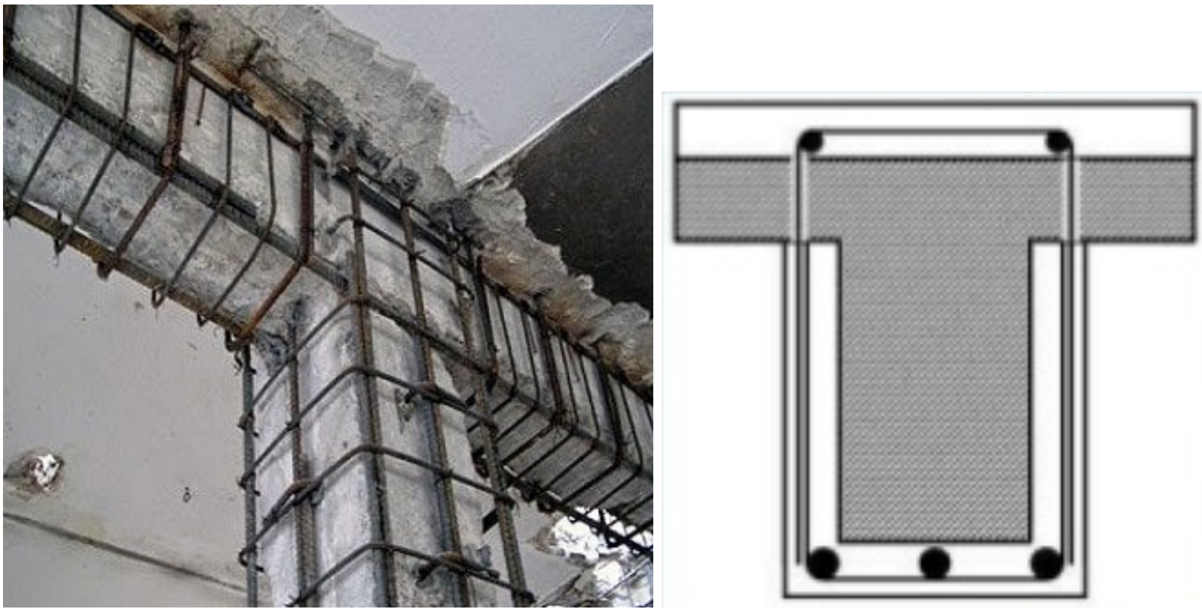


Figure 33: Jacketing of Beam using RCC jacketing *(credit: yash construction)*

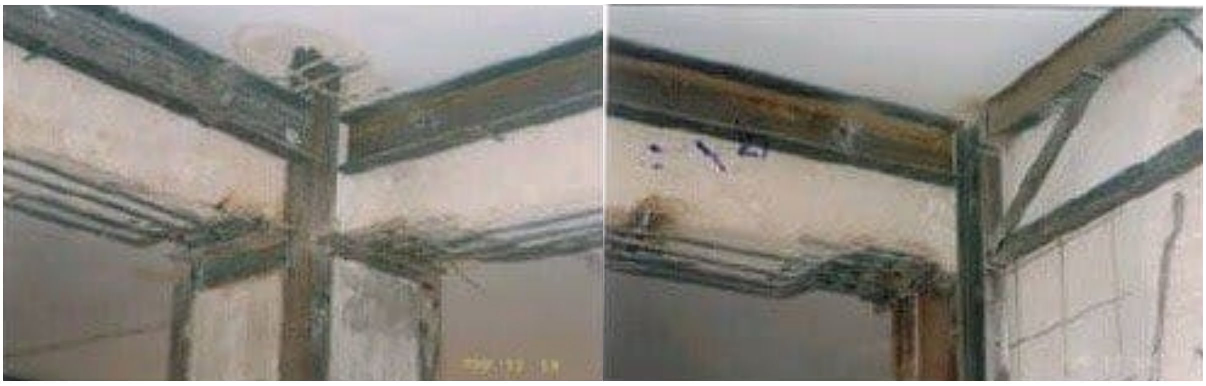


Figure 34: Strengthening a beam, slab & column (left) and Strengthening of beam and slab (right)
(credit: researchgate)

Figure 35: jacketing by bars in beam (left) and Strengthening by steel plate (right) *(credit: researchgate)*

6.2.5 Slabs:

Damage assessment: When a building is exposed to any hazard's situation like flood, landslide or earthquake, probability of damage in slab is always high. In general slab is also damage due to weathering conditions. For the damage assessment of slab several components need to be assessed as follows:

1. Type of slab: one way or two way.
2. Construction material of Slab
3. any physical damage like delamination/ sagging etc.

Figure 36: de-lamination and rusting in slab (left) and de-lamination of plaster in slab (right) *(credit: researchgate)*

Figure 37: surfaces preparation for shot-crete *(credit: researchgate)*

General retrofitting technique:

There are several techniques are available to retrofit the slab, suitable technique must be adopted on the basis of assessment results. Some of the common techniques are as follows:

1. Shot-crete the slab after removal of plaster.
2. In case of sagging, installation of extra beam support.
3. Re-plastering of exposed reinforcement.
4. Re-barring of slab using shear anchor.

Figure 38: retrofitting using FRP (left) and shot-crete in slab (right) *(credit: researchgate)*

6.2.6 Openings:

Damage assessment: Opening the most vulnerable part of the building, in most of the disasters, it is observed that major damage always initiated from opening. In masonry building it is mandatory to have door and window band around the opening. To assess damages due to opening there are several components need to be documented as follows:

1. Percentage of opening to the wall.
2. Status of frame present in opening.
3. Status of door window band.
4. Status of grill present in opening.

Figure 39: structural damage around opening (left) and damage due to flood *(credit: http://db.world-housing.net)*

General retrofitting technique:

On the basis of damage assessment, it is required to adopt more suitable retrofitting technique some of the most common retrofitting techniques are:

1. Installation of door-window band using FRP.
2. Installation of door-window band using wire mesh.
3. Reduce the area of opening by brickwork.

