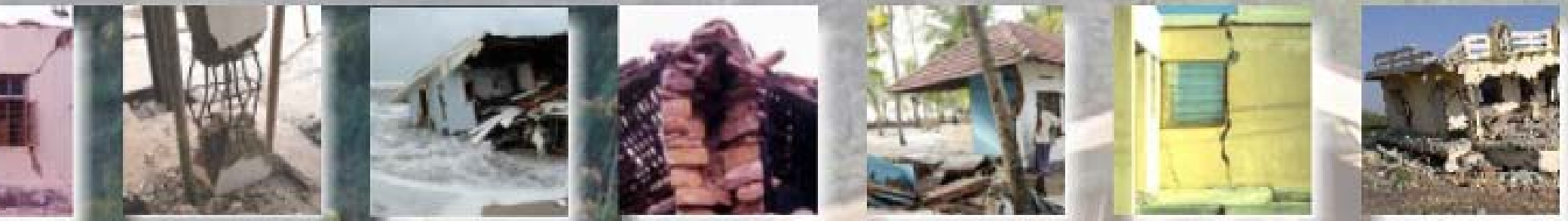

A People's Guide to Building Damages and Disaster Safe Construction

2006
UNNATI - Organisation for Development Education

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Disclaimer

The pages in this document aim to provide general information about the topics they present. A considerable effort has been made in good faith to ensure that the material accessible from this document is accurate. Despite this effort, we understand that errors are possible.

Acknowledgments

Photographs: UNNATI, Hunnarshala and NCPDP
Diagrams: from publications of IITK-BMTPC and Prof. A. S. Arya

Contents

Introduction

In view of recurrent and devastating disasters, it has become essential to understand ways to mitigate their impacts. Unsafe settlements and housing cause the biggest threat to life during natural calamities such as cyclone, earthquake, tsunami, floods or storm surge. Our settlements and habitats are largely owner led developments. However, in past few decades, there has been great loss of local knowledge and traditional artisan skills. There may be many reasons for this. But lately there is a growing recognition of the fact that the most effective mitigation against natural disasters can take place when communities themselves are equipped with knowledge and means to safeguard. Therefore, it is of vital importance for all of us to be aware of consequences of negligent construction practices and safe construction methods.

It is in this context, it is useful to gain knowledge about how buildings are affected during natural disasters, what makes them weak and what can be done to ensure that they can withstand forces of natural hazards. **A People's Guide to Building Damages and Disaster Safe Construction** is a popular learning material brought out by UNNATI with this purpose. It is not exhaustive in its contents but touches upon some of the most common type of damages caused particularly by the earthquakes, tsunami, storm surges or cyclones. It briefly explains the reason of such damages and provides basic guidelines for what will be safer way of construction.

This guide is an effort to communicate construction guidelines in popular format and therefore, the damages and the suggested methods are not exhaustive. However, it gives an elementary understanding of structural damages that occur due to the most common vulnerabilities in houses of poor quality construction. This is based on our own field experiences in post disaster reconstruction work after earthquake in Latur (Maharashtra) and Kutch (Gujarat), tsunami in Tamilnadu and Kerala, and floods in Gujarat. We will like to acknowledge that some of the photographs and sketches used here are adapted and reproduced from the publications of Building Materials and Technology Promotion Council (BMTPC), Indian Institute of Technology, Kanpur (IITK), National institute of Disaster Management (NIDM), Hunnarshala and National Centre for Peoples' Action in Disaster Preparedness (NCPDP) for the purpose of public education.

How to use this Guide

A People's Guide for the Building Damages and Disaster Safe Construction focuses on some most frequently found damages during the disasters. Also it is based more on impacts due to earthquake, floods, storm surge, cyclone and tsunami. It should not be taken as a comprehensive list of the damages or the remedies. This guide is developed using illustrations like photographs and sketches so that one can browse through it easily.

The guide discusses the building in terms of damage to its three major components.

1. Foundation and plinth
2. Walls and openings
3. Roof and overhangs

These components of the house are discussed in form of three main questions.

- What type of damage occurs?
- Why does it occur?
- What can be done to prevent it?

The photographs showcase typical examples of the damage. The reasons of the damage have been explained through the sketches or simple diagrams. The preventive measures are more in form of basic principles. This should strengthen our fundamental understanding for disaster safe construction. For construction of the houses, it is advisable to go through regional safety guidelines and building codes and incorporate the appropriate details.

1

Foundation and Plinth

1.1 Foundation is collapsed mostly in the corners. In some cases the collapse of foundation has also led to damage to the superstructure.

This damage occurs primarily when storm surge or tsunami strikes. It can also happen in the areas of excessive flooding. It is primarily due to washing away of the soil on which foundations rest and is generally known as **scouring**. The loss of the base of the foundations results in its collapse and if it is beyond a certain extent even the superstructure may get collapsed.

The flowing water washes the soil particularly at the corners because of local whirling action when it strikes the building. But it can also happen even along the length of the wall when the soil is loose and water inundates and then drains taking the soil along with it.

1.2

In earthquake affected areas, sometimes foundations get damaged. The foundations develop cracks or even fully collapse at times. In one of the adjacent photographs, we can see the whole building block has tilted and sunk in the ground.

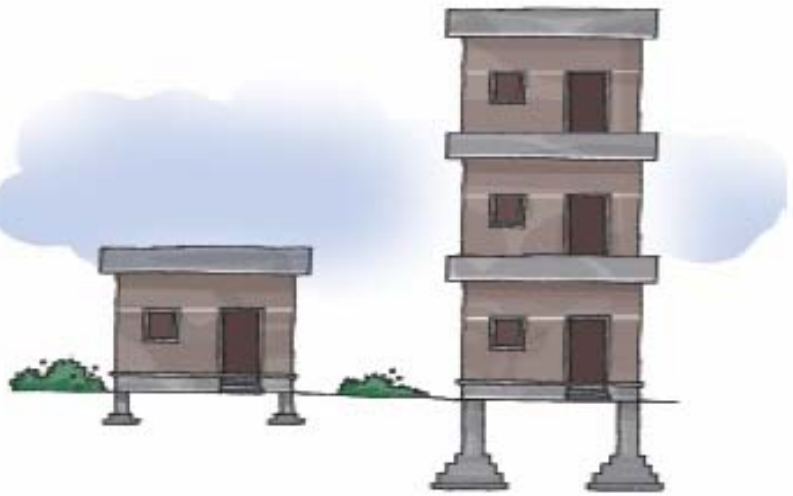
This type of damage occurs primarily in earthquake hit areas. Certain saturated soils may behave like liquids during the earthquake. When soils behave like liquids, they lose their bearing capacity. This phenomenon is called **liquefaction**. In one adjacent photograph, we can see the soil below is lost due to liquefaction and hence the foundations have collapsed. In the other photograph the whole building block has tilted due to sinking of the foundation in soil due to its liquid behaviour.

