Materials

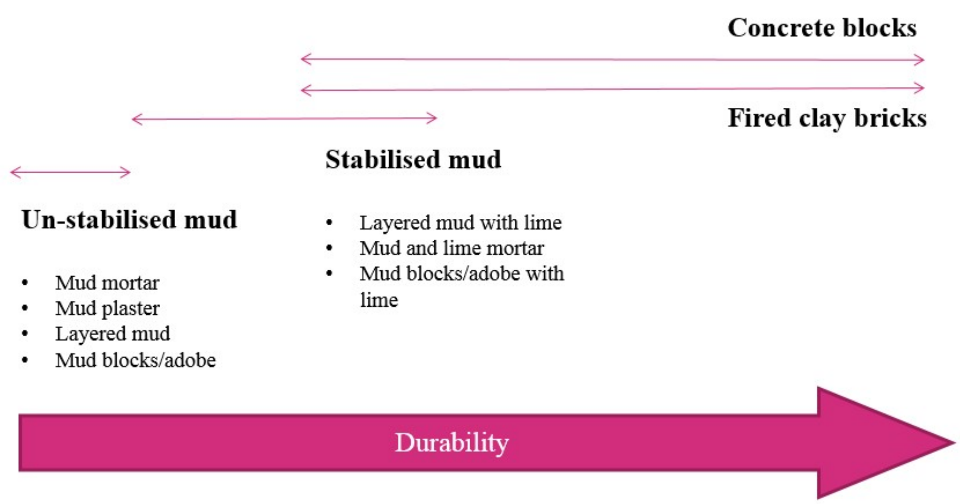


Figure 4 – Durability of materials when immersed in water or subject to rainfall erosion

The relative performance of materials when immersed in water or subject to erosion from rainfall is well established. We know that an un-stabilised mud brick shelter with no DRR features will perform poorly. We know that a fired clay brick with cement mortar shelter will perform well.

The diagram provides a general assessment of the durability of materials when subject to immersion or erosion from water with durability increasing from left to right. The smaller arrows indicate that within a given material there can be wide variation in their performance associated with quality of materials and workmanship.

Understanding flood damage to shelter

The following findings are extracted from a Rapid Technical Damage Assessment[1] conducted by UN Habitat following the 2010 floods.

Typology and Hazard	• Key observations and <u>Potential areas to investigate through testing</u>
Loh Kat – Standing water 	• Foundations eroded • Mud plaster is washed away • Importantly the bamboo/timber frame remains in place meaning that the roof remains intact • Walls can be repaired once water has receded <u>Foundation design</u> <u>Redundancy of walls for improved roof support</u> <u>Lime stabilised plaster</u> <u>Raised floors and plinth protection</u>
Fired Clay – Standing water 	• Bricks are largely water resistant and remain intact • Where used with mud mortar the mud is washed away, the wall no longer has cohesion and collapse follows • Water-logged shallow foundations are subject to settlement, resulting in cracking and collapse of walls. <u>Foundation depth</u> <u>Upper and Lower ring-beam</u>
Adobe/Mud brick – Standing water 	• Walls dissolve and collapse • With no redundancy in the structure the roof also collapses • Water-logged shallow foundations are subject to settlement, resulting in cracking and collapse of walls. <u>Lime stabilisation</u> <u>Wall tie-ing and redundancy (buttresses etc)</u>

[1] Rapid Technical Assessment of Damage and Needs for Reconstruction in Housing Sector, UN Habitat, 2010

Mud roofs – Rainfall 	• Mud roofs become saturated with rainfall causing failure of roof covering and or the roof structure. Load capacity of roofs Roof drainage

The diagram below illustrates how heavy rain and standing water might be mitigated by shelter design features. This helps to identify the design features that physical testing should explore. The impact of additional loading from waterlogging of roof on the roof structure can be explored through structural analysis. The impact of ring beams and other forms of structural tie-ing may not be possible unless tests are conducted on full scale shelter.

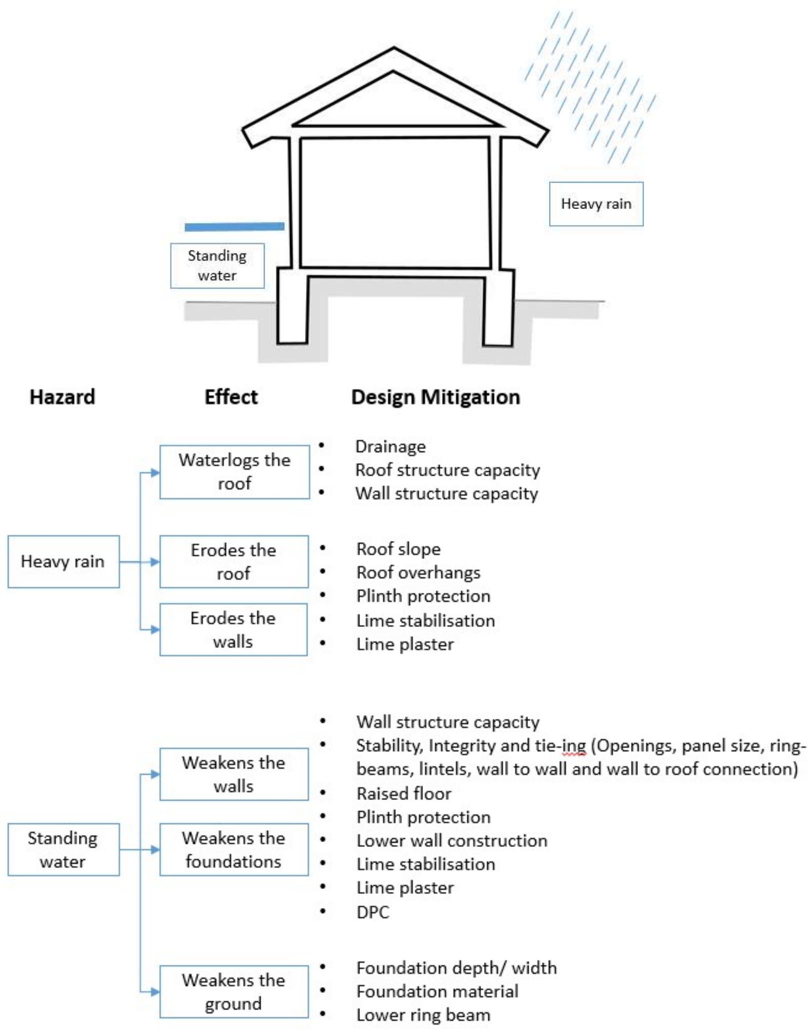


Figure 5 – Possible design mitigation for standing water and heavy rain

CHAPTER 1

INTRODUCTION

1.1 General

Clay is an important raw material for building construction in rural areas of Pakistan and more specifically in Sindh. Every year or two, thousands of houses made up of clay are destroyed due to rainfall and flood in Sindh. Sindh has an area of 140,914 km^2 with one of the world's largest river, River Indus, flowing through it. Human Being has always tried to dwell close to water bodies to use water for domestic purposes and for cultivation. This province of Pakistan houses significant volume of its population in the flood plain of Indus River. Houses in the rural settlements of this flood plain are mostly made in clay and prone to floods and rainfall. Clay has very unique responses when it interacts with water like shrinkage on drying, hardness, and intra/inter-media adhesiveness and cohesiveness when wet. These properties tend to enhance or deteriorate the strength of structures in which clay is used as the major constituent or primary bonding agent. In this study an experiment is carried out to compare the performance of conventional and unconventional clay walls. Clay, when mixed with calcium or natural/synthetic fibres and other engineered constituents affects the durability of clay structures. These walls with conventional and unconventional clay mix design are tested under a flooding condition at a facility at NED University of Engineering & Technology. The Flood Simulator is fed with a pre-defined flood hyetograph of 4' inundation depth. During the test, various methods are employed to measure the deterioration of each of the wall panels under this inundation with time. This report discusses the executed test in detail. The adapted methodology and experimental setup is discussed in chapter 2 and the results of the experiment are displayed in chapter 3 of this report.

1.2 Background

During the course of history, it is witnessed that people reside near the fertile lands, where their livelihood is at ease for being close to resources including food and water. Poignantly, the same rivers that provide them with nutrition make them prone to disaster such as overflow of rivers and consequent flooding. Floods are one of the most intense and hazardous events. Though the cause of flooding varies, it ultimately makes the society suffer devastating losses of lives, infrastructure, economy and environment.

Pakistan lies in the tropical region making it fortunate for not having disasters like volcanoes; hurricanes etc. but floods are not an exception. For Pakistan, there are two major causes of floods, flash floods due to intense rainfall in short duration, and overflowing of rivers and streams due to intense rains or glarier melt. The average rainfall of Pakistan ranges from 125 mm in South-East region to 750 mm in the North-West region. However, the average rainfall in Pakistan isn't enough to cause flooding; nevertheless, the disasters happen either during monsoon or glacier melt and/or as a combination of both.

Pakistan has one of the largest irrigation systems in the world, and her Gross Domestic Product (GDP) index and export is significantly controlled by agricultural production, therefore; it is essential to protect the cultivated areas and human lives and settlements from floods.

Pakistan has witnessed multiple catastrophic floods that originated in the River Indus systems. Floods of 1950, 1956, 1957, 1959, 1973, 1976, 1978, 1988, 1992, 1995, 1996, 1997, 2001, 2003, 2005, 2007, 2010, 2011, and 2014 are the distressing yet memorable events entailing tremendous damage to life and property. The recent two floods that are 2010 and 2011 had been an eye-opener. The flood of 2010 was recognized by the United Nations as the greatest natural disaster in its history, affecting twenty million people. One-fifth of Pakistan was submerged during that flood. These facts express the importance of making the settlements and ultimately the human lives as safe as possible from disasters like floods. Prolonged inundation of houses made up of clay makes it vulnerable for living.

1.3 Objective

The objective of this study is to assess the flood or inundation resilience of structures made up of clay as the primary constituent. Walls with conventional clay mix design and engineered clay mix design (experimental) along with other constituent and fibres are tested. Effect of wall geometry on its resilience is also assessed.

1.4 Scope

This study limits the testing of prescribed wall geometries and clay mix design only. These design parameters are provided by the client. Flood wave at a place arrives with both horizontal and vertical component of velocity. This test limits the simulation if vertical component only. Flood water also brings debris along with it whose impact on structure tends them to collapse, effect of such incoming debris is not incorporated in this experiment.

1.5 Expected Outcome

The expected results of this experiment are the survival time of wall panels under inundation condition that occurs as a result of flood. Clay absorbs water and has relatively higher water holding capacity than other common soil types. The time of exposure of clay to water affects its bonding properties. The 12 walls with varying clay mix designs are tested and time to collapse is observed. Comparing this parameter of time to collapse for the prescribed clay mix design will conclude the most sustainable composition ratio and constituents to be used for flood resilient structures made with clay.

CHAPTER 2

METHODOLOGY

2.1 General

Experiment station consists of a flood tank and a reservoir tank. Wall panels are constructed in flood tank which is supplied with water from the reservoir tank. The test is executed under pre-defined conditions and various observation methods are employed to assess the resilience of clay walls to inundation with time.

2.2 Flood Simulator – The Experimental Setup

The flood simulator consists of two large tanks. One of the tanks is named as flood tank and the other is the reservoir to hold the water to be fed into the flood tank. These tanks are connected to each other with pipes and pumps to transfer water from one tank to the other. The inlets in the flood tank are placed in such a way that the clay structures constructed within it are not affected by turbulence of inflow. Figure 1 shows the view of flood tank from two different points. It can be seen that wall panels are constructed inside the flood tank which. The constructed walls are also provided with some loading conditions as seen in Figure 1, discussed in succeeding sections of the report.

Figure 1 View of flood tank from two different angles

2.3 Testing Conditions

This section discusses the testing conditions applied for the subject experiment

2.3.1 Roof Loads

To incorporate the effect of roof, loading of 100 kg is placed on top of walls centred horizontally. This load in shape of gunny bags filled with sand is fixed by steel straps hooked to the walls to avoid jump at the time of collapse.

2.3.2 Water supply and discharge regime

Before starting the test, reservoir tank is filled with the required volume of water including the losses. The flood tank is supplied with constant flow of water from controlled inlet to keep the turbulence as minimum as possible. Pre-defined supply and discharge regime is defined in Figure 2. The flood profile or regime contains two peaks 600 mm and 1.2 m high representing two phases, phase 1 and phase 2, respectively. The flood tank is filled 600 mm by end of week 01 by supplying constant flow daily during working hours. For week 02, constant level of 600 mm is maintained. It is a fact that water evaporates and this deficit was refilled to maintain water level. Discharging was to be started by week 03 till the end of week 05. However, due to administrative limitations the discharge for phase 1 (600 mm peak) is modified which is shown in Figure 3, Phase 2 is executed as proposed in Figure 2.

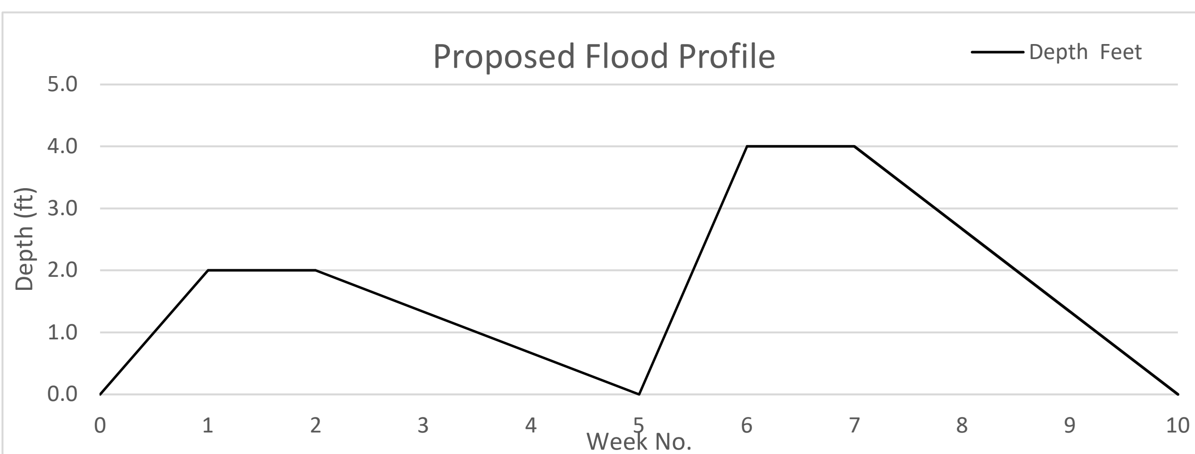


Figure 2 Proposed Flood Wave

Inflow 1	Outflow 1	Inflow 2	Outflow 2

0.286 feet per day	0.095 feet per day	0.571 feet per day	0.190 feet per day

Proposed and Simulated flood profile for phase 1

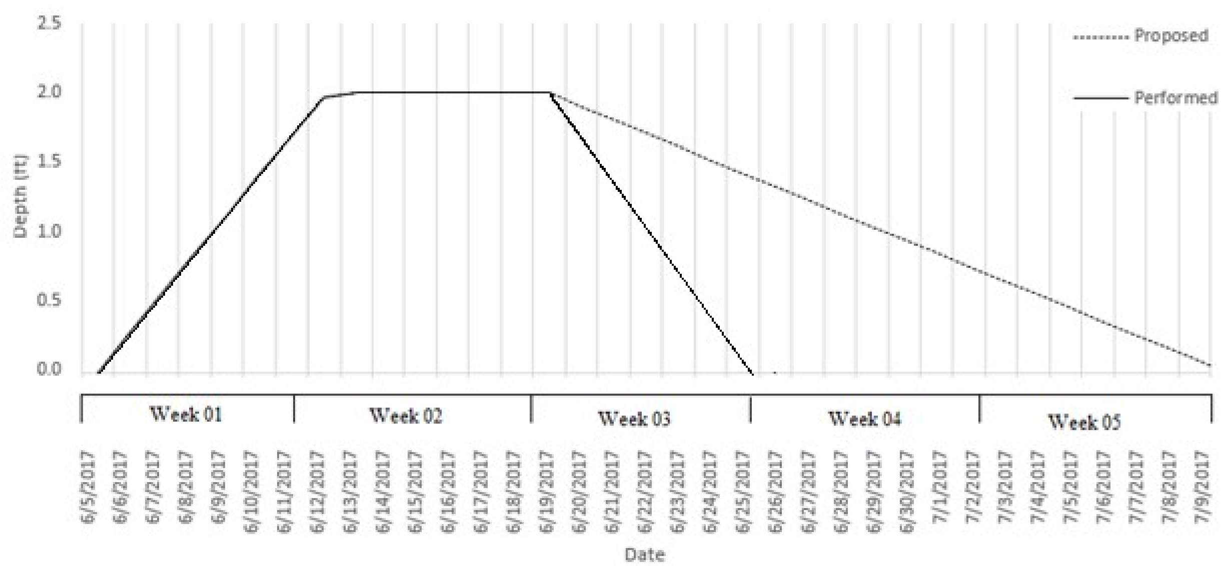


Figure 1 Proposed and performed flood wave (Phase 1)

2.3.2.1 Flood phase 1

The flood tank was filled with water with constant supply to a depth of 600 mm at a rate of 122 mm per day such that the water reaches 600 mm after 5 days. A staff gauge for measurement with custom calibrations was installed in the flood tank as show in Figure 4.