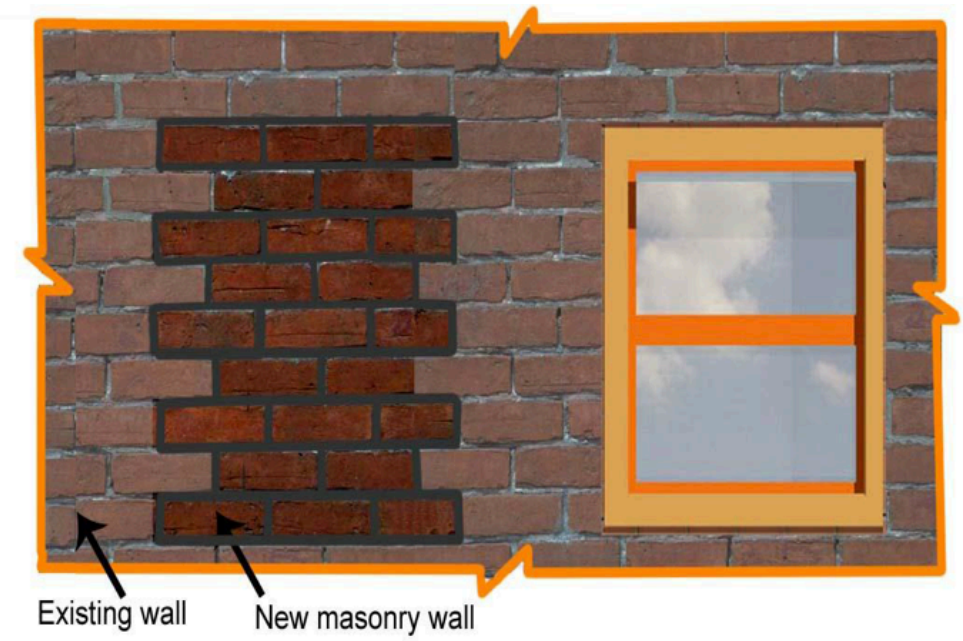


Figure 40: Closing of existing opening *(credit:TESRA ppt)*

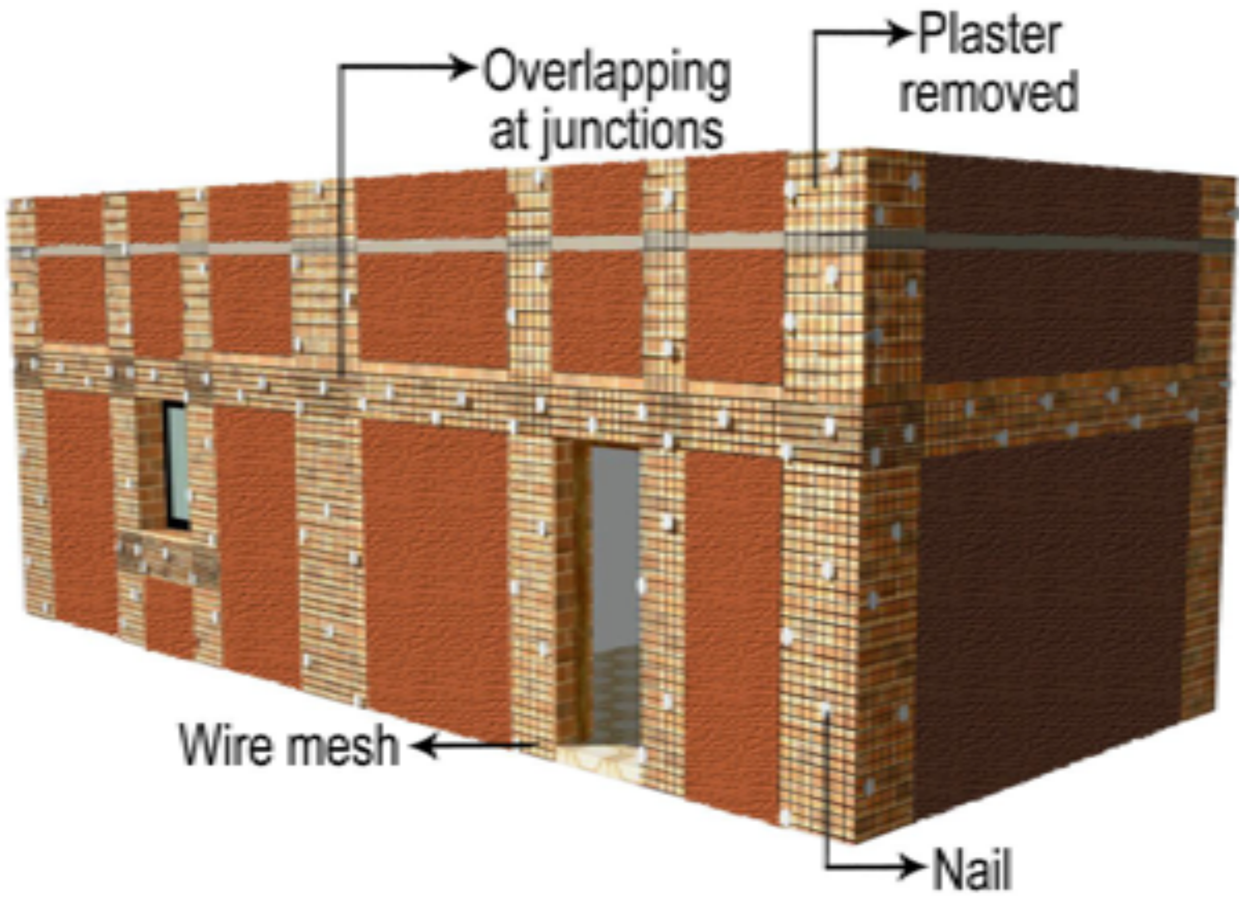
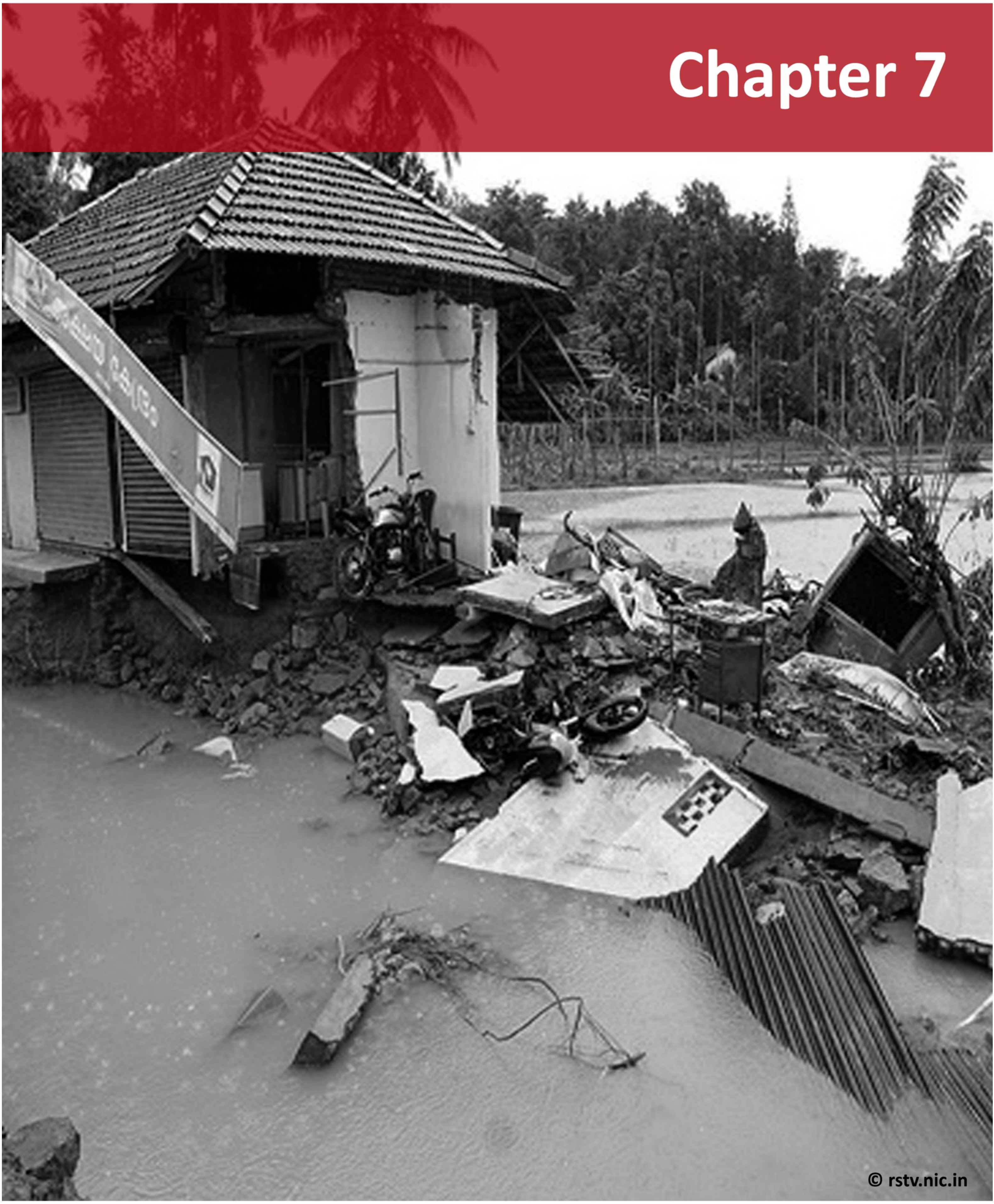


Figure 41: Installation of wire mesh around opening *(credit: TESRA ppt)*

6.2.7 Advantages of retrofitting:

1. Long-term cost savings.
2. Increased comfort and wellbeing
3. Minimized structural damage.
4. Minimize causality.
5. Increase structure life span.
6. Mitigation and management support for post disaster.

Chapter 7



Site Selection & Construction Material Selection Criteria

Chapter 7

Site & Construction Material Selection Criteria

This chapter is all about site and construction material selection criteria which is important to take in consideration before building construction.

7.1.1 Site Selection Criteria:

Site selection plays important role to reduce the risk that may cause due to any disaster. There are several factors which need to be considered while we are going to construct a building in flood or landslide prone area. some of the most important factors as follows:

7.1.2 Site near flood prone areas:

a. Site drainage.
b. Flooding.
c. Soil erosion.
d. Proximity of natural hazards.
e. Distance from nearest water body.

