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Damage assessment of flood affected mud houses in Pakistan

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Abstract

The torrential floods 2010 in Pakistan played havoc with the people and property in general and of Khyber Phukhtunkhwa (KP) in particular. More than two million houses were damaged partly or totally. The most affected housing stock was mud houses, which were mostly collapsed leading to deaths of people and live stock. In this study, the damaged mud houses in flood affected areas have been analyzed and the major causes of the failure of such houses were documented on the basis of field study and observations. Some improvements have been suggested for reconstruction of mud houses on the basis of international and regional building Codes and studies. It has been observed that if these improvements are incorporated in the construction of houses, the flood related damages can be minimized to greater extent. This can surely lead to the enhanced safety of people lives and property.

Keywords: Pakistan; Torrential floods; Mud houses

1. Introduction

Pakistan is exposed to large number of natural disasters such as earthquakes, floods, torrential rains and draught etc. The successive natural disasters of Kashmir earthquake 2005, followed by Baluchistan earthquakes in 2008 and Monsoon floods of 2010 have set unprecedented records of human and property losses. The details of the major natural disasters in last one decade and their associated human and housing losses in Pakistan are given in Table 1 (UN HABITAT-NDMA, 2010).

A great majority of the poor people in the developing countries are living in mud houses mainly due to easy availability of raw material and local skills for its construction. Typically mud houses are classified as Kacha and Pacca. In the areas more prone to floods, the houses are mostly kacha in nature which are further divided into following types on the basis of their construction (UN HABITAT-NDMA, 2010):

1.1. Manna (Grass cottage)

Manna house are made of bushes normally very easy and quick to build. Timber poles (3in-5in dia) are used at spacing of 6-8feet. Height of pole is varies from 7 to 9 feet. Two timber poles at the centre of shorter walls have more height than side poles. These types of houses have slanting roofs with two sloping sides and two gable ends. The house is shown in Figure 1(a). The lightweight of the Manna house (Grass Cottages) makes it good against earthquakes but it may not be very safe in high floods and torrential rains.

1.2. Jumpari (Light frame)

This type is an improved version of gross cottage and built with twigs, which are woven around vertical posts and finally mud plaster is provided. Mostly *Kera*is used as woven material for walling. Timber poles (3in-5in dia) are used at the spacing of 6-8 feet. Height of pole is generally 9 feet.

1.3. Mud houses (walls constructed in mud)

These types of houses are made with molded earth. Earth lumps are made and stacked to make the wall. Earth is not compacted. When wall has been built, it is trimmed to give better finishing to the wall. Environmental performance of these buildings is very good but these are very vulnerable to floods or rain and earthquake.

Table 1. Details of major causes of damages and No/% of houses affected.

Major causes of damage	Houses damaged				Total (Out of 200)
	Fired bricks with mud plaster (Out of 100)		Mud houses (Out of 100)		
	CD	PD	CD	PD	
Undermining of foundation	15 (15%)	25 (25%)	35 (35%)	45 (45%)	120 (60%)
Erosion at the corners of structures	14 (14%)	21 (21%)	29 (29%)	38 (38%)	102 (51%)
Damages due to roof collapses	12 (12%)	18 (18%)	28 (8%)	32 32%)	90 (45%)
wiping out of structures	10 (10%)	14 (14%)	23 (23%)	28 (28%)	75 (37.5%)
Deposition of debris in houses	06 (6%)	09 (9%)	17 (17%)	21 (21%)	53 (26.5%)
Damage due to debris flow	04 (4%)	07 (7%)	13 (13%)	18 (18%)	42 (21%)
Damage due to prolong submersion of buildings in water.	02 (2%)	05 (5%)	8 (8%)	12 (12%)	27 (13.5%)
Capillary rise of water to walls	01 (1%)	03 (3%)	05 (5%)	09 (9%)	18 (9%)

Source: UN HABITAT-NDMA, 2010.

