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RETROFITTING MANUAL FOR MASONS ON FLOOD AND LANDSLIDE RESISTANT SHELTER CONSTRUCTION PRACTICES

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Retrofitting Manual for Masons 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 masons 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 under stand following topics like vulnerability profile of state, existing building typology, site selection criteria, construction material selection criteria, quality construction material selection criteria, 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.

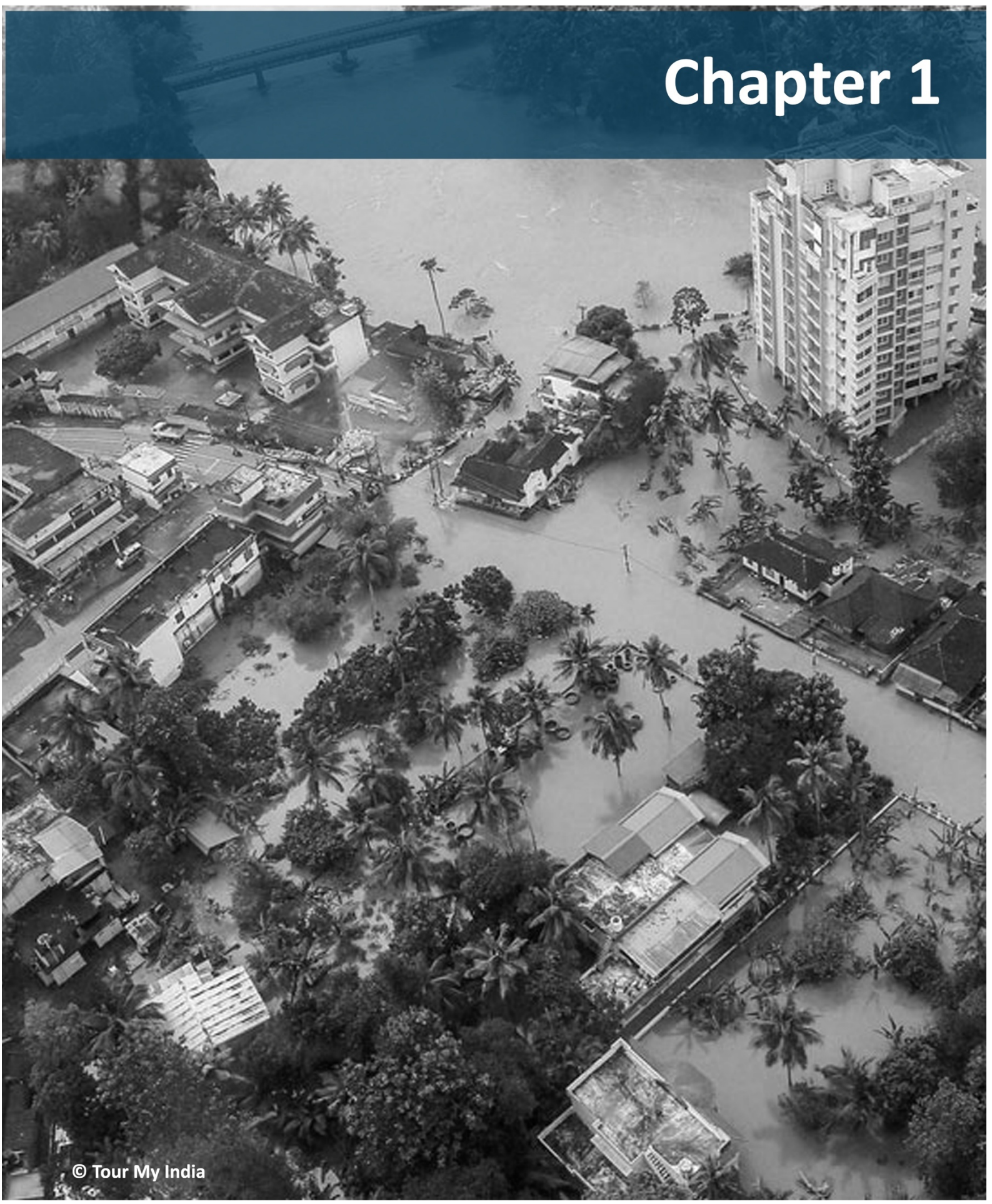
In post disaster management process, it is most challenging part to recreate the damage infrastructure so that disaster victims can rehabilitate. Recreating all the infrastructure is a challenging process which includes three major steps i.e. repair, restoration/rehabilitation and retrofitting. In different 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.

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.

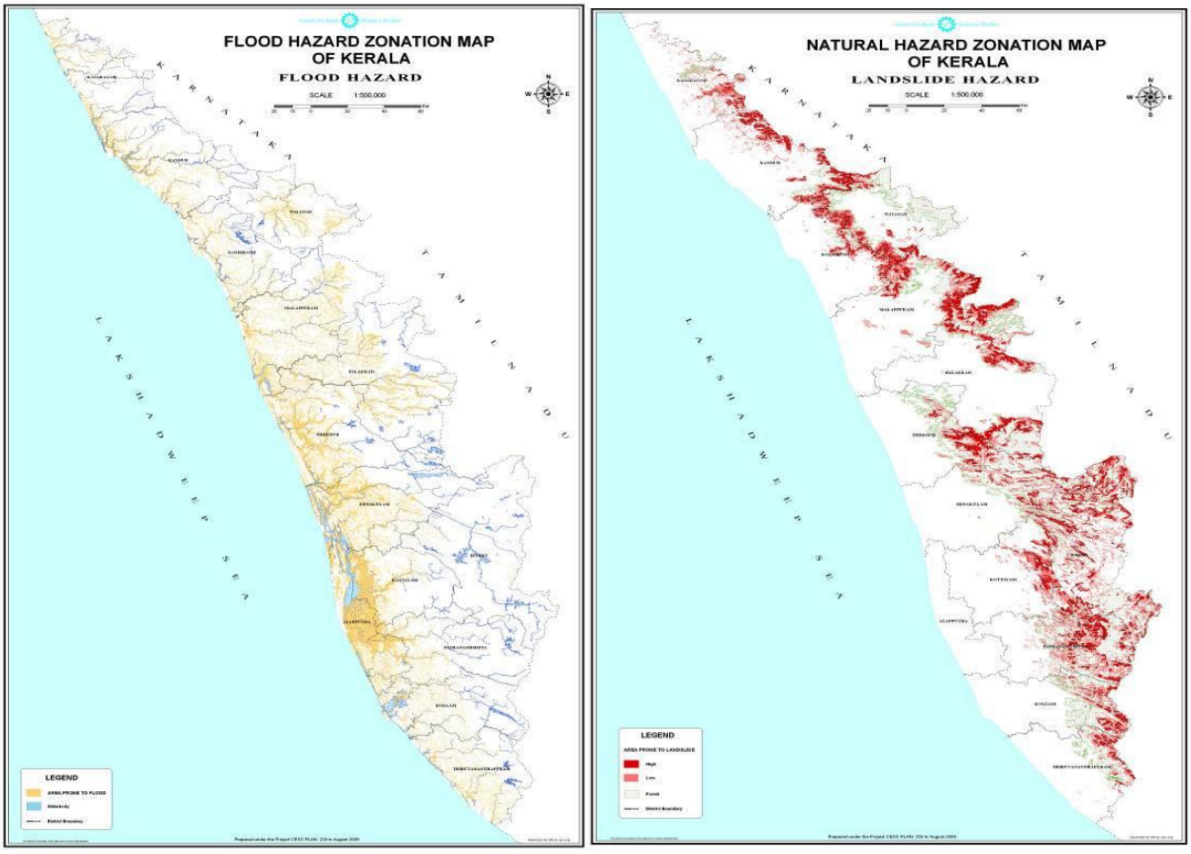


Figure 1: Maps of Flood hazard zonation *(left)* and Landslide hazard zonation *(right)*
(credit: Kerala State Disaster Management Plan Profile)

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.