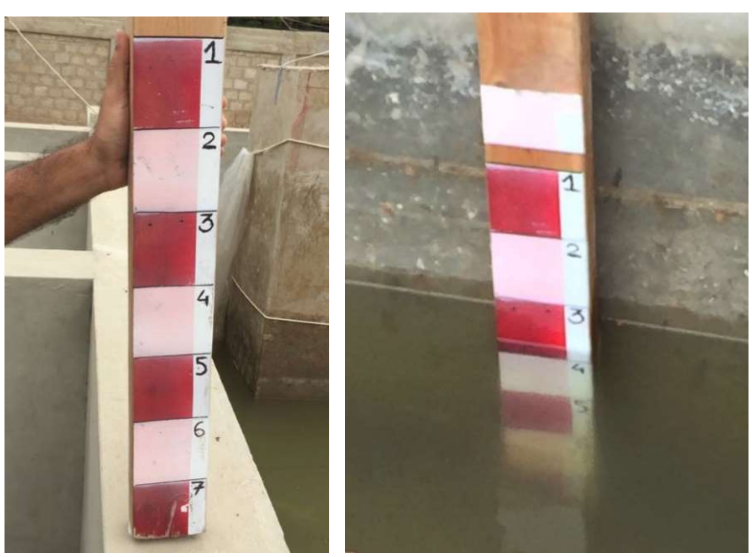


Figure 2 Staff gauge for measurement of water depth in flood tank

Evaporation and infiltration losses are encountered and the tank is refilled to maintain the required depth of 600 mm for the first week. At the end of week 2, water is drained at a rate of 86 mm per day. It is ensured that as the water drains away it does not lead to erosion of the walls or foundations or the ground near the panels.

2.3.2.2 Flood phase 2

For the second phase, as shown in the Figure 2, the flood tank is again filled with water to a depth of 1.2 m in a week with a daily inflow of 174 mm. For the next week, level of 1.2 m is maintained and then the tank is emptied in three weeks. A custom made gauge is placed to note down the depth of water in the flood tank. As discussed in previous section, all losses are incorporated to maintain the daily required depth inside the flood tank.

2.4 Limitations

The limitations of flood simulator tends to give conditional results. The assumptions of the simulation are discussed in this section. Since the flood tank is supplied with constant inflow that increases the depth of water inside the tank, the water particles have minimum effect in its horizontal component of velocity. Hence portraying a scenario of flood wave in a plain with no or very less slope. Flood waves generally arrive with debris and other elements that strike that have significant impact of the structures stability. This test does not incorporates flood wave with debris. The test is limited to inundation resilience of the clay walls only.

2.5 Observation Setup

The changes or deterioration of walls inside the flood tank are recorded by various means. Observation methods are discussed in this section.

2.5.1 Photographic Observation

The still camera set up consists of a number of good quality cameras being moved around the 12 different locations as shown in Figure 5, and placed onto a fixed mount, which has been set up according to trials to ensure that it captures the entire height of the wall in the frame.

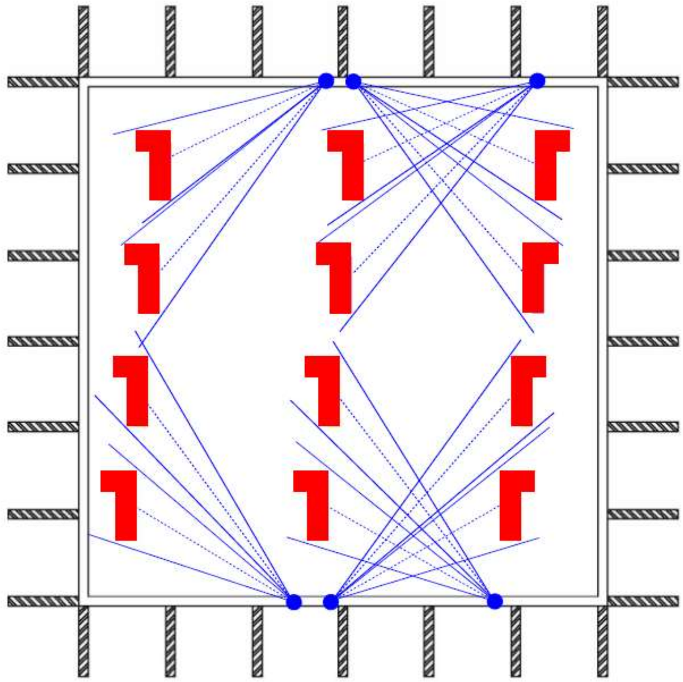


Figure 5 Camera location for still photography

The camera mount set up is made to ensure that it is tamper proof throughout the duration of the tests as shown in Figure 6.

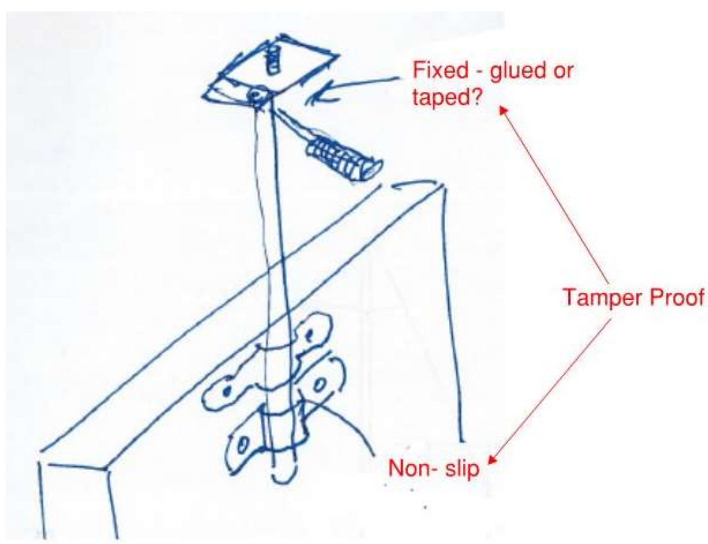


Figure 3 Camera mount

2.5.2 Live video feed

A live video feed is set up to allow streaming of the site online. For monitoring (in case collapse is not captured otherwise) and publicity (via a website or app), these two cameras are set up to view all of the panels. These were installed on a pole near the site, high enough to get a good view. Figure 7 shows the view from mounted camera.

Figure 7 A view from camera installed for video recording

2.5.3 Damage monitoring

The total stations were used to take measurements of 6 points on each of the twelve wall panels as presented in Figure 8. The positions of these readings are marked on the wall so that readings are from the same places each time. It is not possible to record damage to the panels under water. Measurements are; therefore, restricted to above the water level. Following parameters are measured:

a) Level of the top of the wall (to observe sinking)
b) Lateral movement of the wall (to observe drift)
c) Angle of wall surfaces (to observe tilt)

It was possible to process the 6 point observation on each wall by bench marking the distance of these 6 observations from fixed points near the flood tank. Linear distances are observed between the bench mark and the point on walls. The difference in these distances from bench mark depicts the movement of wall panels for sink, drift and tilt.

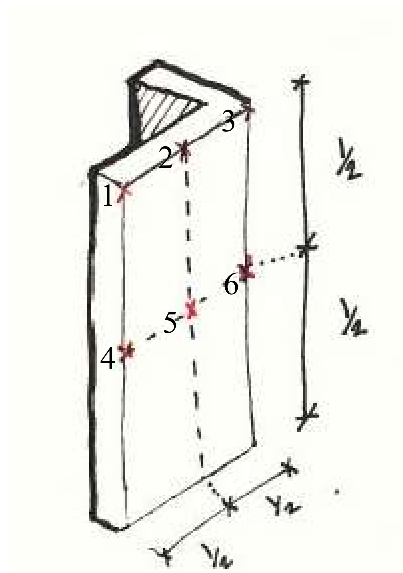


Figure 8 Observation points on wall panels

CHAPTER 3

RESULTS

3.1 Time of Collapse

The observation on time to collapse are discussed in this section. The observations are distributed in two parts, part 1 for the flood wave of 600 mm height, and part 2 for flood wave of 1.2 m height.

3.1.1 Walls Collapsing During Flood Wave 1

Flood wave as discussed in previous chapters was 600 mm high. Figure 9 shows the depth of water in flood water in the flood tank with points highlighting the time of collapse of respective wall panels.

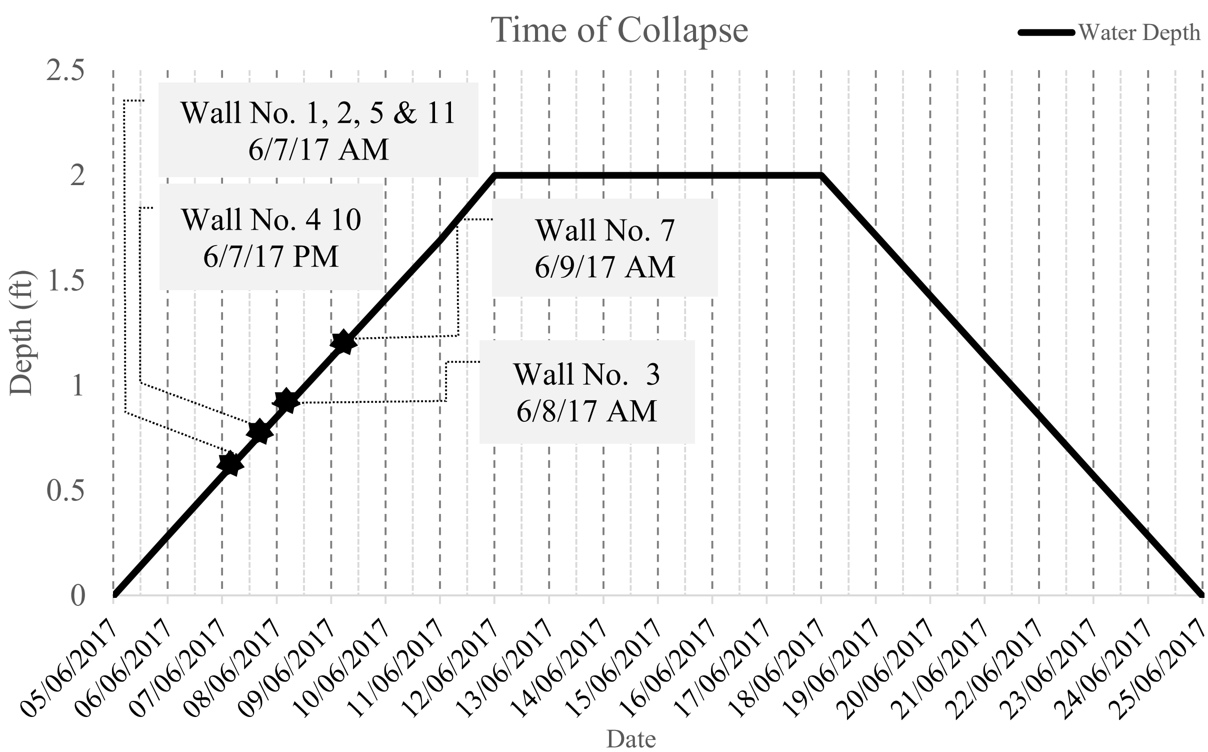


Figure 9 Time graph of collapsing wall panels in phase 1 of flood wave

Wall panel numbers 1, 2, 5 & 11 were the first to collapse from the effect of incoming flood wave. They were not able to sustain inundation depth of 185 mm. Wall No. 4 & 10 collapsed at an inundation depth of 230 mm. Wall No. 7 and Wall No. 3 performed relatively better and sustained an inundation of 300 mm and 380 mm, respectively.

3.1.2 Walls Collapsing During Flood Wave 2

Wall panels sustaining the first phase on 600 mm inundation depth were again put to test for a depth of 1.2 m. The second phase consisted of flood wave of 1.2 m in the first week, maintaining this depth for the next week and taking off the water in three weeks at constant rate. The observations of the wall collapse in this second phase are summarized in Figure 10.

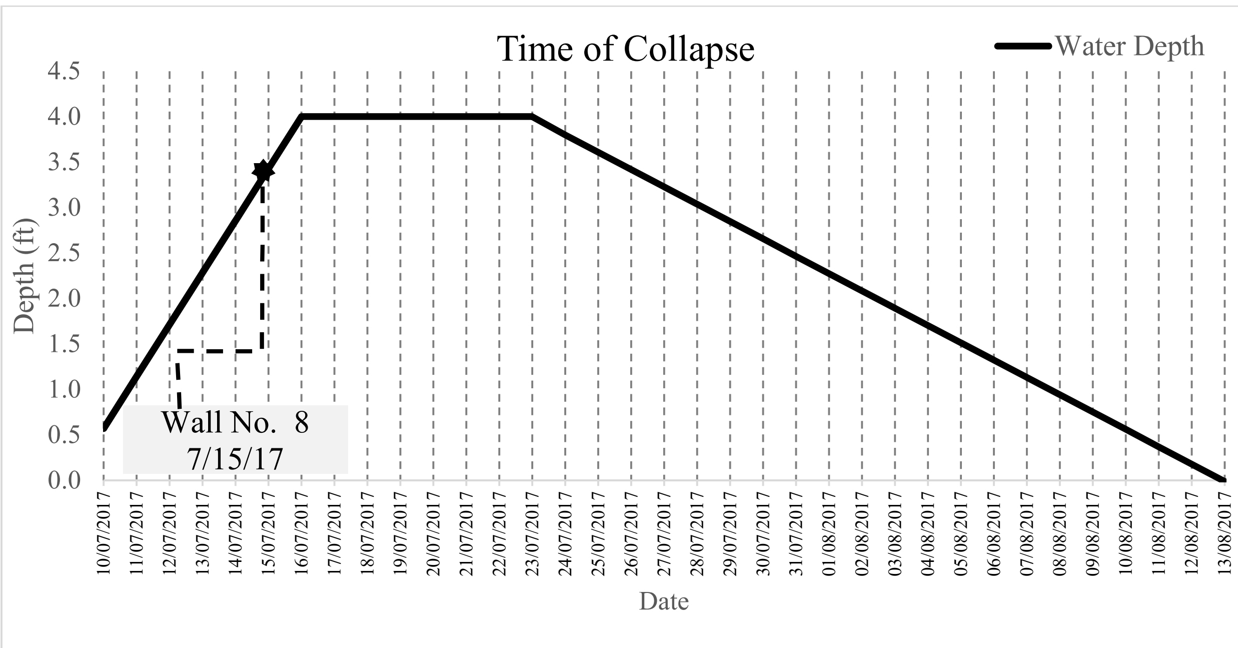


Figure 10 Time graph of collapsing wall panels in phase 2 of flood wave

Wall Panel No. 8 collapsed on 15 July 2017 after sustaining inundation depth up to 990 mm. The left over wall panel number 6, 9, and 12 sustained the second phase of inundation and are still standing in the flood tank.

3.2 Observation from Total Station

Positive (+) signs of maximum lateral movement depict that wall is moving in westward direction while negative shows the opposite meaning. The reference meridian for direction is shown in Figure 11. However, direction of collapse of panel is the function of the observation taken before the panel fails not the maximum value during the observation period.

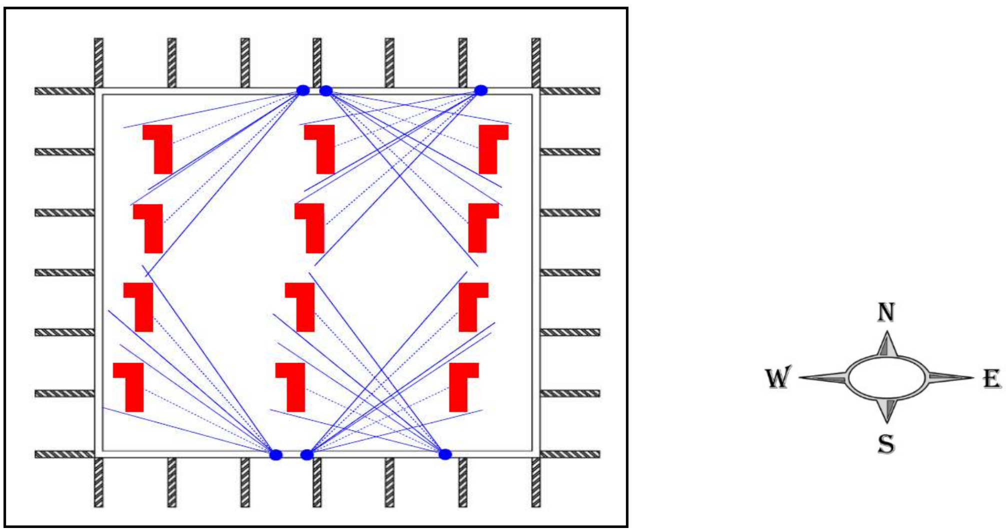


Figure 11 Reference for Direction of collapse

Maximum lateral movement is reported on point 01 to 06 for each of the panel face. Angles were calculated on the basis of the lateral movement and height of the panel. All values of angle reported in radians. Elevation variation was calculated on the basis of the elevation data with reference to a bench mark setup as shown in Figure 12.