1.4. Adobe (walls constructed with unfired mud bricks)

Adobe house made with mud blocks is similar to cement concrete block masonry, but blocks are made with mud, dried in sun and used with mud mortar. Wall thickness is generally 12inches. Adobe house made with mud bricks is similar to burnt brick masonry but bricks are not burnt and dried in sun and used with mud mortar. Generally wall thickness is kept 13.5 inches.

1.5. Fired brick wall (walls constructed with fires bricks and mud plaster)

This is very common type of construction after mud construction. This type of masonry is very quick to build and relatively cheaper in cost than cement mortar. It is constructed with fired bricks in mud mortar. Thickness of wall varies from 9 inches to 13.5 inches. Height of wall varies from 10 to 12 feet. Depth of foundation varies from 1.5 feet to three feet while foundation is 18 inches-wide. Foundation is made with brick or stone.

1.6. Stone masonry (Walls constructed with stone masonry)

This type of construction made with stones either in mud mortar or no mortar (dry stone masonry). Width of the wall varies from 15 inches to 18 inches. It can be coursed rubble masonry or random rubble masonry. This type of construction is commonly found in Neelum valley (AJ&K), Swat, Kohistan etc. Height of these buildings is 10 feet.

The pucca houses include the following sub types:

- Pucca stone masonry
  (Unreinforced stone masonry C/S mortar)
- Pucca brick masonry
  (Unreinforced brick masonry C/S mortar)
- Pucca block masonry
  (Unreinforced block masonry C/S mortar)
- RC confined brick masonry
- RC confined block masonry
- Bhattar (Timber reinforced stone masonry)
- Neelum house
- Dhajji house

Further details about the construction of various types of pucca houses are given below:

1.7. Pucca stone masonry (Unreinforced stone masonry C/S mortar)

This type is constructed in stones masonry with cement sand mortar. Stone masonry is done in two whythes but mostly these two whythes are not interlocked through stones. Dressed stones are used in the front side of stone masonry. Masonry is coursed and each course is 4 to 6 inches high. Width of wall is 15 inches and height is 10 feet maximum.

1.8. Pucca brick masonry (Unreinforced brick masonry C/S mortar)

These types of houses are constructed with brick by using cement sand mortar. Width of wall generally varies from 9 inches to 13.5 inches but in KP 4.5 thick brick masonry walls are also seen. Height of these walls varies from 10 to 12 feet.

1.9. Pucca block masonry (Unreinforced block masonry C/S mortar)

With cement sand mortar, these types of houses are constructed with concrete blocks. Width of the wall varies from 6 to 8 inches and height of the wall is generally 10 feet. Concrete blocks are made with the ratios varying from 1:4:8 to 1:6:12. Block size varies from 16 x 8 x 6 inches, 12 x 6 x 6 inches, 12 x 8 x 6 inches and 12 x 8 x 4 inches.

1.10. Bhattar (Timber reinforced stone masonry)

Here the stone masonry is reinforced with horizontal timber bands with cross ties provided at 2 feet interval in ladder shape. These ladders are provided at 1.5 to 2 feet equal intervals. This type of construction is mostly found in mountainous areas of KP (Battagram, Swat and Kohistan). Width of wall varies from 18 inches to 2 feet.

Neelum house

This is traditional construction in Neelum and Leepa valley. It's mostly two storey. Ground storey is made of stone masonry while upper part is timber frame with timber bracing or timber cladding.

1.11. Dhajji dewari

It is also traditional construction practiced in high altitude areas of AJK. Its timber frame construction with timber bracing, mud and stone as infill. Thickness of wall is minimum 4inches.It has timber base plate and wall plate.

The various types of kacha and pacca houses are shown in Figure 1.

2. Impact of natural disasters on housing sector of Pakistan

After immediate threat to the human lives, the next most vulnerable are the houses. The impact of earthquakes and floods on houses has been enormous and hence the reconstruction of houses after these natural disasters is always an uphill task for the communities. The province-wise statistics to various types of houses damaged in the floods 2010 are given in the Table 2 (UN HABITAT, 2012). The figures show that in total about 1.6 million houses were damaged totally or partially in the flood affected areas. The distribution of these houses is given in Figure 2. The figure shows that 82% of the total damaged houses were various forms of mud houses. This unprecedented damage to the mud houses has resulted to severe housing shortage in the flood affected areas and millions of people were forced to migrate to the safer temporary camps.