How can we construct the foundations to safeguard against these damages?

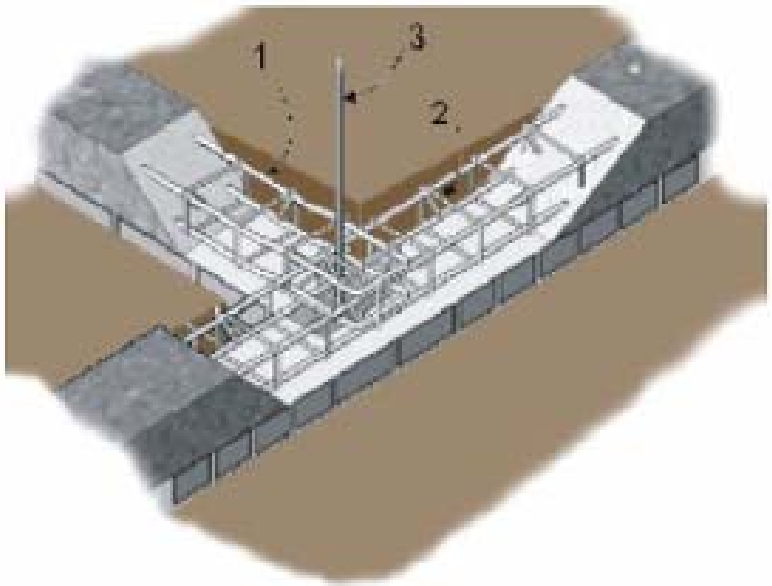
We can follow simple principles to increase our safety during the disaster from such damage to our houses.

The most important principle is to choose the site correctly. The building sites with soil having good bearing capacity should be chosen. It is very easy to get the soil tested in a laboratory. Also local knowledge of soil depth and soil composition can be helpful in making some judgement about it. The soils that are compact, less expansive, and not water saturated should be preferred.

Foundations should be deep enough to rest on the solid base. The depth of foundation depends on number of storeys that it carries.



To safeguard against any settlement of the soil in areas that may be prone to scouring or liquefaction, the grade beam should be installed while construction of the house. Grade beam is a ground level beam on which the walls rest and can save the superstructure in case the foundations below get damaged. Another alternative for preventing damage of scouring is addition of extra plinth all around the building. In case of scouring it is this plinth which will be damaged not the foundations and floor of the building.



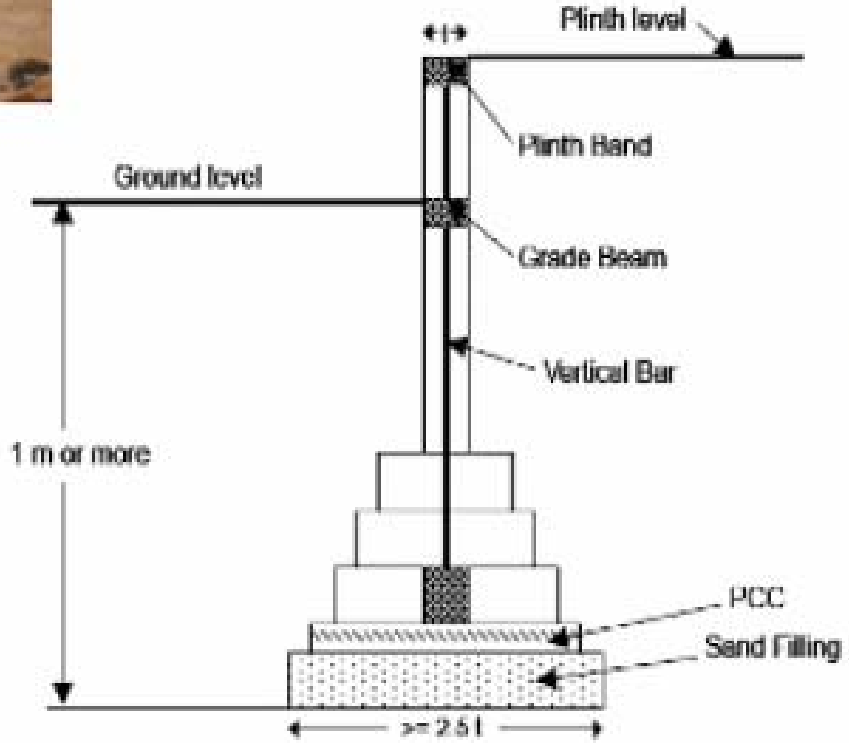
1. Longitudinal reinforcements
2. Lateral Ties
3. Vertical reinforcement at corners

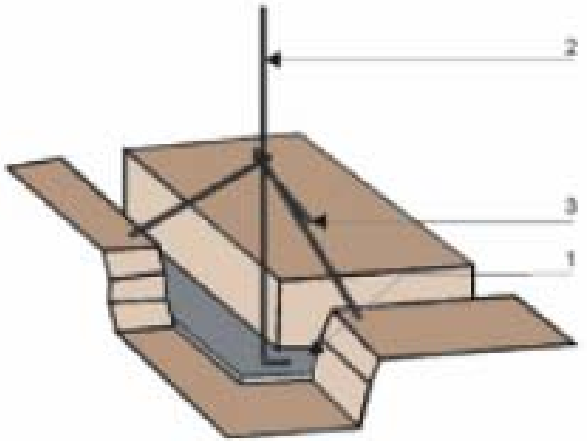
Extended plinth around the building protects from scouring

Grade beam

Plinth band should be provided at the floor level. This helps in holding the plinth together and prevents any cracks due to any uneven settlement in the walls above. The photograph here shows installation of plinth band.

The vertical bar at the corners should tie grade beam and the plinth band as shown in the diagram below and continue upwards till roof.



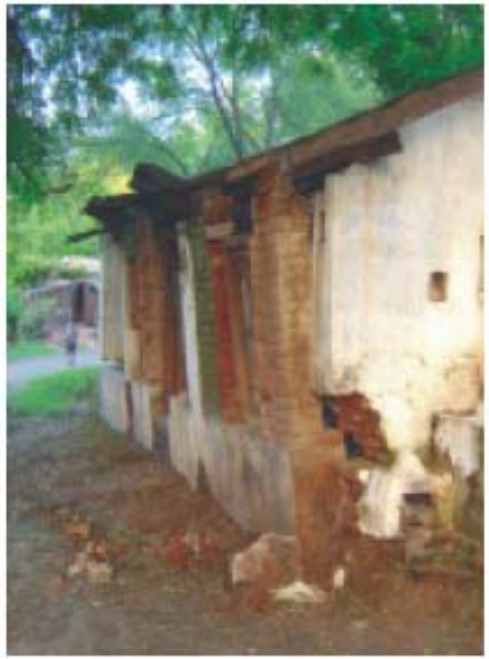


1. Leveling concrete
2. Vertical bar
3. Tripod

2

Walls and Openings

2.1



The photographs here show a typical damage of walls that occurs during many disasters. The walls tend to separate at the corners and develop a vertical crack. Some times one of the walls tilts and goes out of plumb.