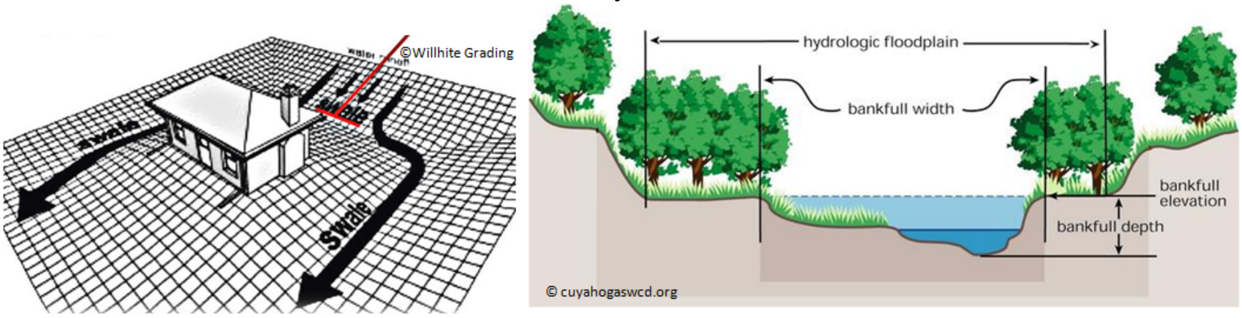


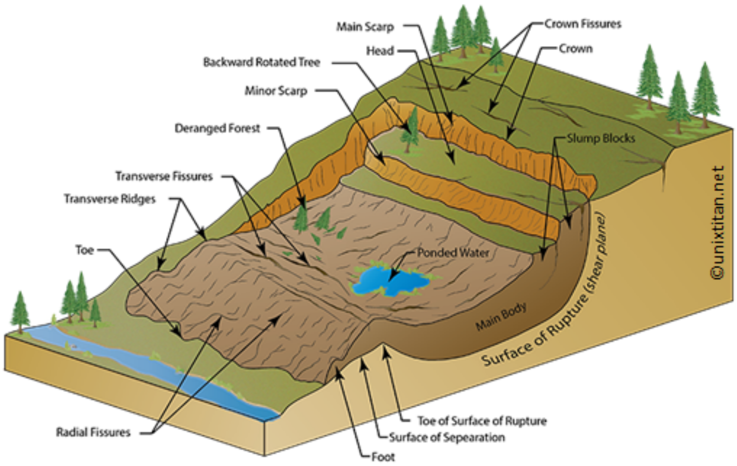
Figure 42: Image showing site drainage (left) and flood prone area (right)

7.1.2.1 Site drainage:

Natural drainage of the site is very important to avoid any flooding condition. If any building is exposed to the flood and water is penetrate in the foundation, it will directly impact on the structural strength, In such cases there is a probability of sinking in foundation will be increased. Before finalizing the site for the construction, one should properly map drainage plan of site w.r.t. surrounding area.

7.1.2.2 Flooding:

Before finalizing any site for the construction, it is very important to gather information of past flooding. If it is found that there was any flood happened in the past than all the precautionary measures should be taken while adopting construction typology.



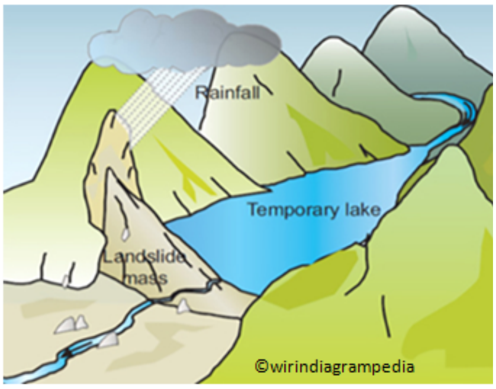


Figure 43: Image showing erosion (left) and Multi-hazard scenario (right)

7.1.2.3 Soil erosion:

Soil erosion causes various structural damages like cracks, collapse of walls, foundation displacement etc. If there is any probability of soil erosion is observed than before construction proper site protection techniques should be adopted.

7.1.2.4 Proximity of natural hazards:

Risk on the site is associated with proximity of natural hazards, before finalizing the construction site detailed multi hazard risk assessment must be carried out on the basis of assessment results. You should adopt different mitigation techniques for the safe construction.

7.1.2.5 Distance from nearest water body:

Detailed mapping process of different types of water body must be carried out before the site selection. if any major river stream or lake is present near the site then proper mitigation technique should be adopted before construction.

7.1.3 Site near Landslide prone areas:

f. Site Slope.
g. Distance from the foothill.
h. Type of Soil.
i. Drainage.

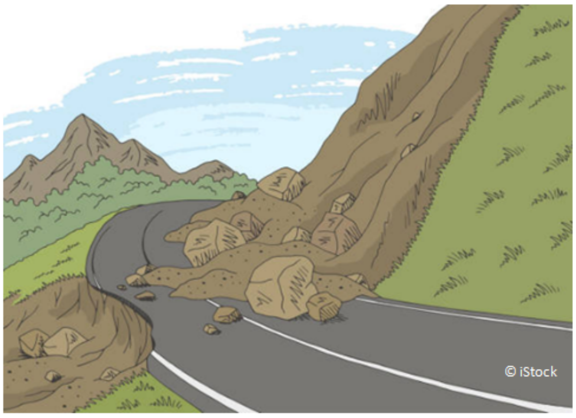


Figure 44: Image showing symbolic landslide prone area (left) and Site slope representation (right)

7.1.3.1 Site Slope:

Natural slope of the site plays a key role to decide structural stability. If the slope is steep then the building is more prone for the damage, in moderate slope the structure will be relatively safe and best site for the construction is flat ground.

7.1.3.2 Distance from the foothill:

Distance from the foothill is very important factor for the site selection. If the site is nearby foothill then proper measure should be adopted. It is recommended to avoid any construction activity near potential landslide hazard zone.

7.1.3.3 Type of soil:

Soil profile is deciding factor which may induced landslides. for example, loose soil is easily drained with rainwater and cause landslide. Before finalizing the site for the construction detailed analysis need to be carried out.

7.1.3.4 Drainage:

Natural drainage of the site is very important to avoid landslide. There are maximum landslides are induced due to heavy rain. If the water drainage of the site is proper, then it will not penetrate in the soil and decrease the probability of landslide.

7.1.4 Construction material Selection Criteria:

Figure 45: Image showing common construction material quality *(credit: www.123rf.com)*

7.1.4.1 Factors to Be Considered Before Selecting Material:

1. **Natural, plentiful or renewable -** Are the products made from material that is rapidly renewable such as cork or bamboo. Wood products are also a renewable resource. Many engineered wood products are made from fast growing trees such as aspen and require less wood to make them than conventional timber.
2. **Durability** - Choose products that will stand the test of time and require little maintenance. This will save time, money and energy on repairs at a later date.
3. **Locally available**: Building materials, components, and systems found locally or regionally, saving energy and resources in transportation to the project site.
4. **Moisture resistant**: Products and systems that resist moisture or inhibit the growth of biological contaminants in buildings.
5. **Healthy environment maintained:** Materials, components, and systems that require only simple, non - toxic, or low VOC methods of cleaning.
6. **Consistent quality:** all the construction material should be consistent in shape, size and property.

Chapter 8

Modern Mechanical Tools

Chapter 8

Modern Mechanical Tools Inventory for Retrofitting

8.1 Introduction:

A machine tool is a machine for shaping or machining metal or other rigid materials, usually by cutting, boring, grinding, shearing, or other forms of deformation.
Retrofitting construction is one of the most technical construction practices which needs precision and quality control. To maintain this, in modern retrofitting practices construction firms are heavily using mechanical tools.

There are different types of mechanical tools are in use at different stages like:

8.1.1 Damage Assessment stage:

In damage assessment process there are a set of data base is required about the structure before analysis. There are many modern tools are in use to obtain structural information. Most widely used tools are:

1. UPV (used for concrete testing)
2. Re-bound hammer.
3. Total Station.
4. Core-cutting tool.
5. Ferro-scan.
6. Bearing capacity testing tool kit etc.

A set of different tools used by engineers to get precise data for the analysis. These modern tools make data collection process more reliable and accurate, which is very important to create retrofitting designs.

