BE CIVIL ENGINEERING PROJECT REPORT

GEO-FORENSIC DISTRESS EVALUATION OF A DAMAGED BUILDING FOUNDED ON COLLAPSABLE SOIL WITH A VIEW TO FORMULATE A REMEDIAL STRATEGY: A CASE HISTORY

Project submitted in partial fulfillment of the requirements for the degree of

BE Civil Engineering

SUBMITTED BY

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MILITARY COLLEGE OF ENGINEERING
NATIONAL UNIVERSITY OF SCIENCES & TECHNOLOGY
RISALPUR CAMPUS, PAKISTAN

(2018)

This to certify that the

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Has been accepted towards the partial fulfillment of the requirements for

BE Civil Engineering Degree

Dr. Sarfraz Ali, PhD
Syndicate Advisor


بسم الله الرحمن الرحيم

DEDICATED TO OUR BELOVED PARENTS, TEACHERS AND ALL THOSE WHO HAVE CONTRIBUTED TO THIS PROJECT

ACKNOWLEDGEMENT

All thanks and praise to Allah Almighty

We bow our heads before Allah Almighty for blessing us with such an opportunity, strength and resources to complete our research work. The completion of this research project was indeed a dauntless task which demanded dedicated efforts from many people whom we owe a lot of gratitude. For timely completion of this project we needed a driving and guiding force. This power was provided to us by our respected advisor Brigadier Doctor Sarfraz Ali. His knowledge in field of Geotechnical engineering has benefitted us in very comprehensive way and imparted life learning lessons not only for our profession but for our daily lives. Through his exemplary guidance and leadership, we were able to achieve the objective of this research. It has been a real honor to have worked and learn under his guidance indeed.

ABSTRACT

House is a necessity of everyone around the world. In one of the house located at Mushtaq street in Risalpur Cantonment, cracks of various width appeared throughout the house. Due to the cracks the house was declared unsuitable for living and evacuated.

This research involved study of geological and geotechnical conditions of the site and also to review the structural condition of the building. The research was based on field tests and lab tests. Settlement analysis was carried out using the modern techniques. The research was carried to save precious money of government as construction of new house cost about 8 to 10 million rupees to the government.

Investigations revealed foundation soil was low plastic silty clay and was collapsible in nature. Moreover, the foundation provided was not sufficient for the building. Poor maintenance was another cause of failure as the water seeped into foundations of most heavily loaded area. In the view of these findings, remediation suggested involved stabilization of soil with lime, relaying of foundation with 24 inches width and structural repointing of slightly damaged walls.

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Chapter 1

INTRODUCTION

1.1 GENERAL

Structural problem related to problematic foundation soil are common in Pakistan and elsewhere. Risalpur is located 5 km from river Kabul and foundation soil is comprised of fluvial deposits of river Kabul. Some of the single storey and double storey masonry buildings in Risalpur have undergone structural problems such as differential settlements, cracks in the walls, sticking of doors and windows, etc.

As part of the final year project, this research study was carried out to investigate structural distresses of a house located at Mushtaq street. The house is a single storey masonry building, which is one amongst many other buildings facing similar problems. So far, no research has been carried out to investigate the casual factors of damages to the building. In the absence of any such research structural problems would continue to grow ultimately leading to collapse of building this would be a huge loss to the government.

1.2 PROBLEM STATEMENT

Structural distresses in masonry buildings in Risalpur is a serious matter. Casual factors attributing to these damages are not known. Since no research has ever been carried out to identify the casual factors attributing to the instability of damaged building. In case remedial measures are not taken many buildings will ultimately collapse with a financial loss of Rs. 50 million per house. Our syndicate felt the need to carry out the research to identify the causal factors, characterize distress in the foundation soil/building and suggest the remedial measures to enhance the safety of damaged buildings in Risalpur.

1.3 SCOPE AND OBJECTIVE

The scope of our research includes, evaluation of casual factors and characterize the distresses in the foundation of house no. 120/2 located at Mushtaq street. The objective of the research is:

- Review of the original design
- Mapping of the distresses.
- To perform forensic geotechnical investigation of site.
- Foundation stability analysis.
- Suggest Remediation for building.
- Develop guidelines for foundation soil of other buildings.

1.4 RESEARCH QUESTION

The research will lead to the answers of following question:

- What is the geology of the site?
- What are the geotechnical properties of the soil?
- Which mechanism started the distresses in the building?
- What is the condition of existing foundation and its effect on the stability of structure?
- What are the different foundation improvement methods available and which is the most suitable?
- What measures should be adopted to prevent distresses in future?

1.5 SIGNIFICANCE OF RESEARCH

The significance this research leads to Identify the construction and design deficiencies that needs to be avoided to eliminate failure in future. This research will recommend remedial measures for the stabilization and strengthening of other damaged buildings, and also help us to develop guidelines for future construction in that area.

1.6 RESEARCH LAYOUT

Research work has been presented in the following chapters as:

- Chapter 2 covers the relevant literature review on the factors responsible for the distresses in the buildings.
- Chapter 3 covers the methodology used in the research.
- Chapter 4 includes site characterization i.e. geological condition, topography, hydrological condition, seismicity etc.
- Chapter 5 includes the settlement analysis of the building which is computed on the GEO 5 software.
- Chapter 6 will cover the results and discussion of the lab and field tests that are covered in methodology chapter.
- Chapter 7 covers the guidelines and recommendation that are developed for future construction.

Chapter 2

LITERATURE REVIEW

2.1 GENERAL

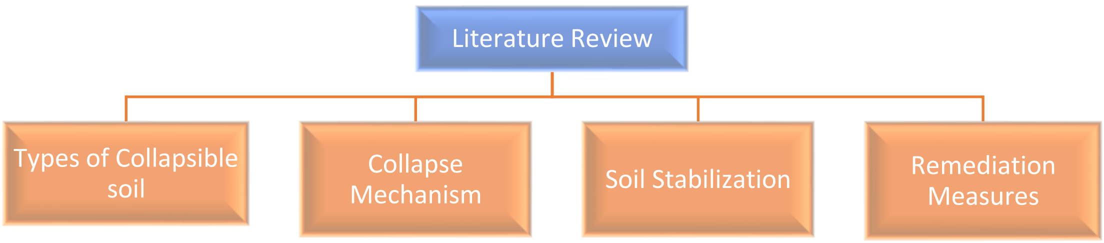
Soil is the layer that supports all the structures built on earth. The structural stability depends upon the strength of its foundation. This leads to the fact that soil has direct impact on the success of any construction project. If underlying foundation soil is not capable of supporting the load of the structure, it needs to be treated prior to construction. If structure shows signs of damages, Geo-forensic investigation is performed to analyze every aspect from design and construction to maintenance, to deduce conclusion what caused the distress.

This chapters reviews the general distresses and failures, and available remedial options.

2.2 FINDINGS OF PREVIOUS RESEARCH

Soil characterization with a view to evaluate collapse potential of Risalpur soil till the depth of 20 feet was carried out by Dr. Abdul Qadoos, Engr. Tariq and their team during 2012. This research is further continuation of researches carried out by previous syndicates, therefore major findings of Tariq et.al (2012) are listed below:

- The Risalpur soil up to 20 feet (the depth of investigation) is collapsible, however the magnitude of collapse generally decreases with depth.
- The collapse at the depth of 4 feet is severe; this depth represents the typical depth of shallow foundations in the area.
- Excessive deformations of UCC specimen due to soaking indicates that foundation can fail quickly when exposed to water, therefore major structural damages are expected if foundation gets inundated.
- The soil regains its strength when it gets dried after flooding. This indicates presence of cementing material which reprecipitates at particle contact on drying.



2.3 TYPES OF COLLAPSIBLE SOILS

Collapsible soils are unsaturated soils which have a tendency to deform and completely change the particle structure while coming in contact with water, with or without loading. These soils normally consist of silts and fine sand size particles. Collapsible soils are mainly found in arid to semiarid regions (Al Rawas, 2000). Some of the common types of collapsible soil are briefly described below:

2.3.1 Water deposits

Water deposits comprise of flash floods, alluvial fans and mud flow deposits. Their structure is usually open and porous. Soil particles are bonded together by cementing agents during deposition. These deposits are found at the bed of water channels in a saturated state. Upon drying, they become hard and less compressible with relatively low density. If these deposits are subsequently exposed to water with or without loading, they may collapse causing large settlements.

2.3.2 Aeolian (Windblown) deposits

They are mainly composed of clay minerals and quartz along with feldspar. They usually have meta-structure, which is bonded by some cementing agent and may become weak upon wetting causing collapse.

2.3.3 Colluvial deposits

These deposits are formed by rain-wash, sheet wash or slow downward creep at hillslopes. They mainly get deposited by the action of gravity with time and are generally composed of unconsolidated sediments as in landslides.

2.3.4 Residual soils

These soils have a particle size ranging from clay to gravel. The collapse mechanism is developed by washing off of colloidal or soluble matter from residual soil. Washing off of these matters results in porous, unstable structure.