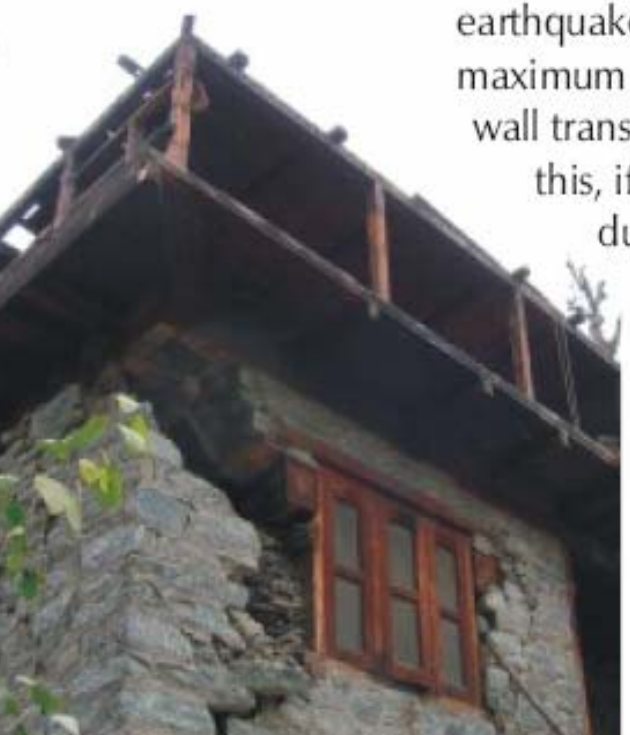
This is primarily due to insufficient bonding between two walls. In case of earthquakes, due to shaking of both the walls, they tend to separate from each other. Similarly, in floods or tsunami or storm surges, if there is any damage to soil below foundation that can cause tilting of the walls, the walls tend to separate at the corners.

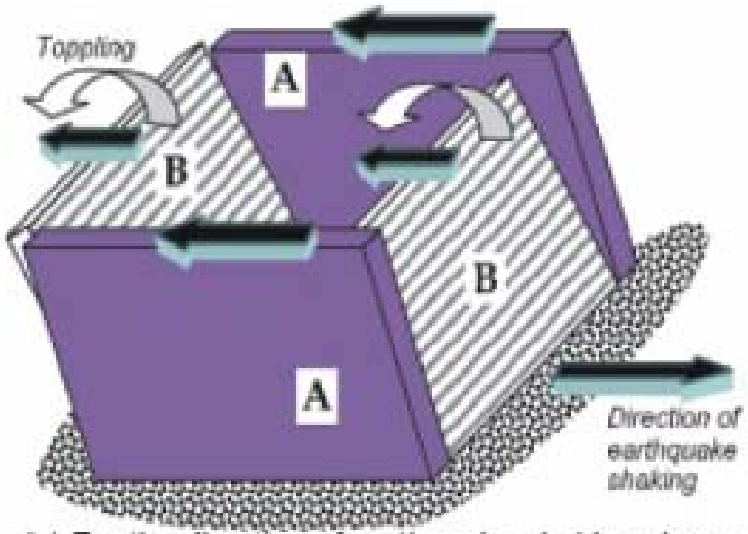
A good bond between two walls would have prevented development of such a crack. Earthquake shaking can also lead to tilting of any wall if the bonding at the corner is not sufficient. The joint between two walls becomes weak if there is insufficient overlap between corner blocks or there is lack of mortar between joints.

2.2

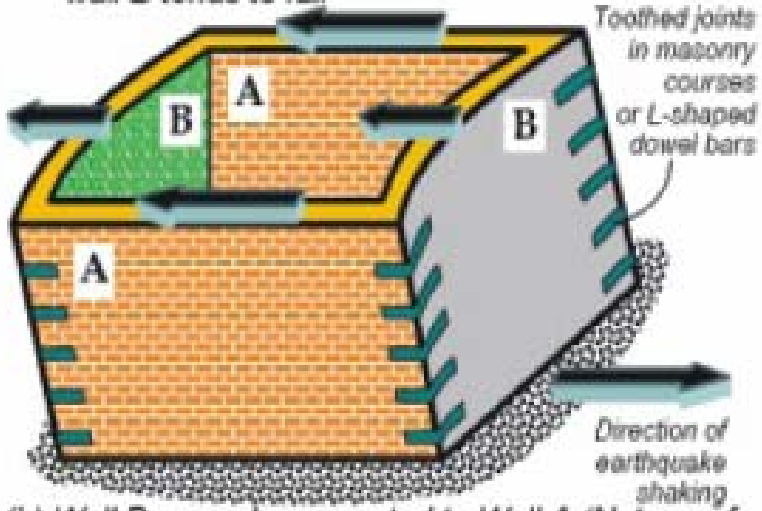
As shown here in the photographs, corners of the walls have collapsed. Though the photographs here show stone masonry but this type of damage can also bee seen in the houses constructed with other materials like bricks and concrete blocks.

This type of damage is commonly observed in the earthquake affected houses. During the earthquake, the corners of the building face maximum stress as that's the point where one wall transfers the force to another. As a result of this, if the corners of the buildings are not ductile enough to transfer the thrust, they can fail like in these photographs. As described above if the corner joints between walls are weak due to insufficient overlap of blocks, the corner failures are more probable during the disaster.





(a) For the direction of earthquake shaking shown, wall B tends to fail

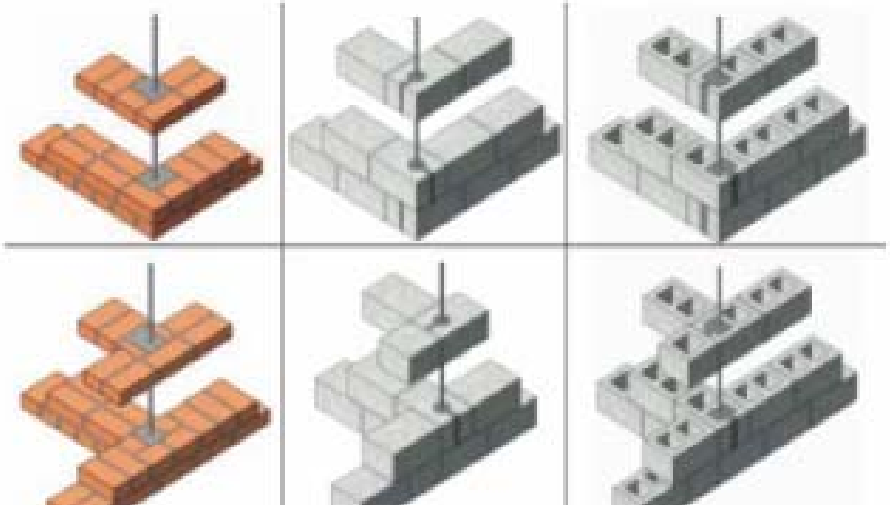


(b) Wall B properly connected to Wall A (Note: roof is not shown): Walls A (loaded in strong direction) support Walls B (loaded in weak direction)

How can we do masonry at the corners to make it safe against these damages?