In this field based research work, data is collected about the nature of damages and the major causes of damages to the mud houses in the flood affected areas. This has also identified the need for collaborative efforts for better design and construction of mud houses to mitigate any such damages in the likely future floods.

Fig. 1. Various types of Kacha and Pucca houses used in the disaster prone areas of Pakistan (UN HABITAT-NDMA, 2010).

3. Performance of mud houses in the natural disasters

A great majority of people in the developing countries of Asia and Africa though still live in mud houses, yet the performance of mud houses in the successive disasters remained poor. Even then mud houses are still the most preferred housing types in the reconstruction due to cheap and wide availability of the raw material and local knowledge for its construction. Majority of the people in Countries of as Latin America, Africa, Indian subcontinent, and other parts of Asia, Middle East and Southern Europe use mud houses (Houben and Guillaud, 1994). Very little research data is available on performance evaluation of mud houses. Extreme Loading for Structures (ELS) was used to simulate the mud structures and its performance by Redman and Smith (2009).

3.1. Mud bricks performance in shear, tension and compression

The mud bricks are very weak in shear, tension and compression. In case of earthquakes, walls separate at the corners and the shear cracks develop across the wall, causing collapse of the structure. Extensive damage was observed during earthquake especially if it occurs after a rainfall. Blonde and Garcia (2003) developed the design and construction manual for the adobe houses on the basis of 30 years experience at the Catholic University in Peru, which were followed in the reconstruction efforts after Pisco earthquake of 2007.

Table 2. Province/region wise damages of various types of houses in Flood 2010.

Province/ Region	Pucca houses			Kacha houses			Total			% of pre-flood stock
	CD	PD	Total	CD	PD	Total	CD	PD	Total	1%
AJ&K	541	2316	2857	0090	2896	3986	1630	5212	6843	14%
Baluchistan	800	1500	2300	73724	3696	77420	74524	5196	79720	1%
FATA	0	0	0	1241	4178	5419	1241	4178	5419	1%
Gilgit-Baltistan	0	0	0	3157	0	3157	3157	0	3157	2%
Khyber Pukhtunkhwa	4107	8282	12389	90605	154300	244905	94712	162582	257294	9%
Punjab	4050	8127	12178	123572	240024	363595	127622	248151	375773	9%
Sindh	56353	70441	126794	554067	199118	753184	610420	269559	879978	24%
National Total	65851	90666	156517	847455	604212	1451667	913307	694878	1608185	13%

Source: UN-HABITAT-National conference on learning from disasters, 22-23 Feb 2012.

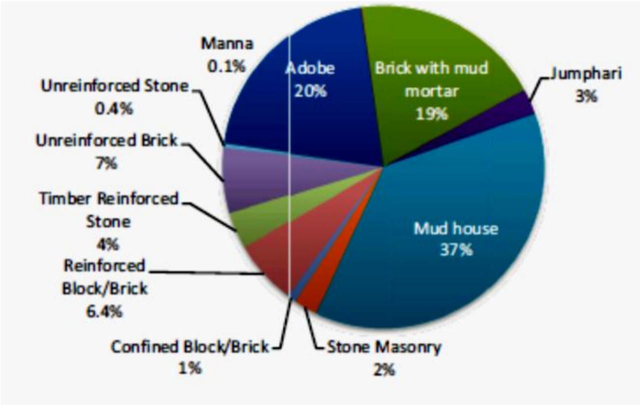

Fig. 2. Distribution of various types of houses in flood affected areas of Pakistan. (UN HABITAT, 2012).

Traditionally straw is more frequently used to presumably improve the compressive strength of mud bricks, but the work of Islam and Wantabe (2001) showed that the straw content less or equal to 1% (by weight) was not effective to improve ductility, however at higher straw contents (1.5-3.0%) both failure strain and ductility were increased. Further increase of straw content beyond this limit however reduced the ductility and compressive strength.