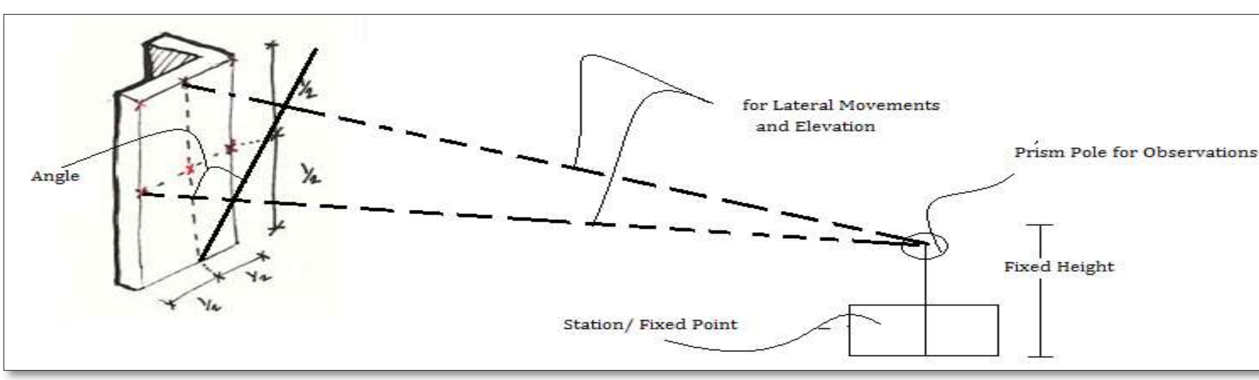


Figure 12 Explanations of Different Measurements

3.2.1 Observation of Sinking Drift and Tilts

This section discusses the observation of tilt, lateral drift, and sinking of wall panels. As discussed earlier these measurement were observed with total station instrument. Table 1 summarises the total amount of tilt, drift, and sinking observed on respective wall panels prior to their collapse.

Table 1 Observed data for sinking, lateral drift and tilting of wall panels

Panel No.	Level Difference/Sinking (ft.)	Max. Lateral Movement/Drift (ft.)	Max. Angle/Tilt (radians)
01	0.01	(+) 0.11	0.01
02	0.06	(+) 0.14	0.01
05	0.07	(+) 0.16	0.03
11	0.03	(+) 0.22	0.02
04	0.08	(+) 0.18	0.02
10	0.06	(+) 0.19	0.02
03	0.10	(-) 0.27	0.03
07	0.07	(+) 0.09	0.01
08	0.12	(-) 0.42	0.05
06	0.98	(-) 0.56	0.03
09	0.10	(-) 0.33	0.21
12	0.41	(-) 1.88	0.08

It should be noted that wall panel numbers 6, 9, and 12 sustained the flood tests. Due to prolonged inundation, these two walls suffered the highest sinking but to their structural stability and clay mix design, sustained the test. During the entire test, wall number six experienced maximum sinking of 300 mm, but still sustained the flood inundation. It is observed that wall panel numbers 6, 9, and 12 despite the highest movement in all three observed directions sustained the flood test. Maximum tilt of 0.21 radians is observed in wall panel number 9 by the end of the flood test. Maximum lateral drift of 575 mm is observed in wall panel number 12. The results show that wall panels indicated movement in the observed direction and ultimately failed. It seems like the clay mix design and geometry of walls were unable to sustain these movements.

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

Based on the observations, the first parameter to judge the best performing wall is the time to collapse. It is evident from the previous chapter that wall number 6, 9, and 12 sustained the entire flood test for both phases hence considered to be sustainable. Wall panels that collapsed were unable to sustain the movement and other changes due to inundation which led them to collapse.

Clay mix design for the sustaining wall panels can be further assessed by introducing debris in flood water along with horizontal component of velocity in the flood tank. This will put the wall panels that can sustain the inundation test to extreme scenario. In order to have exact conclusion about the best performing clay mix design, a downscaled structure with clay mix design used in wall 6, 9, and 12 can be constructed and assessed for real-time performance assessment in flooding.

Chapter 1

INTRODUCTION

1.1 General

Clay is an important raw material for building construction in rural areas of Pakistan and more specifically in Sindh. Every year or two, thousands of houses made up of clay are destroyed due to rainfall and flood in Sindh. Sindh has an area of 140,914 km^2 with one of the world's largest river, River Indus, flowing through it. Human Being has always tried to dwell close to water bodies to use water for domestic purposes and for cultivation. This province of Pakistan houses significant volume of its population in the flood plain of Indus River. Houses in the rural settlements of this flood plain are mostly made in clay and prone to floods and rainfall. Clay has very unique responses when it interacts with water like shrinkage on drying, hardness, and intra/inter-media adhesiveness and cohesiveness when wet. These properties tend to enhance or deteriorate the strength of structures in which clay is used as the major constituent or primary bonding agent.

In this study, an experiment is carried out to compare the performance of conventional and unconventional clay walls. Clay, when mixed with calcium or natural/synthetic fibres and other engineered constituents affects the durability of clay structures. These walls with conventional and unconventional clay mix design are tested under a physical rainfall simulation facility at NED University of Engineering & Technology. The Rainfall Simulator is fed with a pre-defined rainfall hyetograph replicating a historic event of Sindh's rainfall. During the rainfall test, various methods are employed to measure the deterioration of each of the wall panels due to rainfall. This report discusses the executed test in detail. The adapted methodology and experimental setup is discussed in chapter 3 and the results of the experiment are displayed in chapter 4 of this report.

1.2 Background

During the course of history, it is witnessed that people reside near the fertile lands, where their livelihood is at ease for being close to resources including food and water. Poignantly, the same rivers that provide them with nutrition make them prone to disaster such as overflow of rivers and consequent flooding. Floods are one of the most intense and hazardous events. Though the cause of flooding varies, it ultimately makes the society suffer devastating losses of lives, infrastructure, economy and environment.

Pakistan lies in the tropical region making it fortunate for not having disasters like volcanoes, hurricane etc.; however, floods is not an exception. For Pakistan, there are two major causes of floods: flash floods due to intense rainfall in short duration, and overflowing of rivers and streams due to intense rains or glarier melt. The average rainfall of Pakistan ranges from 125 mm in South-East region to 750 mm in the North-West region. Although the average rainfall in Pakistan isn't enough to cause flooding, the disasters happen either during monsoon or glacier melt and/or as a combination of both.

Pakistan has one of the largest irrigation systems in the world, and her Gross Domestic Product (GDP) index and export is significantly controlled by agricultural production; therefore, it is essential to protect the cultivated areas and human lives and settlements from floods.

Pakistan has witnessed multiple catastrophic floods that originated in the River Indus systems. Floods of 1950, 1956, 1957, 1959, 1973, 1976, 1978, 1988, 1992, 1995, 1996, 1997, 2001, 2003, 2005, 2007, 2010, 2011, and 2014 are the distressing yet memorable events entailing tremendous damage to life and property. The recent two floods in 2010 and 2011 have been an eye-opener. The flood of 2010 was recognized by the United Nations as the greatest natural disaster in its history, affecting twenty million people. One-fifth of Pakistan was submerged during that flood. These facts express the importance of making the settlements and ultimately the human lives as safe as possible from disasters like floods.

1.3 Objective

The objective of this study is to assess the flood and rainfall resilience of structures made up of clay as the primary constituent. Walls with conventional clay mix design and engineered clay mix design (experimental) along with other constituent and fibres are tested. Effect of wall geometry on its resilience is also assessed.

1.4 Scope

This study limits the testing of prescribed wall geometries and clay mix design only. These design parameters are provided by the client. Other limitations include simulation of one design rainfall hyetograph and one flooding regime.

1.5 Expected Outcome

The expected result of this experiment is the amount of erosion that occurs as a result of rainfall occurring on the walls directly. This parameter of erosion indicates the resilience of various clay mix design to direct rainfall. Comparing this parameter for the prescribed clay mix design will conclude the most sustainable composition ratio and constituents to be used for rainfall resilient structures made with clay.

Chapter 2

METHODOLOGY

2.1 General

This chapter discusses the experiment setup and facility at which the clay walls with different clay mix design were tested. Limitations, boundary conditions and other essential parameters are also discussed in respective sub headings. The face of wall to be tested was of 2.7×1.5 m; thickness, however, vary.

2.2 Experiment Setup

In order to achieve the desired objectives, a rainfall simulator is constructed at NED University of Engineering and Technology. The rainfall simulator has a concrete cement flatbed of 20×9 m with sprinklers mounted on elevated poles along its periphery as shown in Figure 1.

Figure 1. Rainfall Experiment Setup

The rainfall sprinklers are placed in such a way that uniform distribution is achieved on the simulator's platform. Six walls with prescribed geometry and clay mix design can be tested at a time. There were total 12 samples to be tested in two batches of 6 walls at a time in order to isolate the effects of rain falling one wall to the wall next to it.

2.2.1 Selection of sprinkler and other hardware

For this study, mini spray jet is selected. It is made up of high quality polymer having wear resistance and long trouble free performance. White nozzle colour jet has 2.3 mm nozzle size with spray pattern of 180°, wetted diameter of 7 m, and gives 174.5 l/h flow when operating at pressure of 0.15 MPa. This sprinkler makes a rainfall of 15 mm/h, which is the required average rainfall for 24 hours. The performance chart of mini spray jet is shown in Table 1. Since, the sprinklers are installed at the height of 14 ft (≈4 m); therefore, the pump was operated at 0.19 MPa.

Table 1. Performance chart of mini spray jets

Nozzle colour/Size (mm)	Emitter Exponent (x)	Flow coeff. (k)	Pressure		Spray Pattern/ radius (m)				Discharge	
			kg/cm²	psi	180°	60°x2	140°x2	360°	lph	gph
Blue/1.0	0.50	33.2	0.5	7.11	1.3	1.1	1.2	1.4	23.5	6.2
			1.0	14.22	1.7	1.8	1.6	1.9	33.2	8.8
			1.5	21.33	2.0	2.2	1.9	2.3	40.7	10.8
			2.0	28.44	2.2	2.5	2.1	2.6	47.0	12.4
			2.5	35.55	2.3	2.7	2.2	2.8	52.6	13.9
Green/1.3	0.50	56.1	0.5	7.11	1.7	1.4	1.6	1.8	39.7	10.5
			1.0	14.22	2.2	2.0	2.1	2.4	56.2	14.9
			1.5	21.33	2.6	2.4	2.5	2.9	68.8	18.2
			2.0	28.44	2.8	2.7	2.8	3.3	79.5	21.0
			2.5	35.55	3.1	2.9	3.0	3.6	88.9	23.5
Red/1.5	0.50	78.4	0.5	7.11	2.0	1.6	1.9	2.1	55.4	14.7
			1.0	14.22	2.6	2.2	2.4	2.8	78.4	20.7
			1.5	21.33	3.1	2.7	2.8	3.4	96.0	25.4
			2.0	28.44	3.5	3.1	3.1	3.9	110.9	29.3
			2.5	35.55	3.8	3.4	3.3	4.3	124	32.8
White/2.3	0.50	142.4	0.5	7.11	2.2	2.1	2.1	2.3	100.7	26.6
			1.0	14.22	2.9	3.0	2.5	2.9	142.4	37.7
			1.5	21.33	3.5	3.8	2.8	3.5	174.5	46.2
			2.0	28.44	4.0	4.3	3.0	4.0	201.5	53.3
			2.5	35.55	4.4	4.6	3.1	4.4	225.2	59.6

A pump of 1.5 hp was installed to discharge 10470 l/h water at a total pressure of 1.9 bar. The calculation shows that 1.1 hp pump would meet the requirement with 70% pump efficiency.

Pressure gauges are also installed at different locations on the pipe network to give the exact reading of operating pressure. The gauges installed, have range from 0 to 0.5 MPa pressure, and have least count of 0.01 MPa, which suits the study conditions.

A water filter is installed after pump, which decreases the chances of clogging of jets. The water filter has a capacity of 25 m^3/hour. A flow meter is also installed after the filter to perform the calibration process.

2.2.2 Calibration of sprinklers

Performance chart of spray jets (Table 1) are based on data taken in lab. Therefore, the validation of these values is important to get accurate results because difference in elevation of the jets and wind can cause problems and deviate intensity and pressure values. Spray jets are installed at 4 m; therefore, difference between the pressure at outlet of pump and inlet of spray jet is 0.04 MPa. This means, if the required operating pressure is 0.15 MPa, the pump will actually run at 0.19 MPa pressure. Initially, the calibration is done using one spray jet, but the wind effect is too high to get better readings. Therefore, two sprinklers are used for calibration and verification of the values given in the performance chart.

Meanwhile, the uniformity of the rain is also analysed. At the time of calibration, wind speed varies from 5 km/h to 25 km/h. To check uniformity, two cans are used to see if different amount of water is collected. Results are satisfactory of rainfall at low pressure i.e. 0.19 MPa. Readings from the calibration process are presented in Table 2.

Table 2. Calibration data for sprinklers

Trial	**Duration**	**Radius**	**Pressure**	**Catch can 1**	**Catch can 2**	**Rain gauge**	**Rainfall**	**actual pressure**
	(min)	(ft)	(bar)	(ml)	(ml)	(mm)	(mm/hr)	bar
1	**60**	**10**	**1.9**	**54**	**62**	**296**	**30**	**1.5**
2	60	11	2.4	46	48	308	31	2
3	60	12.5	2.9	30	42	300	30	2.5

2.2.3 Design Storm

A critical rainfall event that is used for assessing the impact of a certain return period is called "design rainfall". As the amount of the design rainfall corresponds to rare frequencies, they have high values of rainfall depth and that is why the design rainfall is usually termed as "design rainstorm" or simply "design storm".

Characteristic elements of the rainstorm are:

- Depth P [mm]
- Duration D [min], [hours]
- Average intensity [mm/min], [mm/hour]
- Maximum intensities on different Δt time intervals

Time distribution of the rain intensities is commonly known as the "rainfall intensity hyetograph". Rainfall Distribution is the variability of the intensity throughout a storm. However, overall depth for a storm will be the same for a given duration no matter which distribution is chosen. There are four (4) different types of rainfall distributions throughout the US – Type I, Type 1A, Type II and Type III. These distributions can be adopted locally in areas other than U.S. if, the local climate and that of U.S. regions climate matches. Figure 2 shows the cumulative distribution of all four types of rainfall. For arid regions, literature suggests that type III rainfall distribution could be used.

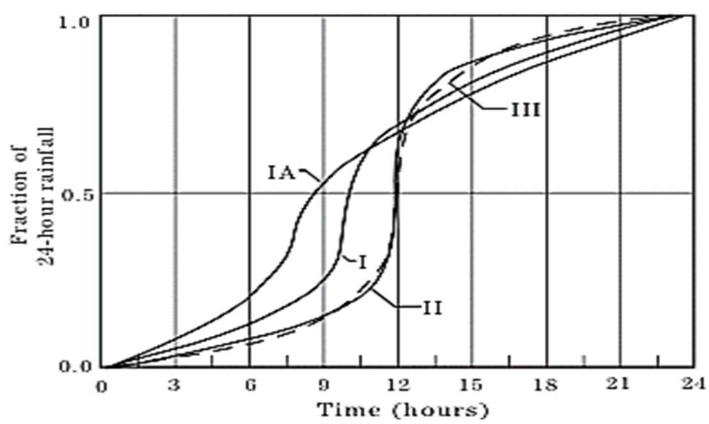


Figure 2. SCS 24-hour rainfall distribution

The rainfall recorded at Tando Ghulam Ali (68.891365°, 25.124217°), a village in Sindh, is recorded as 347.98 mm on August 11, 2011. This is the heaviest rainfall that occurred in Sindh since 1931 and selected to be simulated for this experiment.

Since, Pakistan Meteorological Department (PMD) provides rainfall data at 24-hour interval; therefore, intensity near to the actual values is obtained by assuming that summer rainfall event in arid region is following a type III distribution. The design storm calculation includes the conversion of average value of rainfall over 24 hour to smaller time interval. Figure 3 shows relation between time and intensity of rainfall for total 347.98 mm for 24 hours. Rainfall design module PC-Storm Water Management Model (PC-SWMM, CHI, Canada) is used to convert the 24 hour values over smaller time interval. For an arid region, SCS type III design storm is used. This design storm gives the highest rainfall intensity for an hour - 140.5 mm/hour.

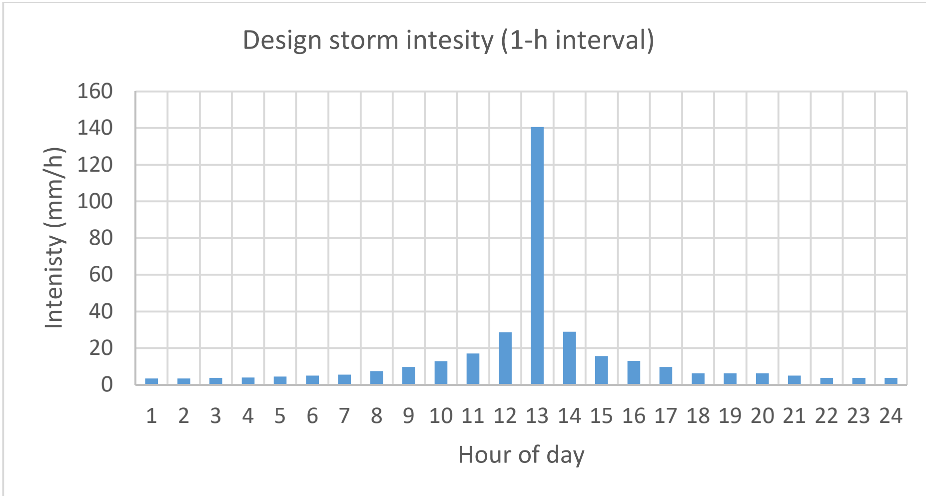


Figure 3. 24-hr distributions for 347.98 mm rainfall

The 24-hour rainfall is transformed into 6-hour rainfall, to help the logistics of testing, by changing the intensity and keeping the total amount of rainfall and probability distribution of the rainfall intensity constant. Figure 4 shows the distribution after transforming 24-hour rainfall into 6-hour rainfall using type II design storm.