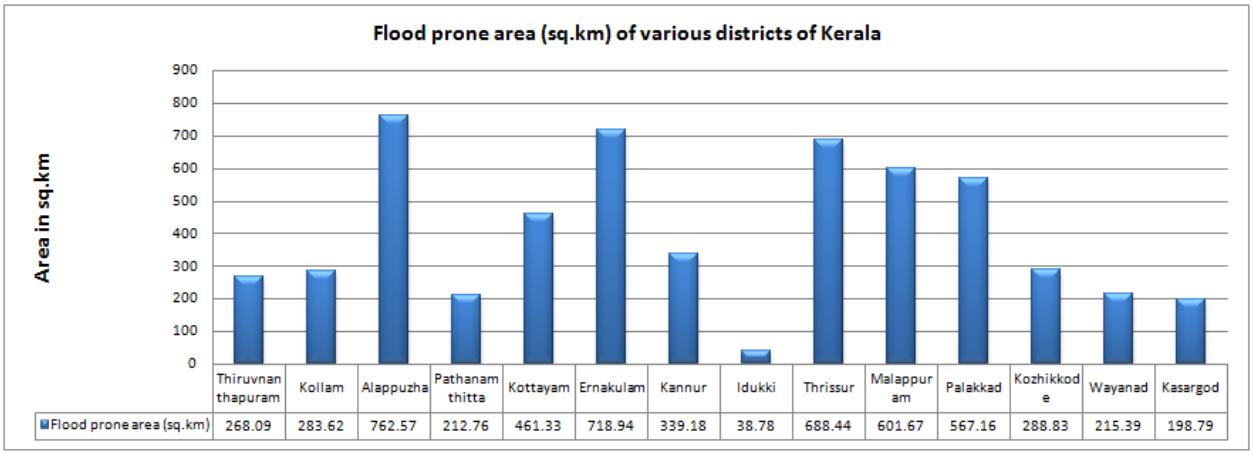
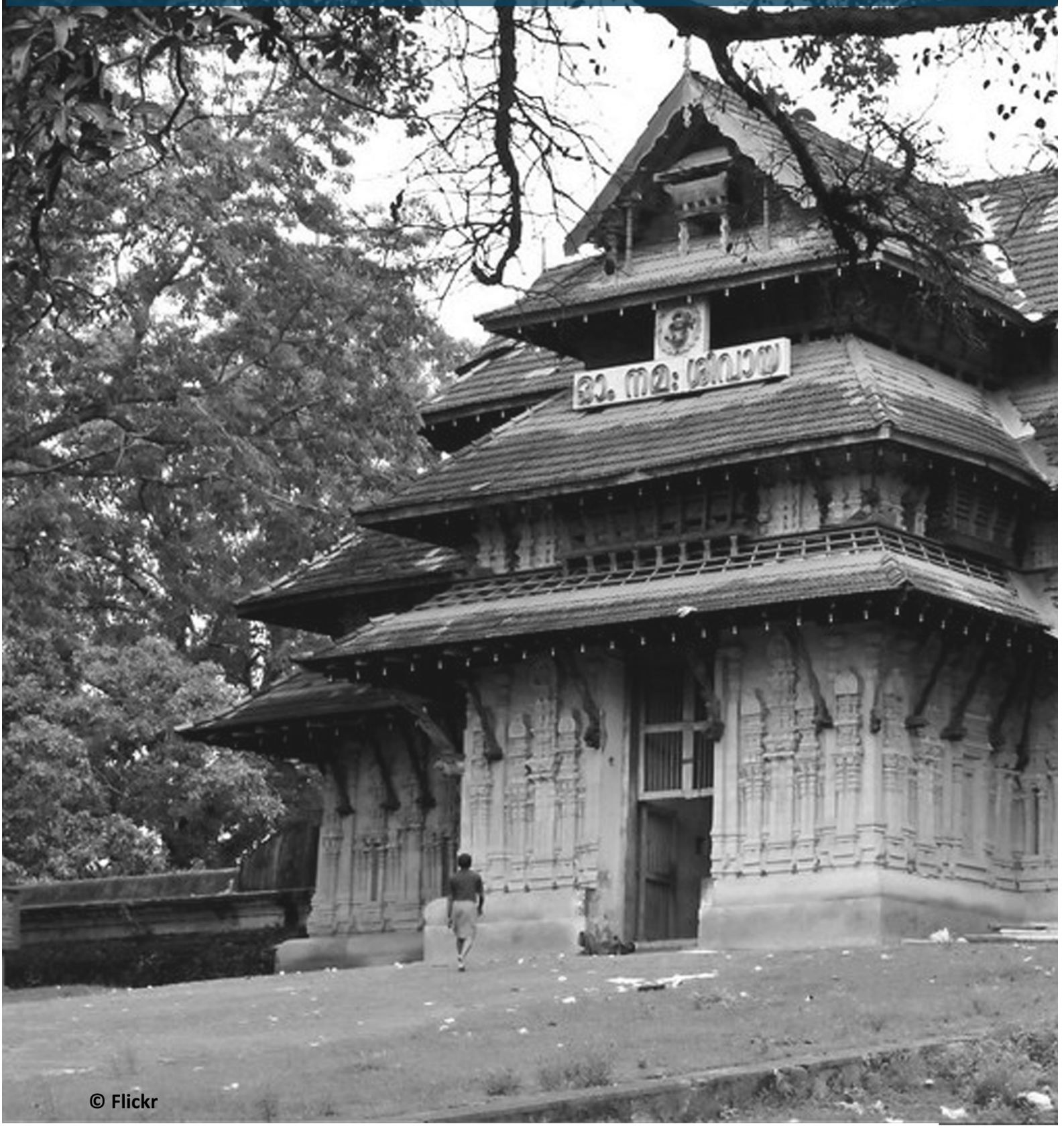


Figure 2: Chart showing Flood scenario in Kerala
(source: Consult CESS, 2010. Plan project 249 for taluk wise area)

Chapter 2



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Construction Practices

Chapter 2

Traditional and Modern Construction Practices

2.1 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.

2.1.1 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)*

2.1.2 Building construction material:

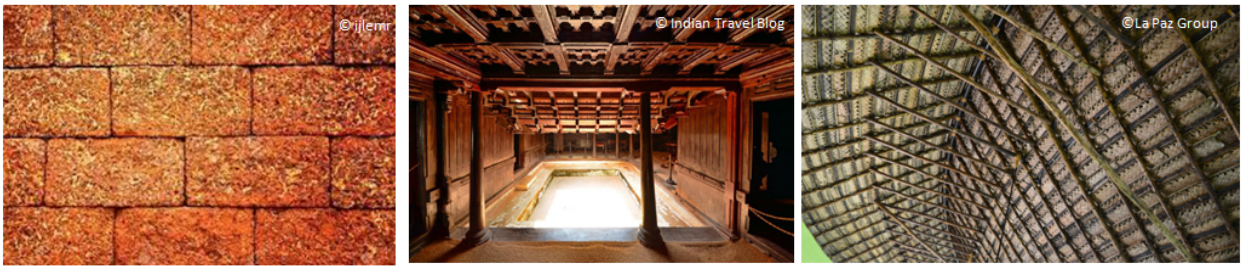
There is different typology of the building present in Kerala, some of the common building typologies are RCC structures, masonry structures (brick masonry structures and stone masonry structures), confined masonry structures, Adobe construction, mud houses, temporary structures, Steel or prefab structures 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)*

2.1.3 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

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Site Selection Criteria

Chapter 3

Site Selection Criteria

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

3.1.1 Site near flood prone areas:

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

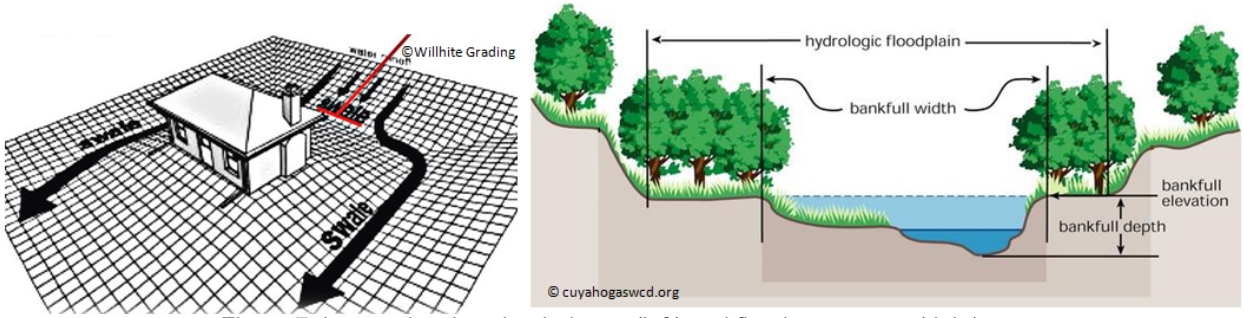

Figure 7: Image showing site drainage (left) and flood prone area (right)

3.1.1.1 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.

3.1.1.2 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.

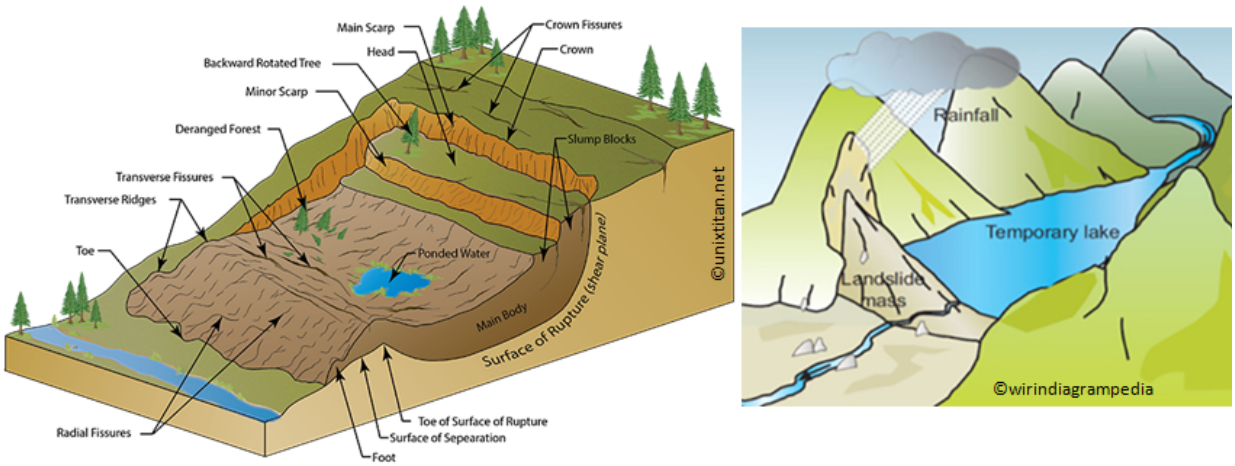

Figure 8: Image showing erosion (left) and Multi-hazard scenario (right)

3.1.1.3 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.