2.4 THE COLLAPSE MECHANISM

Generally following conditions results in collapse of soils (Schwartz,1985)

- There must be a collapsible fabric in soil.
- Partial saturation condition is required
- For collapse mechanism to occur, increase in moisture content is required.
- Applied pressure must be greater than the overburden pressure.

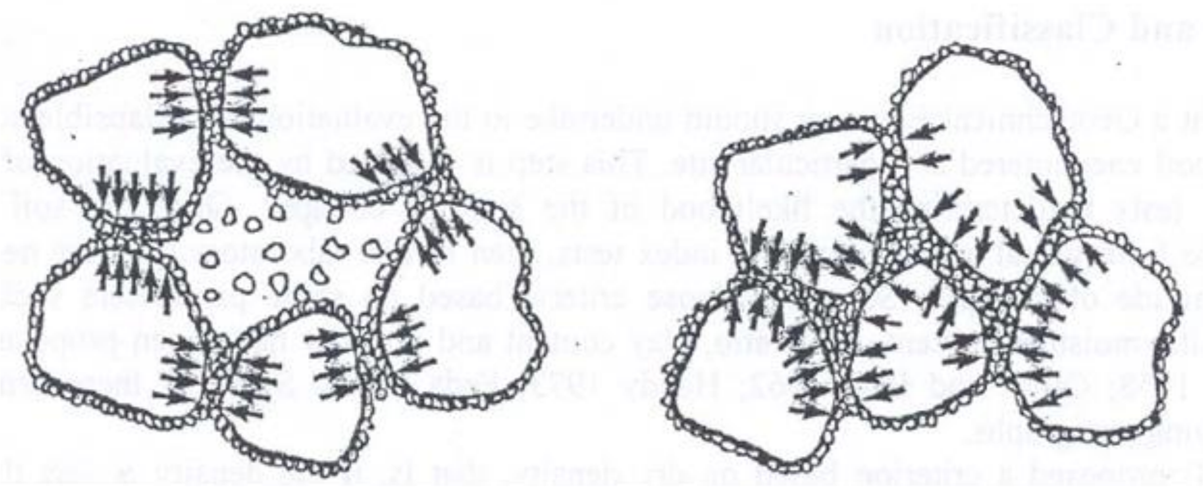
If the above-mentioned conditions are achieved, then collapse occurs simultaneously in following phases (Kulkanova and Frankovska, 1995):

PHASE – 1

This is starting stage of destruction. In this stage the original microstructure changes as the applied stress increases along with moisture. Micro aggregates disintegrate and as a result dissolution and migration of carbonates in soil increases.

PHASE – 2

The total volume of soil fabric decreases as carbonate migration continues and fabric elements compress.



(a) (b)

Figure 2.2 Structure of a collapsible soil (a) Original soil structure (b) soil structure after collapse

(Al Rawas ;2000)

PHASE – 3

After collapse of original structure, new microstructure starts to develop. Clay particle coatings have been destroyed at this stage.

2.5 GEOTECHNICAL DISTRESSES AND FAILURES

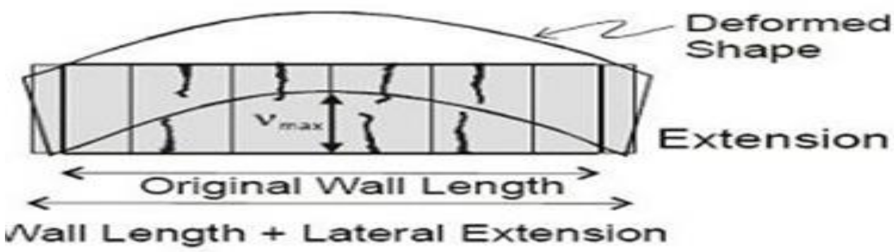
Some of the visual distresses and their possible causes are listed in table 2.1 below:

Table 2.1. Distresses, types and causes

Structure Type	**Distress**	**Possible Causes**
Buildings/ Bridges	Appearance of cracks	Structural Geotechnical: • Bearing capacity failure • Compression • Consolidation • Subsidence
	Visual tilts	Differential settlements Earthquakes
	Complete/ partial Collapse	Over load Erosion of soil Repetitive loading unloading

2.5.2 Distress Pattern

Distress in structure in often linked to foundation failures or displacements. Although after construction every structure undergoes certain amount of deformation, but deformation exceeding safety limits are termed as 'distress'. The crack pattern may indicate the type of distress. Some of common modes are illustrated in figures below (Boone, 2001).



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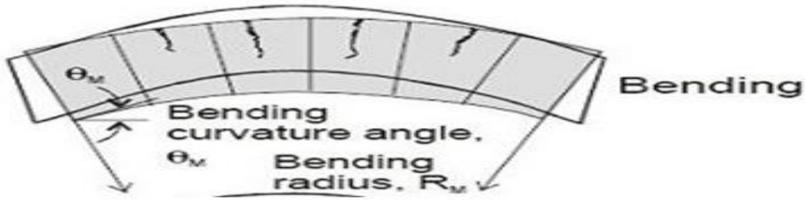

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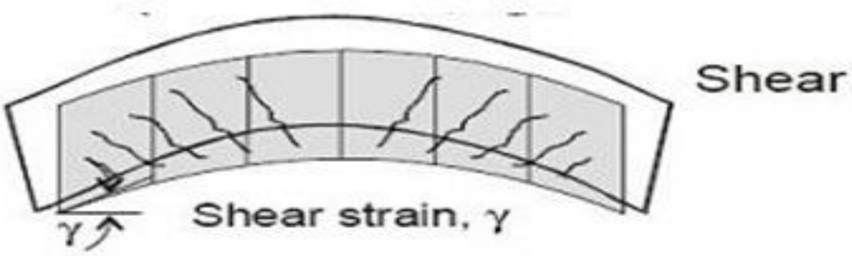


(c)

Figure 2.3 Deformation modes

(a) Extension (b) Bending (c) Shear (Boone, 2001)

2.5.2.1 Differential settlement

Differential settlement occurs when piers or foundation of structure settles unevenly (bestructural.com). Diagonal cracks projecting towards the corners or edges of the walls are visual indication of differential settlements. These cracks usually take a year or two to appear and are caused by settlement of clayey stratum. These settlements may also cause the vertical displacements of floors along with the walls. Detachment of the outer wall apron is also an indication of settlement. If settlement is severe several horizontal cracks may appear along with diagonal cracks.

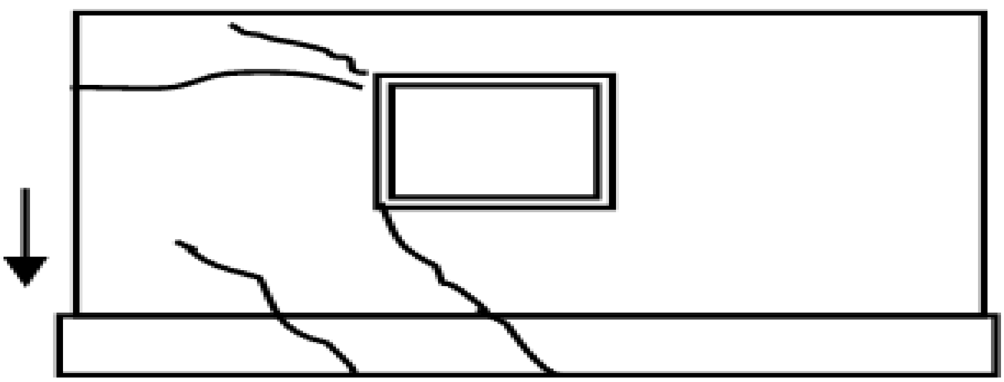


Figure 2.4 Distress in masonry structure due to differential settlements (consolidation)

2.5.2.2 Shrinkage of soil

Shrinkage capacity is the extent to which certain clay minerals of soil would retract when dried. If cracks appear after long period of time, without any change in loading of structures, distress may be result of shrinking soil in foundation. The problem is prominent in exterior walls due to direct exposure to environmental changes. There is no specific pattern of these distresses, but they can be identified by the time period after which they occur. Generally, floors and outer apron is more affected by this type of settlement.