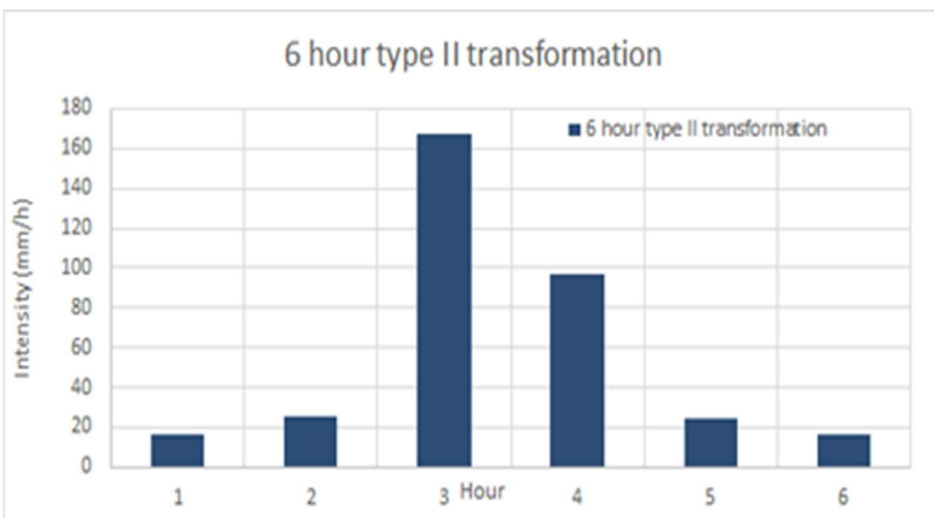


Figure 4. 6-hour distribution of 347.98 mm rainfall

2.2.4 Sprinkler Setup

Sprinklers are mounted on elevated poles along the periphery of the plot to provide equal simulation conditions for each wall panel. Sprinklers are orientated to cover full wall height with the middle of the sprinkler shower hitting the middle of the wall panel as shown in Figure 5**Error! Reference source not found.**. The extent of the sprinkler includes the base of the wall and the floor just in front of the wall, to ensure that the effect of rain at the toe of the wall is simulated accordingly. Figure 6 shows a wall panel on the rainfall experiment setup. Drainage is also provided ensuring that the water runoff will not flood the base of the panel and for drained water sampling as shown in Figure 6.

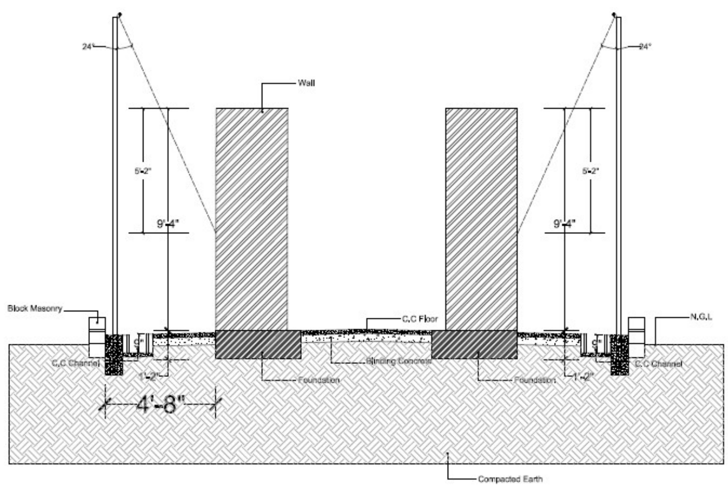


Figure 5. Cross section of the rainfall simulator

Figure 6. Wall to be tested

It was made ensured that backsides of panels are protected so that they only encounter the effect of the sprinkler in front of them and not the sprinkler directed to other walls.

2.2.5 Limitations

The rainfall test is limited to only one design rainfall which is discussed in the previous section 2.2.3. The rainstorm scenario is also curtailed to 6-hour duration storm since its original historic duration is not known as discussed earlier. The rainfall simulator is isolated from local wind effects in real worlds, along with rainfall effects, because wind also plays role in destroying structures. However, in this study wind effect or erosion due to wind is not considered.

2.3 Observation Setup

This section discusses the observation mechanism to collect the amount of erosion. Assumptions for respective observations are also discussed.

2.3.1 Measurement of Erosion

Amount of erosion as a result of rainfall attack on wall panels was measured. The base of panels on the platform of rainfall simulator was provided with boundary to collect the flow around it and direct it towards an outlet where flow was being gauged at hourly intervals for a runtime of 6 hours as shown in Figure 7. This flow brings the eroded wall material to the outlet where it is collected and marked for laboratory. After collection, the samples are tested in laboratory to measure the amount of suspended solids (mg/L) in it which are averaged for one hour in terms of weight (kg).

Figure 7. Sample collection and flow accumulating pit

2.3.2 Calculations for the Amount of Erosion

Total amount of soil eroded is measure from two components. i) Amount of soil taken away by rainfall/runoff water to the drain, and ii) amount of soil left on the ground. Soil taken away by rainfall water is taken by measuring Total Suspended Solids (TSS) in that water. To calculate TSS, samples were drawn in the last ten minutes of every hour. From TSS, erosion is found by Equation (1) as follows:

$$Erosion\ from\ TSS = \frac{\sum_{i=1}^{6} Flow(\frac{lit}{hou})_i \times TSS(\frac{mg}{lit})_i}{1000000\,\frac{mg}{kg}} \quad (1)$$

Amount of soil, which is left behind was collected next morning. This soil is then oven dried for 24 hours to evaporate the moisture content, and then weighed. Total Erosion is the sum of *"Erosion from TSS"* and oven dried "*weight of soil left behind"*. Erosion per unit area is calculated by assuming wall surface area as 2.7×1.5 m. It is observed that top 300 mm of the wall ass not harmed by the rainfall due to presence of the shade; therefore, the top 300 mm was not included in the calculation of erosion amount.

2.3.3 Photographic Observations

A detailed photographic record was also maintained for all the tests. Locations of camera mounts are shown in Figure 8. Photos were taken from fixed location through the duration of irrigation and the study. During the first and the last two hours of simulation, minimum 1 photo from the fixed position camera were taken at every 60 minutes. During the peak hours, hour No. 3 and 4, minimum 1 photo from the fixed position camera was taken at every 10 minutes.

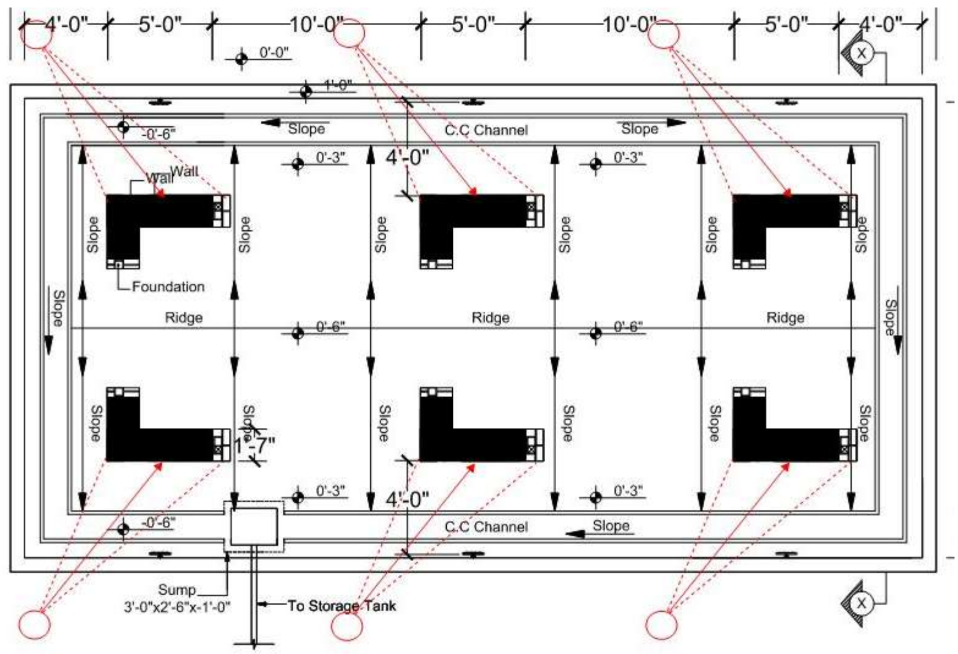


Figure 8. Layout of walls and camera positions

Chapter 3

RESULTS AND DISCUSSION

This chapter discusses the results of experiment in terms of erosion occurred.

3.1 Performance of Walls in terms of Erodibility

The results of samples of water collected according to the described methodology in heading 2.3.1 for wall No. 1 – 12 are shown in Table 3.1– 3.12.

Table 3.2 Observations and erosion (damage) of wall panel 1

Wall Panel 1			TSS	Remarks
Hour	Flow (ml/sec)	lit/hr	(ppm)	
1	5.0	18.0	171	Wall absorbed most of water to increase its moisture level. Only free particles eroded from the wall.
2	7.8	28.0	1270	Water started flowing on the wall and subsequently erosion started.
3	50.9	183.2	4712	Rate of erosion increased in this hour. At the end of this hour, wheat straw was visible on many parts of the wall.
4	106.3	382.8	6268	Because of high intensity rainfall and erosion, soil started falling from both corners and lower mid portion of the wall.
5	12.2	43.9	2430	Due to decreased intensity, the rate of erosion decreased. However, soil kept falling from the above-mentioned areas of the wall.
6	6.1	21.9	2414	At the end of last hour, inner structure of "lokat" was visible, but overall the structure was stable.
Erosion weight (kg)	19.91		3.46	Amount of soil taken away by rainfall water = 3.46 kg Amount of soil left behind = 19.91 kg
Total Erosion (Kg)	23.37			This makes the total eroded soil as 23.37 kg.
Erosion per unit area (gm/sq.ft)	519			Erosion per unit area is 519 gm/ft^2

Table 3.3 Observations and erosion (damage) of wall panel 2

Wall Panel 2			TSS	
Hour	Flow (ml/sec)	lit/hr	(ppm)	Remarks
1	5.7	20.6	218.0	Throughout the test, the wall panel 2 showed resilience towards erosion. First the particles which were loosely attached to the wall area eroded. Other than this, there was very little or negligible erosion from wall panel 2
2	8.3	29.8	82.0	
3	47.7	171.9	57.0	
4	122.1	439.5	115.0	
5	10.3	37.1	92.0	
6	5.4	19.3	227.0	
Erosion weight (kg)			0.08	Amount of soil taken away by rainfall water = 0.08 kg Amount of soil left behind = None / Negligible
Total Erosion (Kg)	0.08			This makes the total eroded soil as 0.08 kg.
Erosion per unit area (gm/sq.ft)	2			Erosion per unit area is 2 gm/ft^2

Table 3.4 Observations and erosion (damage) of wall panel 3

Wall Panel 3			(ppm)	
Hour	Flow (ml/sec)	lit/hr	TSS	Remarks
1	6.3	22.5	57.0	Like wall panel 2, wall panel 3 showed very little or no erosion as well. However, unlike wall panel 2, cracks were appeared on the surface of wall panel 3. Intensity of cracks increased in the lower part of the wall. After revisiting, it was observed that bottom of the wall is expanded due to stored moisture.
2	12.8	45.9	268.0	
3	53.7	193.3	176.0	
4	130.3	469.1	58.0	
5	16.1	58.0	215.0	
6	5.7	20.5	234.0	
Erosion weight (kg)			0.09	Amount of soil taken away by rainfall water = 0.09 kg Amount of soil left behind = None / Negligible

Total Erosion (Kg)	0.09	This makes the total eroded soil as 0.09 kg.
Erosion per unit area (gm/sq.ft)	2	Erosion per unit area is 2 gm/ft^2

Table 3.5 Observations and erosion (damage) of wall panel 4

Wall Panel 4			**TSS**	
Hour	**Flow (ml/sec)**	**lit/hr**	**(ppm)**	Remarks
1	7.0	25.2	646.0	In the first two hours, rainfall did not affect the wall to create any significant erosion.
2	12.4	44.7	590.0	
3	56.0	201.5	1530.0	Erosion from the wall started and eventually corners of wall started falling. Also, wheat straw was visible on roughly 70% of the wall.
4	143.8	517.6	2495.0	In this hour, the erosion process became faster. Soil started falling from corners and some from the center of the wall.
5	20.0	72.2	380.0	
6	7.3	26.2	75.0	There was very little erosion in last two hours.
Erosion weight (kg)	2.1		1.67	Amount of soil taken away by rainfall water = 1.67 kg Amount of soil left behind = 2.10 kg
Total Erosion (Kg)	3.77			This makes the total eroded soil as 3.77 kg
Erosion per unit area (gm/sq.ft)	84			Erosion per unit area is 84 gm/ft^2

Table 3.6 Observations and erosion (damage) of wall panel 5

Wall Panel 5			(ppm)	
Hour	**Flow (ml/sec)**	**lit/hr**	**TSS**	Remarks
1	6	21.6	191.0	Like wall panel 2 and 3, there was very little or no erosion Noted from wall panel 5. Only the final coat layer, which is less than a millimetre thick, was affected at some points.
2	9	33.4	113.0	
3	44	157.6	197.0	
4	95	342.0	237.0	
5	12	42.6	148.0	
6	7	23.9	69.0	
Erosion weight (kg)			0.13	Amount of soil taken away by rainfall water = 0.13 kg Amount of soil left behind = None / Negligible
Total Erosion (Kg)	0.13			This makes the total eroded soil as 0.13 kg.
Erosion per unit area (gm/sq.ft)	3			Erosion per unit area is 3 gm/ft^2.

Table 3.7 Results of erosion from wall panel 6

Wall Panel 6			TSS
Hour	**Flow (ml/sec)**	**lit/hr**	**(ppm)**
1	2.875	10.4	2455
2	5.69	20.5	416
3	38	136.8	5214
4	96.4	347.0	21158
5	15.31	55.1	6580
6	11.07	39.9	1312
Erosion weight (kg)			8.50
Total Erosion (Kg)	8.50		
Erosion per unit area (gm/sq.ft)	189		

Table 3.8 Results of erosion from wall panel 7

Wall Panel 7			TSS
Hour	Flow (ml/sec)	lit/hr	(ppm)
1	2.98	10.7	1026
2	8.07	29.1	1206
3	30.58	110.1	3583
4	88.49	318.6	13821
5	8.77	31.6	4429
6	5.54	19.9	2680
Erosion weight (kg)			5.04
Total Erosion (Kg)	5.04		
Erosion per unit area (gm/sq.ft)	112		

Table 3.9 Observations and erosion (damage) of wall panel 8

Wall Panel 8			TSS	
Hour	Flow (ml/sec)	lit/hr	(ppm)	Remarks
1	6.5	23.4	337	In the first two hours, when rainfall intensity is less, there is not much activity of erosion. However, rain drops started exploiting the initial conditions, which was the weathered surface of the wall. It was observed that the soil erosion started from the top right side of wall panel 8.
2	10.5	37.9	3490	
3	59.3	213.4	3740	In this hour, the extent of erosion area increased. Generally, erosion was noted from the right corners of wall, and areas adjacent to it.
4	138.5	498.6	7995	In this hour, which has the highest intensity, erosion was seen all over the wall. Nevertheless, right corner of the wall was badly damaged in this hour.
5	15.6	56.1	1007	In the last hour, there was no notable activity of erosion.
6	7.4	26.6	909	
Erosion weight (kg)	7.85		5.01	Amount of soil taken away by rainfall water = 5.01

Wall Panel 8			TSS	
Hour	**Flow (ml/sec)**	**lit/hr**	**(ppm)**	Remarks
				kg Amount of soil left behind = 7.85 kg
Total Erosion (Kg)	12.86			This makes the total eroded soil as 12.86 kg.
Erosion per unit area (gm/sq.ft)	286			Erosion per unit area is 286 gm/ft^2.