3.1.1.4 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.

3.1.1.5 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.

3.1.2 Site near Landslide prone areas:

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

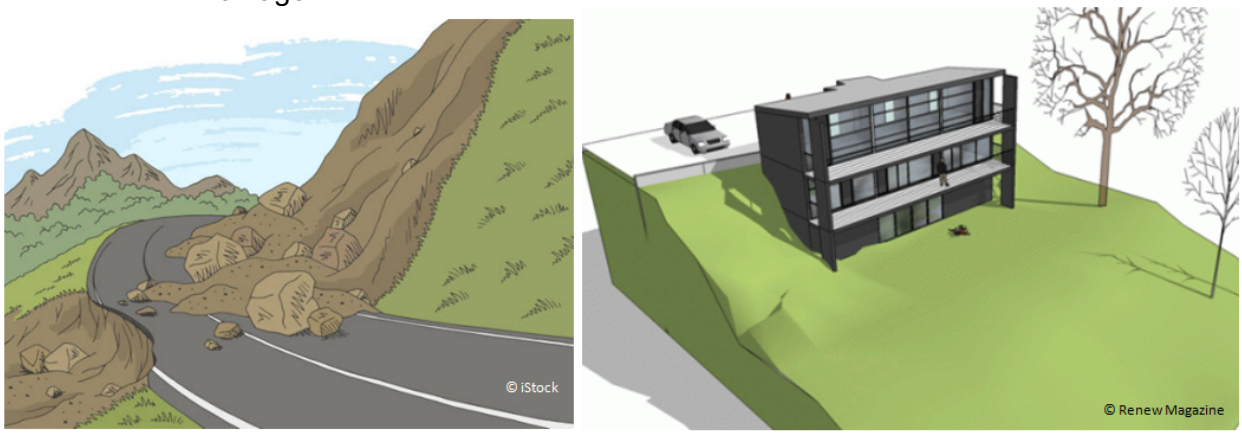

Figure 9: Image showing symbolic landslide prone area (left) and Site slope representation (right)

3.1.2.1 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.

3.1.2.2 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.

3.1.2.3 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.

3.1.2.4 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.

Chapter 4

Construction Material Selection Criteria

Chapter 4

Material Selection Criteria

Figure 10: Image showing common construction material quality *(credit: www.123rf.com)*

4.1.1.1 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 5

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Retrofitting Introduction

Chapter 5

Retrofitting Introduction

5.1 Introduction:

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:

5.1.1 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

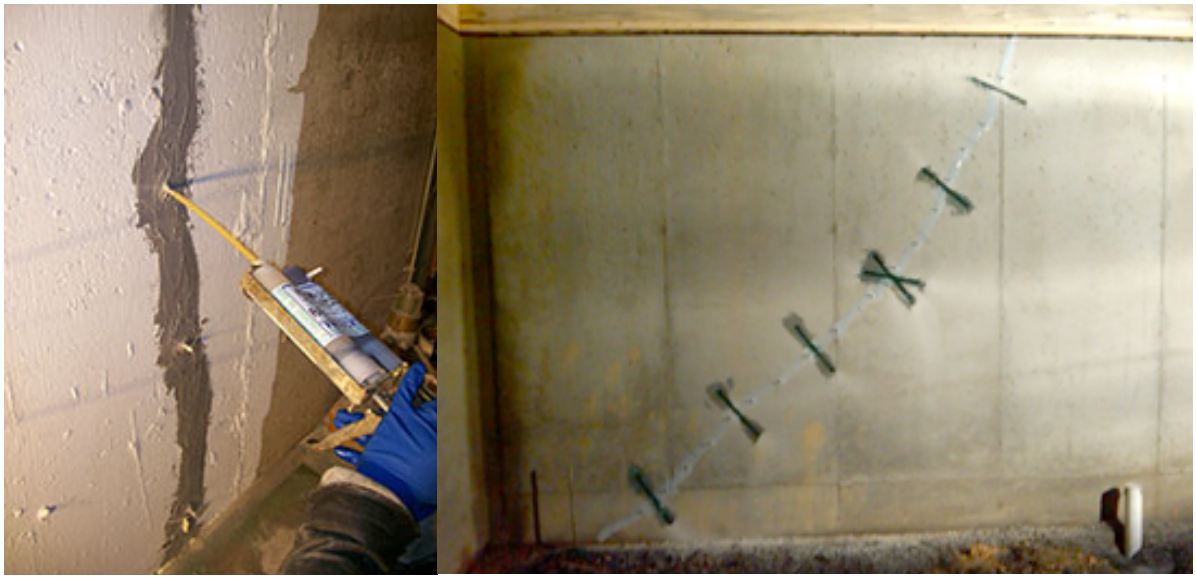


Figure 11:Image showing repair of crack using injection technique *(left)*, repair of crack using diagonal bracing *(right)*. *(credit: www.a1crackrepair.com)*

5.1.2 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 12:Image showing re-plastering and restoration of slab *(left)*, Restoration process of front facade of building*(right).* *(credit: RMS civil repair works)*

5.1.3 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 13: Image 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.

5.2 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 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

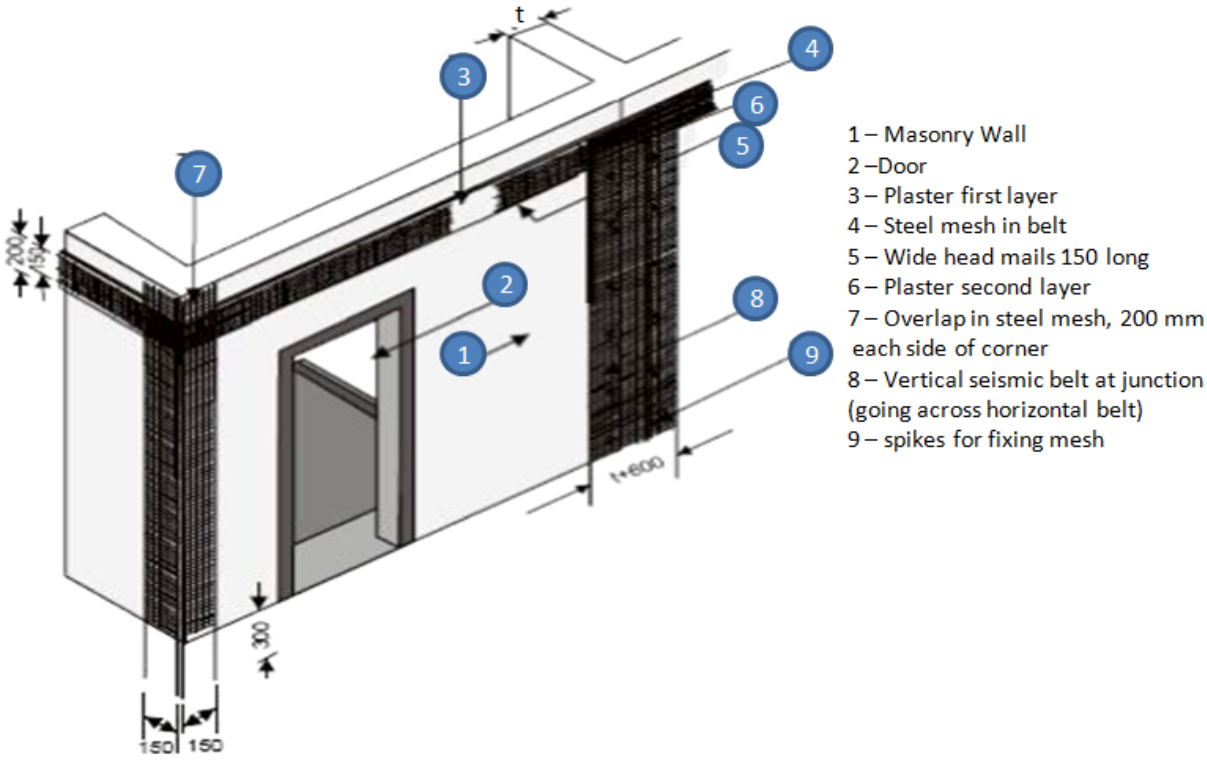


Figure 14: Image showing example of Retrofitting of using wire mesh installation
(credit: urbansolutionsbd.blogspot.com)

