

Disaster mitigation strategies for adobe houses: A case study of District Awaran, Balochistan, Pakistan

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Abstract

Every year disasters affect hundreds of millions of people globally causing damage that can take years to recover from. The process of rebuilding and re-establishing is vitally important to the successful continuation of life, industry and growth of affected societies and communities. Besides human casualties one of the most visible and striking effects of any major disaster is the destruction of houses. Construction of houses will be a major activity in the reconstruction phase of a disaster. The impact of disasters caused by natural hazards such as earthquakes can have serious consequences. Vulnerable populations are faced with unforeseen hardships, misery, and death if their houses and buildings collapse, and supporting infrastructure is severely damaged. Awaran District, Balochistan is one the least developed areas of Pakistan with very low Human development index (HDI). In 2013, an earthquake of M_w 7.7 occurred in the region, causing damage to the houses and human lives. The study covers the findings of the field survey for the damages occurred to the adobe houses in Awaran due to earthquake and analyse the causes of failure of the structures. It further suggests the design strategies and measures for the mitigation and prevention against these damages in order to decrease the loss to housing stock and lower the risks to human life due to failure of structures during earthquake.

Keywords: field survey, earthquake, adobe houses, disasters, design strategies, Awaran

1. Introduction

The natural disasters such as earthquake can have very serious consequences. It is a major disaster responsible for the vast loss of infrastructure and human lives (Mahmood, et al., 2017). The vulnerable populations may face unexpected hardships, misery, and death if the houses or building collapse and the supporting infrastructure is severely damaged. The rehabilitation and redevelopment work efforts would face several challenges since the strategic infrastructure get damaged or destroyed caused by the earthquake. The areas and regions may face economic crisis due to the loss of infrastructure which may lead to the poverty in the area. Many unfortunate people will face social setbacks until the worst outcomes of the disasters can be addressed.

The study focuses on the identification of the damages caused to adobe structures due to earthquake and suggest preventive measures for adobe structures to sustain during earthquakes. At first the existing construction practices for adobe structures in Awaran are analysed, then the damages occurred due to earthquake are identified and lastly the cost-efficient solutions are proposed by using locally available materials with minimum training to improve the skills of local artisans and residents. This paper provides the introduction and the context including the study area and Awaran earthquake, then an overview of the field survey is given which includes the methodology used for the survey and data collection. The materials and methods used for the construction are discussed and the causes of

damages are identified, then disaster mitigation strategies for adobe houses are proposed based on literature and practical implications.

1.1 Introduction to study area

The selected area of study is Awaran District located in the South of Balochistan province, Pakistan. Awaran got the status of a district in 1992, previously it was a sub-division of Khuzdar District (PBS, 1998). Awaran is one of the least developed and considered the poorest district in Balochistan province (PDI, 2007). Awaran is bordered by Kharan to its North-West, Khuzdar to its North-East, Lasbela to its East and South, Panjgur and Kech to its West and Gwadar to its South (Figure 1). The geographical area of Awaran is 29,510 km² (P&D, 2011). It is sparsely populated and according to Population and Housing Census 2017, the total population of Awaran district was 122,011 with 18,172 households (PBS, 2017). In 1998, there were only 338 (1.5%) Pucca houses in Awaran out 21735 whereas only 91 (0.42%) housing units had electricity. The development indicators of Awaran are low in all sectors including, food, health, economy and specially security (Ahmed, 2017). Awaran district and its nearby areas in the region are affected by insurgency and conflict since many years (PIPS, 2010). Army contingents and para military troops are deployed to maintain peace and prevent the conflict (Nation, 2015). The climate of Awaran is hot in summer (with cool nights) and moderately cold in winter (P&D, 2011).

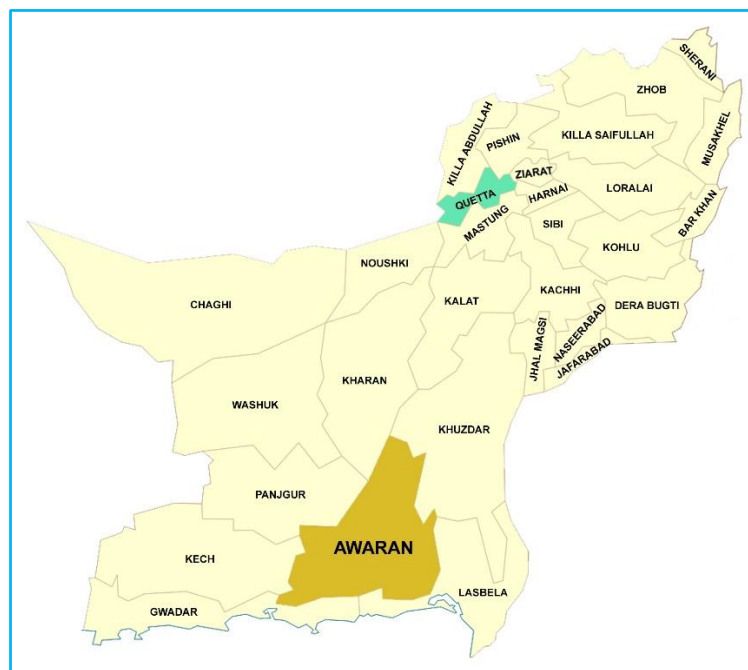


Figure 1. Location of Awaran in Balochistan province
(Note: 4 newly created districts are not shown in the map)

1.2 Awaran Earthquake

Awaran District is also situated in earthquake zone and on 24th September 2013 an earth quake of M_w 7.7 hit the area (USGS, 2013a). An aftershock of M_w 6.8 took place on 28th September 2013 (USGS, 2013b) while the National Seismic Monitoring Centre of Pakistan considered it a new earthquake. The earthquake affected more than 27,000 households or 138,372 people, and destroyed or damaged 19,688 houses, around 500 people died, and hundreds got injured (UNOCHA, 2013). The epicentre of the earthquake was in north-northwest of Awaran at 66km. The loss of lives was not proportionate to the magnitude of the earthquake since the time of earthquake was 16:30 in the afternoon, when most of the people were out of their homes. The damage caused to the structures was, however, of the unimaginable scale. Entire villages and neighbourhoods were turned into piles of debris.