Table 3.9 Results of erosion from wall panel 9

Wall Panel 9			(ppm)
Hour	**Flow (ml/sec)**	**lit/hr**	**TSS**
1	7	25.2	432
2	15.75	56.7	253
3	63.75	229.5	135
4	125.78	452.8	718
5	17.4	62.6	1123
6	5.36	19.3	555
Erosion weight (kg)			0.46
Total Erosion (Kg)	0.46		
Erosion per unit area (gm/sq.ft)	10		

Table 3.10 Results of erosion from wall panel 10

Wall Panel 10			TSS
Hour	**Flow (ml/sec)**	**lit/hr**	**(ppm)**
1	2.63	9.5	912
2	17.11	61.6	283
3	54.54	196.3	195
4	98.3	353.9	258
5	19.9	71.6	1382

Wall Panel 10			TSS
Hour	Flow (ml/sec)	lit/hr	(ppm)
6	10.6	38.2	813
Erosion weight (kg)			0.29
Total Erosion (Kg)	0.29		
Erosion per unit area (gm/sq.ft)	6		

Table 3.11 Results of erosion from wall panel 11

Wall Panel 11			(ppm)
Hour	Flow (ml/sec)	lit/hr	TSS
1	2.05	7.4	110
2	2.81	10.1	490
3	12.32	44.4	336
4	17.34	62.4	765
5	2.6	9.4	512
6	0.8	2.9	115
Erosion weight (kg)			0.07
Total Erosion (Kg)	0.07		
Erosion per unit area (gm/sq.ft)	2		

Table 3.12 Results of erosion from wall panel 12

Wall Panel 12			TSS
Hour	Flow (ml/sec)	lit/hr	(ppm)
1	8.77	31.6	1224
2	14	50.4	1760
3	56.7	204.1	1495
4	70	252.0	718
5	9.57	34.5	412
6	5.21	18.8	854

Wall Panel 12			TSS
Hour	**Flow (ml/sec)**	**lit/hr**	**(ppm)**
Erosion weight (kg)			0.64
Total Erosion (Kg)	0.64		
Erosion per unit area (gm/sq.ft)	14		

It is evident from the analysis for all the walls that the highest amount of erosion is observed in the 3rd and 4th hours during which the intensities were the highest and the second highest, respectively. Figure 9 shows the total erosion plotted against respective wall numbers.

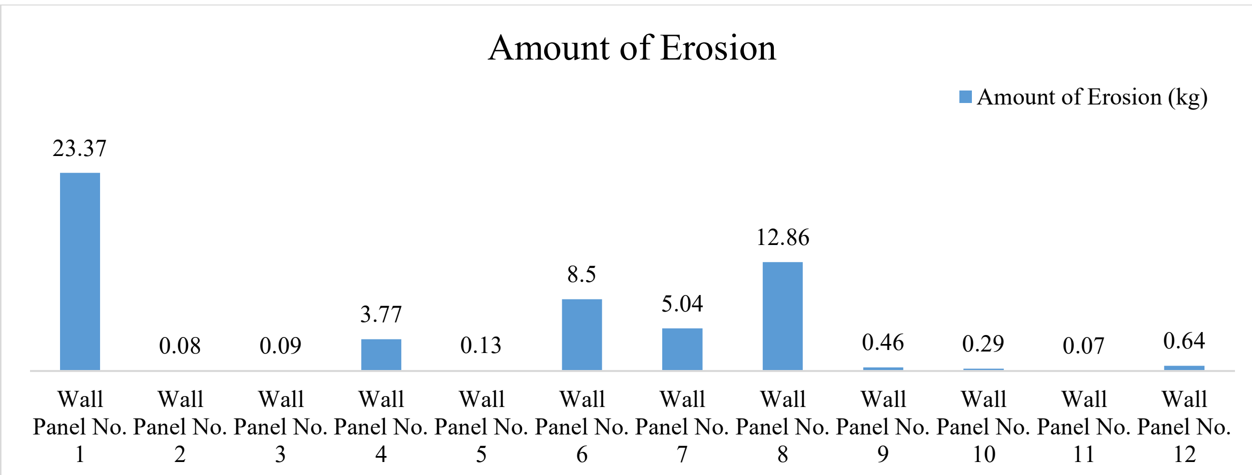


Figure 9. Total erosion in Kgs for all wall panels

The analysis show that wall panel no. 1 suffered the maximum loss due to erosion and wall no. 10 sustained erosion with minimum amount of 0.07 Kg of erosion.

3.2 Pictorial Observations

Pictorial observation for the first hour and the last hour of the two extreme performing walls are shown in the Figures 10 and 11.

Figure 10. Photographs of wall panel no. 1 at the beginning (Left) and at the end of test (Right), respectively.

Figure 11. Photographs of wall panel no. 10 at the beginning (Left) and at the end of test (Right), respectively.

Chapter 4

CONCLUSIONS & RECOMMENDATIONS

4.1 Best Performing Wall Panel

Comparing the performance of the wall panels, it is observed that water absorption profile i.e., the depth of water penetrating the wall is vital. Wall No. 10 sustained the rainfall scenarios to the best and its clay mix design and geometry is considered to be the best suited for construction.

Materials Specification

Soil

Soil to be brought if from Sindh. All soil to be brought from same location for consistency. Location to be recorded. Soil should be tested for suitability for lime stabilisation prior to transportation to NED in line with *Lime Stabilized Construction: A Manual and Practical Guide, Strawbuild, 2015*

Sand

Sand to be procured from local market in Sindh. Sand to be free of silt, clay, salt and other impurities.

Lime

Lime to be procured, tested and prepared in line with *Lime Stabilized Construction: A Manual and Practical Guide, Strawbuild, 2015*

Compressed soil foundation

Formation level to be free of organic material

Compressed soil with lime foundation

Formation level to be free of organic material

Mix: to be determined in line with *Lime Stabilized Construction: A Manual and Practical Guide, Strawbuild, 2015*

Soil blocks (Adobe)

Size: To suit wall thickness

Block and mortar mix: As per local practice

Soil blocks with lime (Adobe)

Size: To suit wall thickness

Block and mortar mix: The mix proportions for the Soil and lime blocks are to be determined in line with *Lime Stabilized Construction: A Manual and Practical Guide, Strawbuild, 2015*

Fired bricks

To be procured from local market in Sindh. All to be procured from same vendor for consistency.

Size: 9"x4.5"x3"

Plaster - soil with lime

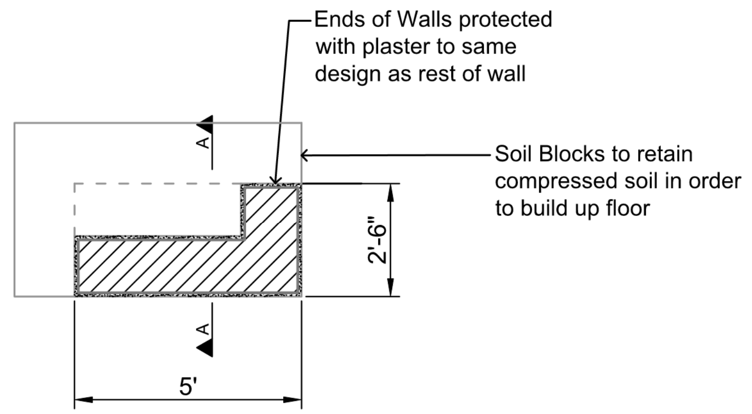
Mix for soil with lime plaster to be determined in line with *Lime Stabilized Construction: A Manual and Practical Guide, Strawbuild, 2015*

Damp proof course

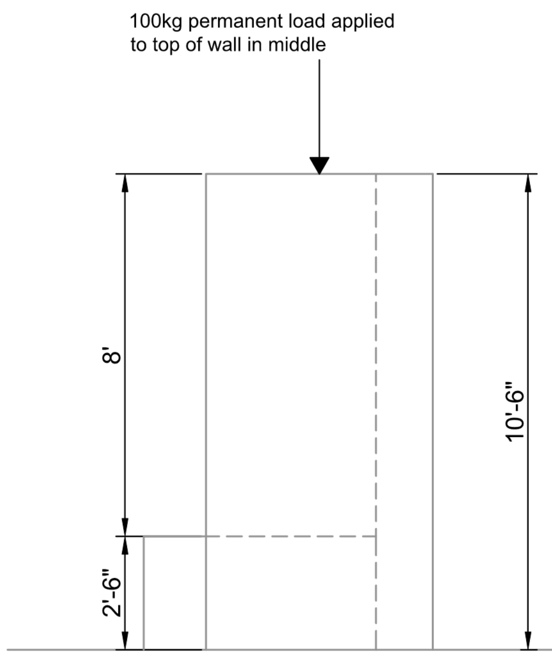
Damp proof course to be heavy gauge plastic sheet

Mortar

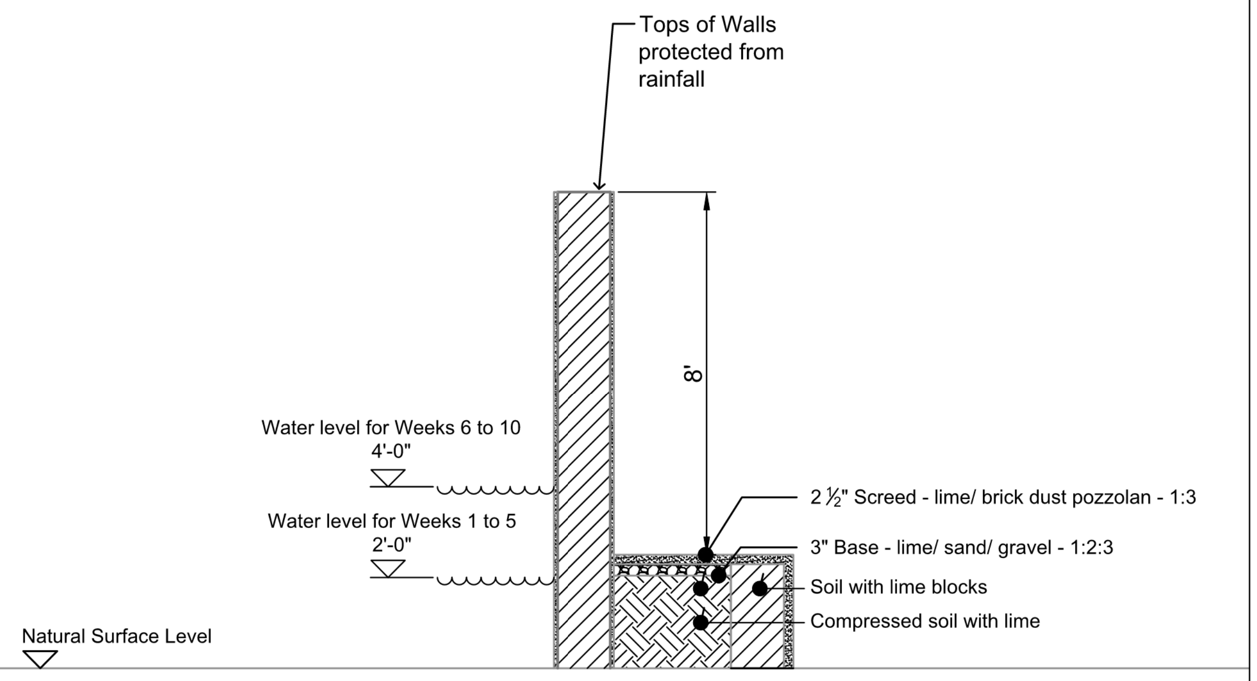
Mortar beds to be 1" thick maximum
Mix to match the block type - Soil blocks: Soil mortar - Soil with lime blocks: Soil with lime mortar



Test Panel Plan



Test Panel Elevation



Test Panel Section A-A

Issue	Date	By	Chkd	Appd
04	27/03/17	LM	TW	RK
03	11/11/16	LM	TW	RK
02	TBC	DSP	TW	RK
01	TBC	IRA	TW	RK

ARUP
13 Fitzroy Street
London W1T 4BQ
Tel +44(0)20 7636 1531 Fax +44(0)20 7580 3924
www.arup.com

Job Title: FLOOD RESILIENT SHELTER RESEARCH

Client: IOM PAKISTAN

FLOOD TEST WALL PANEL PLAN, SECTION, ELEVATION

MATERIAL SPECIFICATION

Scale at A3: 1/2" = 1'