5.2.1 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

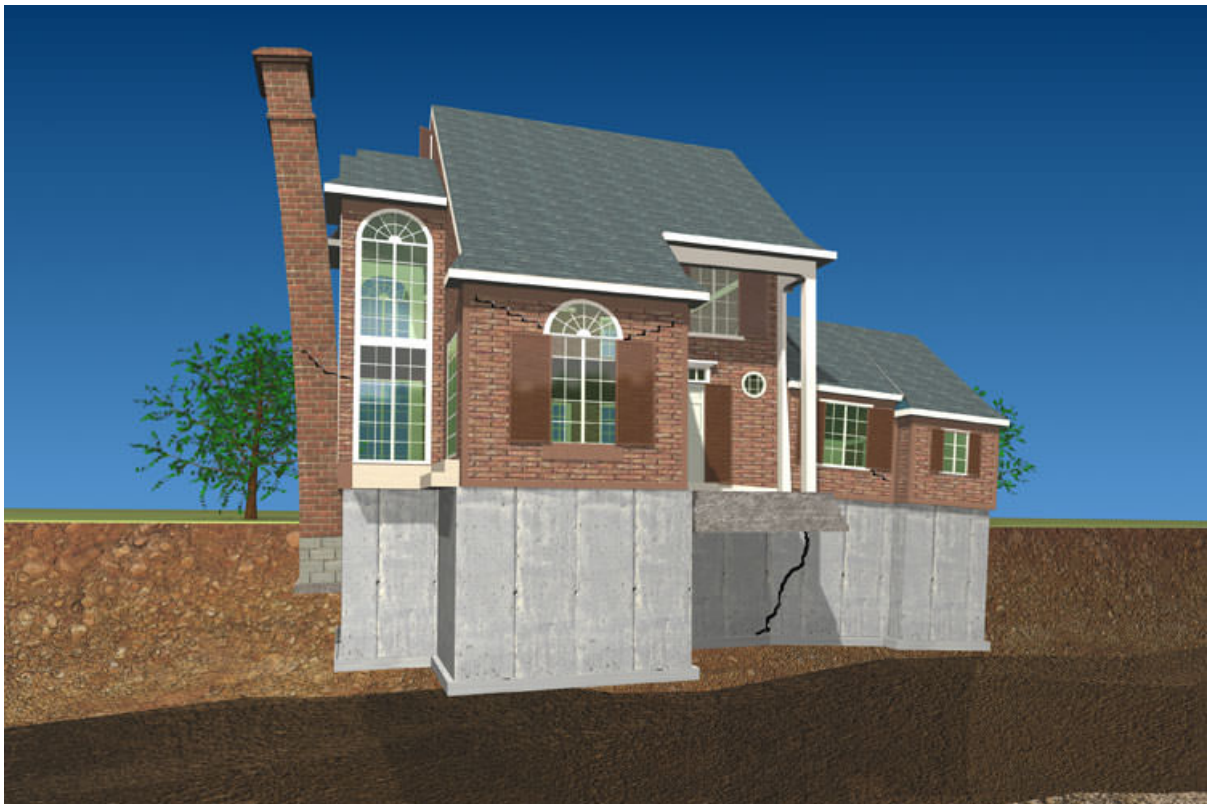


Figure 15: Image showing example of foundation sinking
(credit: www.clarkebasementsystems.com)

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

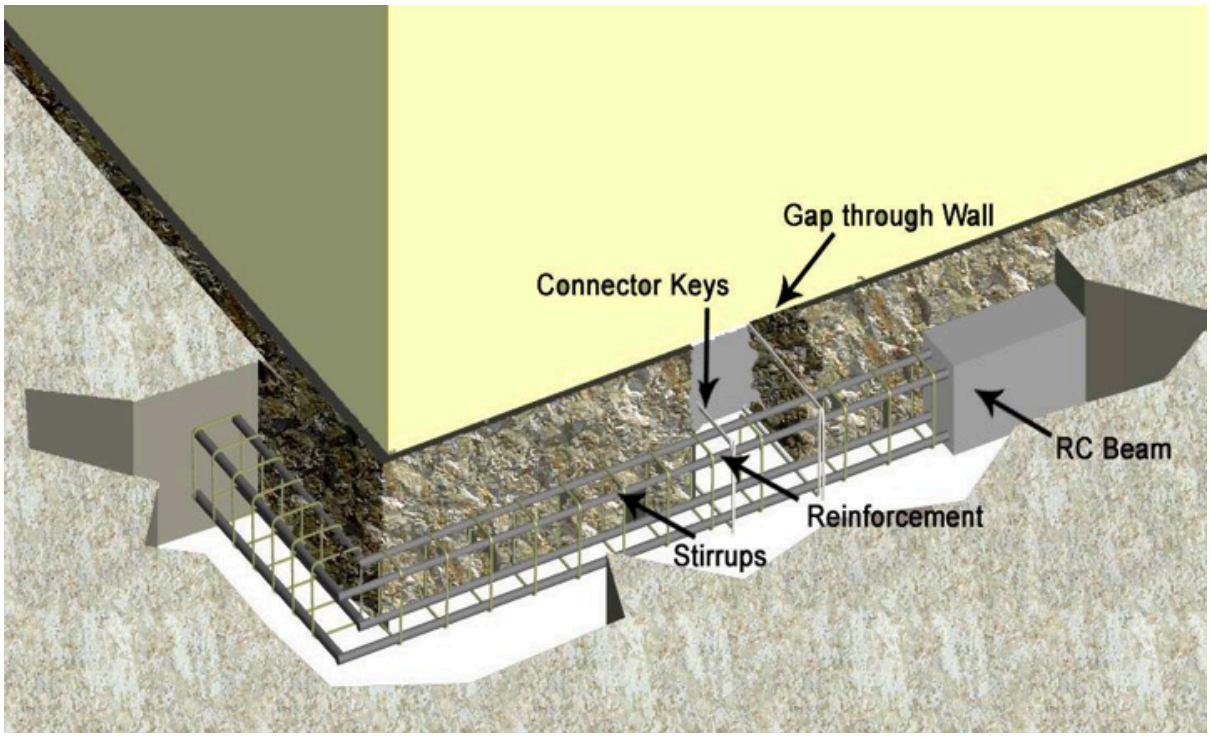


Figure 17: Strengthening of Foundation using RCC frame

5.2.2 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 18:Image showing example of structural cracks in wall due to flood
(credit: www.iitk.ac.in)

Figure 19: 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.

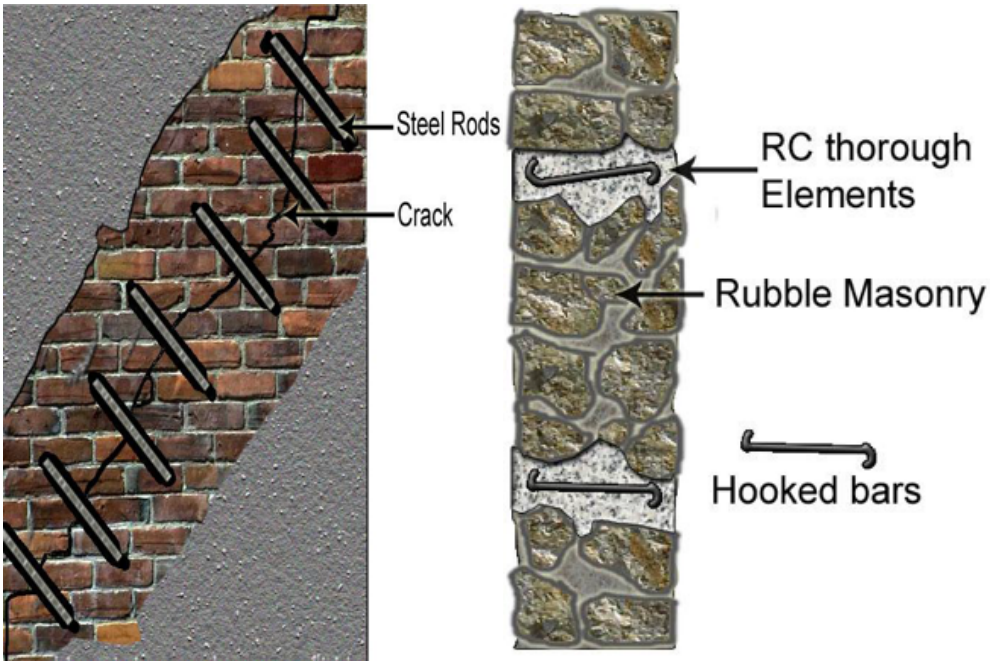


Figure 20: crack repair using 6 mm iron bars (left) and Hook bars in stone masonry wall (right)

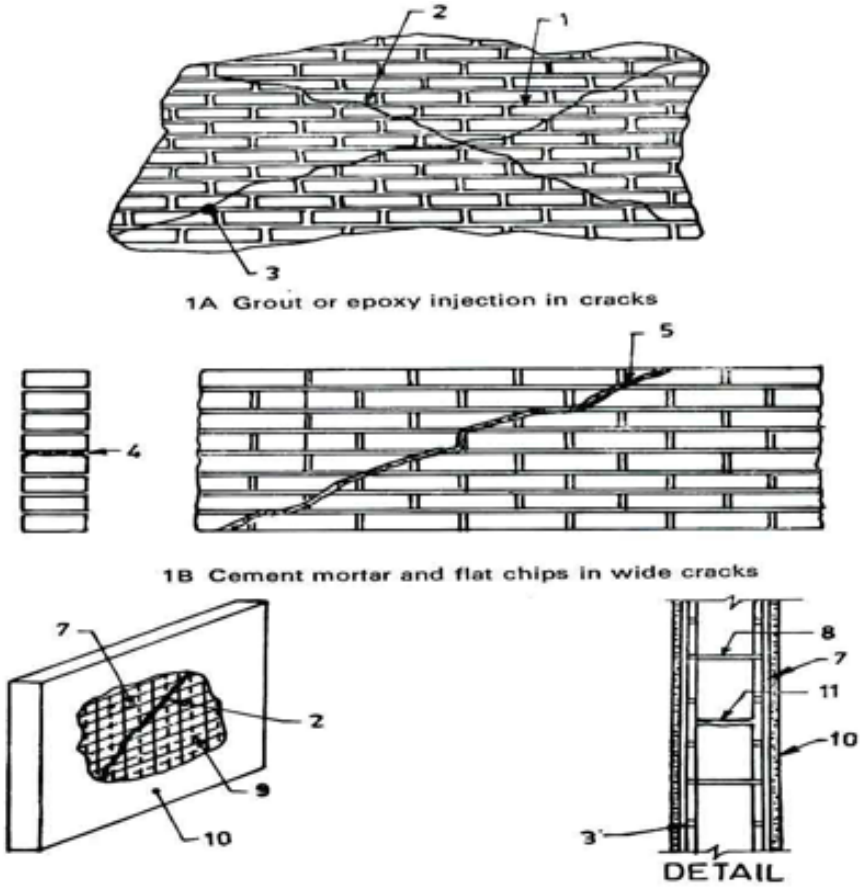


Figure 21: Step wise retrofitting procedure for load bearing wall
(credit: IS code: 19395:2009)