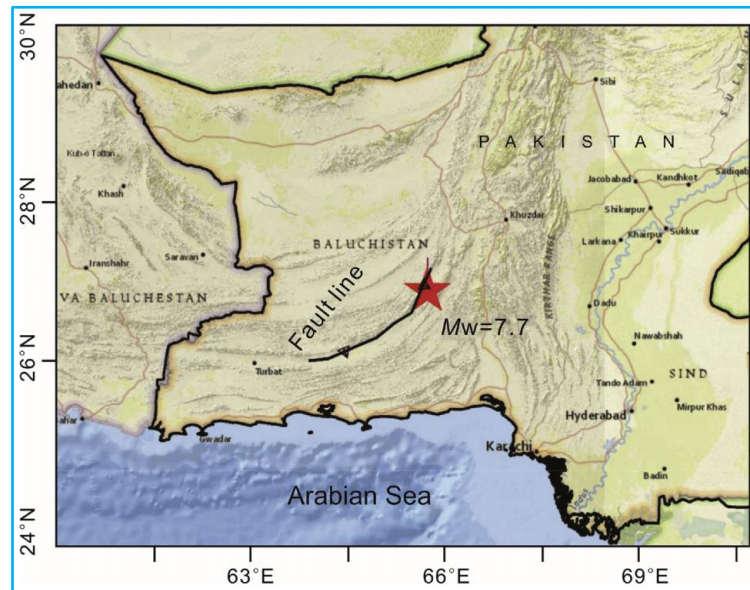


Figure 2. Earthquake epicentre along with fault line
Source: (Shah & Jin, 2018)

2. Awaran Field Survey by BUITEMS Team

In October 2013, the Heritage Foundation of Pakistan contacted Balochistan University of Information Technology, Engineering & Management Sciences (BUISTEMS) Quetta, seeking help in carrying out the survey of the earthquake affected areas and then dissemination of knowledge and implementation of the vernacular methodologies for safe and economic construction so that the damages may be averted in case of a future similar disaster. A survey team was formed consisting 2 faculty members, 4 students and some local volunteers from Awaran district. The team surveyed earthquake affected areas of Awaran District from 8-14 October 2013. The areas covered in this survey includes Nok Jo, Gajjar, Jabry, Kullar, Malar, Mangoli, Gishkore and Dandaar.

Due to the difficult terrain, and lack of roads, it takes more time in Awaran district to move from one village to another. It is also mentioned earlier that law & order situation in Awaran was unsatisfactory and due to that access to some areas was restricted for safety reasons. Moreover, the BUISTEMS survey team had limited time and resources; in this situation it was not possible to carry out a comprehensive survey of each home destroyed or damaged in the earthquake. Majority of the houses in a locality were built using the identical construction techniques and materials and almost all houses shared the factors that caused the damage. Considering all these factors the survey team carried out detailed survey of two representative houses from each locality. The substantial amount of data was gathered from the survey of 26 houses in total located at different villages, neighbourhoods, and localities of Awaran district.

As discussed by (Mahar, 2012), two survey methods are usually used for the reporting of defects or damages: i) Stock condition survey: this includes physical observation and questionnaire ii) day-to-day survey. Stock condition survey method by using questionnaire and physical observation was adopted for this study. A survey questionnaire was designed to record the data of damages and destruction, it further includes the demographic information of the residents, and the materials and construction techniques used in the houses. Since the survey team visited the affected areas, not only the scale and magnitude of damage was realized, but also the causes of damage could be identified. The team also focused on the assessment of locally available materials and construction techniques to identify any shortcomings, which may be rectified to minimize the damage in case a similar disaster strikes again.

The team first arrived at Mangoli and it was then when they realized the scale of destruction. The village of Mangoli was completely razed to the ground except a few adobe huts. The villagers were using some of the tents provided by the earthquake relief as temporary shelters. They set up the tents along with the remains of their houses. The destruction at Mangoli can be seen in figure 3, survey team members are also busy in data collection.



Figure 3. Destruction at Mangoli

After the survey at Mangoli the team moved to Kullar town in Mashkay. The team was then split into two groups. One group did the survey in the twin towns of Kullar and Gajjar whereas the other group moved further north towards the villages of Nok Jo and Jabry. The twin towns of Kullar and Gajjar lie on either bank of the ravine, locally known as ‘Kaur’. The town of Kullar is on the South-Eastern bank of this ravine whereas Gajjar is on the North-Western bank. There is a marked difference in the devastation caused by the earthquake in Kullar and Gajjar. While the town of Gajjar has been completely destroyed as shown in figure 4(a), Kullar has only been partially damaged as shown in figure 4(b). This trend can be found throughout the district. The places that are on the North-Western side of the ravine (presumably there is a fault underneath) have been more damaged compared to those on the South-Eastern side, which includes Awaran town, the district headquarter of Awaran.



Figure 4(a). Damages at Gajjar town



Figure 4(b). Houses standing at Kullar town

As mentioned before the second group moved to Nok Jo and Jabry, they planned to go up in north to record all the damages caused by earthquake. After arriving at Jabry the group realised that this is the last point where the earthquake affected the houses as the damages to houses at Jabry were rather little. However, the scenario in Nok Jo was totally different, as shown in figure 5. The entire houses were razed to the ground and only few straw huts survived the earthquake.



Figure 5. Earthquake damages at Nok Jo

After completing survey at Kullar, Gajjar, Nok Jo and Jabry the team left to Awaran Tehsil. Here the first village visited by the team was Malaar which was entirely destroyed except some straw huts which withstand the earthquake. It was found that stone boulders were mainly used in Awaran Tehsil compared to mud bricks which were commonly used in Mashkay. The houses made of stone boulders not coped well with the earthquake which can be seen in figure 6. The team then continued the survey further south in the villages of Gishkore and Dandaar.



Figure 6. Destruction at Malaar
(stone boulders used in wall construction can be seen in the picture)

The survey fulfilled the primary purpose of collecting information about the damages, and prevailing construction materials and techniques used in the region. Based on the study and recorded observation the team analysed the possible causes of the damages and destruction in the adobe structure and proposed the best possible solutions by using traditional methods, maximizing the use of locally available materials, and using vernacular architectural techniques. People around the world especially living in rural areas of the developing countries often go for reinforced concrete structures in case of earthquake mitigation. However, there are certain concerns that should be taken care of, such as, availability of material, technical skills and labour, and the cost of construction or repair. We also know that, the concrete as a building material has higher value of carbon foot print and high thermal conductivity as compared to mud and bamboo which are locally available in abundance.

3. Construction materials, methods, and techniques

3.1 Materials

Even the area is barren, and it receives very little rainfall, there is some vegetation in the region. The plants and agricultural products grown in the area are also used for the construction of houses. Figure 7(a) shows a plant locally named as Pharha, which is widely grown in this region and its leaves are used for thatching purposes in adobe houses, roofing in houses made from mud-stacks, mud-bricks and sometimes even stone. The leaves of this plant are also used to make mats and other handicraft items, the making and selling of which forms an integral part of the local economy. The survey team observed the presence of large orchards of Date-Palm trees in the Mashkay area consisting of the settlements of Nok Jo, Kullar, Jabry, Mangoli and Gajjar etc. as shown in Figure 7(b), which apart from being a very important export of the locality supporting the local economy, provides the bulk of the material for roofing. Some vegetation in Mashkay is shown in Figure 7(c). There are deposits of alluvial soil brought along by the rainwater from the north, resulting in the abundance of mud available to be used as a construction material. In south toward Awaran tehsil, the quantity of date palms is less and the area consists of smaller bushy plants, Figure 7(c). The available mud for making bricks is also less that is why stone boulders are mainly used in the south of Awaran district.