Discipline: STRUCTURES

Job No: -

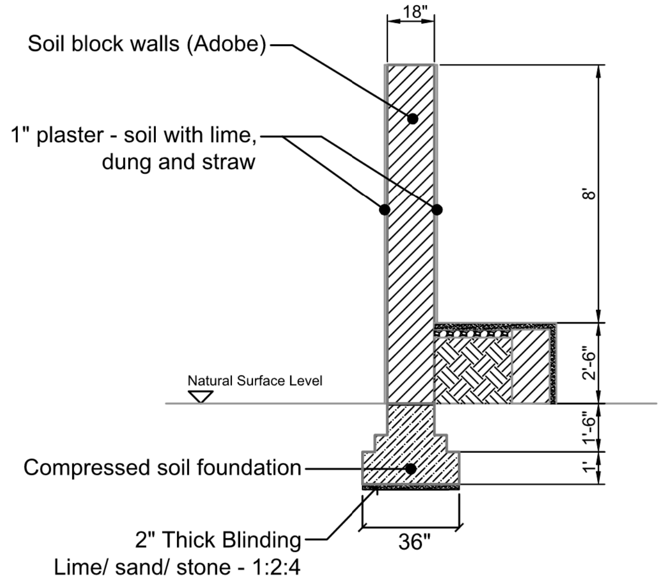
Drawing Status: Issue

Drawing No: IOM-PAK-02

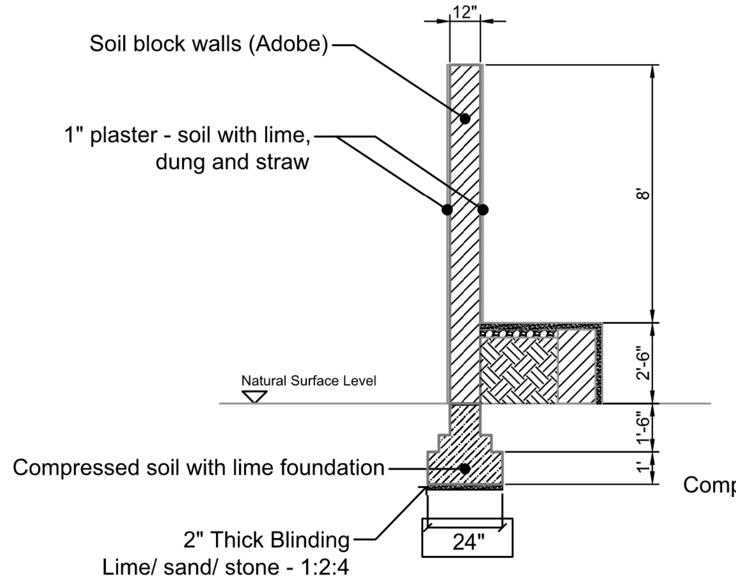
Issue: 04

Do not scale

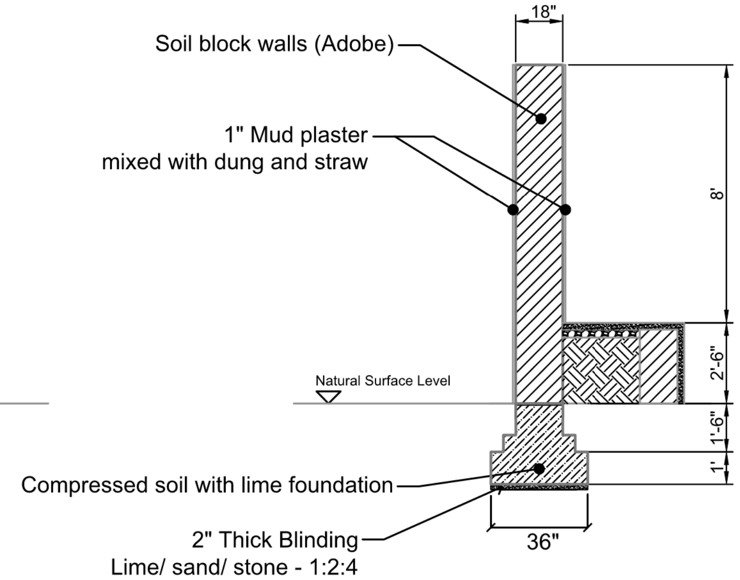
A3 | A | B | C | D | E | F | G | H



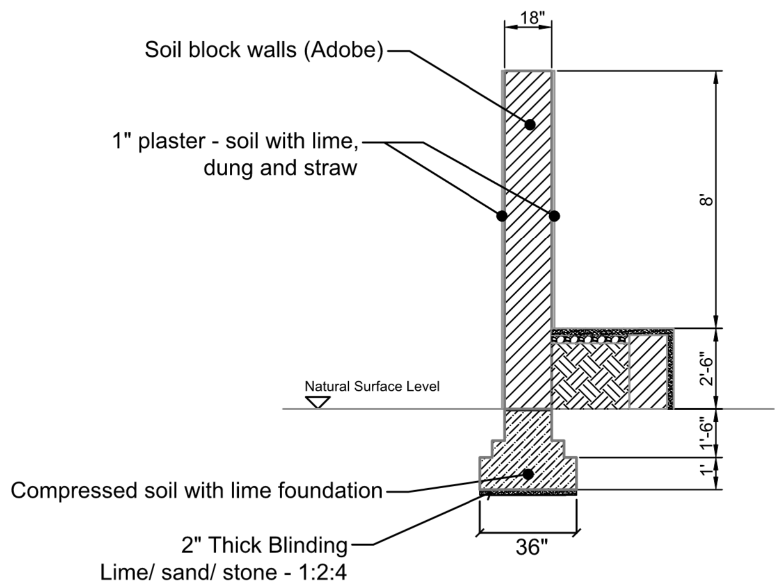
Wall Type No.1



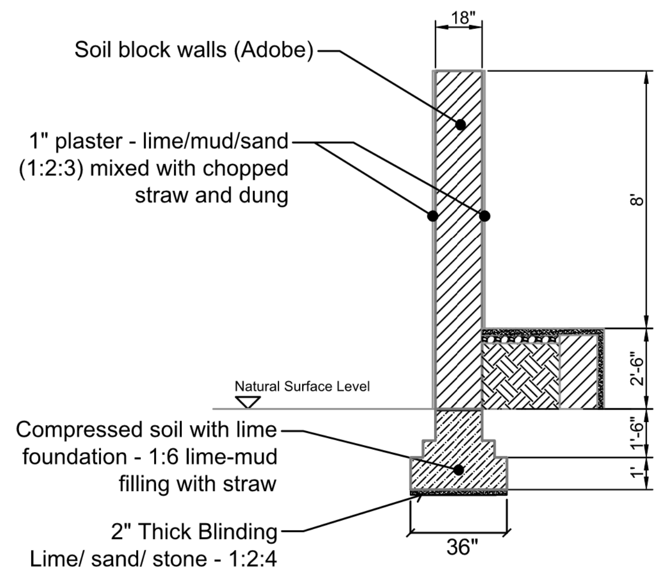
Wall Type No.2



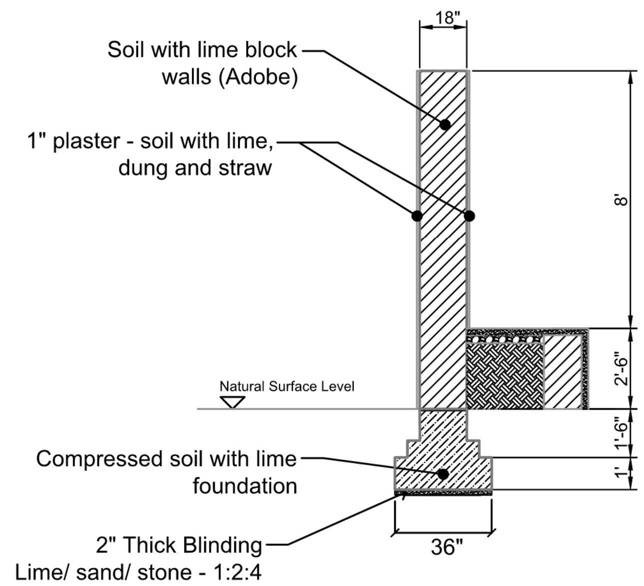
Wall Type No.3



Wall Type No.4
BASE CASE



Wall Type No.5



Wall Type No.6

Key
Box around annotation indicates incremental change in panel design

Issue	Date	By	Chkd	Appd
04	27/03/17	LM	TW	RK
03	11/11/16	LM	TW	RK
02	TBC	IRA	TW	RK
01	TBC	IRA	TW	RK

ARUP

13 Fitzroy Street
London W1T 4BQ
Tel +44(0)20 7636 1531 Fax +44(0)20 7580 3924
www.arup.com

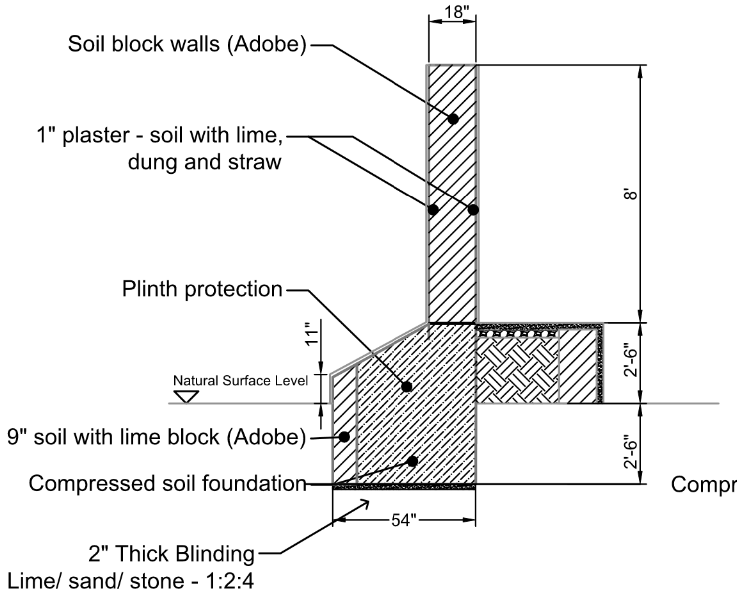
Job Title
FLOOD RESILIENT SHELTER RESEARCH

Client
IOM PAKISTAN

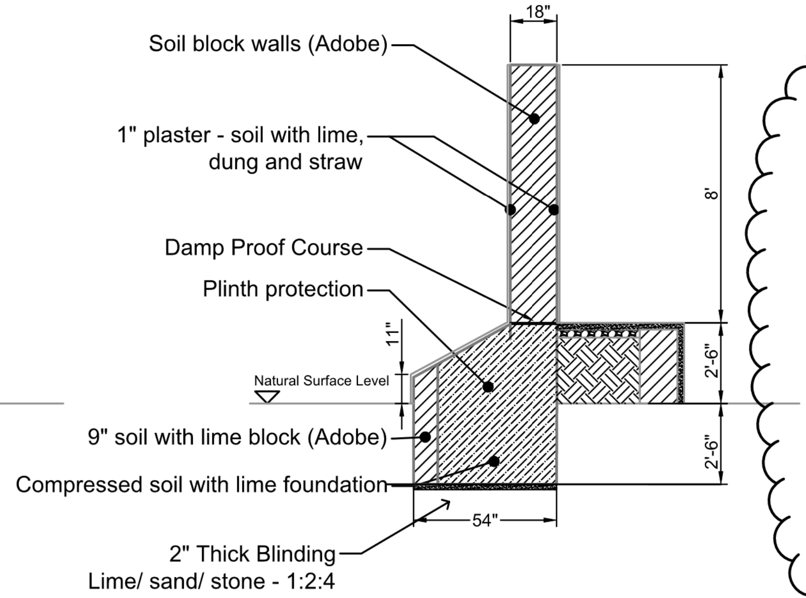
TEST PANEL CONSTRUCTION
SHEET 1 of 2

Scale at A3 Not to scale
Discipline STRUCTURES
Job No -
Drawing Status Issue
Drawing No IOM-PAK-03
Issue 04

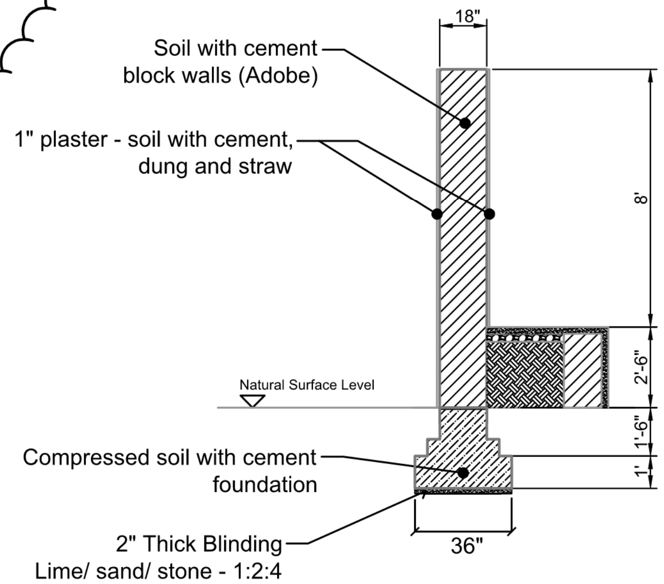
Do not scale



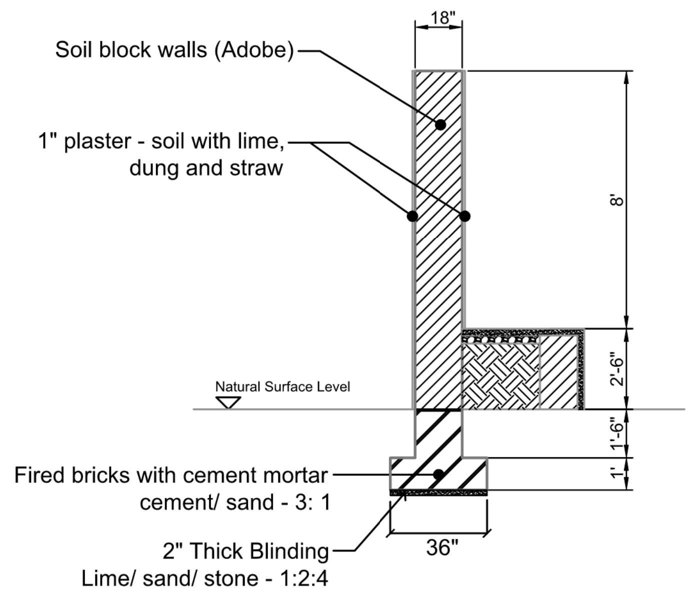
Wall Type No.7



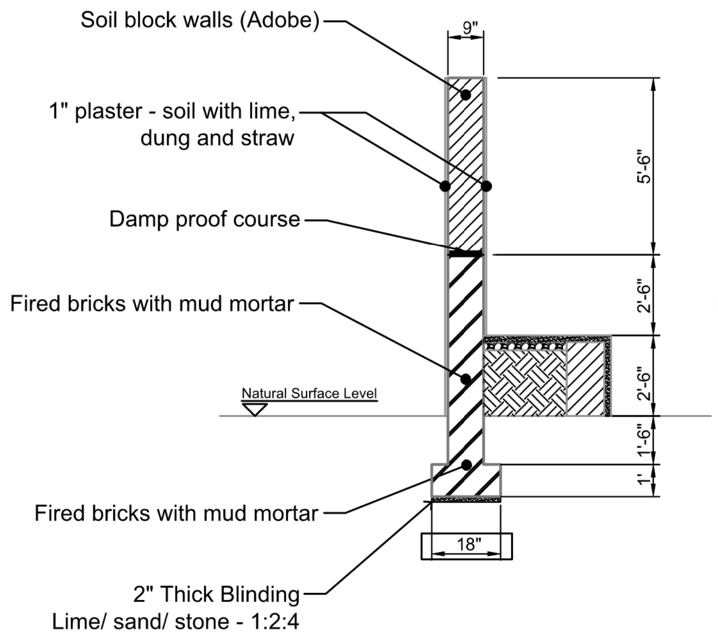
Wall Type No.8



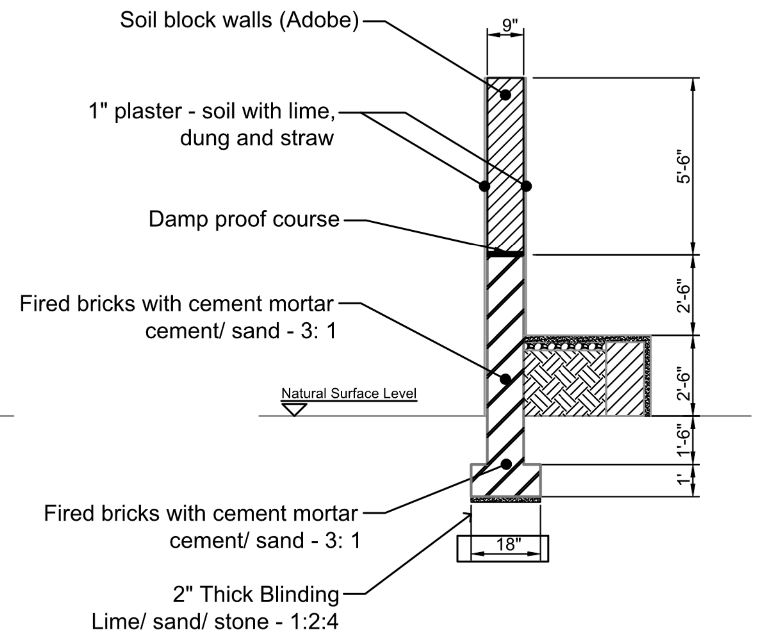
Wall Type No.9



Wall Type No.10



Wall Type No.11



Wall Type No.12

Key

Box around annotation indicates incremental change in panel design

Issue	Date	By	Chkd	Appd
04	27/03/17	LM	TW	RK
03	11/11/16	LM	TW	RK
02	TBC	DSP	TW	RK
01	TBC	IRA	TW	RK

ARUP
13 Fitzroy Street
London W1T 4BQ
Tel +44(0)20 7636 1531 Fax +44(0)20 7580 3924
www.arup.com

Job Title
FLOOD RESILIENT SHELTER RESEARCH

Client
IOM PAKISTAN

TEST PANEL CONSTRUCTION
SHEET 2 of 2

Scale at A3 Not to scale

Discipline STRUCTURES

Job No -

Drawing Status Issue

Drawing No IOM-PAK-04

Issue 04

Do not scale

A3 A B C D E F G H

Materials Specification

Soil

Soil to be brought if from Sindh. All soil to be brought from same location for consistency. Location to be recorded. Soil should be tested for suitability for lime stabilisation prior to transportation to NED in line with *Lime Stabilized Construction: A Manual and Practical Guide, Strawbuild, 2015*

Sand

Sand to be procured from local market in Sindh. Sand to be free of silt, clay, salt and other impurities.

Lime

Lime to be procured, tested and prepared in line with *Lime Stabilized Construction: A Manual and Practical Guide, Strawbuild, 2015*

Compressed soil foundation

Formation level to be free of organic material

Compressed soil with lime foundation

Formation level to be free of organic material

Mix: to be determined in line with *Lime Stabilized Construction: A Manual and Practical Guide, Strawbuild, 2015*, giving 1 lime: 4.5 clay: 1 ash

Soil blocks (Adobe)

Size: To suit wall thickness

Block and mortar mix: As per local practice

Soil blocks with lime (Adobe)

Size: To suit wall thickness

Block and mortar mix: The mix proportions for the Soil and lime blocks are to be determined in line with *Lime Stabilized Construction: A Manual and Practical Guide, Strawbuild, 2015,* giving 1 Lime: 5 clay: 1 straw

Fired bricks

To be procured from local market in Sindh. All to be procured from same vendor for consistency.

Size: 9"x4.5"x3"

Plaster - soil with lime

Mix for soil with lime plaster to be determined in line with *Lime Stabilized Construction: A Manual and Practical Guide, Strawbuild, 2015*, giving 1 lime: 4 clay: 2 straw: 1 River sand or 1 lime: 4.5 clay: 2 straw: 1 ash: 1 River sand

Plaster - soil with cement

Mix for soil with cement plaster to be determined with shrinkage test or equivalent

Damp proof course

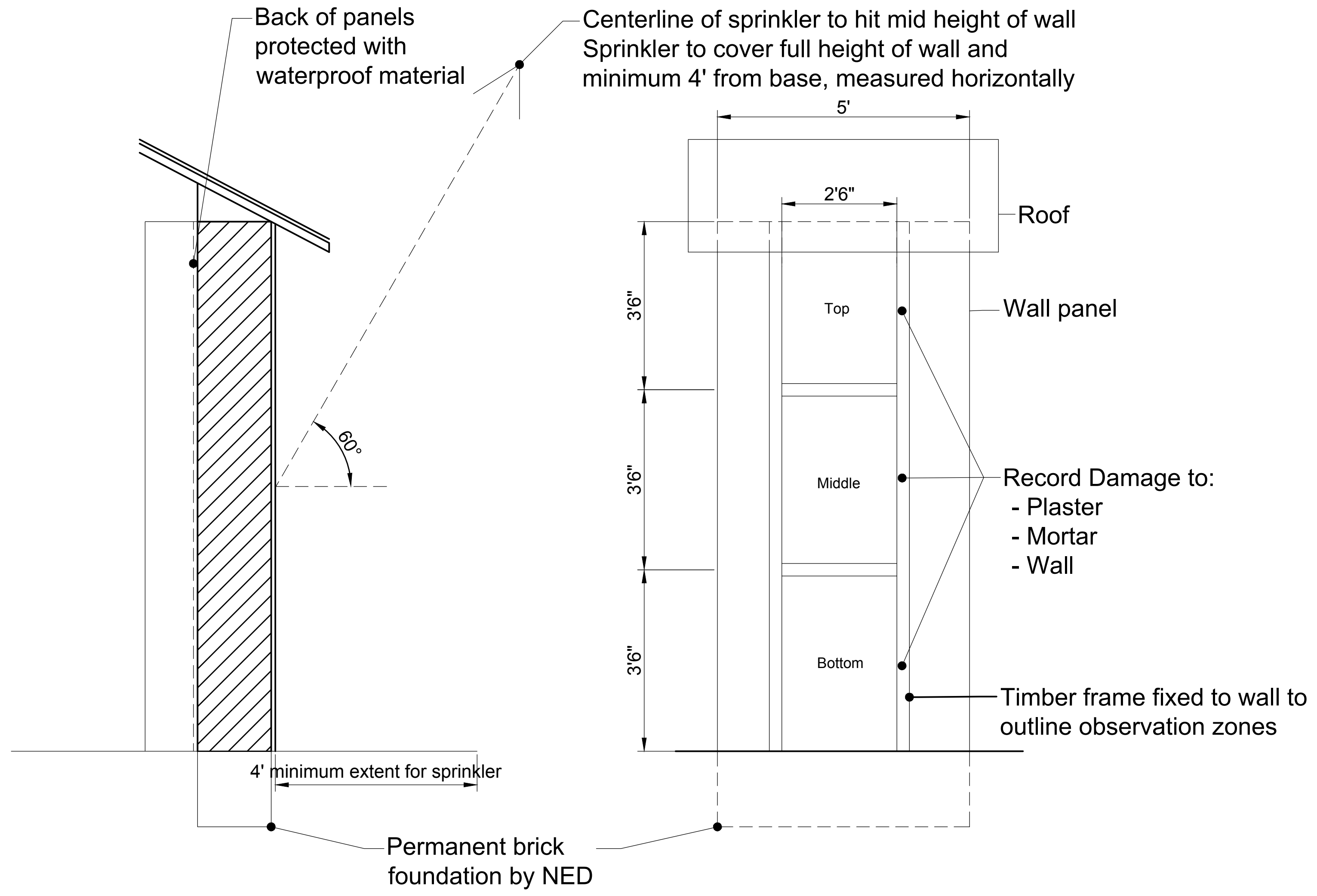
Damp proof course to be heavy gauge plastic sheet