3.2. Seismic performance of mud houses

Performance of traditional adobe construction during numerous Iranian earthquakes has generally been poor as reported by many researchers after assessing the post earthquake damages. Low material strength, poor workmanship, lack of proper connections between building elements, and the excessive weight of the building owning to thick walls and massive roofs, are some of the shortcomings that led to the general weakness of these buildings under earthquake loads (Maheri et al., 2005).

The performance of various non engineered houses was evaluated in earthquakes in successive earthquakes in Bangladesh. It was reported that mud houses are more vulnerable to earthquake than any other type of traditional house, because of its brittle nature and lack of lateral force resisting system. Some design interventions can improve the seismic performance of the mud houses, which may include wooden bracing at the corner location of the beams, metal straps at connections, placing of roof truss at proper location, blocking of excess opening, use of cement plaster over walls, insertion of new walls etc. (Jehangir et al., 2012). On the basis of field survey after floods in Bangladesh, it was suggested that the mud houses are more suitable for low flood areas particularly. The performance of single family two floor mud houses in Bangladesh located in semi urban and rural areas has been reported vulnerable to seismic forces and lateral pressure of the flood flows (EERI, IAEE, 2007).

3.3. Resistance of mud houses to water erosion and moisture

Rodriguez and Saroza (2006) used various organic stabilizers for improving the properties of adobe blocks and reported that the mud blocks with 2% asphalt has given highest strength and moisture resistance.

In most parts of the world mud houses are also exposed to torrential rains and floods. Mud blocks are vulnerable to erosion in case of such rains and floods. Various mineral stabilizers have been used to improve the resistance of mud blocks to water erosion. These may include cement, lime and bitumen emulsion; animal products, such as blood, urine, manure, casein, bee wax and animal glue etc (Ngowi, 1997).

Mercy Corps (2010) introduced the concept of Non Erodible Mud (NEM) Plaster and cement based NEM (cement stabilization) to improve the performance of mud blocks against the floods. The report revealed that NEM plaster performed well during floods and it was also accepted by the communities in Nepal.

3.4. Drying shrinkage of the mud block

To improve the resistance of mud blocks against the water erosion, the drying shrinkage of the blocks must be controlled. Material damage due to rain impact initiates around areas of weakness, which in turn are located in the vicinity of shrinkage cracks.

3.5. Durability of mud blocks

The use of Cactus solution to improve the durability of adobe against the water erosion has also been recommended (Zavoni et al., 1988).The stabilization of adobe with lime depends on the nature of soils used for making the blocks. For rich clay soils, the addition of 2-3 % of quicklime to a soil quickly reduces plasticity by hydration (dries the soil) and breaks up the lumps. For both the clay loam and the sandy soils, the lime content of 2% resulted in a 7-day compressive strength of about 0.7 MPa, but increasing the percentage to 4% resulted in nearly doubling the compressive strength. However further increases in lime content led into no significant increase in compressive strength (Akpokodje, 1985).

In this paper, the major reasons for damages of the mud houses have been analyzed on the basis of filed survey and recommendation for design and construction improvement of mud houses have been made.

4. Objectives

The field based observational research was mainly aimed at identifying the major causes of damages to the mud houses in the wake of torrential floods. This would lead to exploring some better designs and construction methodologies and techniques in times to come.

5. Methodology of research

The flood damaged houses of Mardan and Peshawar valleys were taken as population. Two types of mud house i.e. Adobe block houses and fired bricks houses with mud plaster, were considered in the study. 100 houses were taken as sample for each category of mud houses. The damaged houses were further classified as "Partially damaged (PD)" and "Completely Damaged (CD)". PD refers to house were the house were damaged to the extent that parts of it were damaged but still the people were living in such houses, whereas the CD houses were damaged beyond the repairs and were not suitable for living of the people. Observation sheets were prepared to physically check and record the nature and extent of damages in these houses. The data was then tabulated and analyzed and the major causes leading to the collapse and damages of mud houses were documented. Based on the performance of these houses, some recommendations were made for the improvements of mud houses.