Figure 7(a). 'Pharha or Peesh plant is found in abundance



Figure 7(b). Date-Palm orchards in Mashkay



Figure 7(c). Thick vegetation of Kashum in Mashkay Tehsil

3.2 Planning & design of houses

There is not much variation in the planning of houses from south in Awaran tehsil to the north in Mashkay tehsil. Many houses as per 1998 census consisted only one room, 78%. In the survey it was observed that most of the houses consisted of 2-3 rooms located on the edge of the plot. Houses usually do not have boundary wall. The toilet and kitchen are separated from the main unit, the kitchen being right in front whereas the toilet being located on one side while taking care that it is away from sight of somebody approaching the house. The bathrooms are normally attached to one of the bed

rooms which was not the trend in the past, but it is now increasing. Some wealthy families have bathrooms attached to every room. A plan sketched during the field survey is shown in Figure 8.

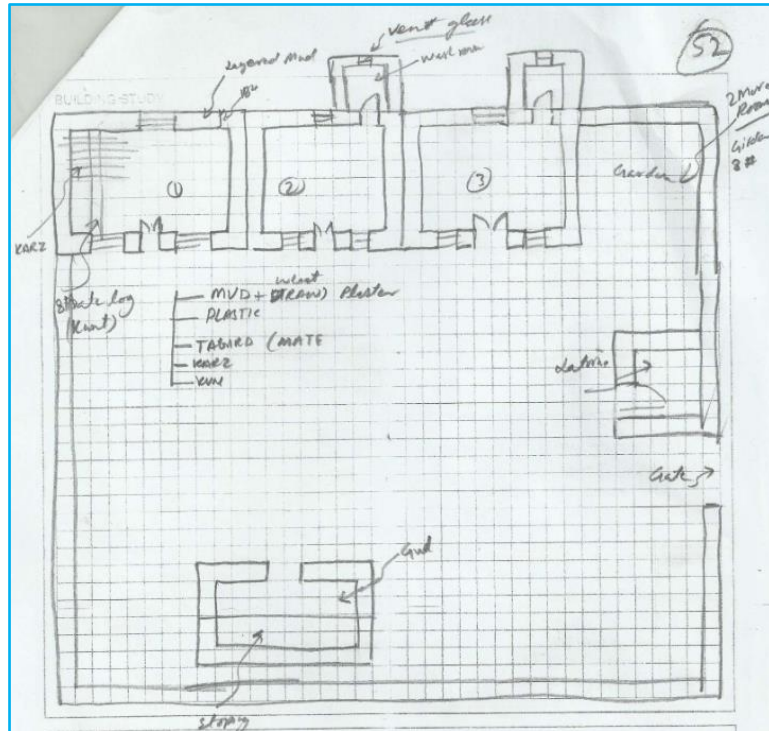


Figure 8. A sample plan of a house in Mashkay

3.3 Construction

3.3.1 Wall construction

Walls were constructed of mud stack in the northern parts of Awaran which changes to the south where stone boulders are being used for the construction of walls. The use of mud-brick is generally more common in the whole region. For mud walls, the wall thickness is constant as well, which was 18" (45.7 cm) for all the houses.

For mud stack walls, wheat husk and animal dung are usually mixed with the mud in order to strengthen the mud, figure 9(a). The foundations are normally laid 1-2 ft. in the ground (30.4-61 cm) with the same mud-stacks but slightly wider than the actual wall. No stiffeners are used anywhere in the wall in horizontal as well as vertical directions. Wooden lintels are sometimes provided on the top of windows and doors in isolation, which have little affect towards strengthening the wall. Whereas the bricks are made from a mixture mainly consist of mud but, small stones with organic materials like weeds and reeds are also used to strengthen the brick. The brick size was, 4"x6"x12" (10.1x15.2x30.4 cm) constant throughout the district. A steel mould is used for this purpose which is open from top and bottom. Moulded bricks are left on the open ground to get dry. The foundations are normally laid 1-2 ft. (30.4-61 cm) in the ground constructed of the same bricks as used in the walls. Foundations with stone boulders were also seen at some locations. No stiffeners are used in brick walls which is similar to the mud stack walls, figure 9(b). Moreover, wooden lintels are also placed on top of the doors and windows, which does not strengthen the walls.

The use of stone boulders for the construction of walls was mainly seen in the south, such as in Gishkore and Dandaar areas. The stones were mainly round and of improper shapes or bounding,

excessive mud plaster was used for the construction of such walls. The walls have the same width as of other walls, i.e. 18" (45.7 cm) and constructed without using any stiffeners, figure 9(c).



Figure 9(a). Mud-stack walls



Figure 9(b). Mud-brick walls

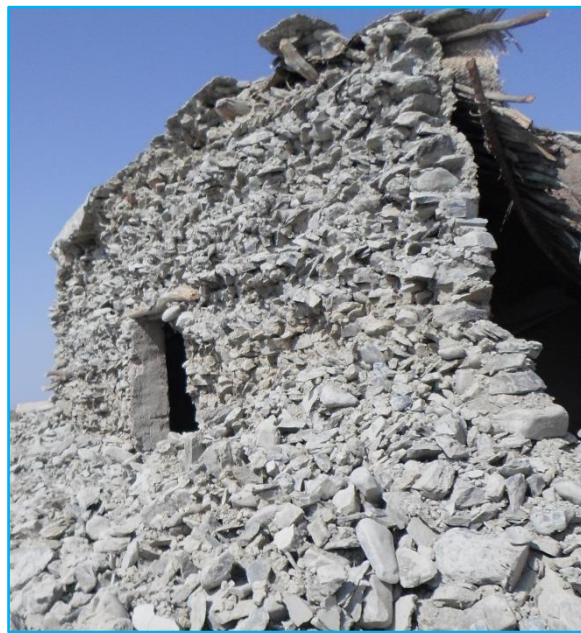


Figure 9(c). Stone boulder walls

3.3.2 Roof construction

The roof construction techniques do not vary much throughout the district. Mainly there were two types of roof construction; the wealthy families used T-iron and girders (commonly known as Tier-Gaarder) roofs in their houses while most of the houses used date palm branches laid over heavy wooden joists.

Figure 10(a) shows the roof constructed of t-iron and girders which is also called tiled roof because of the use of terracotta roof tiles. In this type of roof t-shaped steel sections are placed over the I-shaped steel girders and terracotta tiles are placed on the T-shaped iron bars. The terracotta tile used for this purpose was of the size 12"x12" (30.4x30.4 cm) with a thickness of 1.5" (3.8 cm). A plastic sheet is usually placed on the top to insulate the roof against rainwater then the screed of mud mortar is spread

on the roof to insulate it against the heat. This mud mortar may also include some organic materials for bonding purpose.