Mortar

Mortar beds to be 1" thick maximum
Mix to match the block type - Soil blocks: Soil mortar - Soil with lime blocks: Soil with lime mortar

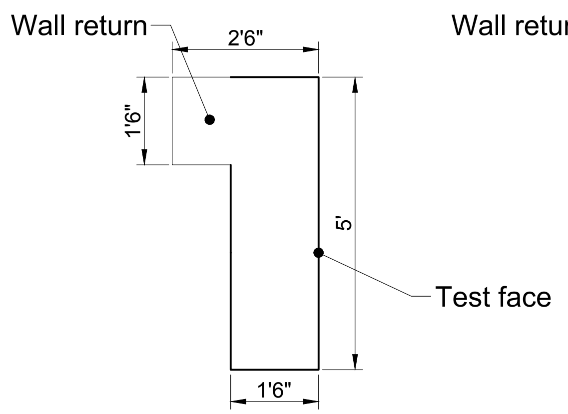
Floor screed

The mix for the floor screed to be determined in line with *Lime Stabilized Construction: A Manual and Practical Guide, Strawbuild, 2015*, giving 1 lime: 1 Sand: 1 Brick powder: 1 Brick Ballast (5mm)

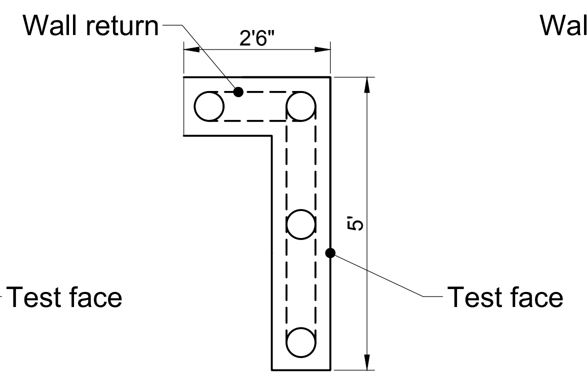


Panel Section

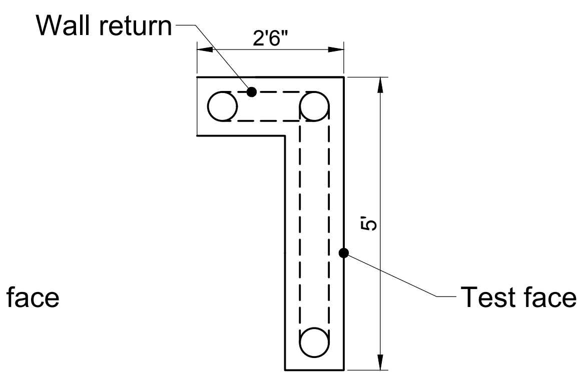
Panel Observation Zones



Abode wall plan



Traditional Loh-kat wall plan



Chicks Loh-kat wall plan

Issue	Date	By	Chkd	Appd
02	13/03/17	LM	TW	RK
01	15/12/16	LM	TW	RK

ARUP

13 Fitzroy Street
London W1T 4BQ
Tel +44(0)20 7636 1531 Fax +44(0)20 7580 3924
www.arup.com

Job Title
FLOOD RESILIENT SHELTER RESEARCH

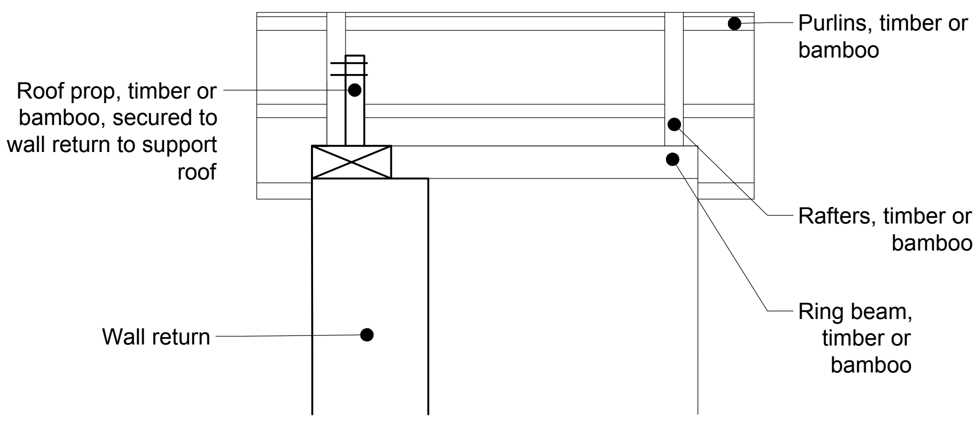
Client
IOM PAKISTAN

RAIN TEST WALL PANEL
PLAN, SECTION, ELEVATION

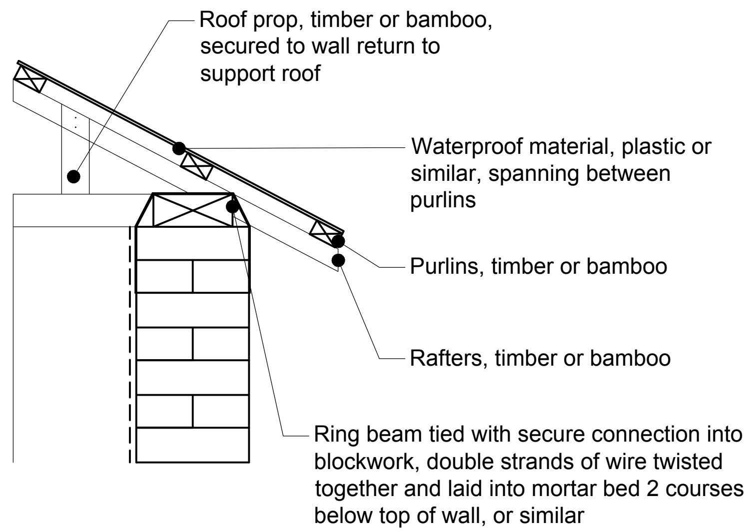
MATERIAL SPECIFICATION

Scale at A3 Not to scale
Discipline STRUCTURES
Job No -
Drawing Status Construction
Drawing No IOM-PAK-10
Issue 02