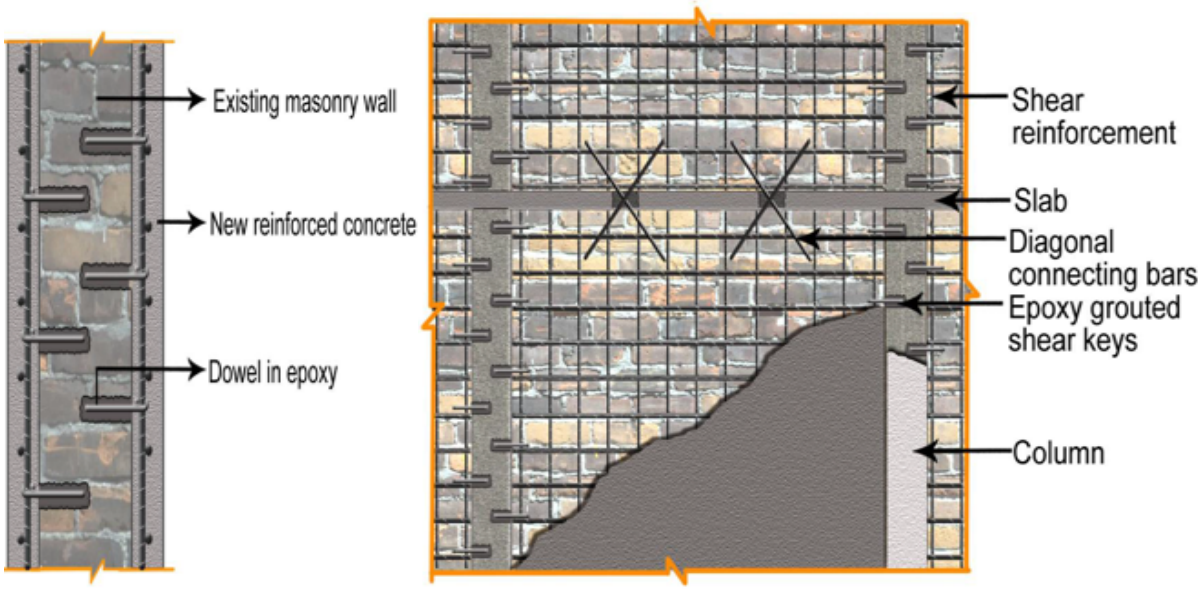


Figure 22: detail of retrofitting procedure for Stone wall *(credit: TESRA ppt)*

Figure 23: Retrofitting procedure of masonry building using iron bars *(credit: www.intechopen.com)*

5.2.3 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 24: image showing damage in columns due to dynamic loading
(credit: TESRA ppt)

Figure 25: 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.

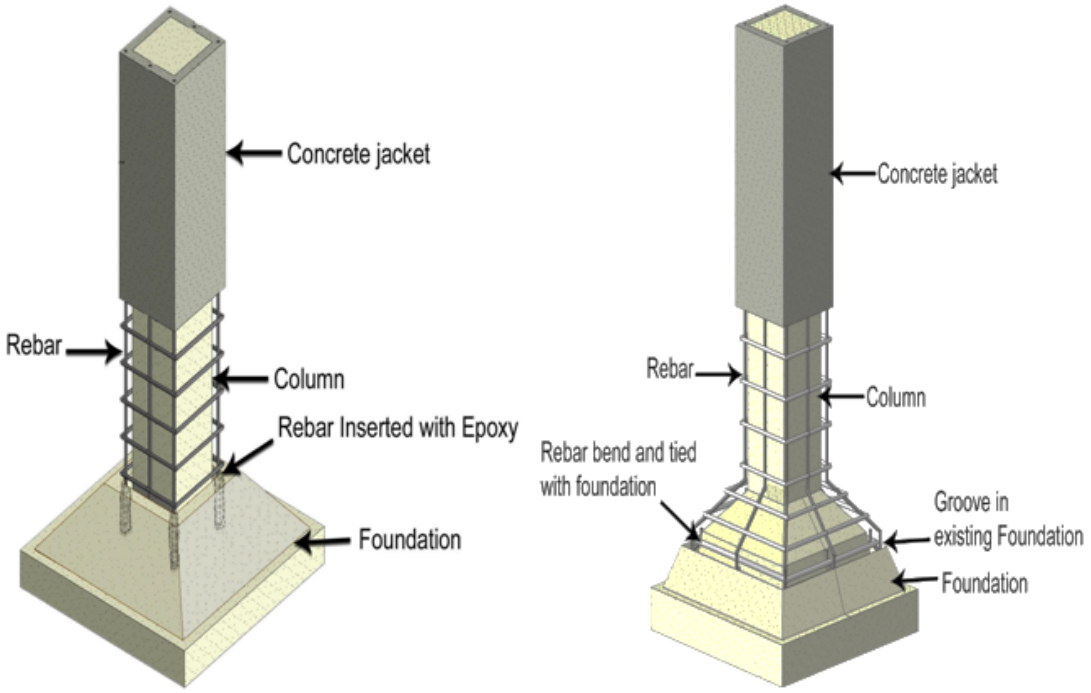


Figure 26: Jacketing of column and foundation *(credit: TESRA ppt)*

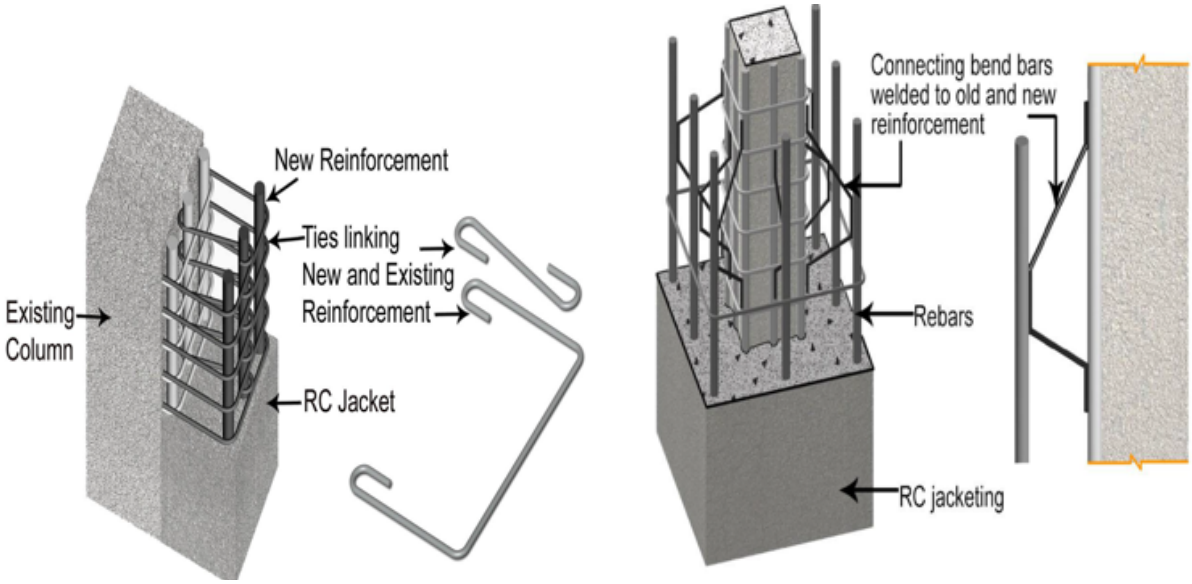


Figure 27: RCC jacketing of existing column *(credit: TESRA ppt)*

5.2.4 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:

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

Figure 28: damage due to sagging *(credit: daily civil)*

Figure 29: 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 30: Jacketing of Beam using FRP *(credit: TESRA ppt)*