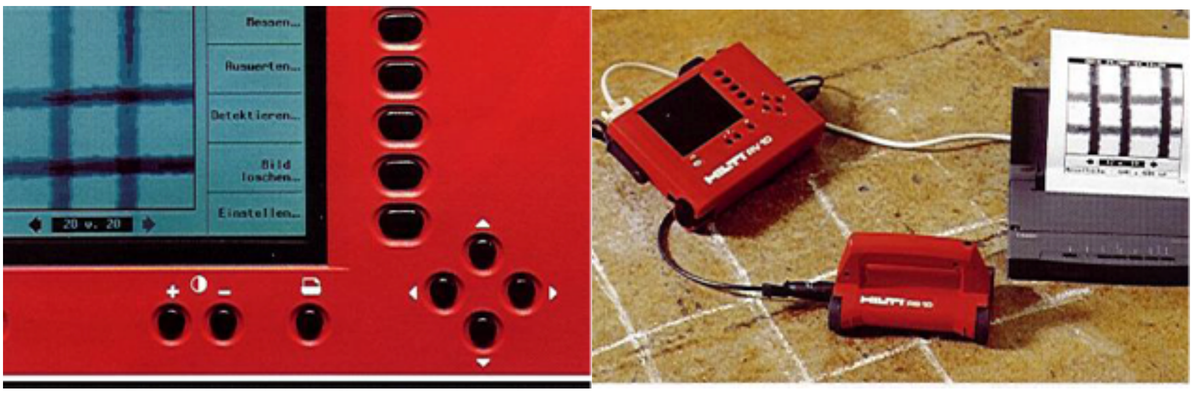


Figure 46: Ferro- scan used for deducting iron bar location *(credit: TESRA ppt)*

Retrofitting Execution stage:
Retrofitting construction is a complex process. In this there are several stages are involved which need precision and fast execution. For the different type of retrofitting method there are different type of mechanical tool are used. Some of the most common tools are:

1. Hydraulic jacks.
2. Hammer Drill.
3. Mechanical cutter.
4. Grinding (abrasive cutting)
5. Multiple edge cutting tools
6. Single edge cutting tools


Figure 47: Ferro- Rotatory hammer drill *(credit: TESRA ppt)*

Figure 48: Re-bar fastening machine *(credit: TESRA ppt)*

- ROTATORY HAMMER DRILLS - Drilling anchor holes in concrete, stone and masonry, drill bit 4 to 20 mm.
- Rebar fastening- rebars can be anchored as if cast in, starter bars for columns, repair with shotcrete, major structural repair.

Figure 49: Re-bar fastening machine application *(credit: TESRA ppt)*

Figure 50: UPV testing of concrete element *(credit: gharpedia.com)*

Figure 51: Re-bound hammer testing of concrete element *(credit: gharpedia.com)*

Chapter 9

Site Supervision Guidelines

Chapter 9

Site Supervision Guidelines of Retrofitting Construction

The site engineer should possess basic knowledge about the practical construction procedures in site, along with the details of how they are planned. This idea of planning and coordination will help him to have proper execution of the activities in the site with desired performance.

9.1.1 Technical Activities

Site activities like establishment of the level and the survey control, which is required for the control of contracts must be performed by site engineer in required conditions. The works have to be set out as per the contract drawings. This requires checks at regular basis on the construction site.

The records maintained have to be accurate and they have to satisfy with the organizational and the legal requirements.

9.1.2 Preparation of Reports and Schedules

The site engineer is the one who have to ensure that the site have adequate resources to complete the tasks. This is conducted by having procurement schedules for the jobs carried out and liaise with the procurement department regarding the same.

A report on the future works to be carried out at site are prepared and produced by site engineers two weeks ahead. This is carried out in conjunction with the site agent. The site engineer is responsible for keeping site diaries and the respective sheets for allocation.

9.1.3 Site Engineer for Health and Safety

For highly dangerous work site, the site engineer will take up the role of safety engineer. He has to ensure that the work carried out by the workers and other related activities are as per the safety regulation of the respective state or area. Every construction organization must possess a safe working culture and practice. Its implementation and practice of following is supervised by the site engineers. There may be other safety, health officers for the organization, but ensuring safety is a common need.

Other responsibilities are to undergo construction activities that will promote the environmental compliance. Each work has to be carried out safely within the deadline.

9.1.4 Quality Assurance by Site Engineer

As we know, quality is a parameter that have to be kept in practice from the initial stage of planning to the end of the project. The major issues with design and documentation can be corrected during the construction by the site engineer based on advice from the structural engineers.

Any undesirable activities in construction brings high loss of quality and money. The site engineer assures quality by the following means:

- Promoting the best construction practices
- Undergo activities and practices that comply with the procedures of the company and the specification.
- Assures the work is completed and delivered without any defect and delay
- One must highlight value engineering opportunities

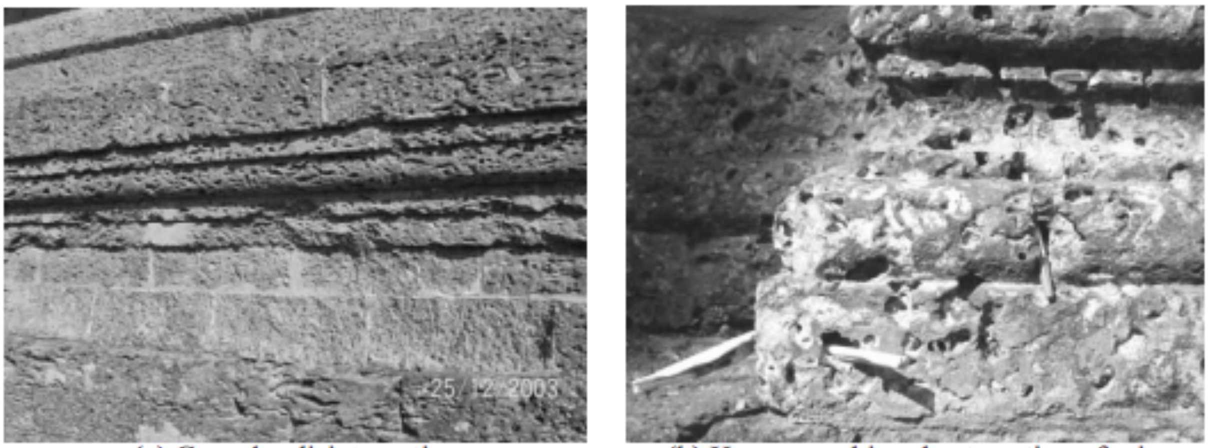
Chapter 10

Damage Scenario due to Flood

with the construction using this material. While visiting Kerala after the flooding, I had found that reconstruction process is widely using this material. Show the building built using this type of stone at Flood prone areas need to be retrofitted by providing protection wall using different material like wire mesh with RCC, stonewall or brick masonry wall.

There are some common effects of flooding on laterite stone are as follows:

1. **Loss of material:** Physical damages caused due to lashing rain, wetting and drying cycles and thermal changes. Loss of cohesion of minerals causes granular disintegration and surface loss of material. Disintegration of laterite mainly in exposed areas of basement was mainly due to the growth of salt crystals.



(a) Granular disintegration (b) Honey combing due to action of rain

Figure 52: Image showing damage pattern in laterite stone *(credit: iwww.hms.civil.uminho.pt)*

2. **Bio-degradation:** Damp surface of laterite attracts dust, dirt, insects, termites and other microorganisms. If this is uncontrolled it gives rise to higher plants and trees. The acidic secretion produced by lichens induces a bio-corrosion in stones.

(a) Growth of moss and lichens

Figure 53: Image showing damage due to bio-degradation in laterite stone
(credit: iwww.hms.civil.uminho.pt)

3. **Salt crystallization**: Formation of efflorescence on exposed surfaces of structure causing unsightly appearance. Formations of salt crystals below the exposed surface result in blistering and scaling of outer layers. Salts seeps into the building by capillary action of ground water. Salts are deposited within the structure (in basement portions) near the exposed surfaces resulting in granular disintegration.

(a) Efflorescence due to deposition of salts on surface
(b) Progressive damage due to deposition of salts internally

Figure 54: Image showing damage due to Salt crystallization in laterite stone *(credit: iwww.hms.civil.uminho.pt)*

4. **Human Interventions:** Improper repair to laterite structure can damage the structure like repair of soft laterite using a hard cement mortar. Cement mortar creates a hard-rigid boundary around the material. The expansion and shrinkage of the material due to thermal variation cycles within the hard-rigid boundary leads to formation of cracks and disintegration of material.

10.1.2 Effect of flooding on Masonry buildings:

Most of the rural and urban areas in Kerala, Traditional building practice is to build with exposed brickwork, if a building with exposed brickwork experience flooding and intensity of flood water is moderate, in that case it is observed that mortar load bearing walls get deteriorated due to flood water, which lead to decline structural strength. It is recommended to carried out proper risk assessment of all the buildings with exposed brickwork with respect to flood hazard. If the area had experienced flood in past then and the building must be retrofitted by introducing plinth protection using non eroded material around the external wall. Some of the common materials are suggested like wire mesh with RCC, FRP, stone cladding for tile cladding etc.


Figure 55: Image showing erosion of mortar due to flood water *(credit: inspectapedia.com)*

Different type of foundation settlements:

2. **Uniform settlements:** In this type of settlement generally no cracks are observed but the whole structure is slinked in the ground.