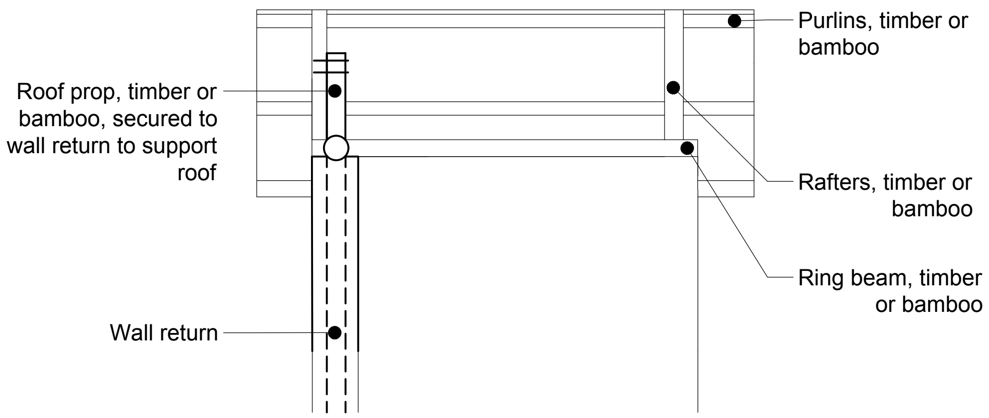
A3



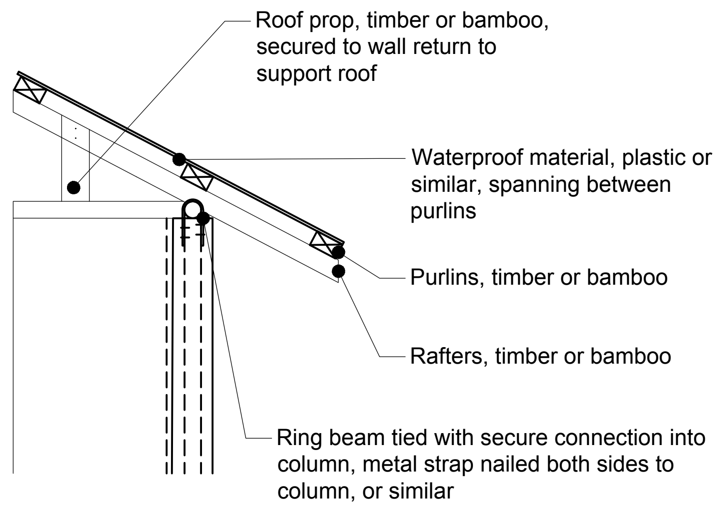
Abode roof construction elevation



Abode roof construction section



Loh-kat roof construction elevation



Loh-kat roof construction section

Key

Box around annotation indicates incremental change in panel design

Issue	Date	By	Chkd	Appd
02	13/03/17	LM	TW	RK
01	15/12/16	LM	TW	RK

ARUP

13 Fitzroy Street
London W1T 4BQ
Tel +44(0)20 7636 1531 Fax +44(0)20 7580 3924
www.arup.com

Job Title
FLOOD RESILIENT SHELTER RESEARCH

Client
IOM PAKISTAN

RAIN TEST PANEL CONSTRUCTION

SHEET 1 of 3

Scale at A3 Not to scale

Discipline STRUCTURES

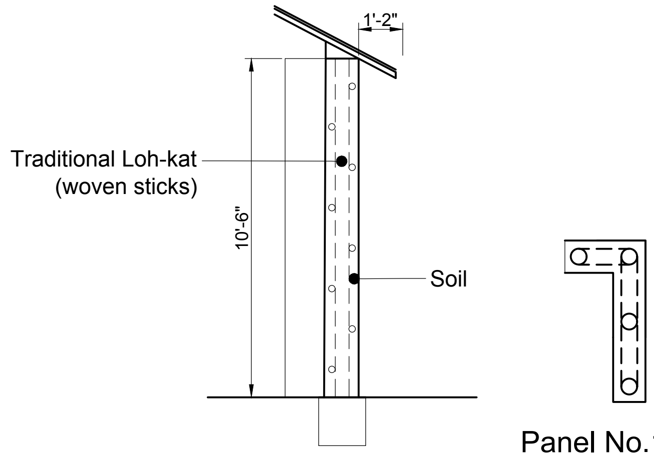
Job No -

Drawing Status Construction

Drawing No IOM-PAK-11

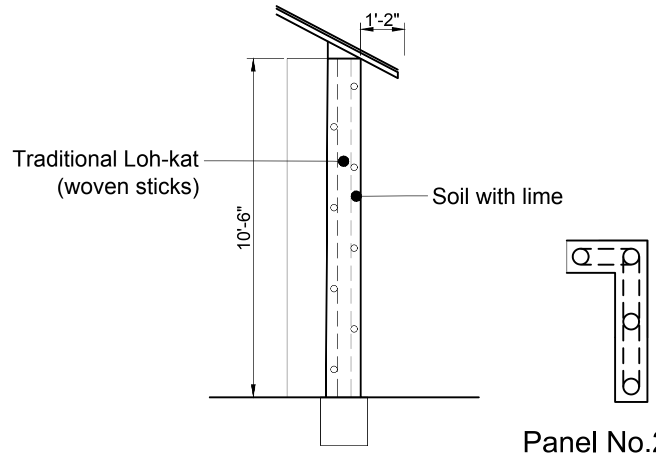
Issue 02

Do not scale



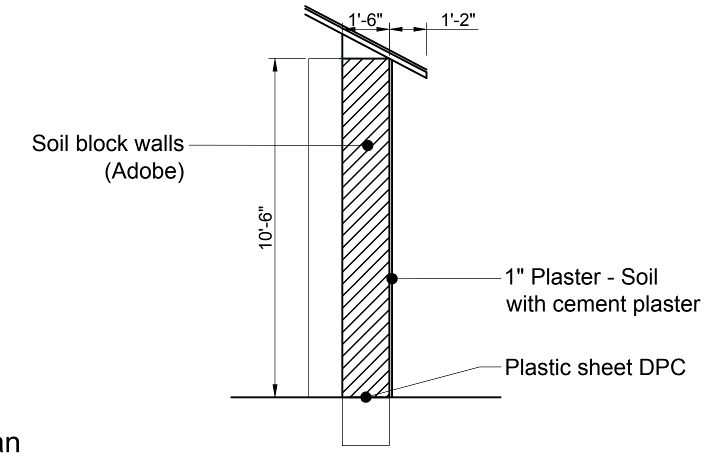
Panel No.1 Plan

Wall Panel No.1

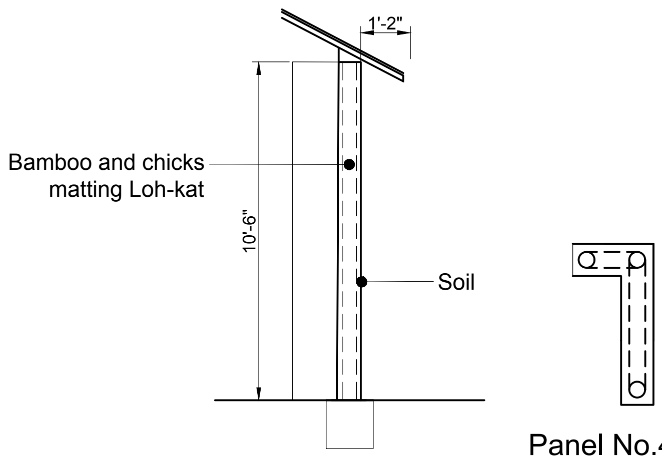


Panel No.2 Plan

Wall Panel No.2

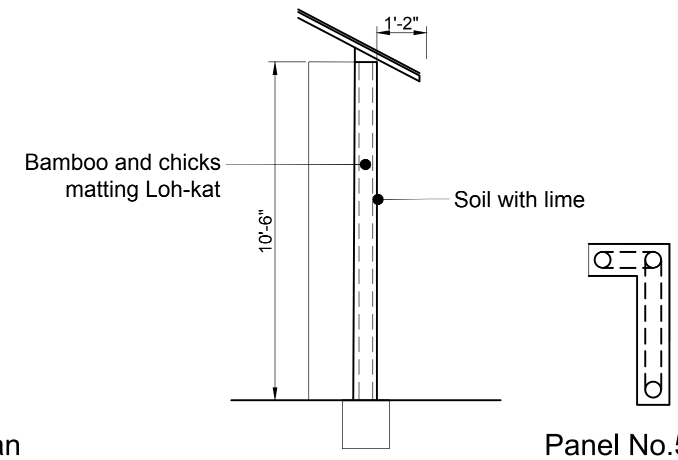


Wall Panel No.3



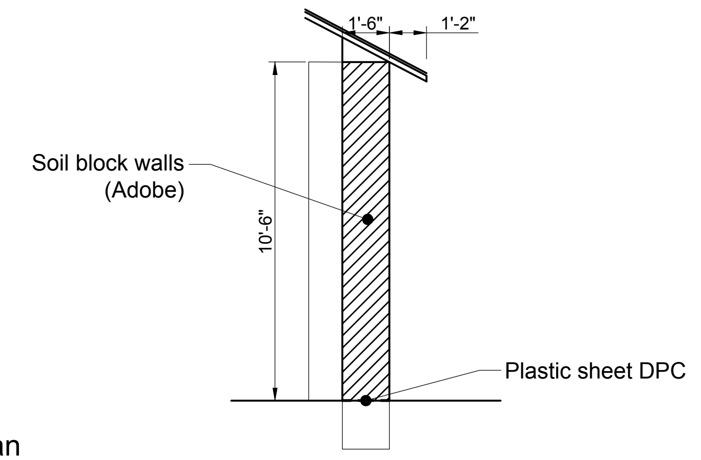
Panel No.4 Plan

Wall Panel No. 4



Panel No.5 Plan

Wall Panel No.5



Wall Panel No.6

Key

Box around annotation indicates incremental change in panel design

Issue	Date	By	Chkd	Appd
02	13/03/17	LM	TW	RK
01	15/12/16	LM	TW	RK

ARUP

13 Fitzroy Street
London W1T 4BQ
Tel +44(0)20 7636 1531 Fax +44(0)20 7580 3924
www.arup.com

Job Title
FLOOD RESILIENT SHELTER RESEARCH

Client
IOM PAKISTAN

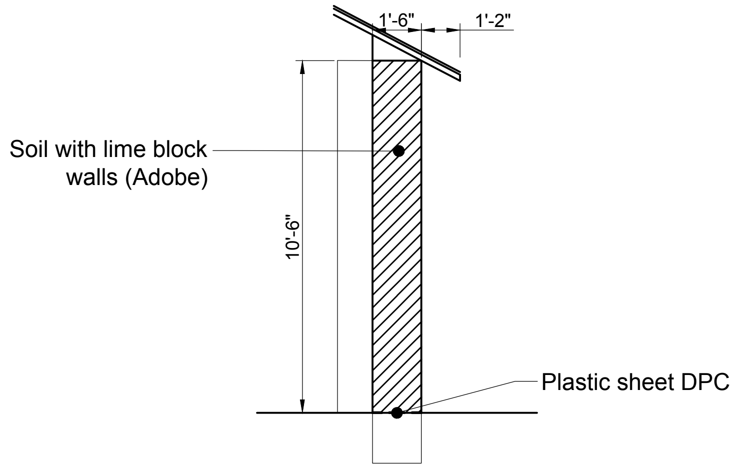
RAIN TEST PANEL CONSTRUCTION

SHEET 2 of 3

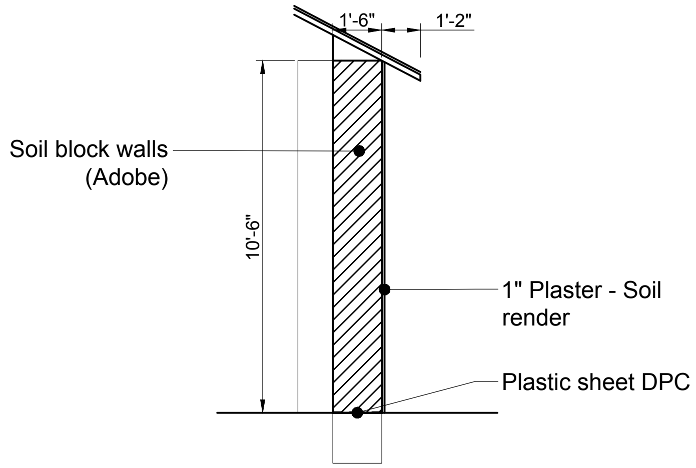
Scale at A3 Not to scale
Discipline STRUCTURES
Job No -
Drawing Status Construction
Drawing No IOM-PAK-12
Issue 02

Do not scale

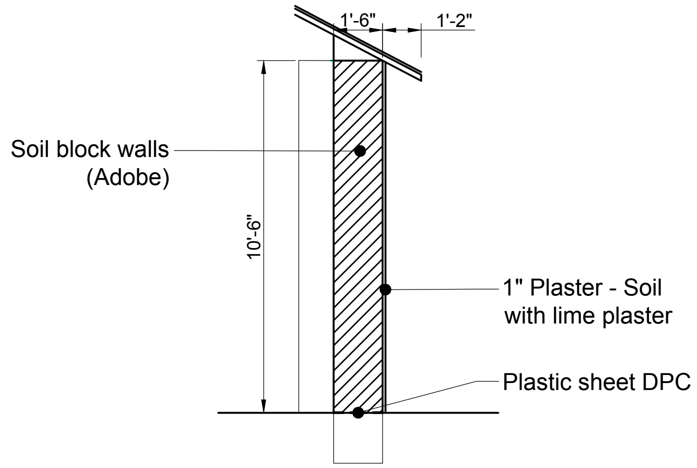
A3



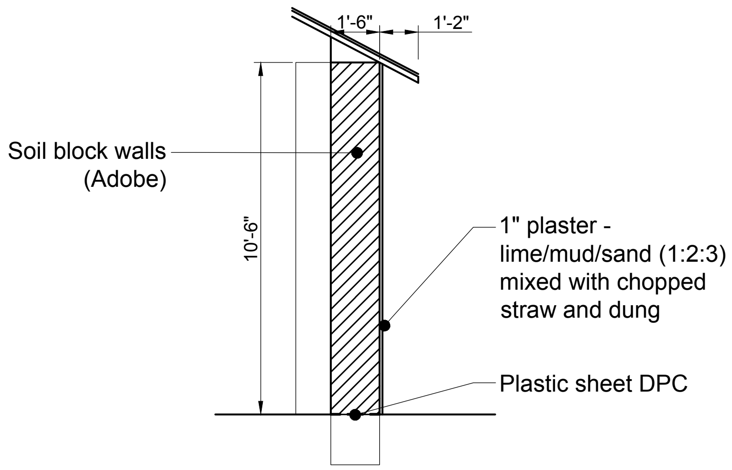
Wall Panel No.7



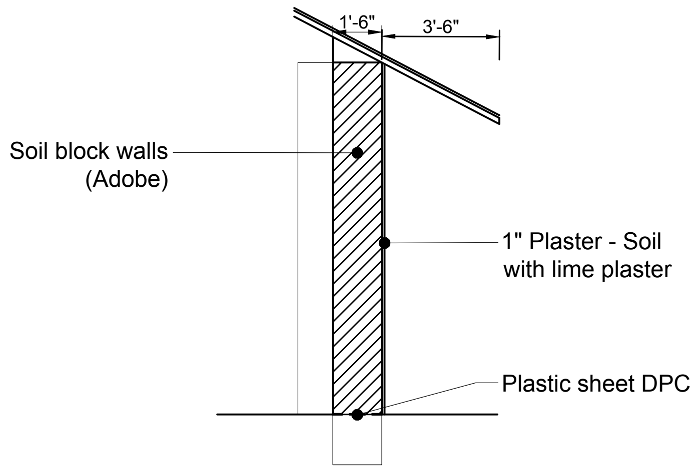
Wall Panel No.8



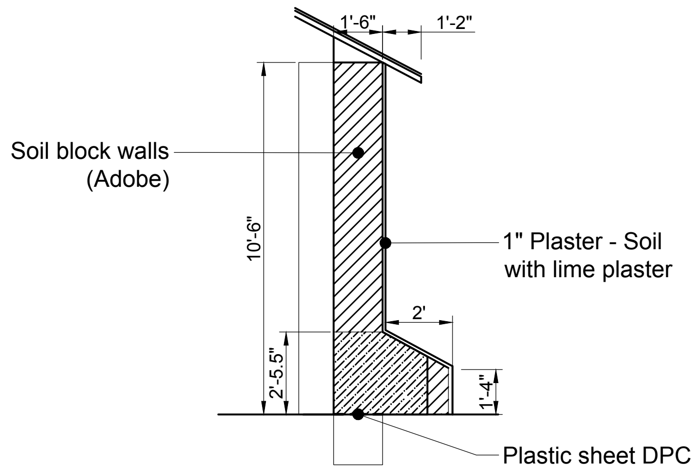
Wall Panel No.9



Wall Panel No. 10



Wall Panel No.11



Wall Panel No.12

Issue	Date	By	Chkd	Appd
02	13/03/17	LM	TW	RK
01	15/12/16	LM	TW	RK

ARUP
13 Fitzroy Street
London W1T 4BQ
Tel +44(0)20 7636 1531 Fax +44(0)20 7580 3924
www.arup.com

Job Title
FLOOD RESILIENT SHELTER RESEARCH

Client
IOM PAKISTAN

RAIN TEST PANEL CONSTRUCTION

SHEET 3 of 3

Scale at A3 NOT TO SCALE
Discipline STRUCTURES
Job No -
Drawing Status Construction
Drawing No IOM-PAK-13
Issue 02

Do not scale

Physical testing results

Key:

Unstabilised earth	Lime stabilised earth	Cement stabilised earth	Fired brick

Rain testing

No.	Wall type	Render type	Other features	Total erosion (kg)	Cost/ m (USD)	Embodied Carbon/ m ($KgCO_2$)
1	Traditional Loh-kat	1 clay soil :4 clay soil:1 sand:3 straw		23.37	4.4	35.8
2	Traditional Loh-kat	1 Lime putty :4 clay soil: 1 sand : 2 wheat straw		0.08	4.7	42.2
3	Soil block walls	Soil-cement render		0.09	7.6	20.8
4	Bamboo and chicks matting Loh-kat	1 clay soil :4 clay soil:1 sand:3 straw		3.77	4.4	35.8
5	Bamboo and chicks matting Loh-kat	1 Lime putty :4 clay soil: 1 sand : 2 wheat straw		0.13	4.7	42.2
6	Soil block walls	none		10.76	4.9	0.0
7	Lime soil block walls	none		7.13	6.3	82.5
8	Soil block walls	1 clay soil :4 clay soil:1 sand:3 straw		12.86	5.0	0.0
9	Soil block walls	1 Lime putty :4 clay soil: 1 sand : 2 wheat straw		0.43	5.3	6.6
10	Soil block walls	1 Lime: 2 soil: 3 sand, dung, straw (HF mix)		0.27	7.2	10.6
11	Soil block walls	1 Lime putty :4 clay soil: 1 sand : 2 wheat straw	Overhang	0.45	5.3	6.6
12	Soil block walls	1 Lime putty :4 clay soil: 1 sand : 2 wheat straw	Toe detail	0.73	5.8	11.2

Flood testing

No.	Foundation type	Lower wall type	Upper wall type	Wall thickness	Plaster type	Toe detail	Collapse water level(ft)	Cost /m (USD)	Embodied Carbon /m ($KgCO_2$)
1	Compressed Soil Foundation	Adobe	Adobe	18"	1" plaster-Soil with lime, dung and straw	NA	0.6	6.1	7
2	Compressed Soil with lime Foundation	Adobe	Adobe	12"	1" plaster-Soil with lime, dung and straw	NA	0.6	4.9	25
5	Compressed Soil with lime Foundation-1:6 lime-mud filling with straw	Adobe	Adobe	18"	1" plaster-lime/mud/sand(1:2:3) mixed with chopped straw and dung	NA	0.6	7.4	34
11	Fired bricks with mud mortar	Fired bricks with mud mortar	Adobe	9"	1" plaster-Soil with lime, dung and straw	NA	0.6	37.1	436
4	Compressed Soil with lime Foundation	Adobe	Adobe	18"	Soil with lime, dung and straw	NA	0.75	7.4	35
10	Fired bricks with cement mortar cement/sand-3:1	Adobe	Adobe	18"	1" plaster-Soil with lime, dung and straw	NA	0.75	22.0	205
3	Compressed Soil with lime Foundation	Adobe	Adobe	18"	1" plaster-Mud plaster mixed with dung and straw	NA	0.9	7.1	29
7	Compressed Soil Foundation	Adobe	Adobe	18"	1" plaster-Soil with lime, dung and straw	Soil toe with lime blocks to outside and lime render	1.25	7.9	21
8	Compressed Soil with lime Foundation	-Adobe	-Adobe	18"	1" plaster-Soil with lime, dung and straw	Soil with lime toe with lime blocks to outside and lime render	3.25	11.8	113
6	Compressed Soil with lime Foundation	Adobe with lime	Adobe with lime	18"	1" plaster-Soil with lime, dung and straw	NA	No collapse	8.8	118
9	Compressed Soil with cement Foundation	Adobe with cement	Adobe with cement	18"	1" plaster-Soil with cement, dung and straw	NA	No collapse	32.7	436
12	Fired bricks with cement mortar cement/sand-3:1	Fired bricks with cement mortar cement/sand-3:1	Soil block walls-Adobe	9"	1" plaster-Soil with lime, dung and straw	NA	No collapse	43.5	487

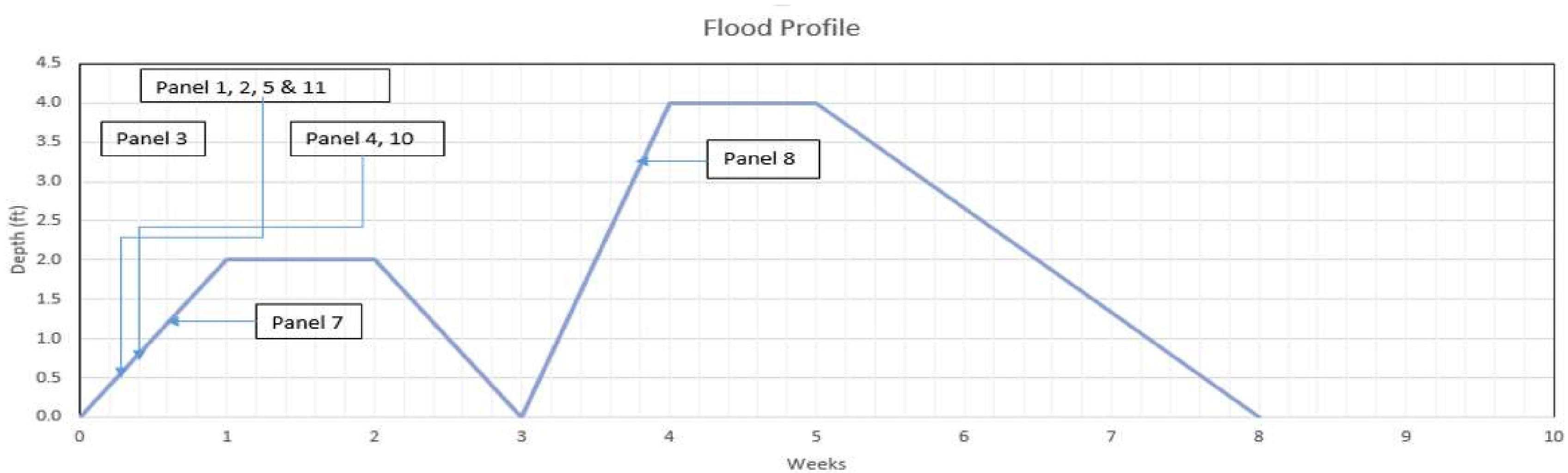


Figure 1 – Flood profile indicating time and depth of collapse of different panels

Panel 1:

ARUP

Panel 2:

ARUP

Panel 3 :

ARUP

Panel 4:

ARUP

Panel 5:

ARUP

Panel 7:

ARUP

Panel 8:

ARUP

Panel 10:

ARUP

Panel 11:

ARUP

Panel 1: Traditional Loh-kat with clay soil, sand & straw render

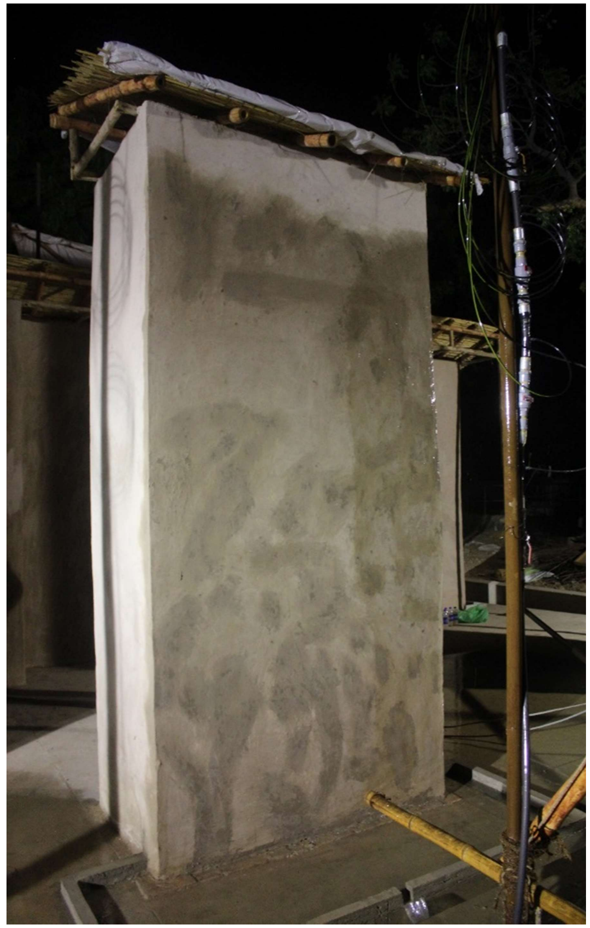
Start

Finish

Panel 2: Traditional Loh-kat with lime putty, clay soil, sand & wheat straw render

Start

Finish



Panel 3: Adobe block walls with soil-cement render

Start

Finish

Panel 4: Bamboo and chicks matting Loh-kat with clay soil, sand & straw render

Start

Finish

Panel 5: Bamboo and chicks matting Loh-kat with lime putty, clay soil, sand & wheat straw render

Start

Finish

Panel 6: Adobe soil block walls with no render

Start

Finish

Panel 7: Adobe lime soil block walls with no render

Start

Finish

Panel 8: Adobe soil block walls with clay soil, sand & straw render

Start

Finish

Panel 9: Adobe soil block walls with lime putty, clay soil, sand & wheat straw render

Start

Finish

Panel 10: Adobe soil block walls with lime, soil, sand, dung & straw render

Start

Finish

Panel 11: Overhang Adobe soil block walls with lime putty, clay soil, sand & wheat straw render

Start

Finish

Panel 12: Toe detail Adobe soil block walls with lime putty, clay soil, sand & wheat straw render

Start

Finish