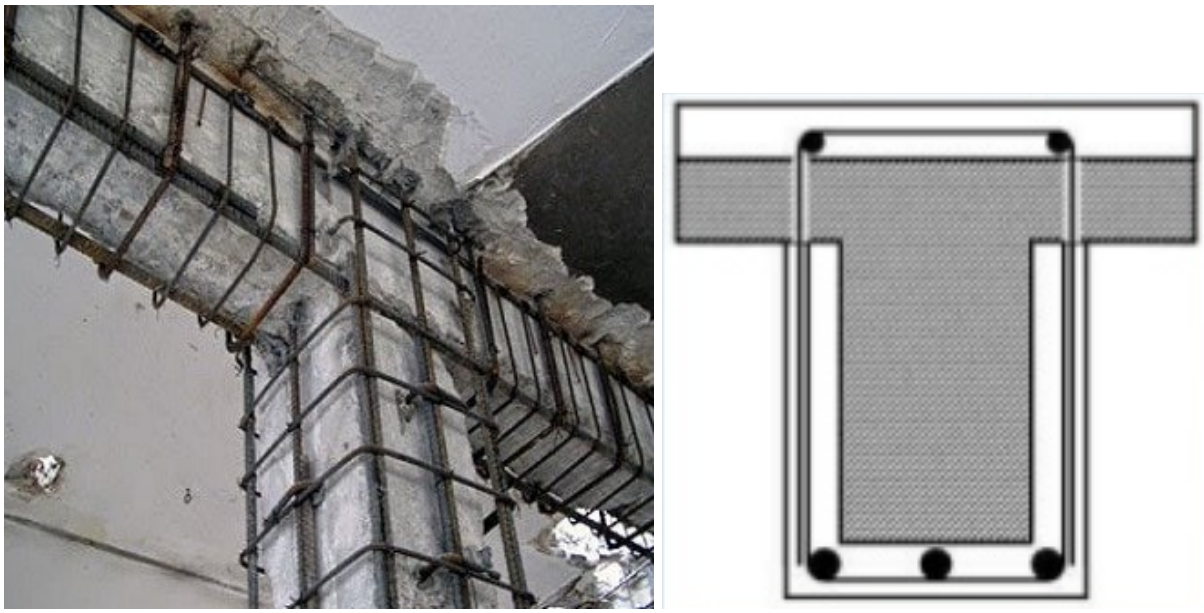


Figure 31: Jacketing of Beam using RCC jacketing *(credit: yash construction)*

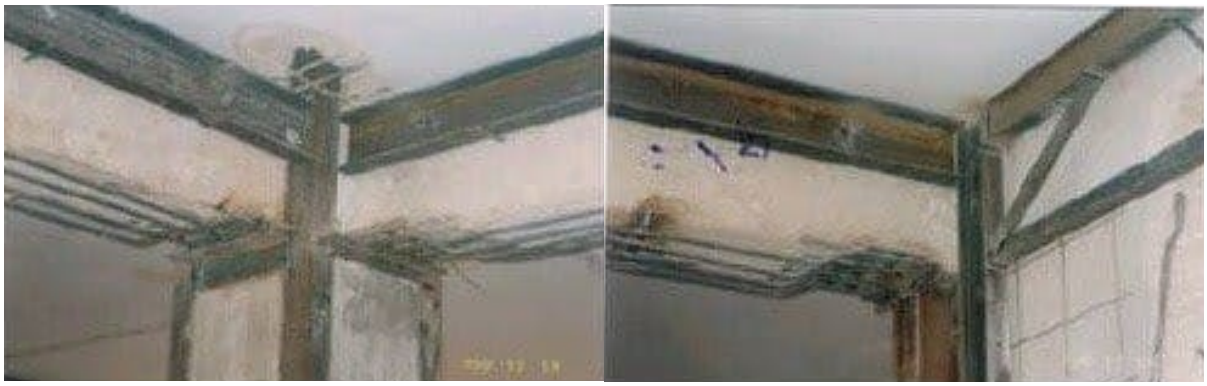


Figure 32: Strengthening a beam, slab & column (left) and Strengthening of beam and slab (right) *(credit: researchgate)*

Figure 33: jacketing by bars in beam (left) and Strengthening by steel plate (right) *(credit: researchgate)*

5.2.5 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 34: de-lamination and rusting in slab (left) and de-lamination of plaster in slab (right) *(credit: researchgate)*

Figure 35: 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 36: retrofitting using FRP (left) and shot-crete in slab (right) *(credit: researchgate)*

5.2.6 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 37: 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.

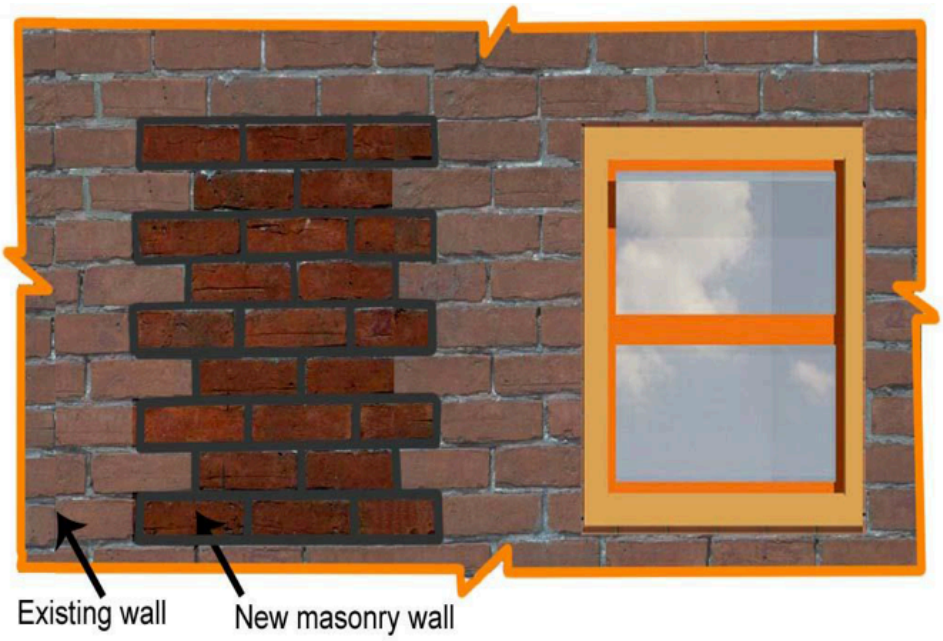


Figure 38: Closing of existing opening *(credit:TESRA ppt)*

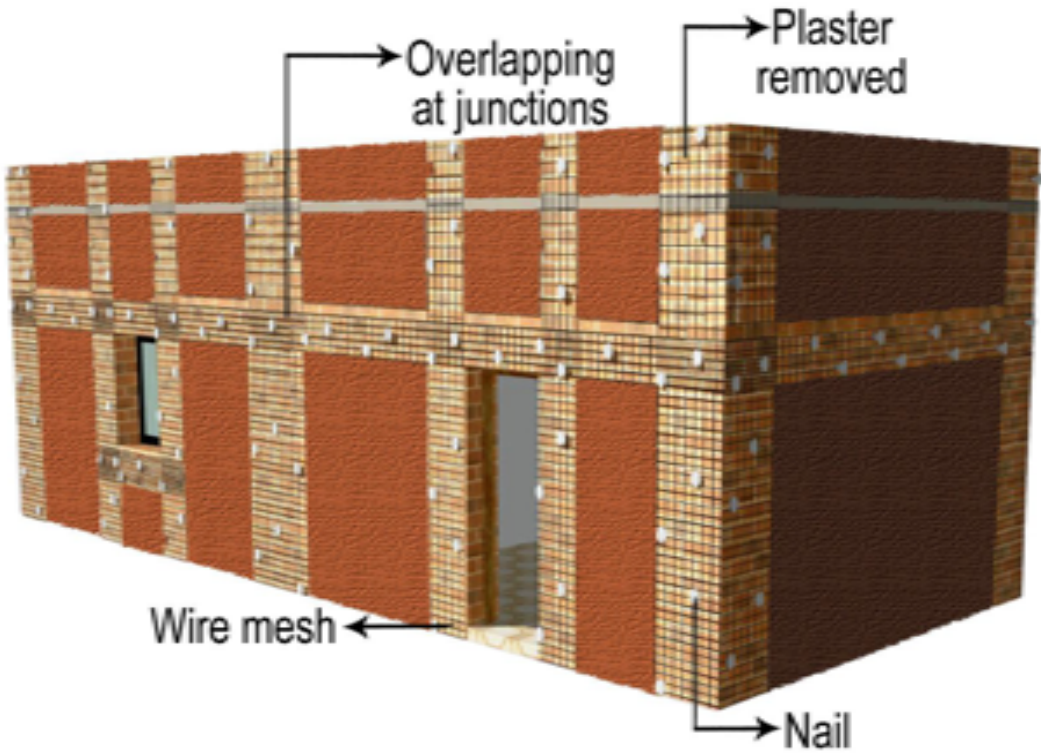


Figure 39: Installation of wire mesh around opening *(credit: TESRA ppt)*

5.2.7 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 6

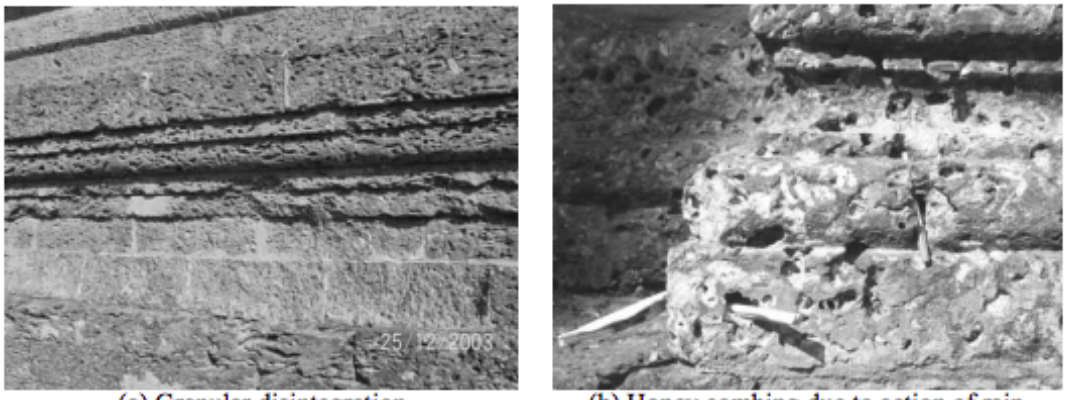
Damage Scenario due to Flood

Damages and Retrofitting due to Flood Hazard

6.1.1 Effect of flooding on buildings built by laterite stone:

In the Kerala laterite stone is broadly used for the construction of different type of buildings. it is locally available material and widely acceptable. Due to this it has an advantage of Most economical material with traditional construction approach. Most of the masons are friendly 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.
2. Bio-degradation.
3. Salt crystallization.
4. Formation of efflorescence.
5. Human Interventions.