Figure 10(a). T-Iron and girder roofs with terracotta tiles

Date palm roofs as shown in the figure 10(b) are very common in most of the houses, since the date palm is locally available in the region. According to local tale, the date palm is termite proof if cut in the winter season. The roof consists the joists made from date palm tree trunk. The use of steel girder and telephone line poles was also seen in some houses. The joists or girders are placed directly on top of the walls without using lintel band or ring beam. A net made of date palm branches is commonly used on the top of joists or girders. A mat is placed on the date palm branches then a plastic sheet for insulation against water. At the top, finally a layer of mud mortar is laid for the insulation against heat.



Figure 10(b). Roof made of Date-Palm joists and Date-Palm branches serving as purlins

4. Causes of damage

The factors responsible for the major damages occurred in the houses were identified by the survey team and are discussed below:

4.1 Inappropriate brick making

The mud bricks made locally and used for the construction of houses were of improper shape and form with round surfaces and uneven edges making it essential to use extra mortar during the construction of walls, figure 11. The material mix used for the brick making was not up to the standard as it contained boulders and organic materials, such as reed stalks etc.



Figure 11: Bricks placed for drying

4.2 Improper brick bond

During the construction of a wall, the brick courses were placed without following any proper bond pattern, see Figure 12. Some bricks were placed slanted while some were placed vertically. Whatever, was the reasons for using bricks in such manner, it made the walls vulnerable to even a slight jolt.



Figure 12: A wall with the lack of bond

4.3 Weak corners

It was observed that in most of the construction, the corners were not strengthened and as a result they gave in easily when the walls started shaking, as shown in Figure 13, the wall is damaged at the corner.



Figure 13. Wall damaged due to weak corner

4.4 Use of heavy girders

Heavy girders were used in majority of the houses without having any mechanism for the distribution of loads, see figure 14. As a result, the concentrated load from the heavy girder was applied to only a few bricks which failed easily. The heavy girders caused more structural damage and may also been responsible for any loss of life that occurred.



Figure 14. Heavy girders caused damage

4.5 Lack of projections

The roofs were placed on the walls, as shown in Figure 15, such that there were no projections on any side. As a result, when the walls even slightly moved, the roof came down pushing the walls further while doing so. As a result, the entire houses collapsed.



Figure 15. Lack of projections

4.6 Pre-earthquake damages

Most of the mud and mud brick walls were already weakened by the rainwater mainly due to spouts and not having the required projections to stop the rainwater penetration into the walls, as shown in Figure 16. This had made the walls weak and thus vulnerable.



Figure16. Damage caused by water spouts

5. Solutions and strategies

The use of mud for the construction is one of the old practice and the use of sundried bricks is traced back to 8000 B.C. (Houben & Guillaud, 1994). Adobe houses are very common in many parts of the world even in the most hazard-prone areas (Blondet, Garcia M., Brzev, & Rubinos, 2011). Approximately, 3 billion people or 30%-50% of the global population lives or works in earthen buildings (Rael, 2008). Around half of the population in developing countries and at least 20% of the urban population, live in earthen dwellings (Houben & Guillaud, 1994). However, adobe construction is mainly used in rural areas and houses are typical one story high. Adobe houses are low cost, locally built by communities and can be constructed in less time. In many parts of the world the adobe houses are constructed without specific design consideration which make them weak to the earthquake or other disaster. By adopting some construction techniques, these houses can resist the earthquake movements which would save the damages to property and humans lives during possible disasters. Some disaster mitigation strategies and solutions for adobe houses are discussed here in order to construct the adobe houses to withstand the earthquake disaster.

5.1 Brick making

It is necessary to make the brick of proper and even size. The soil should be first passed through the sieve to separate the gravels and small stones before formation of the mix. The proper moulds should be used to mould the bricks and then moulded bricks must be placed on even ground or surface to let it dry, figure 17(a) and 17(b).



Figure 17(a) and 17(b). Brick making

5.2 Wall construction

Walls and roof are main components of a house and it is an important decision to make while rebuilding the house that what kind of roof or walls would be safe. Most of the Awaran disaster victims will probably need to rebuild spending as little as possible for materials. Trash and cement and rebar may be luxuries they cannot afford. But some simple techniques and a few supplies can allow them to rebuild with local earthen materials in a significantly stronger way. These simple techniques

are important to reduce danger to adobe from earthquakes. Using a strong bond beam on top of the walls, figure 18(a) and adding mesh-reinforced plaster to inner and outer walls that is tied together through the walls can preserve a low-strength earthen building through an earthquake. Either wood or bamboos can be used for a ring beam and must be overlapped and braced at corners. Opening like doors and windows should be kept away from each other and the corners as shows in figure 18(b).

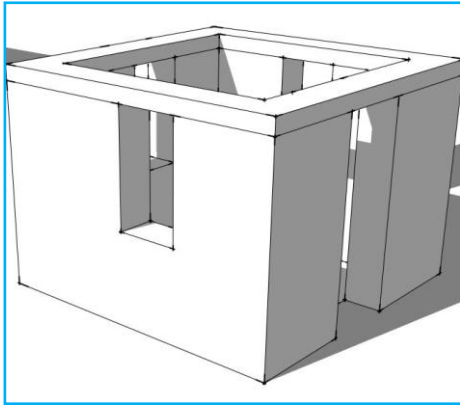


Figure 18(a). Bond beams on wall tops
Source: (Shah S. , 2014)

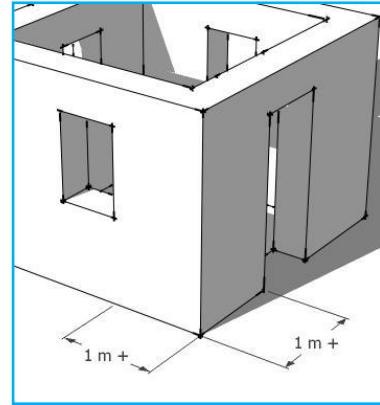


Figure 18(b). Doors & windows far from the corners
Source: (Shah S. , 2014)

Using long lintels on the doors and windows would provide better reinforcement, Figure 19(a). One of the cheapest way to reinforce this type of wall against earthquakes is by adding piers or buttresses, shown in the Figure 19(b). The mass of the corner structures helps to reduce the damage to walls. Buttresses of same type must be used at all the corners and at the distance of every 5-6 m on long straight walls. Piers or buttresses do not need to be vertical but can tapered or diagonal as the walls rise.