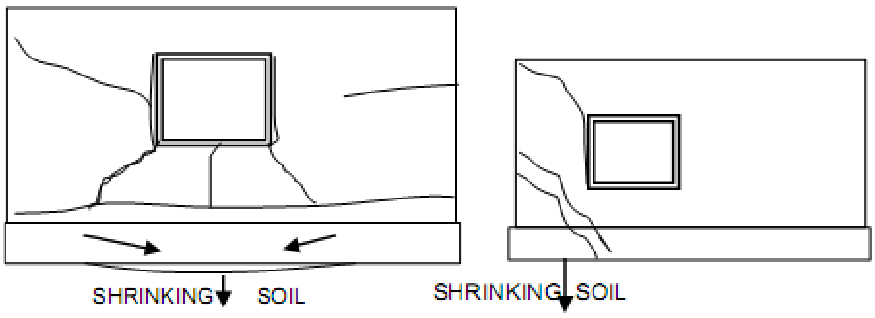


Figure 2.5 Distress in masonry structure due to differential settlements (shrinkage in foundation soil)

2.5.2.3 Swelling Soil

Swelling capacity is the extent to which certain clay minerals would expand when wetted. This type of distress is more chaotic and results in increased differential settlement. Wide cracks are visible between interface of roof slabs and walls. Hogging of foundation can occur below large openings like doors and windows and may result in sticking and detaching from frames. In this type, cracks usually start appearing from interface of lintel and walls, as shown in figure below:

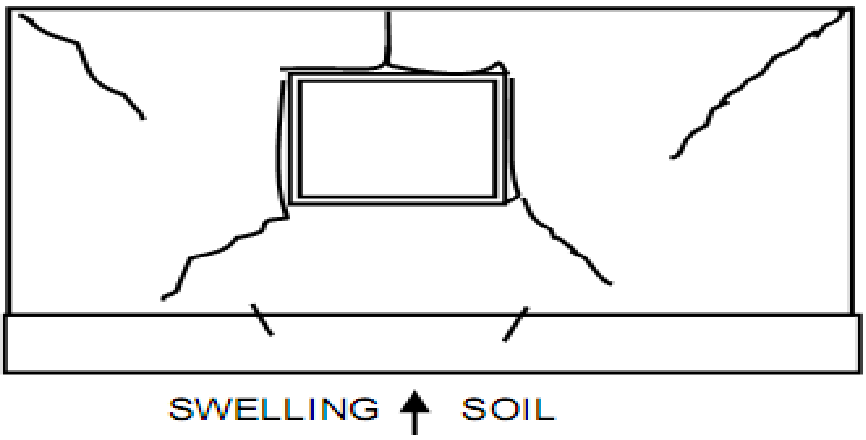


Figure 2.6 Distress in masonry structure due to swelling of foundation soil

2.5.3 Geotechnical Failures

Bearing capacity, consolidation and compression settlements and subsidence are the examples of geotechnical failures.

2.5.3.1 Bearing capacity failure

Bearing capacity is soils ability to support the loads applied to ground. Bearing capacity failure commonly occurs in clays in undrained conditions and can also occur in very loose sandy soil if loaded instantaneously. Bearing capacity failures leads to excessive displacements, which in most cases results in failure.

2.5.3.2 Compression settlements

Compression is the reduction in the volume of soil upon increase of stress. This type of settlement mostly occurs during the construction period. It is common in foundations where soil is loose sand. Varying load of different components of same structure may cause this type of settlement. This type of failure may result in vertical cracks.

2.5.3.3 Consolidation settlements

Consolidation is the reduction in volume of saturated clay due drainage of pore water gradually over course of time, due to application of load. It occurs slowly after construction. Consolidation depends on the depth of the consolidation layer below the influence region of foundation. Varying load of different components of structure can cause differential settlement. This type of failure results in diagonal cracks.

2.5.3.5 Subsidence

Subsidence is the downward displacement of the foundation soil making the structure unstable. Some common reasons include; vibrations, shrinkage of soil or deep mining below site. Subsidence is generally gradual and slow. Visual signs include appearance and widening of cracks or sticking of doors and windows.

2.6 SOIL STABILIZATION

It refers to the process of improving soil properties, strength and durability using various methods. Conventionally, soil is improved using chemical admixtures like lime and cement or by prewetting or mechanical stabilization. Pre-wetting and mechanical stabilization need to done before the construction starts but in case of our research this is not possible.

2.6.1 Lime Stabilization

Lime stabilization is one of the oldest and cheapest technique of soil stabilization of fine grained soil. The process of lime stabilization suitable for soils carrying > 35% of fine particles as this process relies completely on the reaction between lime and soil and no cementitious calcium silicates and aluminates are formed during the process. Lime is added to soil in form of quick lime CaO, or hydrated lime [$Ca(OH)_2$], the former being more suitable as it is more cost effective and easy in handling (Powrie; 2004).

2.6.1.1 Feasibility of Lime Stabilization

Clayey soils with >25 % passing #200 sieve and plasticity index >10 are considered suitable for stabilization using lime (NLA, 2004). Soils with organic content >1% or sulfates >0.3% requires additional lime content (NLA, 2004).

2.6.1.2 Chemistry of Lime Stabilization

2.6.1.2.1 Drying

Quick lime reacts with water and releases heat. Soil dries up as water present directly participates in reaction, while heat produced can evaporate additional water. The hydrated lime then reacts with clay particles and more drying is achieved. Decrease in capacity of soil of holding moisture increases the stability of soil.

2.6.1.2.2 Modification

After initial reaction, Calcium ions Ca^{++} migrate to surface and displace water and other ions from clay particles. The plasticity index of soil, along with shrink and swell capacity of soil decreases at this stage. This process of flocculation and agglomeration occurs in a matter of few hours.

2.6.1.2.3 Stabilization

The amount of lime necessary for stabilization of a particular soil is determined by series of tests according to the test procedures described by Eadges and Grim test (ASTM D6276). The lime and water added increases the pH above 10.5 at which clay particles star breaking. Silica and Alumina released react with calcium to form Calcium aluminate hydrate (CAH) and Calcium silicate hydrate (CSH) which have cementitious properties. The matrix formed by their reaction makes the soil relatively impermeable and increases bearing capacity. If properly designed matrix formed is durable, strong, flexible and relatively impermeable. Matrix formation may take a year.

2.6.1.3 Effect of Lime stabilization

Following changes in soil properties were observed after stabilization with lime (previously):

- The Plasticity index of the soil decreases due to increase in Plastic limit. Plasticity index can be reduced to a point where soil becomes non-plastic (Little, 1987).
- Due to flocculation and cementation the maximum dry density of the soil decreases by 3-5 pcf while optimum moisture content increases by 2-4 percent (Hausmann, 1990)
- The soil passing #40 sieve decreases due to agglomeration making soil coarser (Winterkon, 2002).
- UCC tests indicate increase in the strength of soil. Strength increase depends upon curing period, increase of 100 psi has been achieved in many soils cured for 28 days at 73°F (Dallas et al, 1987).
- Prolonged exposure to water produces damaging effects in soil and ratio of soaked and un-soaked soil is high. The compressive strength varies from 0.7 to 0.85 (Dallas et al, 1987).

2.6.2 Stabilization using Polyurethane (PU)

Polyurethane is relatively a new method of soil stabilization. It is a patent process that uses a chemical grout composed of two parts; isocyanate and polyol. This grout is capable of lifting, sealing and realigning structures. This grout is being used worldwide due to versatility and flexibility in following construction processes:

- Strengthening of subsoil.
- Strengthening of brick or stone masonry.
- Insulation and sound proofing of buildings.
- Sealing of joints.

2.6.2.1 Feasibility of Polyurethane stabilization

Polyurethane polymer has a 3-dimensional solid network structure. When isocyanate and polyol are mixed in liquid form, their volume increases along with generation of heat. The grout would achieve 90 % of its maximum compressive strength within 15 minutes (Nazariam et al, 2009) (minimum compressive strength 0.276 N/mm^2). Chemicals used in its formation are environment friendly and nontoxic and have indefinite life span (Properties are listed below in Table 2.2).

Method of PU grouting is similar to cement grouting. Grout is injected by drilling hole, installing packer and filling voids in soil (shown in figure 2.7). However, due to its quick hardening process special injectors are used in which the two components are mixed in the nozzles as it hardens in less than 2 minutes.

Table 2.2 Properties of Polyurethane Foam.

Property	Polyol	Isocyanate	
Density, 25°C	1.10 g/cm³	1.23 g/cm³	
Viscosity, 25°C	1500 mPa.s	220 mPa.s	
	Units	Test Method	Results
Density	kg/m³	ASTM D-1622	160
Ultimate Compressive Strength at 20°C	kPa	ASTM D-1621	
- Force parallel			2,290
- Force perpendicular			2,040
Thermal Conductivity at 20°C Fresh Foam	W/m.K	ASTM C-518	0.0379
Percentage of closed-cells	%	ISO 4590	91
Water Absorption at 20°C	% by volume	ASTM D-2842	0.33