To strengthen the corners during the masonry, we need to take care of the following points.

- Vertical reinforcements should be put in all the corners and junctions of the walls. This adds ductility at the corners for easier transfer of the forces.



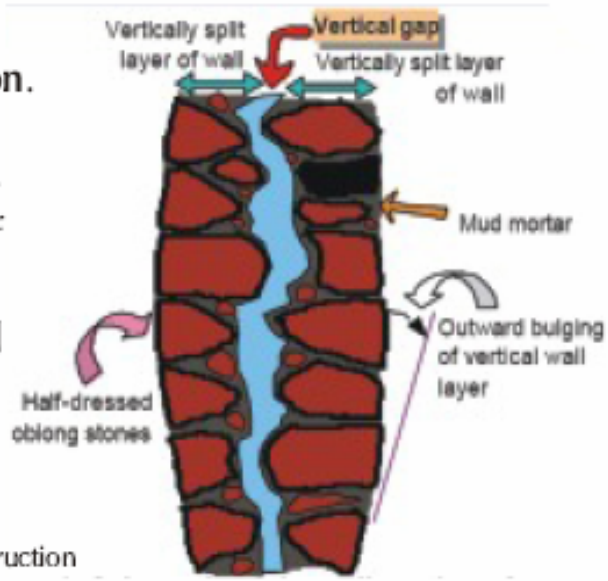
- Walls should be constructed layer wise and all the walls of a house should be constructed simultaneously. The practice to construct one wall very high leaving teething to join with other wall when that is constructed is a faulty practice. Due to this the mortar is not filled in such joints resulting in weak corners. Instead of teething, stepping masonry should be made for joining the walls.

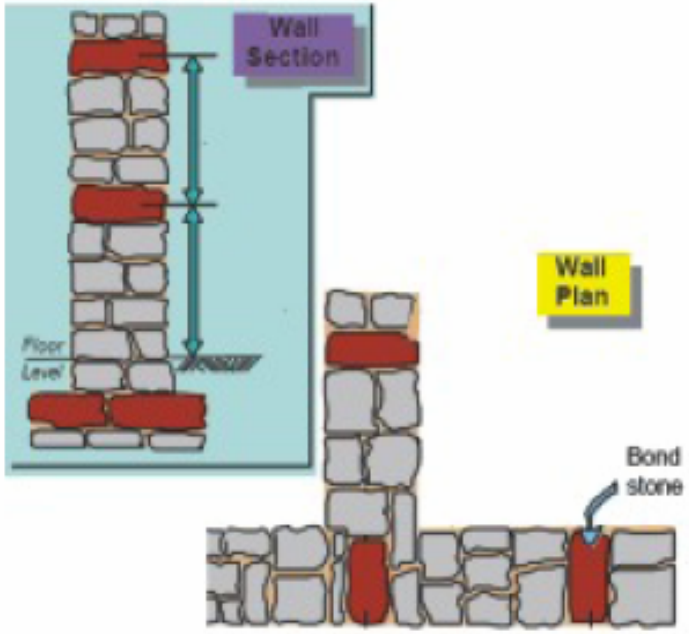
- Continuous vertical joints in brick & stone masonry should be avoided.

No vertical joints in the masonry of the walls

2.3 In thick stone walls the inner and outer face of the walls have separated. In the photograph shown here, the separation of faces has led to bulging of the wall from mid height. In other photos the outer face has totally separated and fallen of causing severe damage to the structure.

This type of damage is typical in thick stone walls when such walls face horizontal shaking. As the stones are not properly interlocked, both faces of the walls open up. As the walls are held from the bottom with the foundation and at the top with the roof, **bulging** tends to happen mostly from the mid-height. When two faces completely separate and outer faces collapses, it is called **delamination**. In sloping roof structures where there are gable end walls which are vulnerable to this type of the damage. Delamination can cause collapse of roof due to weakening of the load bearing structure. The walls with such damages can not be repaired and it is the best to rebuild them.





How can we ensure that bulging and delamination doesn't take place in the walls?

The walls can be constructed in such a way that bulging and delamination doesn't take place. Following practices should be adopted while construction of stone masonry.

- When constructed stone walls, full width stones should be used at regular intervals along the length and the height of the walls. These stones hold both the faces of the walls together and are called **through stones** or **bond elements**.

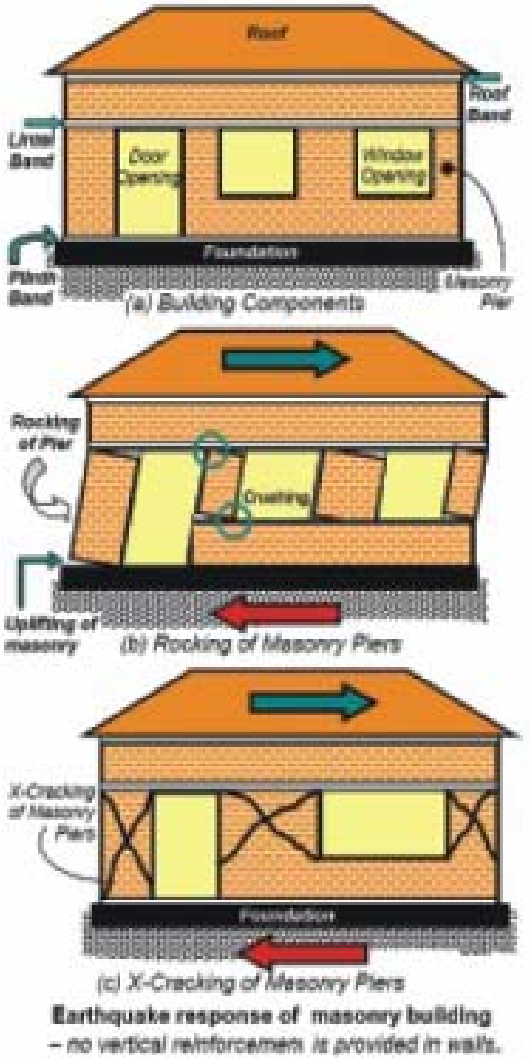
- Generally, two stones with good faces are put on the sides and small stones are just filled in the middle portion. This is a faulty practice. We should ensure proper interlocking of the stones of the both faces in the masonry.