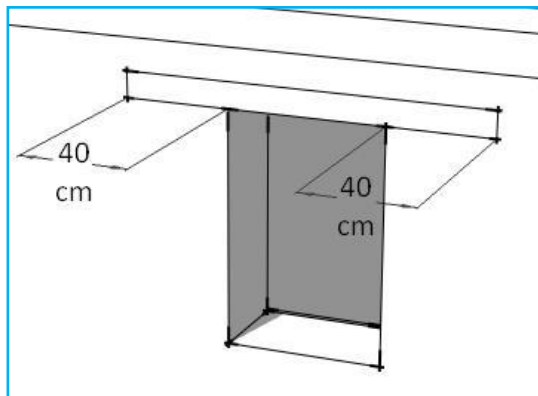


Figure 19(a). Extra-long lintels
Source: (Shah S. , 2014)

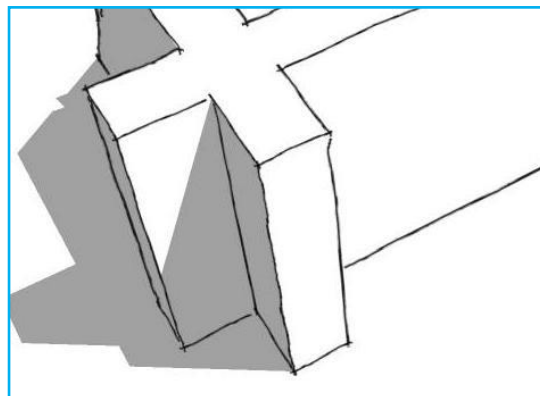


Figure 19(b). Buttresses at wall corners
Source: (Shah S. , 2014)

Reinforced plaster should be used to save the adobe houses. The reinforcement can be done by using small wooden poles, heavy mesh strips or a light layer of plastic mesh and the reinforcement should be tied through the walls. An earthquake may destroy the plaster when mesh layers are attached through the walls. But the cracking of plaster will allow more of the building walls to be preserved. And plaster is easier to repair than the walls. If the wall is built on a sandbag base, light fishnet or bird netting can be used to reinforce the walls. This will greatly cost much less than plastic geo-mesh or plastic barrier fencing.

Soil and its properties has great influence on the strength of the adobe houses. For this purpose, a soil test or dry strength test must be done. Make five mud balls from the selected soil of 20 mm diameter. Let them dry for 24h and then try to crush each ball between your thumb and forefinger. If you are unable to crush the balls, figure 20(a) then soil is appropriate for adobe construction and if one or more balls can be crushed, figure 20(b) then soil has inappropriate contents of the clay and is not suitable for building adobe houses.

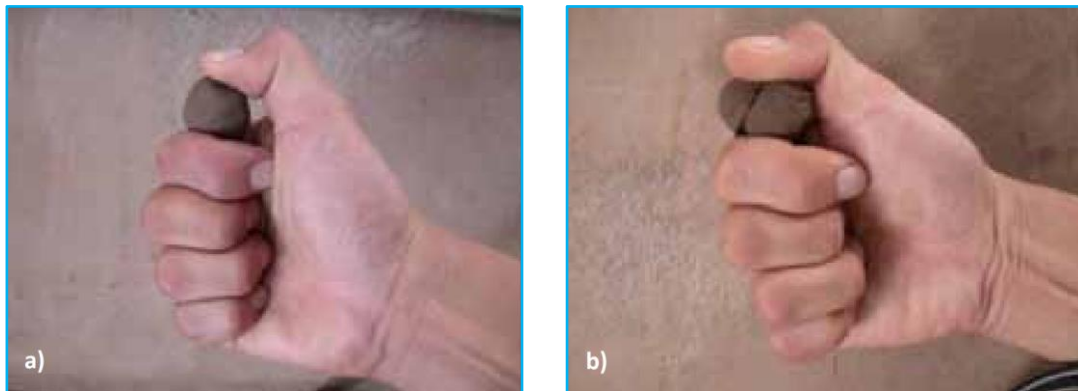


Figure 20(a) and 20(b) Crushing of mud balls
Source: (Blondet, Garcia M., Brzev, & Rubinos, 2011)

As mentioned in section 4.2 that the improper brick bond was also a cause of damages. The bricks should be properly bounded to strengthen the bond. The corner can be strengthened by using bamboos as reinforcement on the corner which is shown in figure 21.

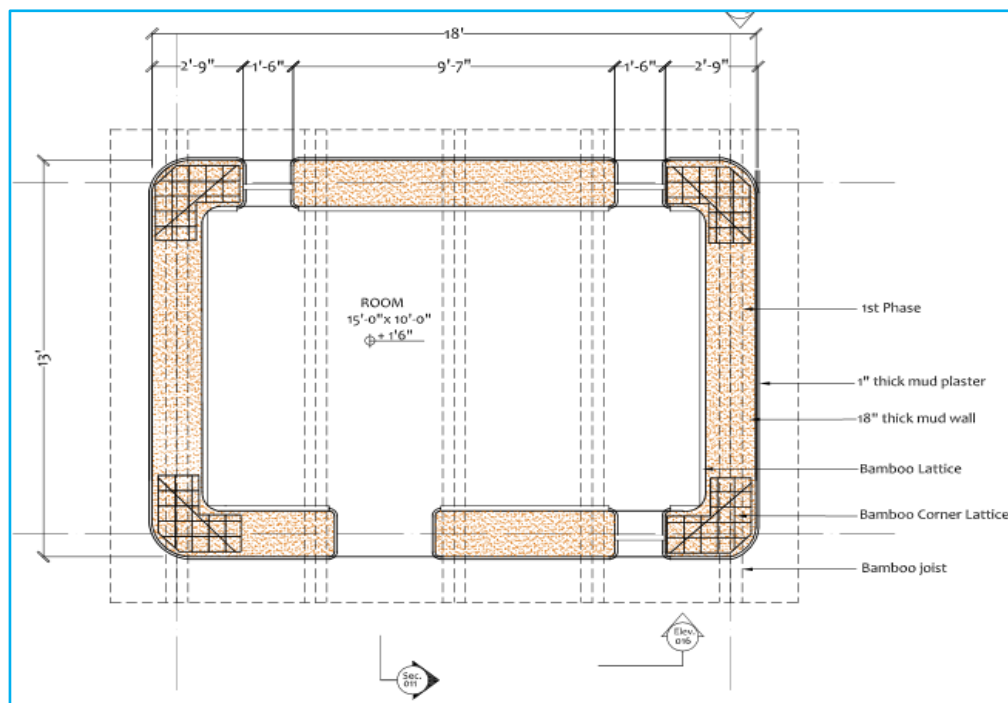


Figure 21. Corner strengthening using bamboos as reinforcement
Source: (HPF, 2013)

5.3 Roof construction

Several buildings fail in the earthquake as the unevenly distributed weight of heavy roof pushes the walls in one direction. Light roofs reduce stress on walls in earthquakes. Lighter walls with a light weight roof can survive even severe quake vibrations with little reinforcement better than heavy walls and roofs. The adobe house shown in Figure 22(a) can hold up a light-weight roof. It must consist a special base and plastic mesh to reinforce the walls. The same size house shown in Figure 22(b) with a heavy-weight roof should have heavy earth piers at all corners to help brace the walls against the weight of the roof moving in an earthquake.