3. **Tipping Settlement:** In this type of settlement the building is settled from one side and lifted from another site. In some cases, the structure is properly designed and structurally integrated then there is no cracks is observed. This type of settlement in future can cause building instability and damages.

4. **Differential settlement:** In this type of settlement, due to rainwater or non-compact ground soil will settle in non-uniform way. The settlement will cause structural cracks near plinth area on the walls. this type of settlement can cause building collapse.

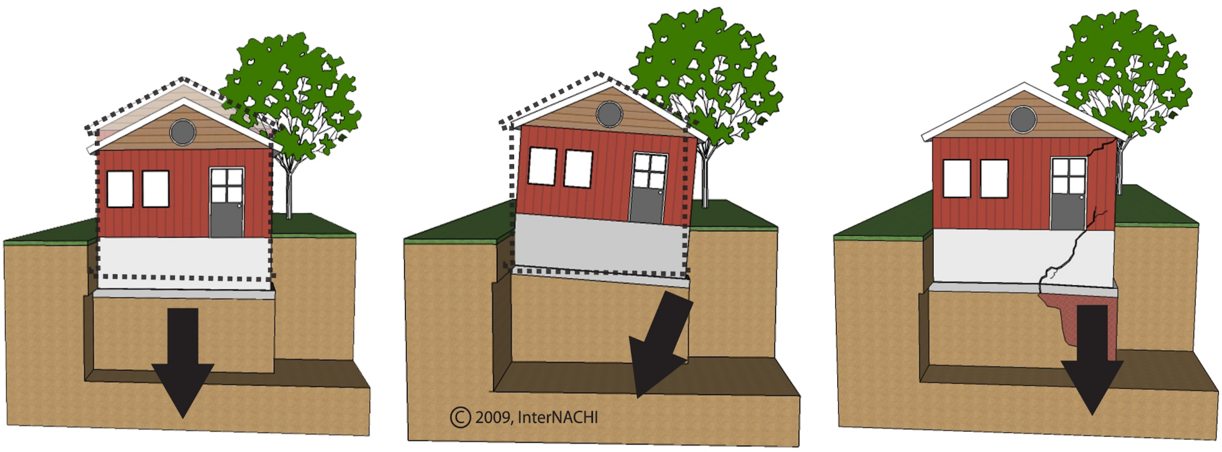


Figure 56: Image showing ground settlement pattern due to flood *(credit:www.nachi.org)*

10.1.3 Major retrofitting techniques for the buildings exposed to flood hazard:

2. Elevation

a. Elevation of the existing structure on fill or foundation elements like, solid perimeter walls, piers, posts, columns etc.
b. If the structure is built on frame structure, then introduce the lateral bracing between all the columns.

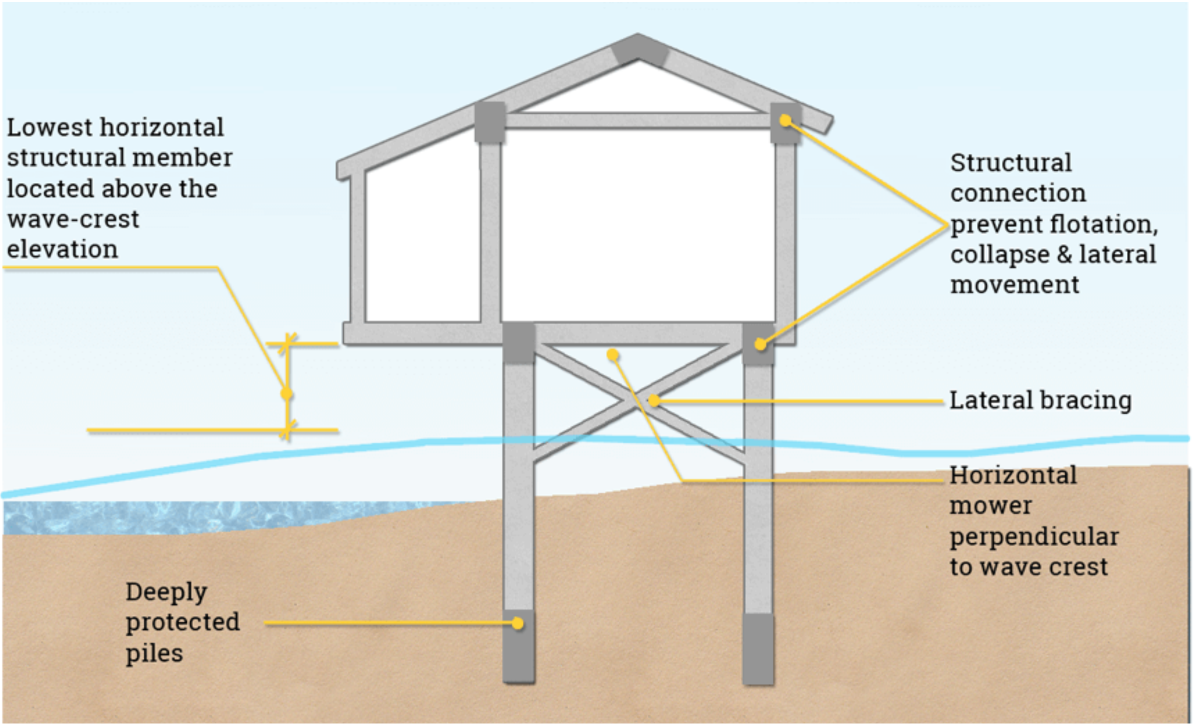


Figure 57: Image showing introduction of bracings between columns *(credit: andhitapradipta.github.io)*

3. Relocation

a. Relocating existing structure outside the flood plain

4. Dry Flood proofing

a. Strengthening of existing foundation, floors and wall
b. Sealing the portion of structure below flood level.
c. Use of sealants, wall coating, water proofing for sealing components
d. Door-window, sewer and water lines and vents closed with permanent or removable valves.

5. Wet Flood Proofing

a. Water resistant during the period of flood within the structure
b. Modifying structure to allow flood water to enter in a way to minimize damage, feasible only if structure has space available, basement etc.

6. **Measures for protection against Flood damage**

a. Proper drainage system around the building, slope adjustment etc.
b. Raising the plinth level to HFL
c. Grounded edge near the building to protect against scouring by pitching, vegetation etc.

    d. Flood Wall/Level
7. **Measures for protection against rain damage**
    a. Water Proof Plastering on Leaky Roofs
    b. Proper drainage of roof through adequate slope adjustment
    c. Plastering the top of parapet wall to avoid water absorption in walls
    d. Damp proof layer on wall up to minimum 450 mm or till high flood level

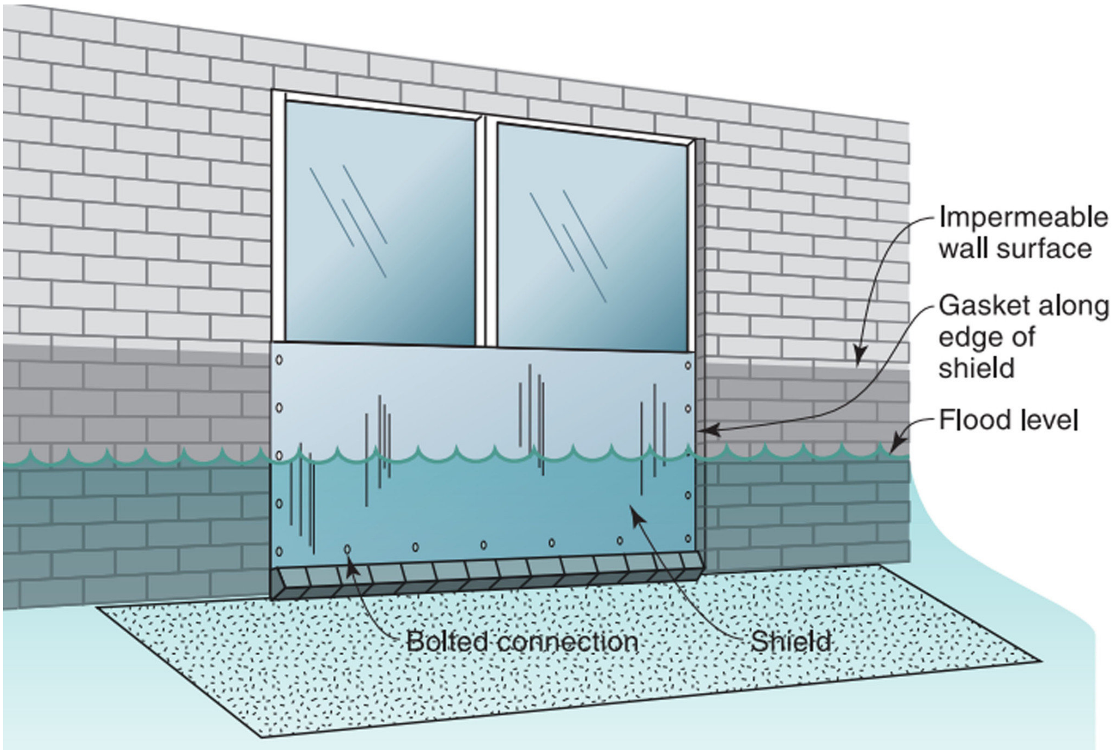


Figure 58: Image showing introduction of Temporary support to avoid flood water *(credit: andhitapradipta.github.io)*

Chapter 11

Damage Scenario due to Landslide

Chapter 11

Damages and Retrofitting due to Landslides

11.1 Introduction:

This chapter is all about different causes, effect and damages done due to landslides and if a structure faces landslide hazards then which option victim can adopt to mitigate effect of landslide as well as re-strength building.