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

Figure 40: Image showing damage pattern in laterite stone *(credit: iwww.hms.civil.uminho.pt)*

(a) Growth of moss and lichens

Figure 41: Image showing damage due to bio-degradation in laterite stone
(credit: iwww.hms.civil.uminho.pt)

6.1.2 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 42: Image showing erosion of mortar due to flood water *(credit: inspectapedia.com)*

Different type of foundation settlements:

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

2. **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.

3. **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.

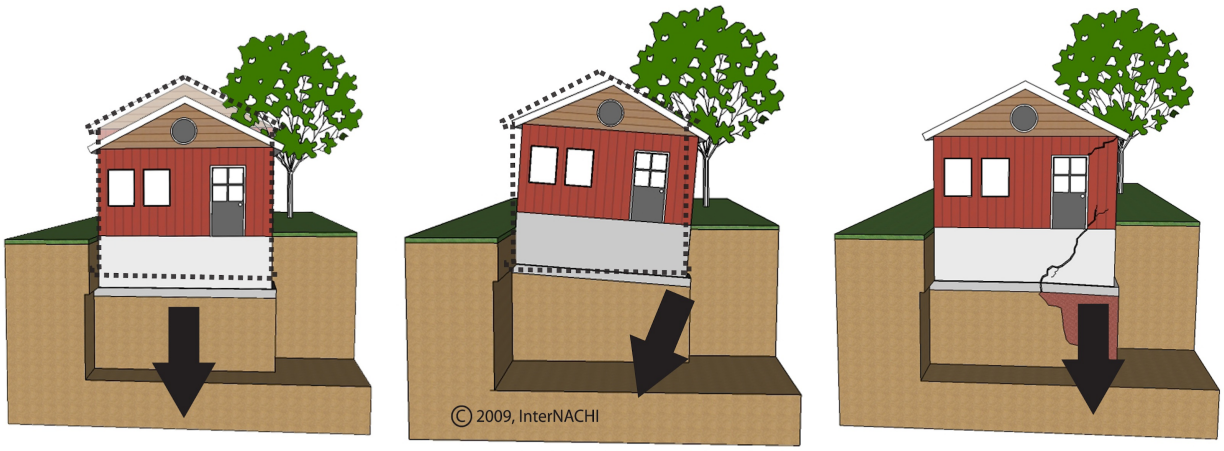


Figure 43: Image showing ground settlement pattern due to flood *(credit:www.nachi.org)*

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

1. **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.

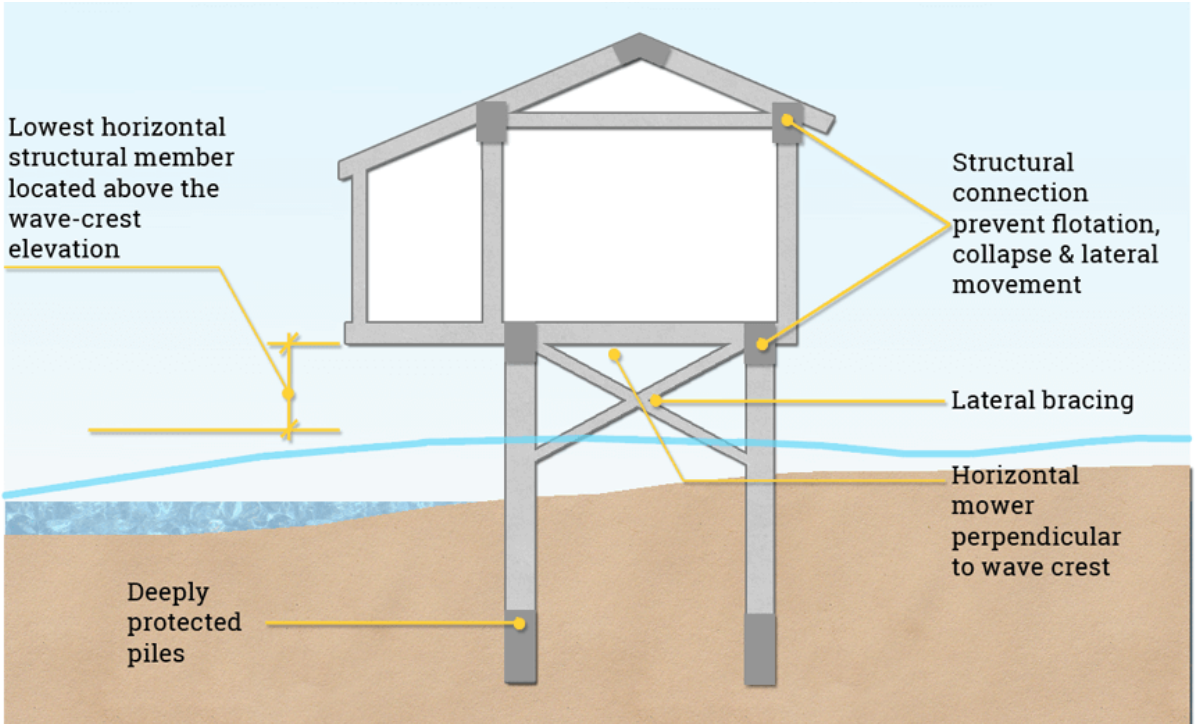


Figure 44: Image showing introduction of bracings between columns *(credit: andhitapradipta.github.io)*

2. **Relocation**

a. Relocating existing structure outside the flood plain

3. **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.
4. **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.
5. **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
6. **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

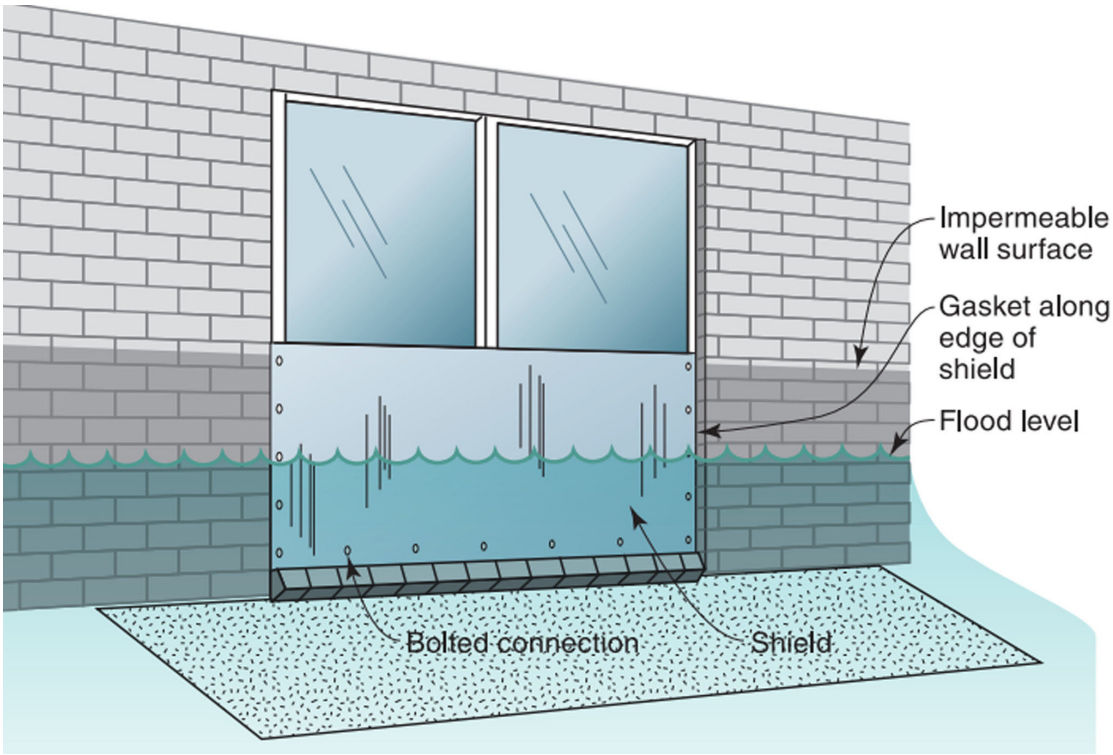


Figure 45: Image showing introduction of Temporary support to avoid flood water *(credit: andhitapradipta.github.io)*

Chapter 7

Damage Scenario due to Landslide

Chapter 7

Damages and Retrofitting due to Landslides

7.1 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.