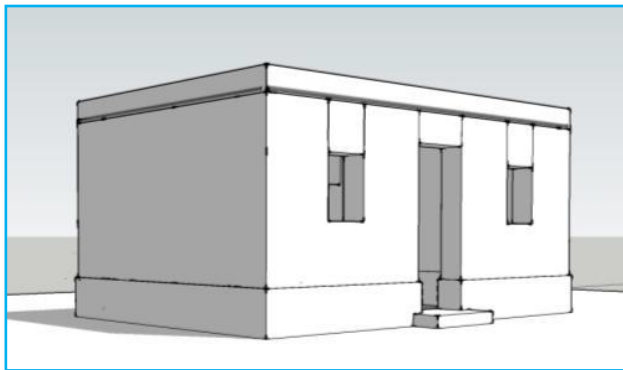


Figure 22(a). Walls for a light roof
Source: (Shah S. , 2014)

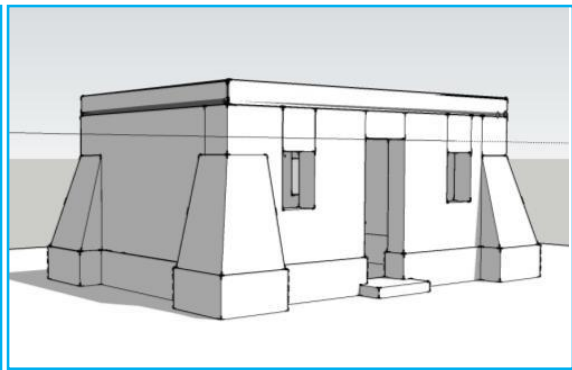


Figure 22(b). Walls and piers for a heavy roof
Source: (Shah S. , 2014)

The construction of roof using bamboo purlins is shown in the figure 23, the roof projections on all four sides can also be seen.



Figure 23. Roof construction and the projection

5.4 Site or location of the houses

The site conditions play an important role in seismic safety of a building. Hazardous sites should be avoided for building construction to minimize risks against natural disasters. Site investigations may assist in identifying potential danger of sliding, erosion, land subsidence or liquefaction during an earthquake. The local practice of managing any such hazard should be given due considerations. A safer site is the one having; no danger of landslides, sufficient plantation on slope, trees not too close to the house, mild slope and far from river banks. Some potential hazardous sites are mentioned below:

5.4.1 Steep and unstable slopes

A house should not be constructed near steep and unstable slopes. The cliffs made of soft or crumbly, clay loam; or deposits materials, etc. should be avoided. Figure 24 shows the failure of house due to the location on unstable slope.

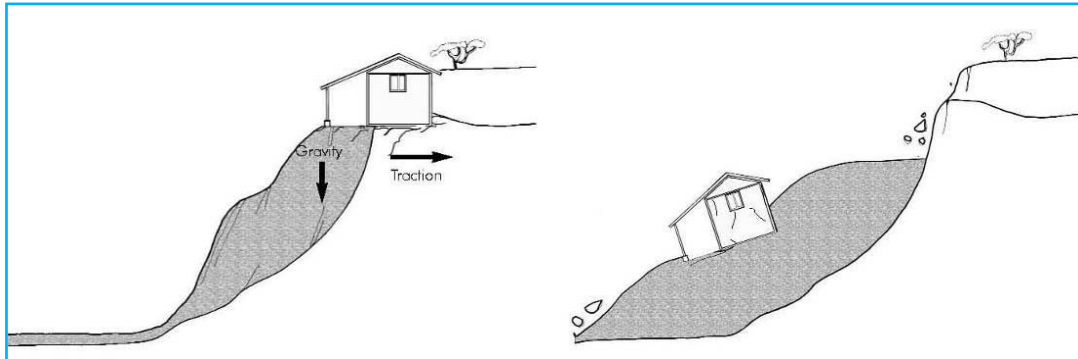


Figure 24. Failure of house due to steep or unstable slopes
Source: (Shah S. , 2014)

5.4.2 Areas susceptible to landslides and rock fall

Landslides or rock fall areas should be avoided while selecting a site for building construction, figure 25. Apparently, some slopes may look stable, but failure could be triggered by an earthquake. Landslides and rock fall can damage buildings partially or completely. However, building in these areas can be constructed after providing proper retaining walls and green barriers. Simple indication of sustained stability of a slope is the presence of upright standing trees on it. Abnormally inclined trees on a slope indicate instability of the hill slope.

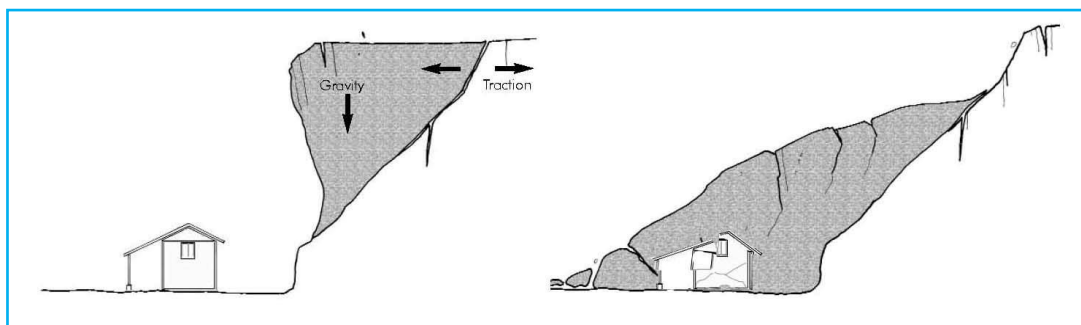


Figure 25. Building damage due to landslide or rock falling
Source: (Shah S. , 2014)

5.4.3 Fill areas

A house should not be constructed on loose fill or soil. In a filled ground, the bearing capacity of foundation subsoil is low, and settlement of foundation may occur, figure 26.

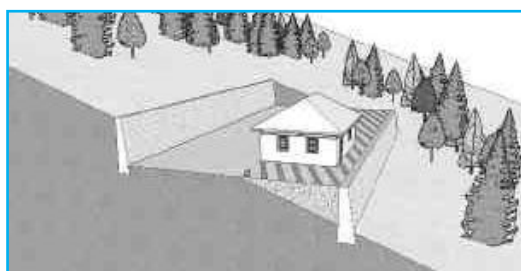


Figure 26. House in filled ground; Source: (Shah S. , 2014)

5.4.4 River banks

A house should be far enough from the river to avoid flash flood and earthquake damage, figure 27.