A landslide, sometimes known as landslip, slope failure or slump, is an uncontrollable downhill flow of rock, earth, debris or the combination of the three. Landslides stem from the failure of materials making up the hill slopes and are beefed up by the force of gravity. When the ground becomes saturated, it can become unstable, losing its equilibrium in the long run. That's when a landslide breaks loose. When people are living down these hills or mountains, it's usually just a matter of time before disaster happens.

11.2 Common building damage due to Landslides:

Effect of landslide on building is varying in wide range, in most of the scenario landslides causes major structure damage that can lead to collapse, but if landslide deducted earlier and intensity is also low than there is some common failure observed in buildings are as follows:

1. Partial land shift can cause vertical structural cracks.
2. Horizontal structural crack.
3. Base soil erosion.
4. Multiple structural cracks.
5. Sinking in foundation.
6. Partial building collapse.

Figure 59: Base soil under foundation eroded due to landslide (*credit: http://www.stuff.co.nz)*


Figure 60: Building partially buried due to landslide (*credit: http://www.stuff.co.nz)*

11.3 Building Retrofitting techniques damaged by Landslides:

Retrofitting of the building depend on the type of damage occurred in the structure due to landslide, before adopting retrofitting techniques detail damage assessment need to be carried out, on the basis of that retrofitting measures applied. Some of the common retrofitting methods are as follows:

1. Anchoring of retaining wall using steel rods and plates.
2. Retrofitting of cracks using FRP.
3. Retrofitting of cracks using Wire mesh.
4. Extension and support foundation using jacks and RCC.
5. Increase the thickness of retailing wall.


Figure 61: retrofitting using steel plates for basements (*credit: TESRA ppt)*

Chapter 12

Do & Don't for Engineers

- Simple Square/Rectangular and Symmetrical plan is Suitable - Length of Building ≤ 2xWidth.
- Separation of wings into different rectangles in plan is preferable.
- Shorter wall facing wind direction.

AVOID

- Row house settlement with roads leading to Sea.
- Longer wall facing the direction of wind.

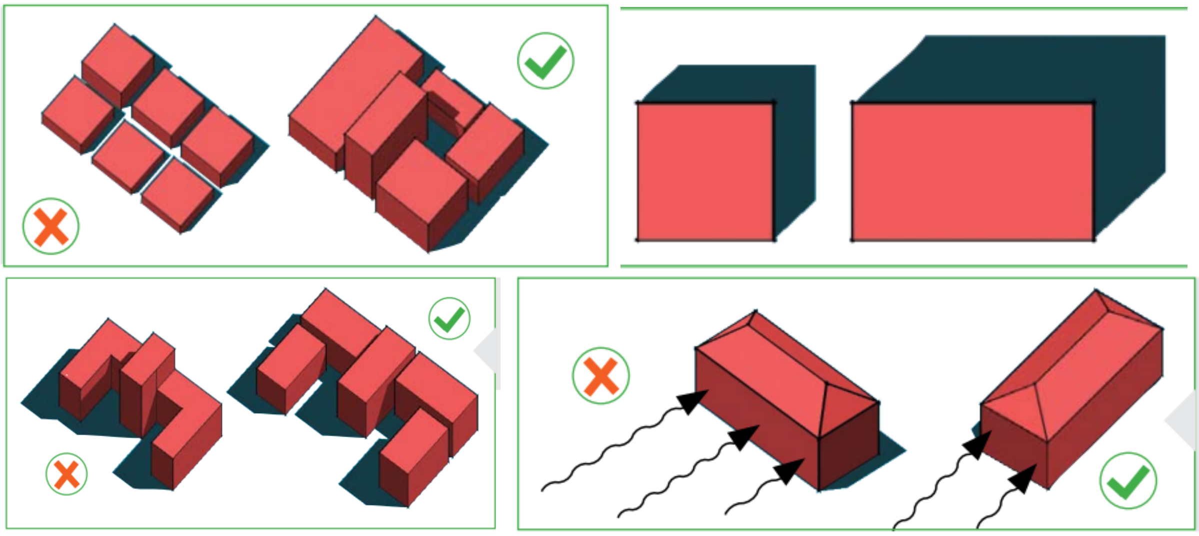


Figure 62: Disaster resilient building design pattern (*credit: TESRA ppt)*

12.2 Foundation:

PROVIDE

- Slightly Slanting cut - Sand Compaction thickness more than 150mm - PCC thickness more than 75mm.
- Foundation width should be 2½ times thickness of the wall or 0.8m, whichever is more.
- Use baked bricks and stones.
- Minimum depth should be 1000mm.
- Foundation on Hard Soil.

AVOID

- Straight Cut - Sand compaction less than 150mm - PCC less than 75mm.
- Foundation width should not be less than 2½ times thickness of the wall.
- Never make a wall without foundation B. Don't use unbaked bricks in the foundation.
- Foundation on Loose or Soft Soil.

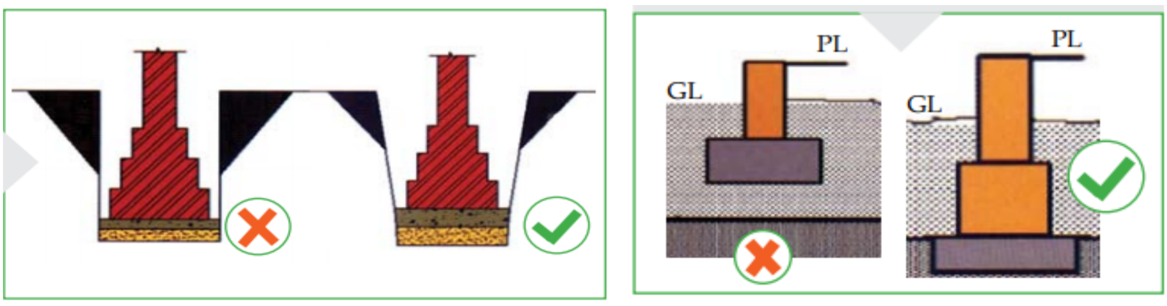


Figure 63: Foundation design and execution

12.2.1 Walls

PROVIDE

- Average wall height should be 2700 to 3000mm.
- The length of the wall should not exceed 8 times the thickness - Addition of a buttress wall reduces L/H Ratio.

AVOID

- Too High Walls.
- Walls that are too high or too long

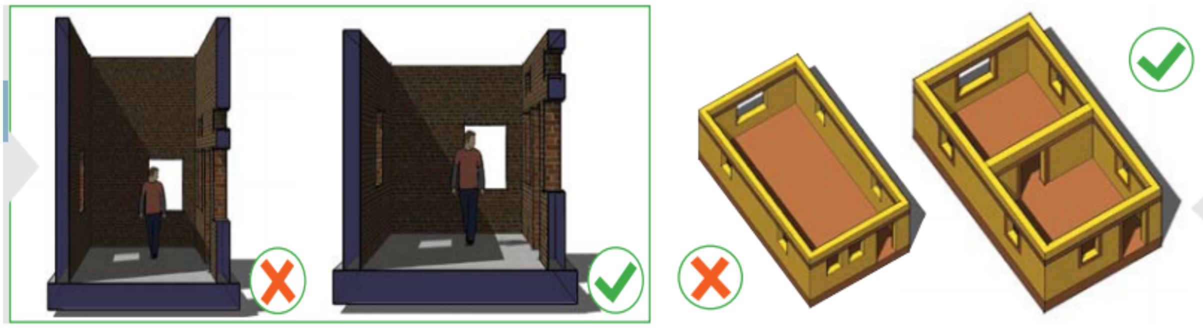


Figure 64: disaster resilient wall features (credit: TESRA ppt)