- The wall thickness above plinth should not be more than one and half feet or 45 cm. If the walls are thicker, making interlocking joints becomes more difficult and much longer stones are required.

2.4

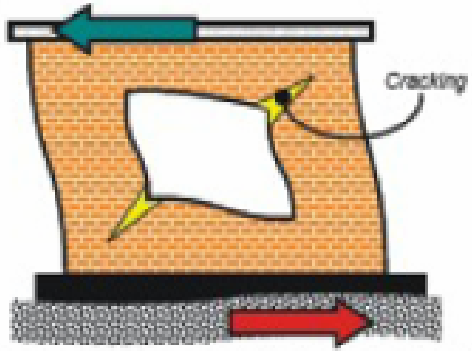
As visible in the photographs, the diagonal cracks develop on the corners of the door and window openings. These corner cracks may develop on both - top and bottom - corners of the window opening.

When the shaking takes place the edges of the opening tend to deform and stresses develop at the corners in diagonal direction. These stresses cause cracks to develop in the walls below and above the openings starting from the corners. Similarly when there are series of openings in a wall. These stresses can cause X shaped cracking in the walls in between the openings. When the lintel above the openings is not sufficiently embedded, these cracks may become more prominent.

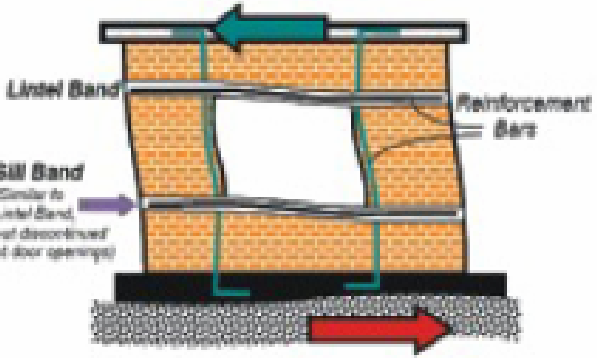


Earthquake response of masonry building
– no vertical reinforcement is provided in walls.

How can we avoid the cracks around the door and window opening?

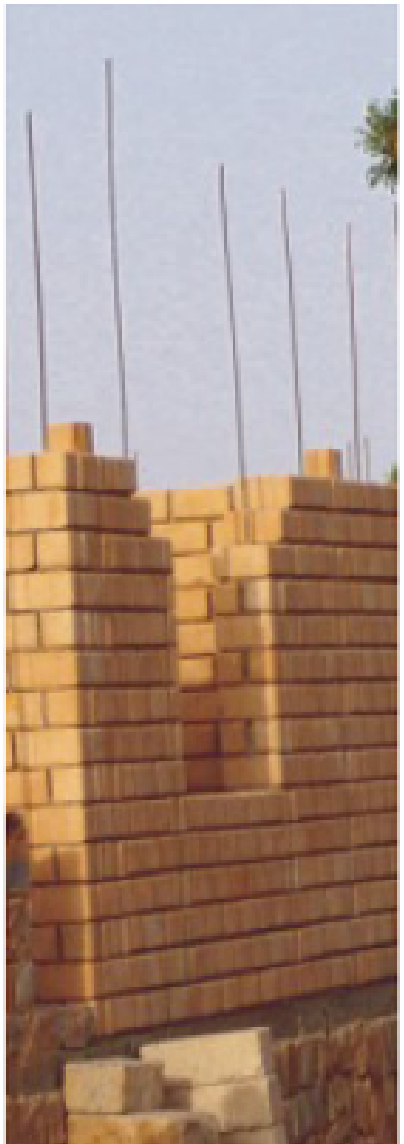


Cracking in building with no vertical reinforcement



No cracks in building with vertical reinforcement

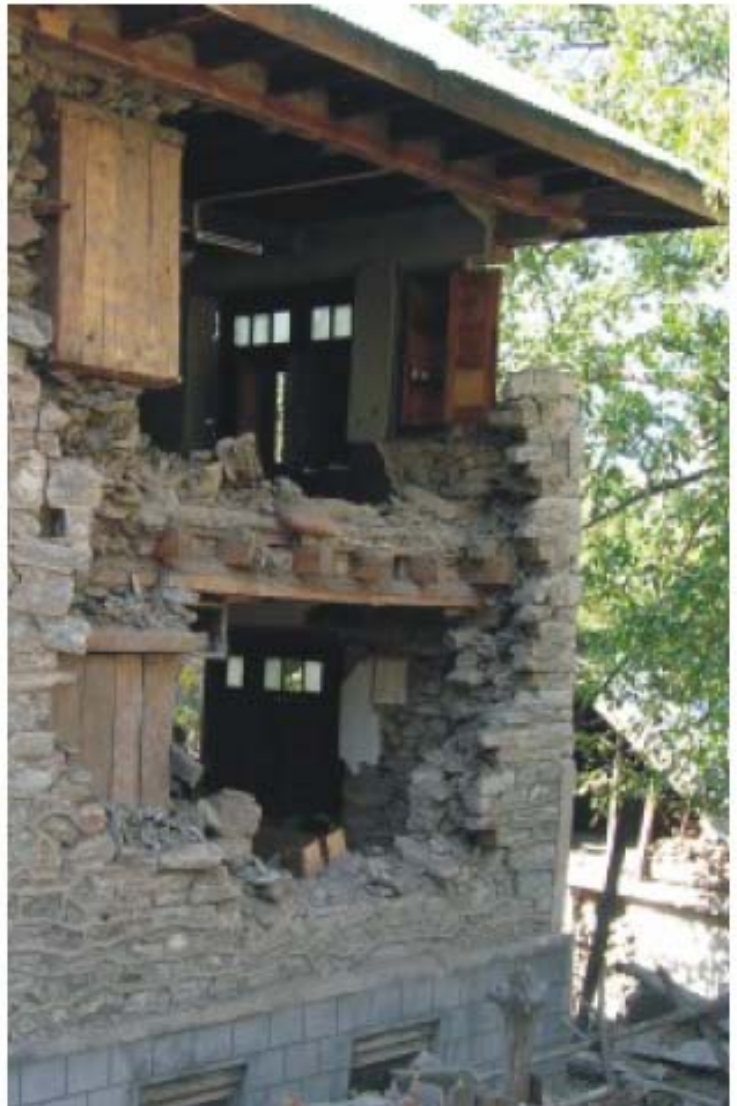
- Lintel and sill band also prevent such cracks from developing. These bands should be incorporated in the construction.



The cracks in the walls around the doors and windows can be prevented by following simple principles.