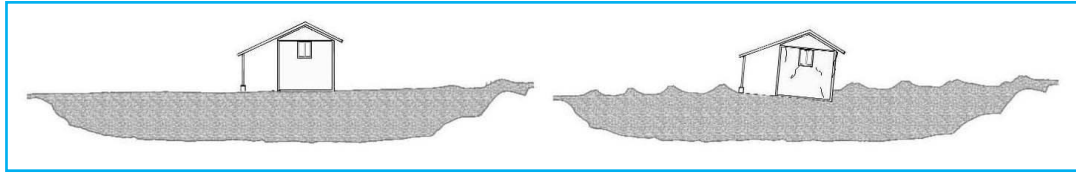


Figure 27. House near river banks

Source: (Shah S. , 2014)

5.4.5 Geological fault and ruptured areas

Geological fault and ruptured areas are usually visible, permanent, deep, and active. These are not suitable for the construction of a building, figure 28. A house may preferably be built at a distance of at least 250 m from such fault lines.

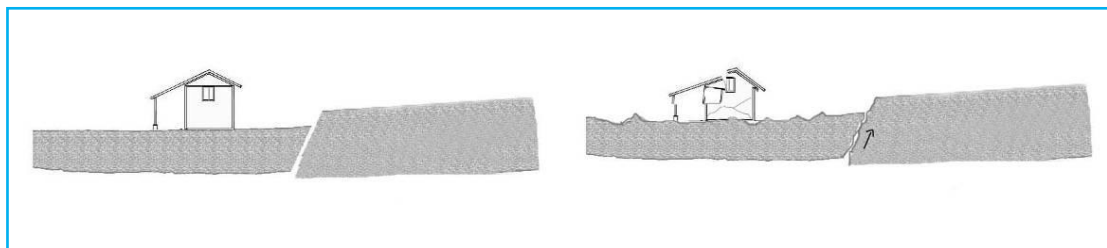


Figure 28. House near geological fault areas.

Source: (Shah S. , 2014)

5.4.6 Forest and trees

The forests are useful to stop landslides, but buildings should not be constructed close to any big tree, as there might be a possibility of falling of the trees during earthquake. The distance between tree and house should preferably be at least equal to the height of tree or house, whichever is greater, figure 29.



Figure 29. Distance of house from the tree

Source: (Shah S. , 2014)

5.4.7 Distance from a building

A building should not be constructed close to another building: there might be a possibility of falling of building during earthquake. The distance between two houses should be at least equal to the height of house, figures 30(a) and 30(b).



Figure 30(a). Not recommended distance between houses Figure 30(b). Recommended distance btw. houses

Source: (Shah S. , 2014)

5.5 Design and planning

The shape, size and layout of the building is important for its seismic safety. Constructions with asymmetrical plan and elevation are more vulnerable to earthquake than those having symmetrical plans elevations.

5.5.1 Regular shape

Regular shaped buildings like square, rectangular, or circular resist the earthquakes more effectively as compared to irregular buildings and are therefore preferable in earthquake prone areas. During the earthquake movements the corners of nonuniform buildings are stressed more and may be damaged. Complex shaped buildings, shall therefore be made simple by providing gaps at appropriate locations. Some complex shapes and their simplified solutions are shown in figure 31.

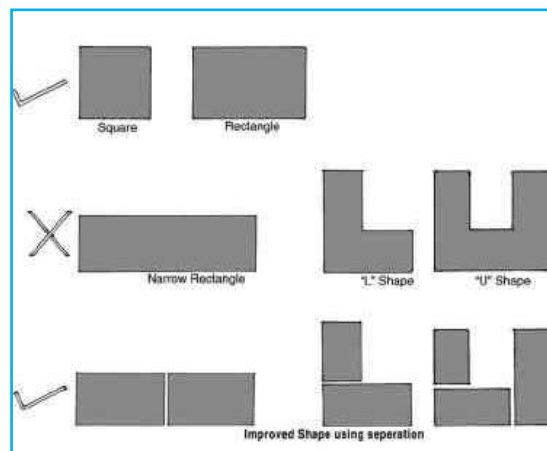


Figure 31. Building shapes
Source: (Shah S. , 2014)

5.5.2 Short walls

In long and narrow buildings, longer wall is weak against earthquake forces and can easily fell during an earthquake. Therefore, if long and narrow buildings are constructed, they should be divided into two or more blocks with sufficient gap between them. The individual length of separate blocks should not exceed three times its width. The foundation of these blocks may be connected to each other and separation can be made only in the superstructure. The other alternatives include provision of cross walls and buttresses as shown in figure 32.

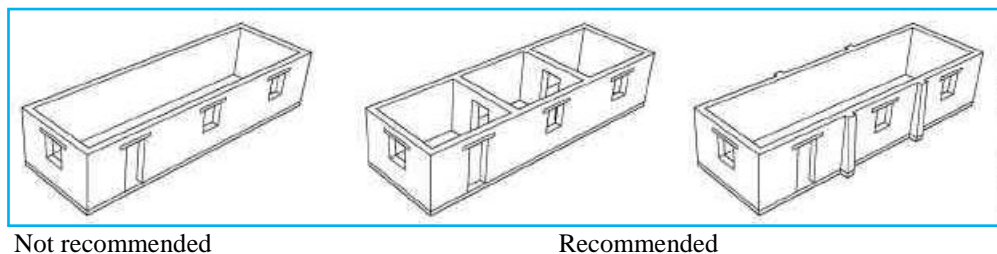
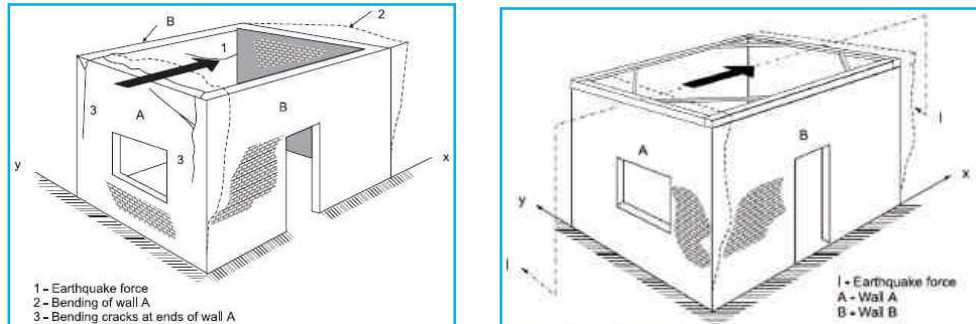


Figure 32. Short and long wall lengths
Source: (Shah S. , 2014)

5.5.3 Box effect

One of the essential principles of earthquake-resistant construction is to use a compact, box type layout. Furthermore, all the components of the building such as walls, floor, and roof structure, should be well tied up with each other, so the building could act as a box during earthquake vibration. The

maximum length of wall between cross walls shall preferably be limited to 15 ft. (4.5 m) for an effective box action, figures 33(a) and 33(b)



Figures 33(a) and 33(b). Box effect

5.5.4 Foundation

Foundation is the part of the building below the ground level. The purpose of the foundations is to transfer the load of the construction to the ground. The weight of the structure must be suited to the load capacity of the ground which in turn shall be stable. The structure must also be correctly joined and anchored to the foundations. Generally, stepped strip footing should be adopted for load bearing wall construction. The width of foundation should be sufficient so that soil is able to bear the weight of the building without excessive settlement. If the foundation soil is soft, the width of foundation should be more. Similarly, if the building weight is more, the foundation should have a greater width. A minimum width of 2.5 ft. (76.2 cm) is suggested for single story construction.