12.2.2 Stone Masonry

PROVIDE

- Through stone should be placed horizontally at a minimum spacing of 1200mm center-to-center.
- Through stone should be placed vertically at a minimum-spacing of 600mm.
- Vertical Rod should be placed at 125mm from the inner face of the wall.
- Vertical Rod should be placed at 245mm from the inner face of the Brickwork **Rat-trap Bond (L-Joint)**
- Vertical rod must be connected using extra “L” bar with main steel of Plinth band and Lintel band. The bar will be able to perform efficiently if it is anchored at Foundation and Slab and linked with plinth and lintel band.
- .Joints in brickwork should be staggered.
- For regular bond use only mortar of 1:6 or richer and for Rat - Trap bond 1:5 or richer.
- Vertical rods should be protected with a minimum cover of 40mm in M20 concrete
    1. Joints in brickwork should be staggered.
    2. For regular bond use only mortar of 1:6 or richer and for Rat - Trap bond 1:5 or richer.
- Vertical rods should be protected with a minimum cover of 40mm in M20 concrete

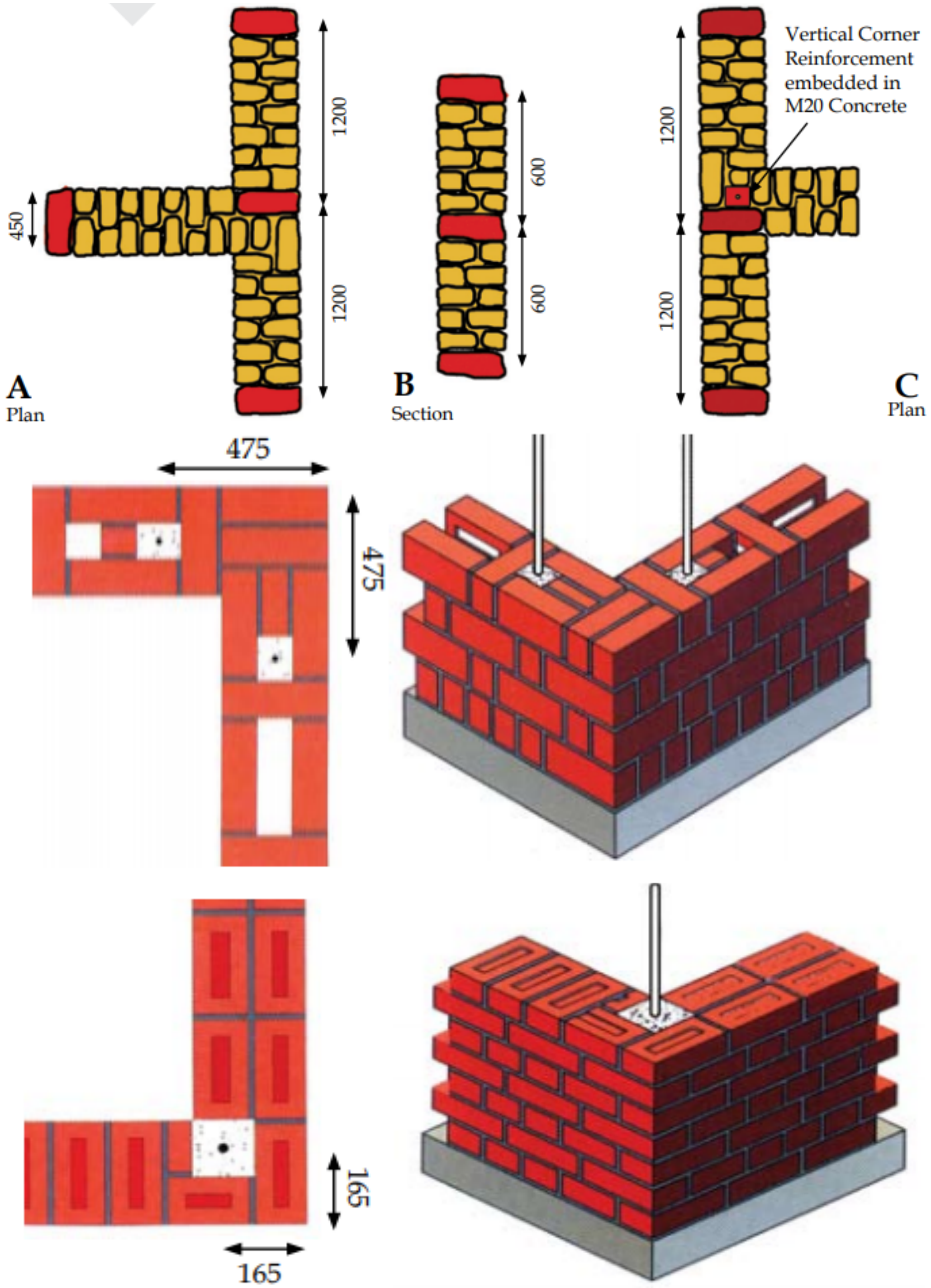
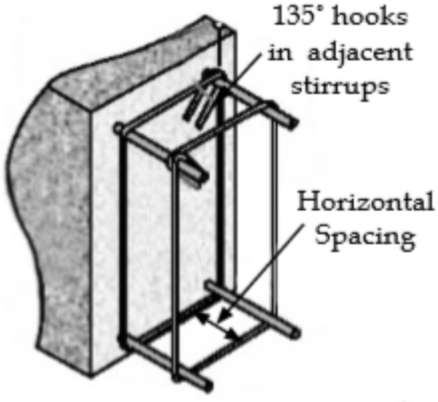
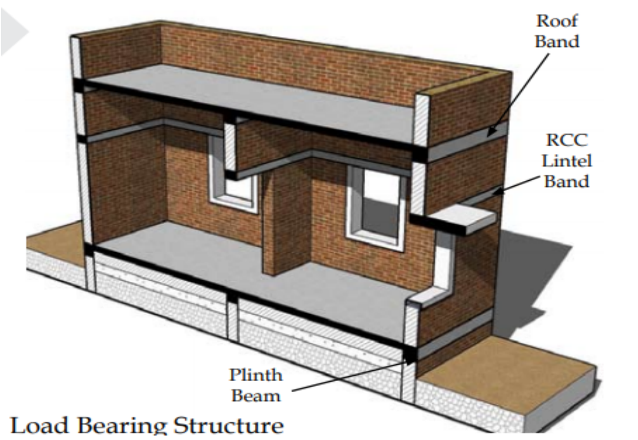


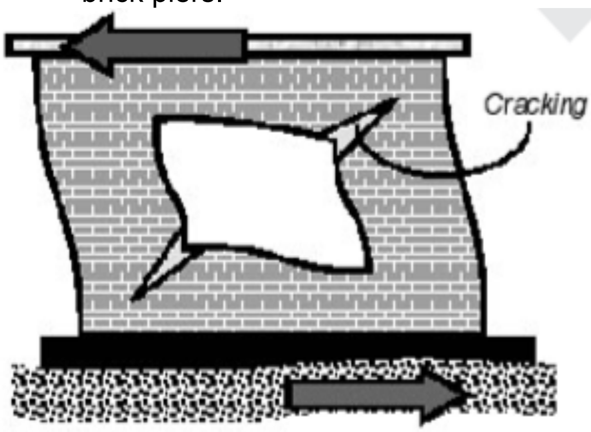
Figure 65: Different type of disaster resilient brick bonds *(credit: TESRA ppt)*





12.2.3 Openings

- Openings are the most Vulnerable part in a building. Large shear forces get accumulated around openings and therefore, edges of the openings should be specifically strengthened.
- Due to lateral thrust openings are subjected to movements attempting to make them a Rhombus - stretching opposite diagonals as shown. Because of this it is likely that after an Earthquake; diagonal / shear cracks occur around unsecured openings and brick piers.