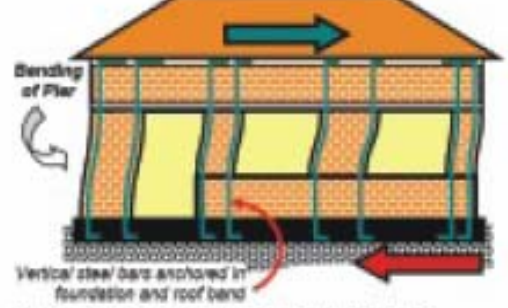
- The edges of the openings should be built to behave in more ductile way. This can be done by adding vertical reinforcement at the jamb of the door and window openings.

2.5 **The photographs here depict collapse of the walls. The collapse of walls threatens complete building as the walls are load bearing.**

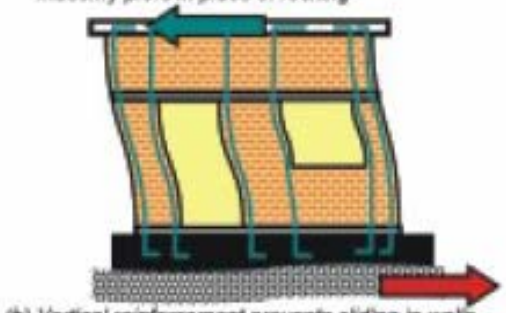


The collapse of walls happens due to various reasons. Where major portion of walls is collapsed, it is due to failure of walls due to shaking in the direction of its thickness. The walls are weaker in this direction. The walls are stronger to resist shaking if it is in the direction of its length. As a result of shaking and lack of cross walls, it can go out of plumb and collapse. The walls with more height are more susceptible to such damages for example gable end walls. Similarly free standing walls such as boundary wall or a parapet can also have **out of plane collapse.**

The walls can also be damaged and collapse when they face horizontal impact, say for example, in case of tsunami. With such high impact, the walls can disintegrate in pieces leading to total collapse of the structure.



(a) Vertical reinforcement causes bending of masonry piers in place of rocking



(b) Vertical reinforcement prevents sliding in walls

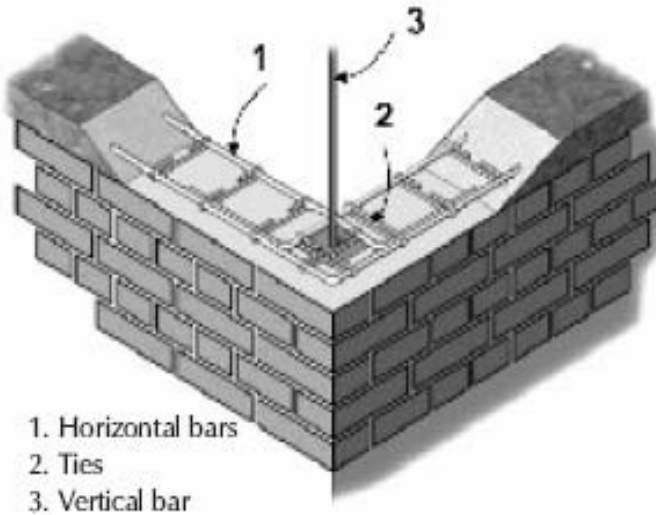
How can we strengthen the walls to resist horizontal shaking

To resist the horizontal thrusts, the walls need to be strengthened in the direction of its thickness. The following guidelines can be useful in this regard.

- The house should have cross walls to provide bracing at certain interval in a long wall. The walls can also be braced with buttresses and piers.

- Horizontal and vertical reinforcements in the walls add to its ductility. It is, therefore, desirable have horizontal bands at different heights of the walls such as plinth, sill, lintel and roof. Similarly vertical reinforcements should be added at the junctions of the walls and jambs of the openings.

- Also large openings weaken the walls. It is preferable to have smaller openings. There are guidelines about the proportion of the length of openings against total length of the wall. Normally it should not exceed more than 50% to ensure strong and safe construction.

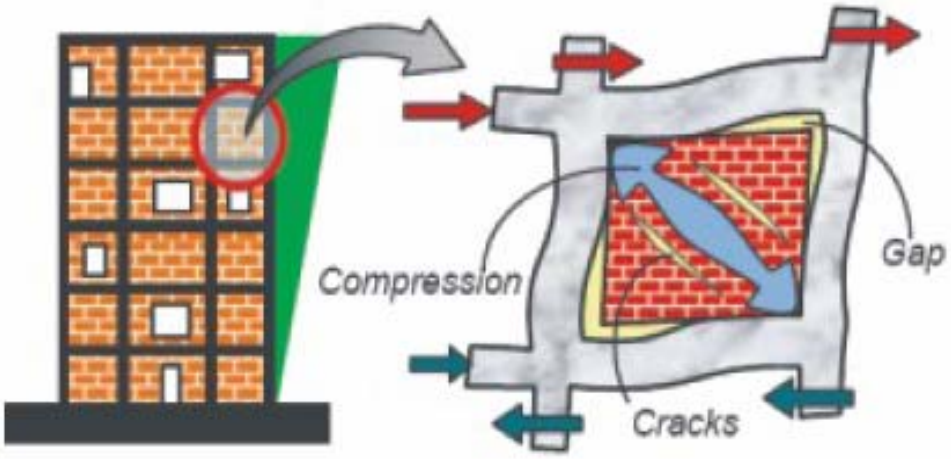


1. Horizontal bars
2. Ties
3. Vertical bar

Source: Technical Guidelines by Prof. Arya

2.6

In the buildings that are frame structures, i.e. with column and beams as load bearing system, the cracks develop between the structural frame and the filler walls.



This is primarily due to the fact that both the filler walls and the column beam structure are not connected and shake independently. Also there is a continuous vertical joint between the filler wall and the column which tends to open up when the building is under horizontal stress and sway. In severe cases, the filler walls can face shear failure causing damage and its collapse.

How can we prevent cracks from developing between the filler walls and the structural frame of the RCC buildings?

These cracks can be minimised by

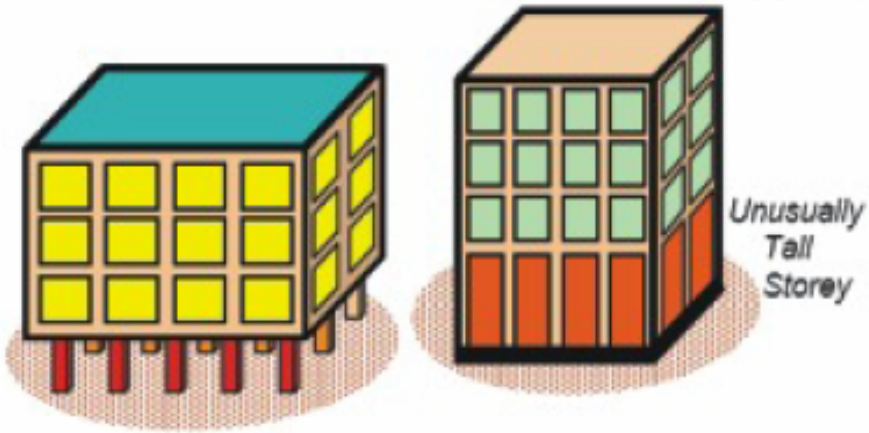
- Incorporating better connection between filler walls and the columns so that vertical joints do not run through the entire height of the structure. This can be done by incorporating sill level band in mid height.