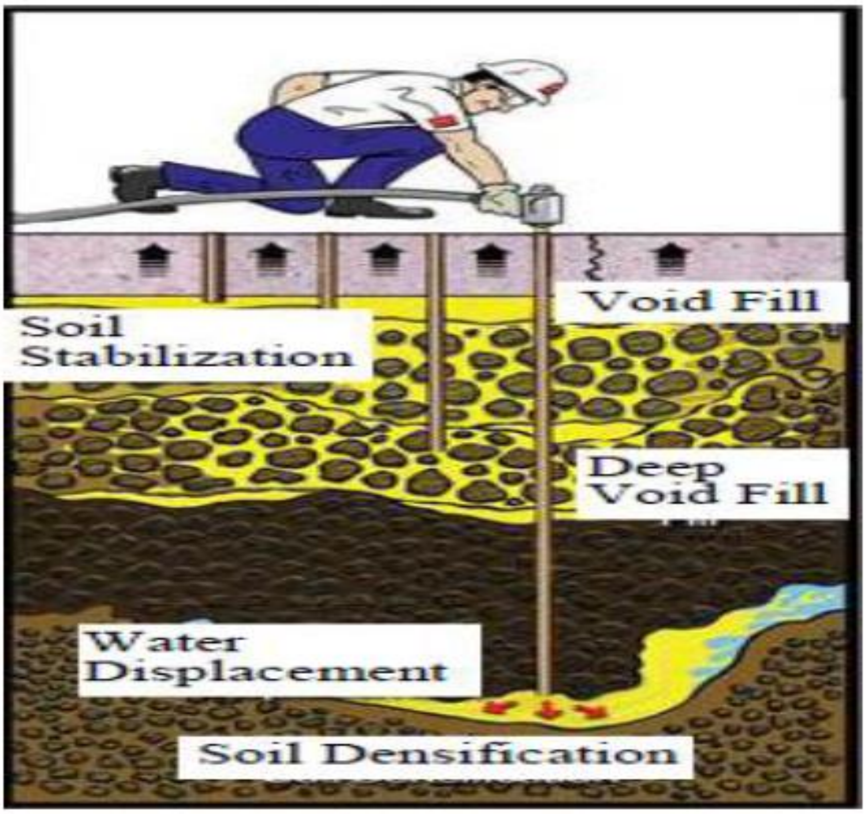


Fig 2.7 Injection system of Polyurethane foam.

2.6.2.2 Stabilization process

The grouting material in liquid form flows through the voids. The grout starts hardening within 1.5 minutes of mixing. During hardening process CO_2 is produced and is responsible for foaming of mixture. Foaming is intense if it comes in contact with moisture. Increase in volume is observed during foaming process and mixture is pushed into open structures i.e. voids, driving out water and forming foam. The viscosity of material keeps on increasing and flow stops, at this stage increasing the pressure may cause opening of new structures which is indicated by the drop-in pressure. Curing continues after the pump is stopped, foam achieves 90% of its compressive strength in 5 minutes. The strength achieved depends upon the curing of the material (Nazariam et al, 2009). Compact structure is formed if grout is injected under high pressure whereas porous structure is formed at low pressure not increasing soil properties up to required level.

2.6.2.3 Effects of Polyurethane stabilization

Following changes were observed in soil properties during soil stabilization and uplifting of slab project in Malaysia (Fakhar, 2016).

- The bearing capacity of soil is improved due to expansion of foam in the voids (Mohamed et al, 2015)
- Lightweight characteristics of PU reduces settlement rate while expansion causes lifting of soil (Mohamed et al, 2015).
- PU has characteristic of light weight, expansion with high specific strength, it is strong in bonding stresses with other materials, anti-aging properties and it cures in very short time (Mohamed et al, 2015).
- After modification of soil with PU, the strength increased to 600KPa and soil was classified as Hard soil as no. of blows for equal penetration increased from 40 to 150 (Fakhar, 2016) as shown in figure 2.8 below.
- The maximum compressive strength values for stabilized soil were 1 to 3 times higher than natural soil. Natural soil 62.10 to 145 KPa while modified 190.3 to 199.3 KPa respectively (Fakhar, 2016).
- Table below shows change in void ratio, C_c, Cs, pre-consolidation pressure.

Soil	Initial void ratio, e_o	Compression index, c_c	Swelling index, c_s	Preconsolidated pressure, p_c (kPa)
KLIAud04	0.635	0.076	0.023	52
KLIAms04	0.435	0.075	0.009	56

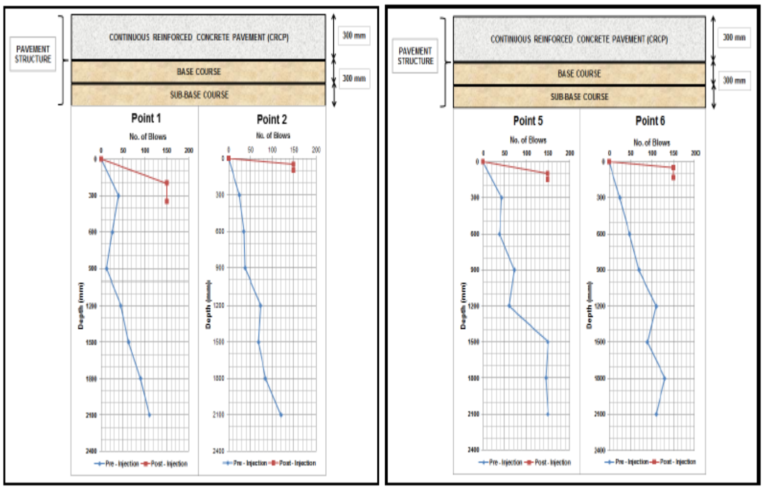


Fig. 2.8 SPT blow count result before (blue line) and after (red line) stabilization

2.6.3 Stabilization using Shredded Rubber

The technique of stabilization of soil using shredded rubber is relatively new, in this technique shredded waste rubber, which pollutes the environment if not properly disposed, is used in a constructive way for stabilization of soil. Literature review indicates that this method is quite suitable for clayey (Singh et al, 2017) soil as UCC performed on clayey sample reinforced with 1% rubber shredding indicated 7.38% increase in the soaked strength. Low quantities of rubber are used because lighter rubber particles start replacing soil particles which decreases the dry density of soil (Jagtar, 2017). Literature also indicates due to its easily availability and light weight this method is extensively used in highway fills to decrease weight of fill and increase strength (Brooks, 2009)

2.7 RETROFITTING OF MASONRY STRUCTURES

Masonry is the structure made up of individual units such as bricks or concrete block bonded together with some cementitious material such as cement mortar. Masonry structure is brittle and strength is very severe in cyclic loading and in bending. Masonry structure is prone to failure or collapse in events like seismic activity and settlements. Bonding layer between brick units is weak plane and failure occur along this layer as shown in figure below

(a) Diagonal shear cracking through mortar joints (b) Diagonal shear cracking through clay bricks

Fig 2.9 failure mode of masonry

Most of the old structures and some new small structures have unreinforced masonry structure and different techniques have been developed over the years for re-strengthening of these structure. Some of the methods are discussed below:

2.7.1 Improvement of Foundation

In most of the old masonry buildings foundation used to be only 13 inches thick instead of spread footings of today. This exerted more pressure on the soil causing bearing capacity failures. These foundations need to be enlarged for stopping further settlements.

2.7.1.1 Enlargement of foundation

Foundations can be enlarged using concrete. The connection between concrete and existing foundation is made by means of connectors. Foundation needs to be excavated till the bottom to place formwork (Appleton, 2003). The foundation may further be improved by filling gaps with mortar as shown in figure 2.10.

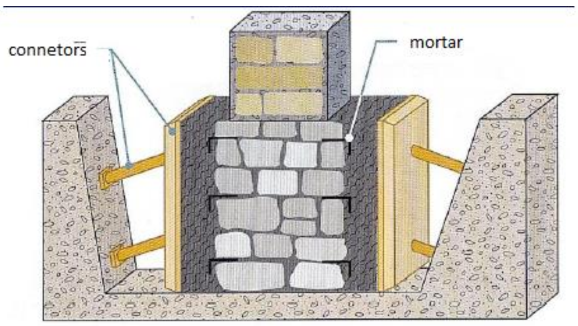
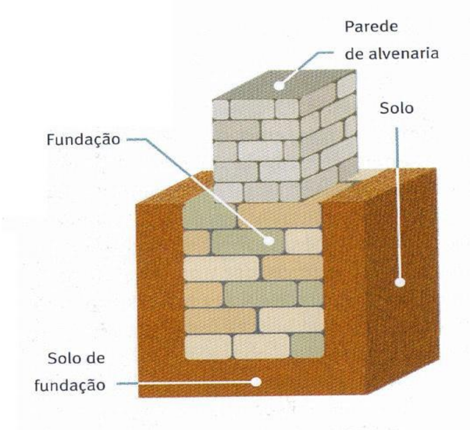


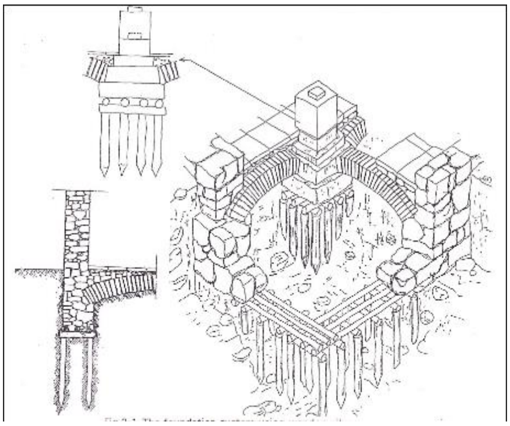
Fig 2.10 Enlargement of foundation

2.7.1.2 Strengthening of foundation using Micro piles

Micro piling is an emerging method to deal with foundation failures and settlements due to increasing load of structures resulting from modification. The micro piles transfer load from structure to deep layers of soil. Micro-piles consolidate shallower layers and mobilizes deep layers of soil (Marco de, 2013).