6. Observations

On the basis of the damage assessment of the 100 sample houses partially and completely damaged, the major causes responsible for the destruction of these houses are as given below:

i. Undermining of foundations
ii. Scouring/erosion at the base of the walls
iii. Scouring/erosion at the corners of structures
iv. wiping out of structures
v. Deposition of debris in houses
vi. Damage due to debris flow.
vii. Damage due to prolong submersion of buildings in water.
viii. It has been observed that many mud buildings were damaged even water did not touch the floors and due to the capillary rise walls lost strength.

The major causes of damages of the mud houses in the flood affected areas are given in Figure 3.

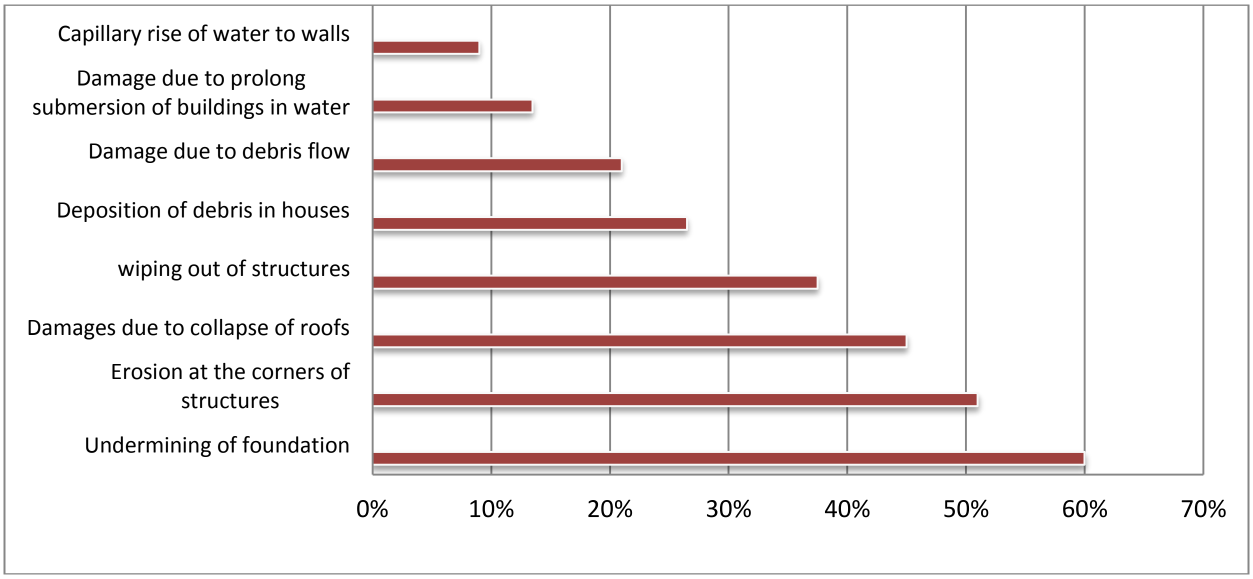

Fig. 3. Major causes of collapse of the mud houses in the flood affected areas.

Further explanation of these causes is given as follows:

6.1. Undermining of foundation due to flood waters

In most of the cases there was no plinth protection to prevent access of flood water to the foundations. This subsequently led to the settlement of foundation and ultimately collapse of mud houses. In Figure 4, two such houses are shown. In some cases, where raised platform was constructed around the building or building was constructed on elevated platform, the relative damages were less.

6.2. Erosion of the corners of walls and structures

The corners of the wall in mud houses always provide weak areas for the earthquake and floods, due to lack of proper bond. In floods, due to continued exposure to the walls to the torrential rains, these weak corners are further expose and the top cover of mud plaster is washed away, thereby making these corners further weaker. Some of such damages are shown in the Figure 5.

6.3. Damages due to collapse of roofs

The collapse of roofs remained another major cause of damage. Due to saturation of the mud roofs with no water proofing, the dead weight of the roofs increased substantially leading to the sagging to wooden roof structure and ultimate collapse. In Figure 6, some of such houses are shown.