- There can also be teething between the columns and the filler walls to improve the connectivity.

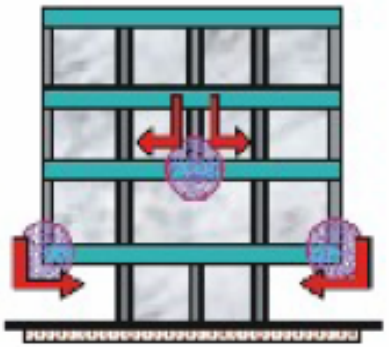
2.7

The photographs show that columns of the buildings have been damaged in the earthquake. The reinforcements of the columns have spread outwards and the stirrups holding the vertical reinforcements have failed. Also the concrete part of the columns has been damaged. It is also noticeable that it has occurred at the junction with the beams or the foundation. In other photographs, columned storey has completely collapsed and building has come down.

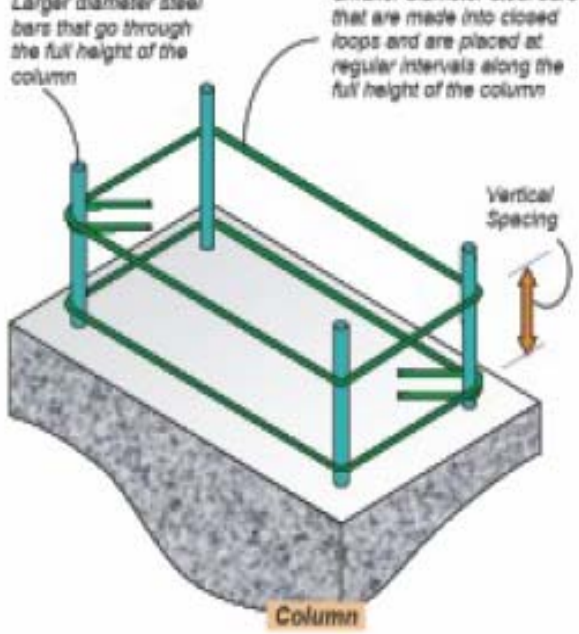
This type of damage is known as **buckling** of the columns. The buildings that are on the stilts and have a clear storey are particularly vulnerable to such damages. The height of clear storey is very critical. If the columns are too long or too short, they can fail due to the shear forces. As the shear force is the maximum at the junctions of the beam or of the foundation, the failures are more likely to occur there. Inadequate and faulty installation of the stirrups in along the height of the column makes it further weak. The failure of the columns due to shear can result in the complete collapse of clear storey and the whole building can come down as in the photographs.



Weak or Flexible Storey



Hanging or Floating Columns

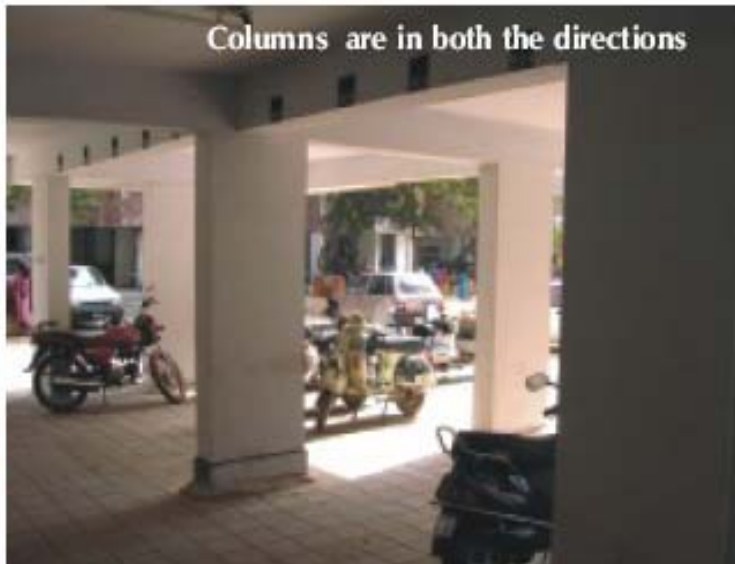


How can we ensure that columns are strong enough to resist buckling during the earthquakes?

- The performance of the columns to resist shear forces can be improved by ensuring proper installation of the stirrups. Also the care should be taken to install them at appropriate interval as per building codes.
- Particular care should be taken to strengthen the joints of the columns and the beams and the joints between columns and the foundations. Usually the stirrups will be more closely placed in these areas.
- A trained and registered engineer should be involved to help in design of these structures. The IS codes for engineering design of such structures should be followed.

Following basic guidelines should be followed to ensure safety of the building from such extensive and life threatening damage.

- The columns in stilted buildings should be designed considering the shear forces. Having columns in both the directions of the building as shown in the photograph adds to the shear strength.
-


Columns are in both the directions

3

Roof and Overhangs

3.1

The roofing components fly off due to cyclonic winds. And sometimes even the understructure of the sloping roof gets dislocated.

This is primarily due to poor anchorage of tiles or the roofing sheet to the understructure and poor connection between the roof understructure and the walls.

During the cyclones, wind tends to lift the roof and light weight components if not anchored properly fly off.

How can we prevent the loss of roofing components due to cyclonic winds?

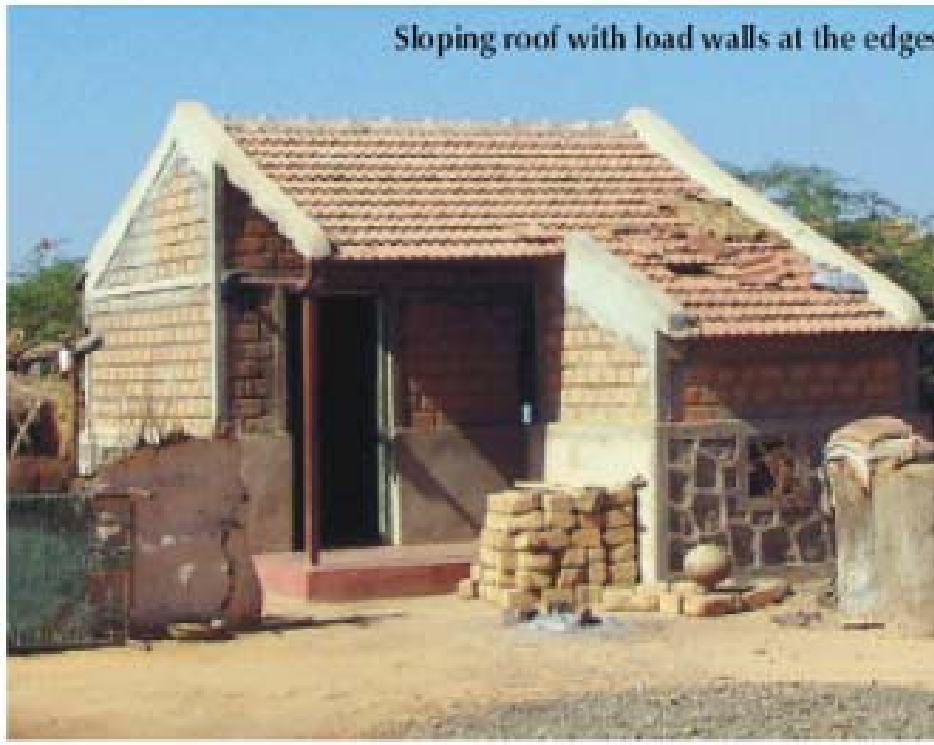
Almost all the coastal areas are prone to cyclonic winds and have traditional houses with mangalore pattern tile roofs. Following principles can prevent this damage.