Micro piles are usually 8, 10 or 12 meters long. It consists of steel casing with RC heading, steel bars acting as reinforcements are also placed in some cases, the casing is filled with cement grout under high pressure and usually there is a bulb of cement at the bottom. The piles are loaded after construction (Marco de, 2013).





(a) (b)

Fig 2.11 (a) Typical foundation of old masonry structures (b) Micro Piles to improve foundation

(a) (b)

Fig 2.12 (a) Micro pile drilling machine (b) Micro pile casing

2.7.2 Strengthening of walls

Distresses generated in masonry may be due to various causes. Some of the geotechnical related causes have been discussed previously in this chapter, apart from those distress might appear due to following causes:

(a) Cracks due to deflection of slab

(b) Cracks due to thermal movements

(c) Cracks due to shrinkage

(d) Cracks due to moisture expansion

(e) Cladding failure due to moisture/Thermal movement and insufficient ties

Fig 2.13 Different causes and patterns of distresses in buildings

Complete reconstruction of whole building is a very expensive and long procedure, so in order to save time and money certain procedures have been developed for strengthening of these types of structures.

2.7.2.1 Injection of cracks

Injection of cracks with some cementitious material is a conventional process of strengthening, masonry wall distress, that is irreversible. Holes are made in walls with injection tubes and grouting material is injected into the cracks which hardens over time and work as a bonding layer. Special care should be taken while selecting grouting material, it should have good bonding characteristics with the structure being grouted (Marco de, 2013).

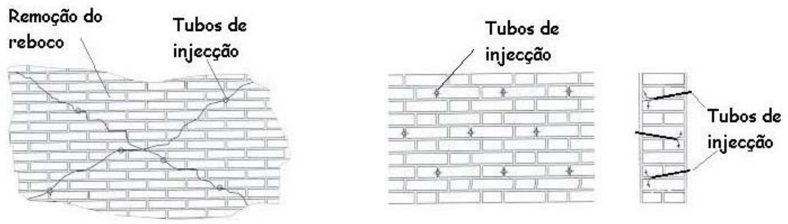


Fig. 2.14 Injection of grouting material to fill internal and external cracks

2.7.2.2 Strengthening with cement coating

In this technique layer of steel mesh is used to strengthen masonry buildings, particularly old single storey building. Steel mesh is tied to exterior or interior of walls based on the ease of accessibility and shotcrete with cement paste. This technique is particularly adopted for strengthening in active seismic zones.

A test experiment conducted on stone masonry reinforced with steel meshes and coated with cement paste and found that the strength increased 3 to 6 times of original strength in compression and shear (Appleton, 2009).

(a) (b)

Fig. 2.15 (a) steel mesh reinforcements applied on walls (b) spraying of cement grout on walls

2.7.2.3 Strengthening with propylene mesh

Propylene is a common packing material used extensively in packing availability due to its high strength and cheap availability. In this technique mesh of polypropylene straps are used in a same way as steel mesh and then cement plaster is applied over it. One of benefit is its simplicity, it is simple enough to be applied by the local contractors, Cement or mud plaster must be applied on outside to avoid damage by ultraviolet rays (Shrestha et al. 2012).

Experiments and advanced numerical modeling indicates that seismic capacity is dramatically increased by PP-mesh (P. Mayorka and K. Meguro, 2008).

Fig 2.16 Application of PP-meshing

2.7.2.4 Structural repointing

A. Using steel

In structural repointing mortar or bricks are grinded to about 2.5 inches and steel bars are placed perpendicular to the cracks at regular selected interval, at least 6 inches on the either side and joints are repointed. This stops the propagation of crack and increases strength as well as ductility of the structure.

B. Using CFRP

Strengthening of masonry with composite material like CFRP (Carbon reinforced polymer) and GFRP (Glass reinforced Polymer) is relatively new. Experiments have indicated them to be suitable materials for reinforcement as they increase the strength from 50% to 80% and can increase up to 100% depending on the binding material used. The technique is similar to steel repointing except epoxy binding material is used instead of mortar as shown in Fig 2.17.

(a) Grinding of mortar joints

(b) Masking of joints to avoid stains

(c) Injection of epoxy paste

(d) Insertion of GFRP bars

Fig 2.17 Structural repointing using GFRP bars

Experiments indicate reinforcement in horizontal and vertical direction and on opposite side of walls shows more ductile behavior as shown in Fig 2.18.

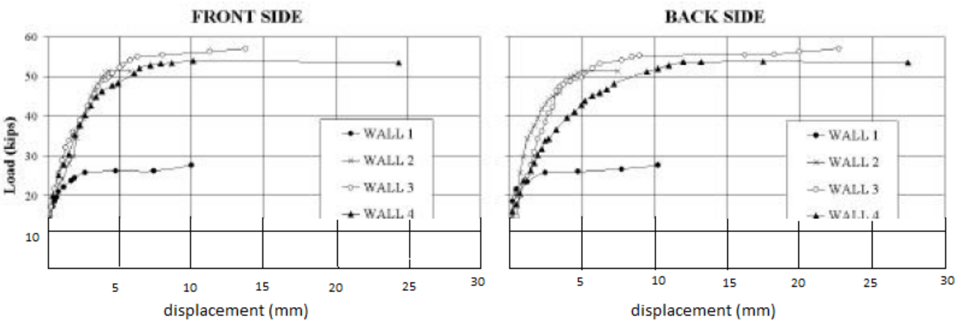


Fig 2.18 Behavior of walls to structural repointing

2.8 KNOWLEDGE GAPS

Literature review indicates various methods for strengthening of soil and structure both. The materials like basalt fiber, polyurethane foam were not available which shows excellent increase in strength of the soil. Both have indefinite life span. Literature review indicates the SPT blow counts of a soil treated with polyurethane increased from 40 to 150. While basalt fiber is a natural material its strength increases with time.

Moreover, due to non-availability of Structures labs, new methods of masonry strengthening, like reinforcement with carbon fiber, glass bars, steel strips, polypropylene strips were not tried as these methods are relatively new and testing is required to use them practically in a structure. These methods are very promising research areas as they are relatively new and research can be done once structures lab is constructed.