Fig. 4. The damaged houses due to undermining of the foundation by flood water.

Fig. 5. Damaged houses due to splitting of corners.

Fig. 6. Damaged roofs of the mud houses.

6.4. Wiping out of the structure

In some cases, the houses have been completely wiped out by the floods. Most of such houses were constructed in the floods plains. In some cases, the collapse of the roofs also caused the major damages. Some of such houses are shown in Figure 7.

6.5. Deposition of debris in houses

After receding of flood water, the debris mostly comprised of slit and clay remained dumped in the houses for long time, which also damaged the houses. The clearance of the debris remained a major post flood activity in the affected areas. In Figure 8 the debris in the houses are cleared by the residents and volunteers.

6.6. Damages due to prolonged submergence of houses in the standing water

In plain areas, having no proper drainage, the flood remained standing for months, which has been eroding and undermining the foundations and other parts of the substructures of mud houses leading to collapse of walls. This is more common in the areas located in thick populated settlements, where drainage of water is relatively difficult. In Figure 9 some houses damaged due to standing waters can be seen.

Fig. 7. Flood damaged houses due to wiping out of houses mostly located in the flood plains.

Fig. 8. Damaged houses due to deposition of debris after floods.

Fig. 9. Effect of standing water on the mud houses.

7. Proposed design and construction improvements for the mud houses in the flood affected areas

The monsoon floods is recurring feature of the flood affected areas and there is a need to create awareness and local skills for improvements in the housing construction efforts. Many organization like UN-HABIAT, PLAN PAKSITAN etc have already started capacity building and training & development of the locals for flood resisting mud houses, even then there is a need for more interventions. On the basis of consultation with experts, peers, consultants and other organizations as well references from Codes, the following improvement have been suggested (Khan, 2011).

7.1. Raising of platform for construction of mud houses

Rising of platform and plinth above ground level will protect the mud houses from the access of water. The following improvements have been suggested (Design hand book, 2010):

i. The platform must be raised at least 1ft above to regular flood level with compacted earth and extend the edges minimum 3ft away from building footprint.
ii. The slope of platform may be maintained for sandy soil at 1V to 2H (For each vertical ft height, horizontal width of 2 feet) and for clayey soil; 1V:1.5H.
iii. The water must be drained away from the building. For control of erosion of platform, deep rooted edge plants, bushes or grass may be grown on edge. Alternatively brick pitching may be provided.

7.1.1. Foundation and plinth

The depth of foundation is very important particularly when mud houses are subject to standing water for prolonged period. The following important points must be considered for foundations and plinths of the mud houses.

i. The depth of foundation may be taken as min 4 feet for soft soil and 2 feet for hard soil. The width of foundation may be taken as twice the width of wall for soft soil and 1.5 times the wall width for hard soil.
ii. The material to be used in foundation may be stones, fired bricks, solid blocks, dry stone masonry or plum concrete of nominal ratio of (1:3:6) with 40% of stones of total volume, where stones are available.
iii. The plinth must be raised at least 6in above the high flood level. The Damp Proof Course of heavy polythene and water proof mud. For plinth protection 3 feet wide apron of burnt bricks having 3 in slope outwards may be provided.

7.1.2. Joinery works

Opening in the mud walls provide weak points for access to water. Joinery works and its location in the walls need careful considerations. The following guidelines may be adopted:

i. The doors and windows must be placed at least 4 feet away from corners of the rooms and the distance between two adjacent opening should not be less than 4 feet. The width of opening must be restricted to 4 feet.
ii. For opening lintels of proper sizes must be used and at least 18 in bearing over the walls must be provided to avoid the slipping of lintels.

7.1.3. Walls

Thickness of wall is very important in mud houses. The following design and construction guidelines may be kept in the mind:

i. For compressed adobe walls, the minimum thickness must be kept as 12in to 13.5 in and the height of the unsupported wall may be restricted to 8 feet and length to 14 feet.
ii. For molded clay walls the wall thinness at the bottom may be kept as 18 in and the thickness of the wall at the top must be 12 in to increase the stability of the wall.