- The roofing components should be anchored with the understructure. The CGI sheets should be fixed using J shaped hooks. And hooks should also be incorporated to hold mangalore pattern tile roofs as shown in the photograph. With this anchorage, the tiles can not fly off.

- The roofing understructure should also be fixed with the walls.

- Four way hipped roofs face less upward pressure due to their shape. However, the performance of two way sloping roofs increases if the load walls are installed on its edges.

- Steep roofs on low height walls have better performance in the cyclone than less slope roofs on high walls.



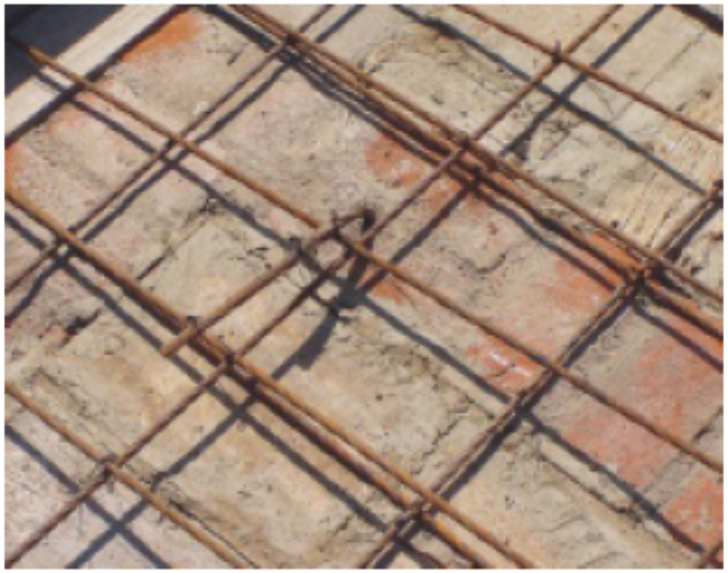
Sloping roof with load walls at the edge

Hipped roof

3.2

The damage in photograph shows that the sloping roof has dislocated from its position. In the other photograph we see that RCC roof has separated from the walls and a crack has developed all along.

This type of damage occurs due to independent movement of the walls and the roof. When the walls and roof are not properly connected, they tend to separate during the sway. Too much of dislocation with insufficient bearing can also cause collapse.



How can this damage of the roofs and walls be prevented?

The principles that can help us in making our houses with safeguard against such a damage are as follows.

- The roof and wall should be tied with each other so that both move together in case of any horizontal thrust. The vertical bars from the walls should be taken into the roof slab to fix it with the wall.

- Similarly in case of sloping roofs, the wooden understraucture should be fixed with the walls by tying the wall plate with the wall.
- In sloping roof the understructure should also be provided with in plane bracing so that when the roof moves all the elements move together without any distortion in the shape and the form to avoid any disintegration.

3.3

The adjacent photograph shows the damage to a cantilever structure. The cantilever structure can be a verandah roof, balcony, chhajja or window and door shade.

Cantilevers develop stress at the junctions with the walls as a result it is this point where most of the failures occur. Parapet walls also behave like a cantilever during the earthquake and therefore can get damaged.

How can we ensure that cantilevers do not get damaged during the earthquake?

The foremost principle to prevent this type of damage is to avoid large size cantilever. And any kind of uneven structural loading on the cantilever should not be made. The reinforcement design should consider the shear force at the junctions and sufficient embedment in the walls should be provided. The design of such structures must be based on the building codes.

Let's recapitulate

Various natural hazards can cause different type of damages to the building depending on many factors such as location, materials and technology used. This guide is focused only on some of the most common type of damages that occur due to earthquake, floods, storm surges and cyclone. It doesn't cover all the damage types. However, the basic principles of safe construction can be understood from the study of these damages. It would be useful to go through these principles once more.

1. Safe site should be selected. A site which is elevated enough to be safe from storm surges, flooding or the tsunami, a site with soil having good bearing capacity, a site that might be have natural protection in form of sand dunes or tree groves in case of cyclones or storm surges.
2. The building that is constructed should follow the building codes as established by the Government. These codes are based on technical knowledge and the past experience of the structural performance of different buildings during the disasters. Though technical in nature, the government has been making efforts to simplify these for use by people.
3. Ten basic principles for the building construction as explained in this guide can make building disaster safe.
   i. **Foundations should rest on strong base.** The foundation depth and width may be decided depending on the soil conditions and number of storeys.
   ii. **Grade beam and plinth band should be incorporated** in the buildings as per the technical guidelines of the Government. Grade beam is a ground level beam and plinth band is put at the floor level.
   iii. **The walls should have good joint with the foundations below.** Vertical reinforcement ties the super structure with the foundations.
   iv. **Corner vertical reinforcements should be provided** to prevent the failures of the corners. It should be provided at the each corner and wall junction.
   v. To ensure strong corners, **proper and sufficient bonding between the blocks of two walls** should be made.
   vi. The door and window openings should not be large and have sufficient distance between each other. **Provision of reinforcement in the jambs of the openings** prevents cracks around it.
   vii. **Horizontal bands should be incorporated** in the building to tie all the walls of the building together. These horizontal bands should be put at plinth, sill, lintel and roof level.
   viii. Masonry courses should be done maintaining horizontal level in plumb. Care should be taken to ensure that there are **no vertical joints in the masonry.**
   ix. **Roof and walls should be tied well.** Vertical reinforcements from the walls should be fixed with the roof slab or the wall plate in case of sloping roof.
   x. **Large cantilevers, floating columns, etc. should be avoided.**
4. The Government has brought out detailed technical guidelines that provide guidance for safe construction. We should adhere to these guidelines and building codes. For RCC construction, a qualified structural engineer should be consulted.

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