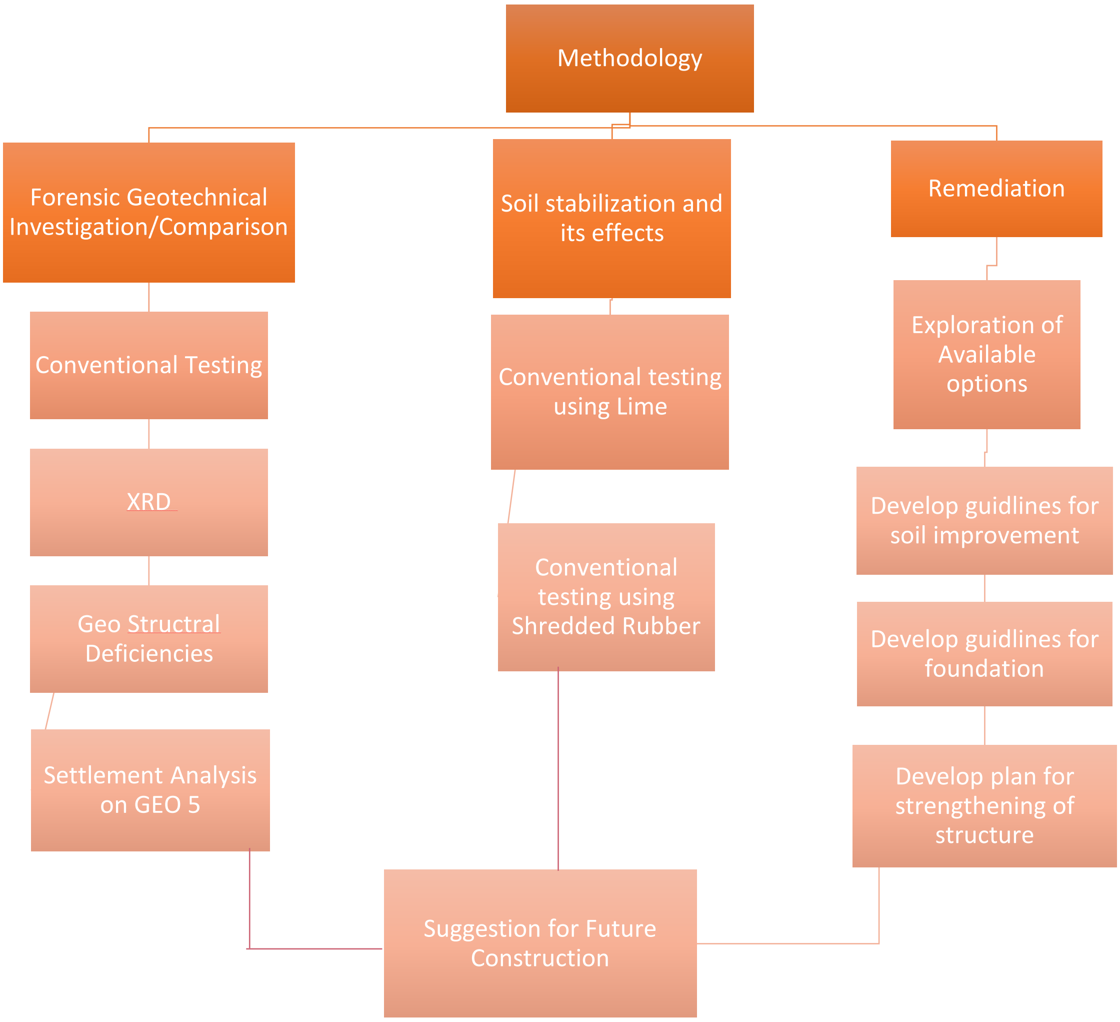
Chapter 3

METHODOLOGY

3.1. GENERAL

Methodology defines the course/path that would be followed during the research. Our methodology involves geo-forensic investigation to suggest a solution for the building under investigation. Our main research focus is to stabilize the collapse potential of soil and suggest remedial solution for the building using most economical and effective method

Table 3.1 Flow Chart for Methodology



This chapter deals with the methodology which would be followed during this research. table 3.1 illustrates the methodology adopted.

3.2. FORENSIC GEOTECHNICAL INVESTIGATION/ COMPARISON

Due to the heterogeneity of soil, geotechnical investigations need to be performed to understand the behavior of soil and suggest suitable solution.

The tests performed are performed are explained below:

3.2.1. Conventional Testing

In this type of testing sample is obtained from the test site by various means and then lab tests are performed over the sample collected. During this project, two types of samples were collected; 1. Undisturbed block sample (Fig.3.1), 2. SPT sample (Fig.3.2).

Fig. 3.1 Undisturbed Block Sample

Fig. 3.2 SPT sample collection

The tests performed on the sample collected are explained below:

3.2.1.1. Grain size distribution

Test for grain size distribution was performed according to procedure define in ASTM D2487. 300g of oven dried sample was wash graded through #200 sieve, then remaining sample was again oven dried sieve analysis was performed. Hydrometer analysis is performed on sample passing #200 sieve. This test is used to classify soil. Soil was classified according to unified classification system (UCS).

3.2.1.2. Atterberg Limits

The procedure for this test is defined in ASTM D4318. These tests are performed to determine Liquid limit, Plastic Limit and Plasticity index of soil.

3.2.1.3. Moisture Content Determination

Procedure for this test is defined in ASTM D 2216-80. We placed the wet samples in oven for 24hrs at 110ºC temperature. Wet and dry weight were calculated and moisture content was obtained by using following formula.

M.C = weight of water/weight of dry mass

3.2.1.3. Moisture Density relationship:

Procedure for this test is defined in ASTM D1557-02. Modified Proctor test was used, with 10lb hammer and 18 inches drop. Soil was compacted in five layers with 25 blows each layer to obtain the relationship.

3.2.1.6. Specific Gravity

Procedure for this test is defined in ASTM D 2216-80. Specific gravity of soil is specific soil parameter that is used for evaluation of degree of saturation. It is ratio of weight of given volume of material to weight of equal volume of water.

3.3. XRD testing

XRD stands for X-Ray Diffraction; this test is used for determining the minerology of the sample. For the purpose of X-Ray diffraction analysis, 5gms of sample is pressed in sample holder and put into XRD system. The Geoscience lab at Quaid-e-Azam University has fully automated XRD system (RIGAKU GEIGER FLEX – ME 20 / PAS) with computer control of diffractometer, digital data collection and computerized search – match facilities which can scan the whole XRD database over 3500 phases.

3.4. TESTING FOR DETERMINATION OF EFFECTIVENESS OF REMEDIAL MEASURES

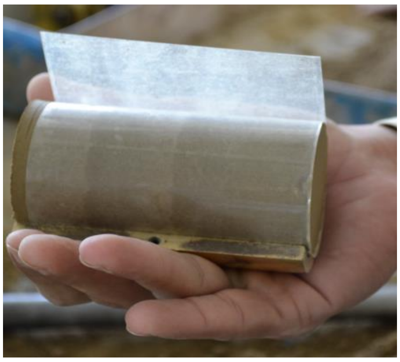
Due to the collapse potential of the soil it needs to be stabilized for durability of structures built on it. Risalpur soil is collapsible up to 20 feet, while collapse potential is severe at 4 feet depth, typical depth of shallow foundation (Abdul Qudoos, 2012). For structures to be durable, soil needs to be stabilized. Soil stabilization was attempted using Lime and rubber, Polyurethane foam was not tested because of non-availability of specialized pump.

3.4.1. Stabilization using Lime

For determination of effectiveness of this method samples were fabricated according to ASTM D 5102-96. This testing procedure requires test sample should have height to diameter ratio of 2:1. A mould having 4 inches height and 2 inches was used. The compaction effort was calculated on the basis of energy delivered per unit volume of soil during modified compaction procedure. The hammer used for compaction had a weight of 2.47 lbs and the drop height was 12” Specimen was prepared by compacting in 3 layers using 12 blows per layer. The samples were then allowed to cure for 2 days and 7 days. The mould and curing process is shown below:

(a) Mould

(b)



(c)

(d)

Fig 3.6 Mould and Sample preparation

3.4.2. Stabilization using Rubber

Rubber is a lightweight material and literature review indicate that it can be used for soil stabilization. Procedure adopted was same as Lime stabilization, with rubber content from 0.5%, 1% up to 2.5%, to determine the most effective percentage. Curing was not required for rubber as no chemical reaction was involved.

Fig 3.7 Rubber used for Stabilization

3.4.3. Unconfined Compression Strength (UCS) Test

Procedure for this test is defined in ASTM D5102-96. Two samples of same lime/ rubber content prepared according to the procedure discussed earlier were tested and their average strength was determined and it was compared with the virgin soil sample prepared by following same procedure. Lime Sample cured for 7 days was tested separately after 7 days.

Chapter 4

SITE CHARACTERIZATION

4.1 GENERAL

Soil is a heterogenous material and its composition and properties differ with location. Considering this fact, it is important to perform test and characterize soil prior to analyzing it and suggesting remedial options. Site characterization is broadly defined as the defining of existing soil properties and conditions at a given site (Coduto 1999).

Site characterization is done in order to find the causes that triggered failure of soil on which construction was done. Characterization of a site helps to focus on improvement of design and construction procedures. It provides the important information and data required for the identification of site problem and hazards. All tasks performed for site characterization are shown in flow chart (Fig 4.1).

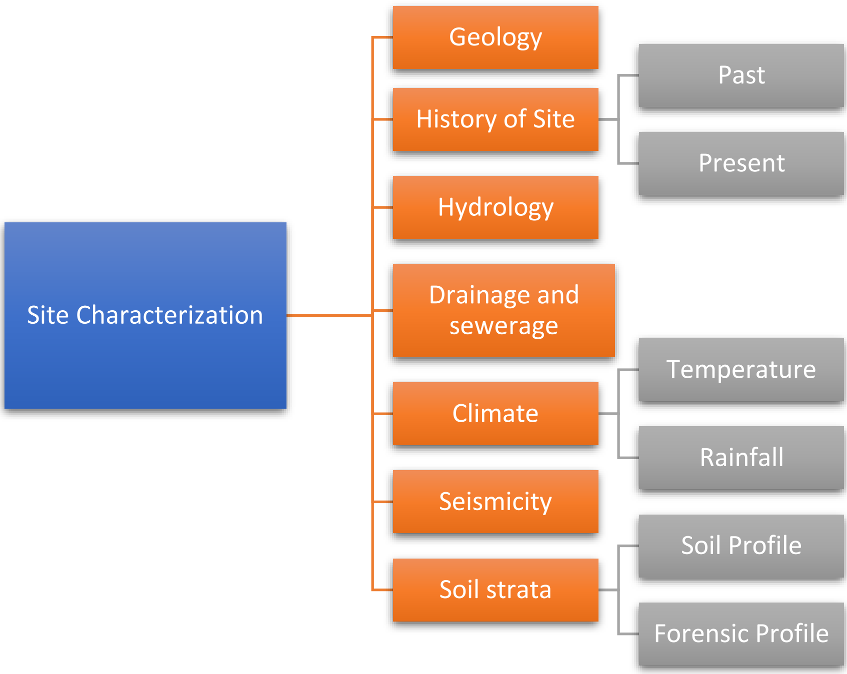


Fig 4.1 Flow chart for site characterization

4.2 GEOLOGICAL CONDITION OF TEST SITE

Risalpur is a city in Nowshera district of Khyber Pakhtunkhwa, Pakistan. It is bounded on south and west by Kabul and Kalpani rivers respectively. The soil composition and environmental conditions favors formulation of collapsible soil deposits. Fig. 4.2 indicates position of Risalpur on generalized geological map of Pakistan.