7.2 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 46: Base soil under foundation eroded due to landslide (*credit: http://www.stuff.co.nz)*

Figure 47: Building partially buried due to landslide (*credit: http://www.stuff.co.nz)*

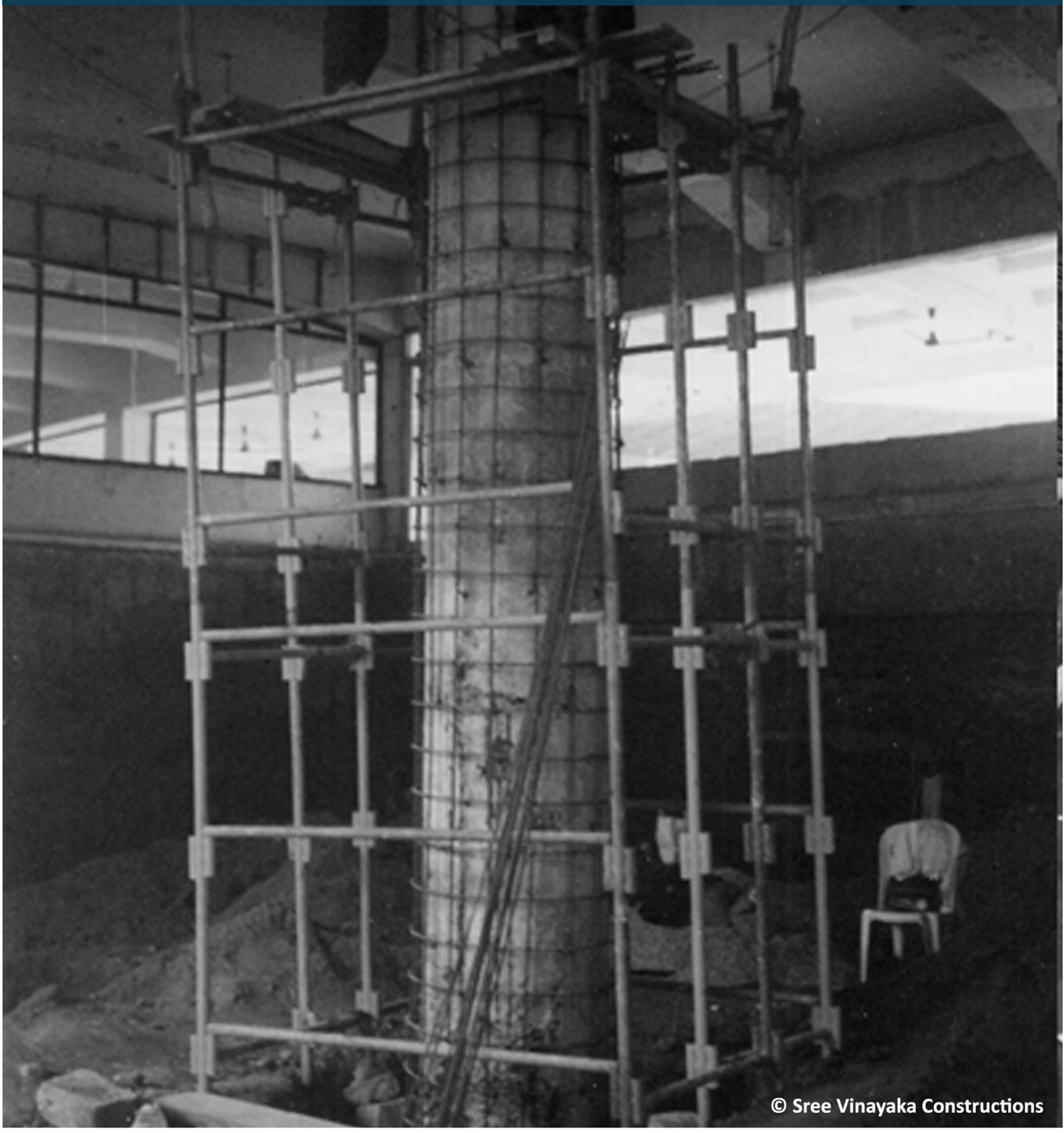
7.3 Building Retrofitting techniques damaged by Landslides:

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

Chapter 8



Retrofitting Execution Methodology

8.1.1 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

7. Mark the height or width of the desired plating based on the weld mesh number of longitudinal wires and the mesh size
8. Cut the existing plaster at the edge by a mechanical cutter for neatness and remove the plaster (see figure below).
9. Rake the exposed joints to a depth of 20 mm. Clean the joints with water jet.
10. 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.
11. 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).
12. 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.
13. 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 49: Removal of plaster and raking of joints process *(Credit: www.bptp.com)*

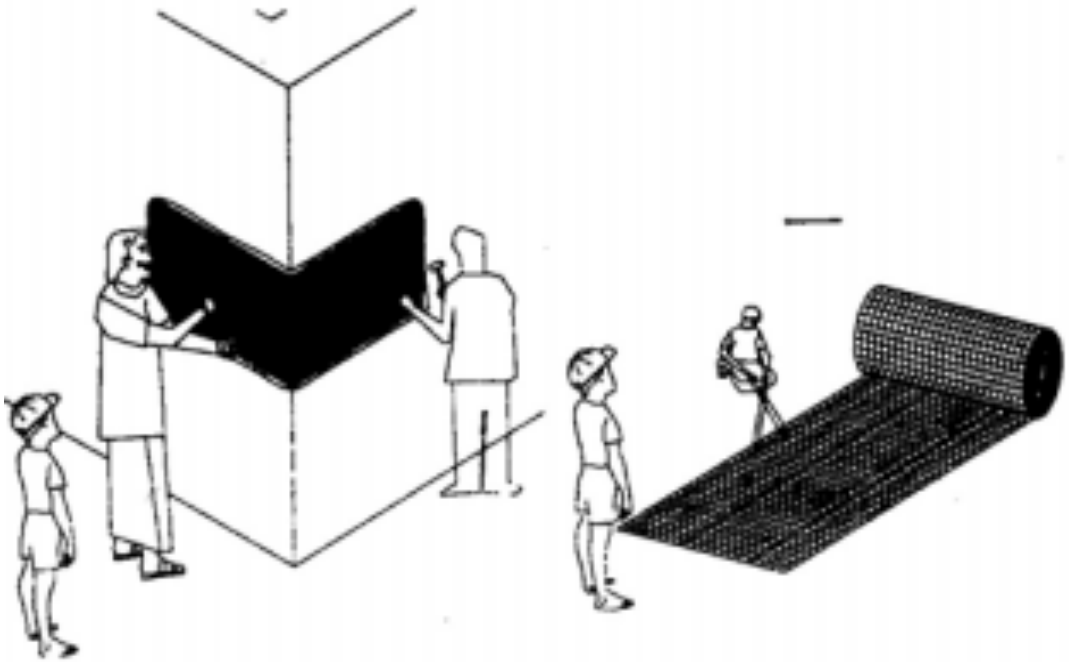


Figure 50: Galvanized steel wire mesh *(Credit: www.bptp.com)*

8.1.2 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.

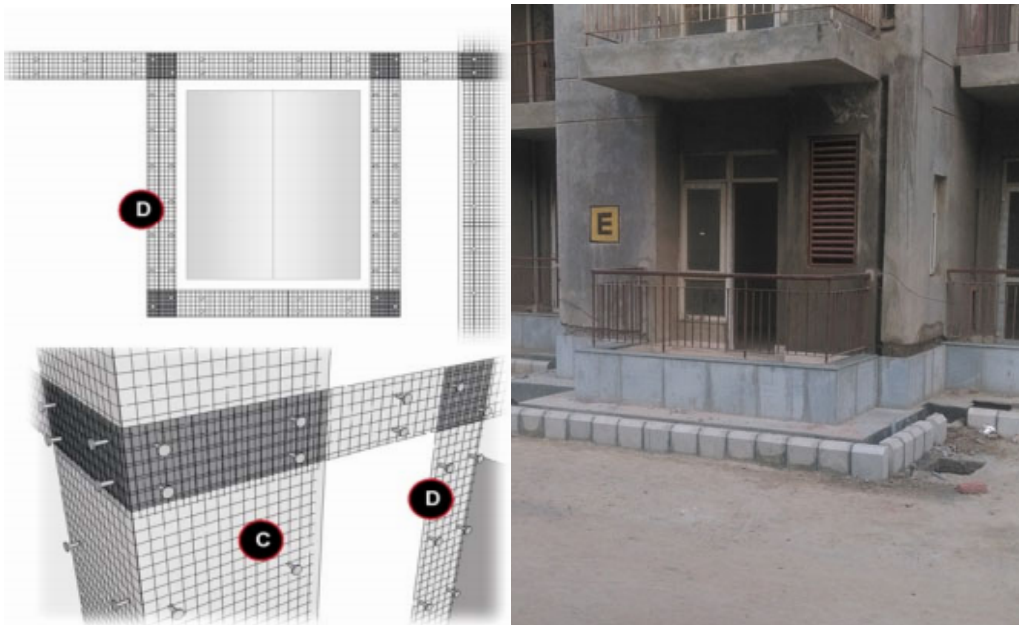


Figure 51: wire mesh installation for plinth protection (left) Stone plinth protection installation (right)
(Credit: www.bptp.com)

Chapter 9

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. Quality control of construction material needed to be regulated by local engineers, government.
7. Awareness campaign on retrofitting and quality construction needed to be executed at different level.
8. Physical demo units needed to be constructed with all the detail demonstration of safe construction techniques in different districts.

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