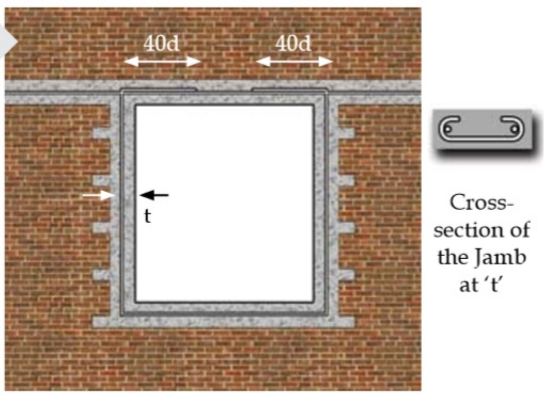
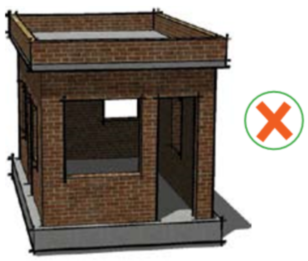
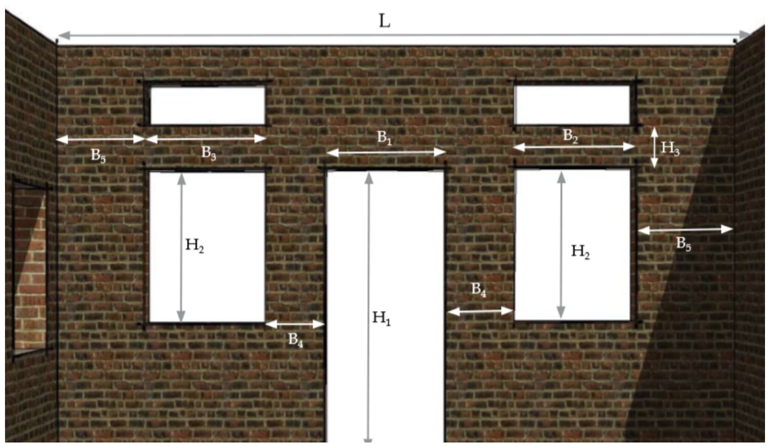


Figure 66: Protect Openings with Reinforced Band all around as shown.





Design Considerations -Avoid too many openings in the wall -The minimum distance between unreinforced openings should be 600mm

Brick Masonry

- B1+B2+B3 ≤ 0.5L (for One Storey) ≤ 0.42L (for Two Storey) ≤ 0.33L (for Three storey)
- **600mm ≤ B4 ≥ 0.5H2)]** Horizontal distance (pier width) between two openings should not be less than 50% the height of the shorter opening (and not less than 600mm)
- **600mm ≤ B5 ≥ 0.25H1]** Openings to be located away from the corners by clear distance equal to at least one fourth of the height of opening or 600mm whichever is more.
- **[H3 ≤ 600mm or 0.5(B2 or B3)]** Vertical distance from an opening to opening above should not be less than 600mm and half the width of smaller opening.

Stone Masonry

- B1 + B2 < 0.3L
- B4 ≥ = 0.50H2 ≮ 600mm
- B4 ≥ = 0.25H1 ≮ 600mm

12.2.4 Columns & Beams

Columns and Beams are main elements of the RCC frame construction. They should be designed for Earthquake resistance and detailed as per the ductile detailing norms. If the ductile detailing is not followed, the structure will be damaged in the event of a dynamic loading during disasters. Min. concrete Grade for RCC should be M20 i.e. 1: 1.5 :3 for volumetric proportioning. Where 3 is a mix of 10mm and 20mm down aggregates in 50/50 or 60/40 ratio.

PROVIDE

- Bend the Stirrup through 135°
- Adequate Lap Length with slope of 1:6
- Beam bars bent in joint region overstress the core concrete adjoining the bends
- Column should have minimum four 12 diameter bars. It is preferable to use TMT bars near the coast line
- Reinforcement Detail of Beam Column Joint at Roof Level.
- Reinforcement Detail of Beam Column Joint at Floor Level.

AVOID

- Inadequate Stirrup Details
- Splice with Offset Cranked bar in a Column

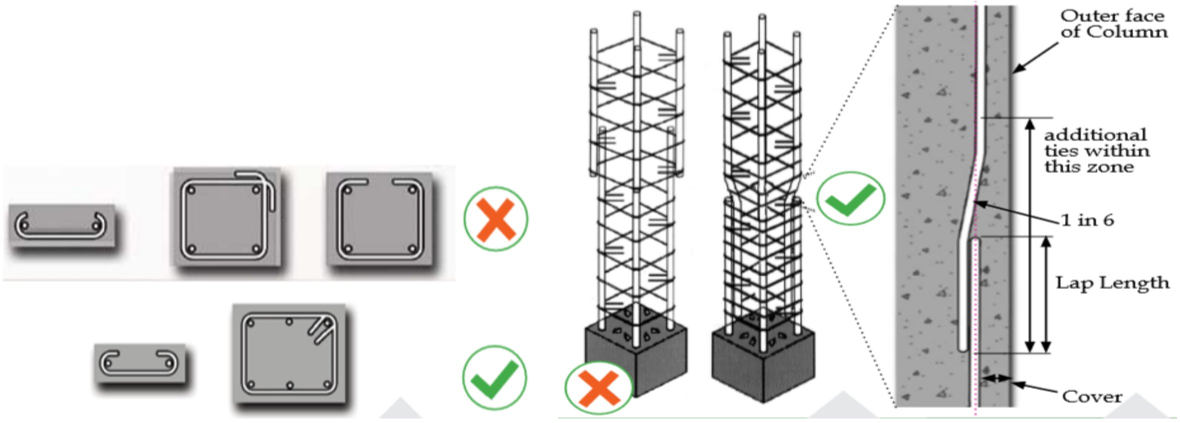


Figure 67: Reinforcement pattern in column and bar bending details *(credit: TESRA ppt)*

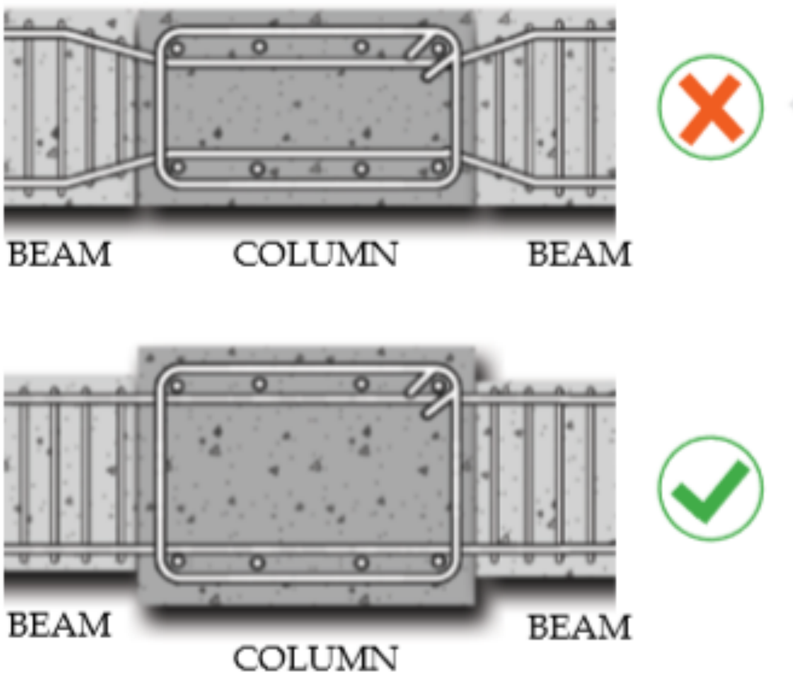


Figure 68: Reinforcement pattern on beam column joints *(credit: TESRA ppt)*

Chapter 13

Key recommendation & Conclusion

As per the overall studies, in Kerala all the structure which are built with stone & brick masonry without reinforcement are highly vulnerable for the damage, if it experiences any kind of disaster like earthquake, flood and landslides. In Kerala these types of structures are available in very high number and most of these types of structures are available in rural area which are prone for the flooding and landslides. Before proposing or executing any retrofitting techniques it is important to follow step wise process of it. Damage assessment is one of the important aspects which needs to be carried out and then retrofitting needed to be performed.

Some of the key recommendations are:

1. Identify available hazard which can affect proposed or existing construction site.
2. Documentation of past history of disaster event is needed to be document to analysis the frequency.
3. Detail damage assessment of different existing buildings must be carried out.
4. Retrofitting methodology needed to be adopted on the basis of major damage type.
5. In Kerala it is need of this hour to carry a detail survey of all flood effected area and create a common structure damage pattern inventory for the vulnerable structure which shows damage or vulnerable for the damage than a retrofitting program needed to be conducted with the practical session to selected masons.
6. Detail assessment proforma needed to be created to make assessment standardized
7. Quality control of construction material needed to be regulated by local engineers, government.
8. Awareness campaign on retrofitting and quality construction needed to be executed at different level.
9. Physical demo units needed to be constructed with all the detail demonstration of safe construction techniques in different districts.
10. Different level engineering training programs needed to be conducted at all the level in state.

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