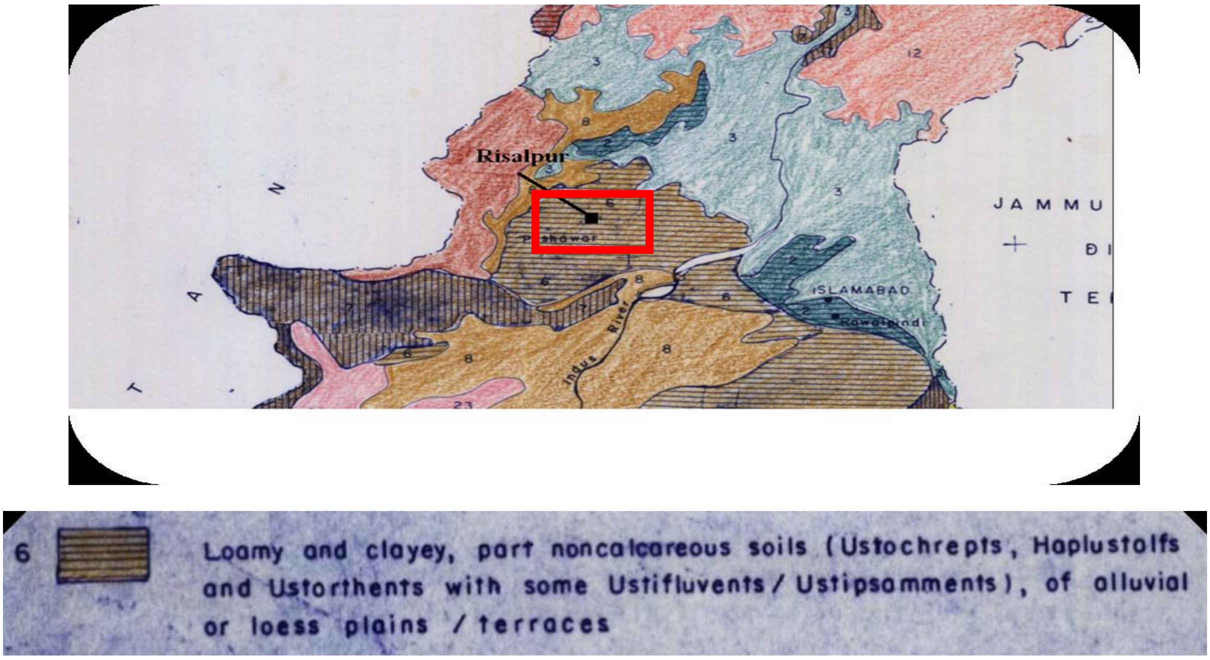


Fig. 4.2 Geological classification of Risalpur.

4.3 HISTORY OF SITE

4.3.1 Past condition at site

Geology and past researches classifies Risalpur soil to be collapsible, it also indicates the presence of a river nearby our site in past. A consolidation test was performed on the soil near most damaged part of house. From the consolidation test a pressure of 100kpa was obtained, which verifies presence of a river. Later after further research it was found that it was river Kabul. This 100kpa load can also be defined as 'Maximum effective vertical stress that soil has ever experienced.

4.3.2 Present condition at site

Since the river Kabul changed its path so the soil has become over consolidated. River Kabul changed its direction to south of Risalpur. The house is a single storey building and has a lawn at front side as well as at the back. Investigations indicate strata is silty and clayey. The stratum has a plastic nature and is naturally weak. The water table in this region is also quite low. Swelling and shrinkage of soil is high which is probable cause of crack in walls. This house and many other houses of same design were built in 1980s for accommodation of officers. The cracks in the walls appeared mainly due to poor maintenance as other houses built on same designs do not have problem as severe as house under investigation.

4.4 HYDROLOGY

From the research we came to know that river Kabul used to cross this path and it brought a lot of silt and sand which were deposited here. Now the river Kabul has changed its direction and now lies to the south of Risalpur.

4.5 DRAINAGE AND SEWERAGE

The underground drainage system of most of the house was found to be well built but no proper drainage system for overflow of over-head water tank and surface drainage was provided and resident told us that this water used to seep directly in to the foundations before concrete apron in fig 4.3 was laid. Sewerage system was also well built, sewerage pipes and tanks were at a distance of 4 to 5 feet.

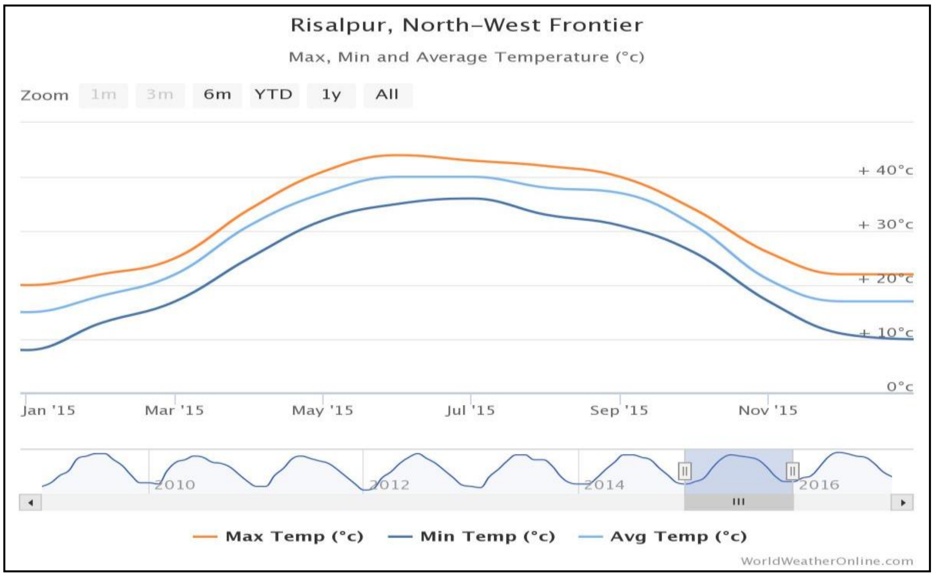
Fig. 4.3 Drainage of overflow water

4.6 ATMOSPHERIC CONDITION

Risalpur is influenced by local steppe climate. This climate is considered to be BSh (hot to semi-arid climate) according to Koppen-Geiger.

4.6.1 Temperature

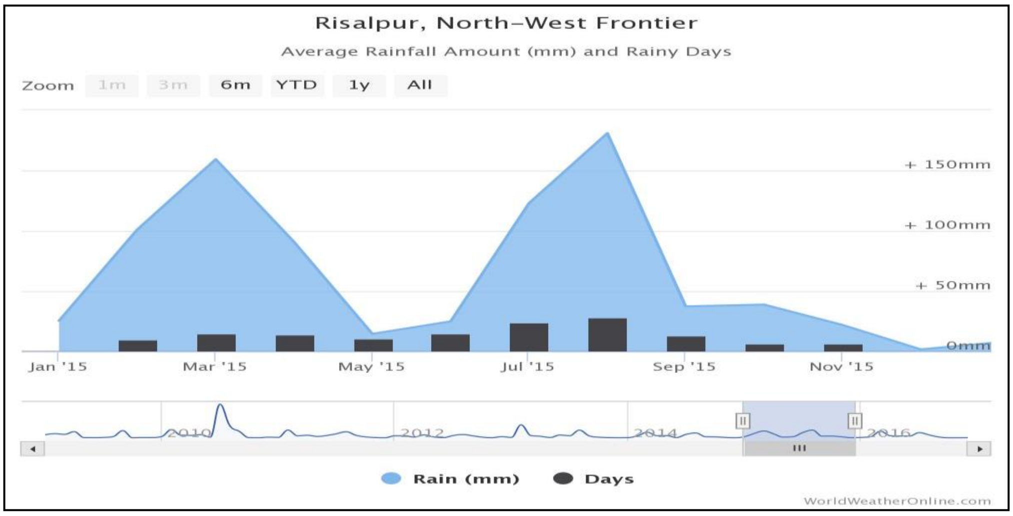
Most of the year Risalpur weather is dry. Winter season begins from mid of November to march; May to September are the summer months. The maximum temperature of Risalpur is up to 45°C. The minimum temperature in winter season is up to 1°C. spring starts in the mid of March. The average annual temperature of Risalpur is 22.5°C. High temperature causes the soil to loss moisture and it becomes hard, increasing strength of soil.



Graph 4.1: 2015 Temperature Graph of Risalpur

4.6.2 Rainfall

In Risalpur, there is little rainfall throughout the year. Precipitation process starts in winter and late springs. The winter rainfall is due to western winds and it shows higher record during July and September. The most precipitation is recorded in August. The driest month is October, with 13mm of rainfall. The rainfall results in increase in moisture, which percolates between soil particles decreasing interparticle friction and increasing collapse potential. Proper drainage is required to drain this water as soon as possible.