Mud or mud bricks are not strong enough to resist earthquake forces at the foundation level. It is recommended that the foundation should be preferably built by using dressed stones, burnt clay bricks or concrete blocks. A 3.5 ft. (7.6-15.2 cm) thick pad of lean concrete shall be provided under the foundation. The concrete mix proportions for this pad shall be 1:4:8 (one-part cement, four parts sands and eight parts crushed aggregates). The depth of foundation below existing ground level should be at least 3 ft. (91.5 cm) for soft soil and for rocky ground the depth of foundation may be reduced to about 1.5 ft. (45.7 cm).

5.5.5 Plinth construction

The plinth masonry should preferably be constructed using stone or burnt bricks laid in cement mortar. Cement mortar or lime mortar is stronger than mud mortar in binding the stones or bricks in the wall together to resist earthquake forces. The height of the plinth should be above the flood water line or a minimum of 1 ft. (30.4 cm) above ground level. Wherever possible the height of plinth shall not be more than 2.5 ft. (76.2 cm). Where higher plinths are required the thickness of walls below plinth shall be increased. A details of plinth protection is shown in the figure 34.

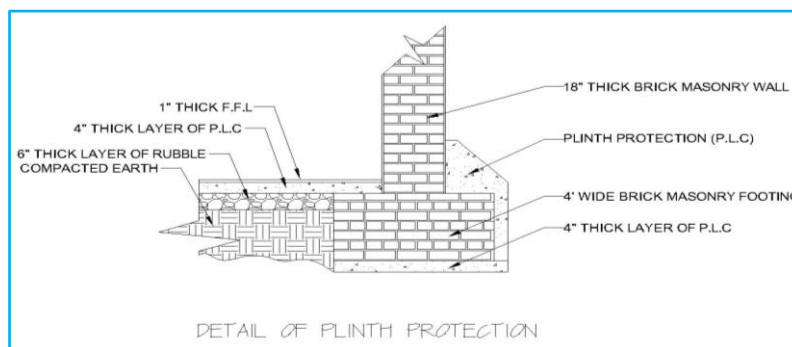


Figure 34. Detail of plinth protection

5.5.6 Waterproofing and drainage

As water makes the foundation soil weak. In an area that experiences rainfall or snowfall, it is recommended to use a waterproofing layer at the plinth level before starting the construction of wall above the plinth and provide an apron and drain around the house to prevent runoff water that might wet walls or enter the foundation. In 2007, Awaran was highly affected by flooding which caused 20 deaths and more than 1800 houses were entirely collapsed (PDI, 2007). Figure 35 shows the effect of plinth decay due to water.



Figure 35. Plinth decay

6. Conclusion

It can be concluded that the large devastation during Awaran earthquake was caused due to the prevailing improper construction techniques and by using materials which were not suitable, such as using heavy girders in roofs. The study explains how an adobe house can be built with proper design and construction techniques and by using efficient locally available materials which will help the structures to withstand the unexpected event of earthquake. By using these techniques, we can not only save the damage and loss to property but can also save human lives which are usually lost during disasters. The suggested design and construction techniques can easily be implemented at local level by providing proper training and knowledge to local artisans and labours who are associated with building construction.

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References

- Ahmed, N. (2017). Housing reconstruction in a conflict zone: lessons learned from Awaran District in Balochistan, Pakistan. *Planning Malaysia: Journal of the Malaysian Institute of Planners*, Vol. 15(Issue. 3), pp. 39-50.
- Blondet, M., Garcia M., G., Brzev, S., & Rubinos, A. (2011). *Earthquake resistant construction of adobe houses*. EERI/IAEE World Housing Encyclopedia.
- Houben, H., & Guillaud, H. (1994). *Earth construction - A comprehensive guide*. ITDG Publishing, London, United Kingdom.
- HPF. (2013). *Awaran Earthquake 2013: Seismic Resistant Vernacular Construction*. Heritage Foundation of Pakistan.
- Mahar, W. A. (2012). Defects on building facades in Desa Bakti employee housing, Universiti Teknologi Malaysia, Skudai, Johor, Malaysia. Master Thesis M.Sc. (Planning-Housing), Faculty of Built Environment, Universiti Teknologi Malaysia.
- Mahmood, I., Iqbal, M., Mughal, M., Shahzad, M., Tariq, S., & Kalim, U. (2017). An investigation of 2013 Mw 7.7 Awaran Earthquake, Pakistan. *International Letters of Natural Sciences*, Vol. 61, pp. 36-42.
- Nation, T. (2015, March 25th). *Six suspected insurgents killed in Awaran in Mashkhay- one soldier died*.
- P&D. (2011). *Awaran: District Development Profile*. Planning & Development Department, Government of Balochistan.
- PBS. (1998). Population & Housing Census 1998. Pakistan Bureau of Statistics (PBS), Government of Pakistan.
- PBS. (2017). Population & Housing Census 2017. Pakistan Bureau of Statistics (PBS), Government of Pakistan.
- PDI. (2007). *Awaran District Balochistan Flood Assessment*. Participatory Development Initiatives (PDI), Khuzdar, Pakistan.
- PIPS. (2010). *Conflict and insecurity in Balochistan: Assessing strategic policy options for place and security, Final report*. Pakistan Institute of Peace Studies (PIPS).
- Rael, R. (2008). *Earth Architecture*. Princeton Architectural Press, New York, NY.
- Shah, M., & Jin, S. (2018). Pre-seismic ionospheric anomalies of the 2013 Mw = 7.7 Pakistan earthquake from GPS and COSMIC observations. *Geodesy and Geodynamics*, Vol. 1(Issue. 10).
- Shah, S. (2014). *Post Disaster Housing (Shelter for the earthquake affectees of Awaran)*. Bachelor of Architecture Thesis, Department of Architecture, BUITEMS Quetta, Pakistan.

United States Geological Survey. (2013a). Retrieved March 21st, 2018, from
<https://earthquake.usgs.gov/earthquakes/eventpage/usb000jyiv#executive>

United States Geological Survey. (2013b). Retrieved March 22nd, 2018, from
<https://earthquake.usgs.gov/earthquakes/eventpage/usb000k1gb#executive>

UNOCHA. (2013). *Balochistan Earthquake 2013: Findings and Strategies*. United Nations Office for the Coordination of Human Affairs.