7.1.4. Roof band and ring beams at lintel and plinth

i. The bands may be made of wood, wire mesh, Reinforced Bricks (RB) or Reinforced Concrete (RCC), as feasible at site.
ii. For wooden lintels, ladder type lintel may be made of 3in x 1.5 in with nails and cross pieces f 2in x 1.5 in @18 in c/c. Similarly wooden bands can be made of single piece of size 4in x 2 in with diagonals at the corners.
iii. Roof bands must be tied with lintel and lintel bands by nailing diagonal woods at wall face, to provide stability against roof and wind. In case wood is not available, two courses must be provided with burnt masonry.

7.2. Roof

i. For light weight flat roof, shorter than 14 feet, light weight mud roof may be used as per following details:
ii.
   a. Here I-section of steel girder of 6'' web @6ft spacing for 12ft span and 8'' web@6ft spacing for less than 15ft span on roof band with the help of2/8 dia bar already embedded in roof band is fixed.
   b. Wooden runners (batten) 4'' x2'' @2ft C/C. or 2'' diameter bamboo @1.5 ft c/c are laid over I section and each batten/bamboo is tied at mid by GI wire with girder and batten ends with roof band by driving nail on bottom side roof band.
   c. Polythene sheet is placed on chick, overlap pieces 12'' minimum and the masonry cornices are raised by 9'' above the polythene surface. Extended brick tile may be used as drip course.
   d. Earth layer of 6'' thick is laid over it, forming a slope of 12% towards spout and small amount of water is sprinkled to compact it to 4in and left for 2-3 days.
   e. Mud is prepared by using wheat husk and the roof surface is plastered 1'' thick.
   f. 1.5 ft extended spout is used or vertical drop of cemented spout with 1:3 to drain rain water is provided. For better rendering wire mesh should nails in wall and then plastered.

iii. For pitched CGI sheets may be used for span up to 16 feet and the following recommendations may be followed:

   a. CGI Sheets 26 SWG gauge are placed at angle 25-35 degree having king post trusses @5ft c/c and tie beam , rafters 3''x4'', king post 3''x3'', purlins of 2.5''x2''
   b. Longitudinal slope (1:300) should be provided in one side to harvest rain water and Projection up to 1.5 ft.

iv. For light weight Thatch roof with mud plaster, the following improvements may be followed:
   a. Wooden/Bamboo having ridge beam, 3'' dia ridge pole, 3'' dia rafters @ 4 ft may be used. 1.5 in dia-purlin @ 1.5 ft spacing are provided.

7.3. Material selection for the mud structures

Selection of appropriate material for the mud construction is an important consideration. The following recommendations were made by the experts:

i. For molded clay construction, soil with Sand 50-60%, Clay 20-25%, Gravel 20%, and Straw/chaff 5kg/CuM and Water 20% of total volume was recommended.
ii. Soil for adobe and rammed earth may contain sand 40-45%, silt 15-30% and clay 10-25%.

7.4. Site selection for mud houses

Most of the mud houses collapsed during the floods 2010 was located in the flood plains. The site selection is of prime considerations in the construction of mud houses. For construction of mud houses, the raised and elevated platforms are more suitable to avoid threat to the buildings. The soil must be well compacted.

8. Conclusion and recommendations

The analysis of major causes of damages to mud houses both partially and completely affected houses has been carried out on the basis of field survey of 100 houses from each category. The analysis has revealed the following major causes of damages to the mud houses:

i. Undermining of foundations
ii. Scouring/erosion at the base of the walls
iii. Scouring/erosion at the corners of structures
iv. wiping out of structures
v. Deposition of debris in houses
vi. Damage due to debris flow
vii. Damage due to prolong submersion of buildings in water
viii. Prolonged exposure of building to standing flood water

On the basis of follow up surveys and consultation with the experts, some improvements in the design and construction of mud houses have been suggested which may be used in the reconstruction of mud houses to enhance its performance in the floods. There is also need to study other types of kacha houses such fire brick works with mud plaster, stone masonry with mud plaster and Jumpari houses.

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