Graph 4.2: 2015 rainfall data of Risalpur

4.7 SEISMICITY

Pakistan is located in one of the most seismically active regions on earth. As per the Seismic Zoning Map of Pakistan, Project site lies in zone 2B, having moderate seismic risk, with Peak

Ground Acceleration of 0.16g to 0.24g having no fault lines at all. All the buildings in Nowshera and its vicinity should be designed to resist above mentioned accelerations. The Map and Table below shows the zoning of KPK according to building code of Pakistan 2007.

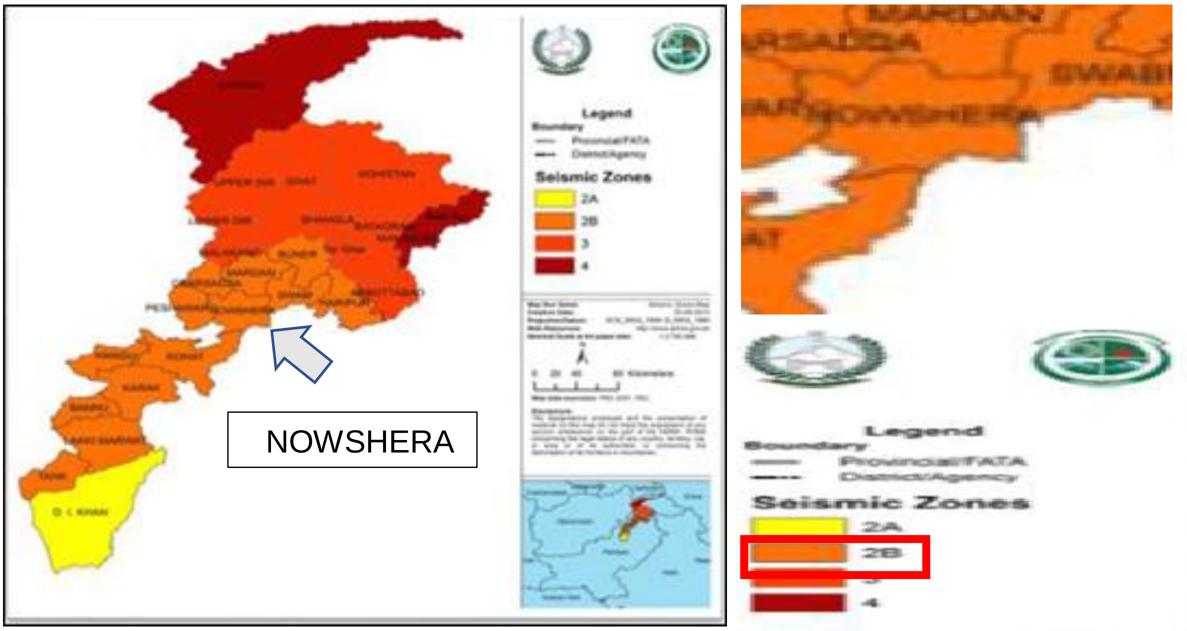


Fig 4.4 Zoning map of KPK

Table 4.1: Seismic table of KPK

Tehsil	Seismic Zone	Tehsil	Seismic Zone	Tehsil	Seismic Zone
NWFP					
Chitral	4	Swabi	2B	**Kurram**	
Drosh	3	Lahore	2B	Lower **Kurram**	2B
Lutkoh	3	**Charsadda**	2B	Upper Kurram	2B
Mastuj	3	Tangi	3	Kurram F.R.	2B
Turkoh	3	**Peshawar**	2B	**Orakzai**	
Mulkoh	3	**Nowshera**	2B	Central **Orakzai**	2B
Dir	3	**Kohat**	2B	Lower Orkzai	2B
Barawal	3	Lachi	2B	Upper Orkzai	2B
Kohistan	3	**Hangu**	2B	Ismailzai	2B
Wari	3	**Karak**	2B	**South Waziristan**	
Khall	3	Banda Daud Shah	2B	Ladha	2B
Temergara	3	Takht-E-Nasrati	2B	Makin (Charlai)	2B
Balambat	3	**Bannu**	2B	Sararogha	2B
Lalqila	3	**Lakki Marwat**	2B	Sarwekai	2B
Adenzai	3	**Dera Ismail Khan**	2A	Tiarza	2B
Munda	3	Daraban	3	Wana	2B
Samarbagh (Barwa)	3	Paharpur	2B	Toi Khullah	2B
Swat		Kulachi	2B	Birmal	2B
Matta	3	**Tank**	2B	**North Waziristan**	
Shangla/Alpuri	3	**Bajaur**		Datta Khel	2B
Besham	3	Barang	3	Dossali	2B
Chakesar	3	Charmang	3	Garyum	2B
Martung	3	Khar Bajaur	3	Ghulam Khan	2B
Puran	2B	Mamund	3	Mir Ali	2B
Buner/Daggar	2B	Salarzai	3	Miran Shah	2B
Malakand/Swat Ranizai	3	Utmankhel (Qzafi)	3	Razmak	2B

The major earthquake occurred in October 2005 having magnitude 7.4, and then again in 2015 having magnitude 8.1. The earthquake might be the triggering factor of these distresses but no proper analysis and data collection was performed.

4.8 SOIL STRATA

Exploration was done by Standard Penetration Test (SPT) which shows that strata includes only cohesive soils. Two boreholes of 45 and 30 feet were used, their location is shown in fig. 4.5

Fig 4.5 Borehole location

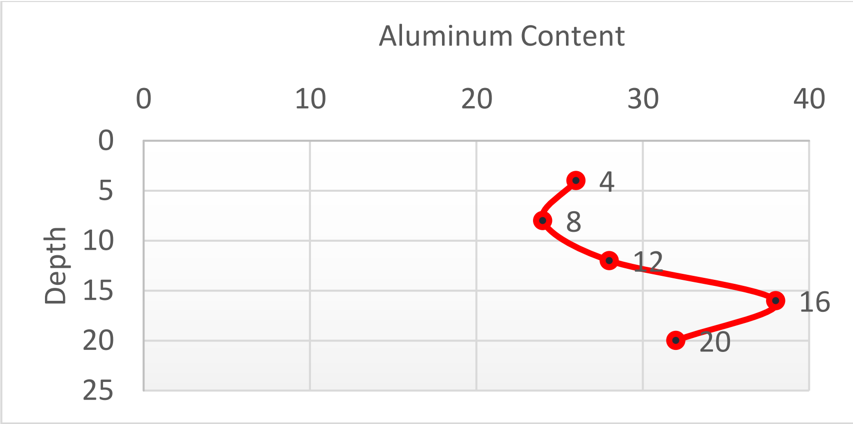
4.8.1 Soil profile

The soil profile of the site was prepared using the data collected from the bore holes and the using the SPT correlation graphs. The data for each five feet interval has been collected and used for making of soil profile. The SPT value used is the average SPT blow count value at the specified height. The soil profile will give the overview of the soil strength parameters at the site at different depths below the ground. The bore-log is attached at the end of this chapter.

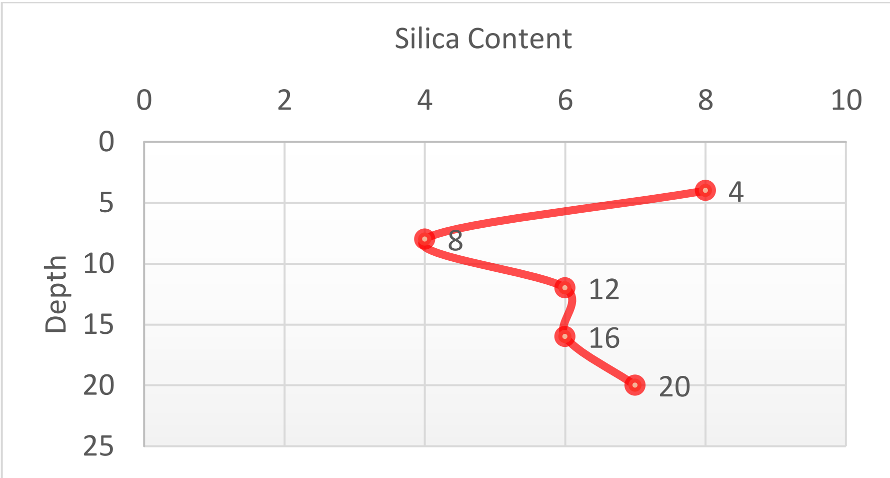
4.8.2 Forensic Profile

Forensic investigation using XRD performed at Quaid-e-Azam University are summarized below in graph 4.3 and 4.4.

The graphs indicate soil is low in silica and alumina which are major component of Calcium Silicate Hydrate (CSH) and Calcium Aluminate Hydrate (CAH) which are major cementitious agents in soil. Due to their low concentration soil has low strength.



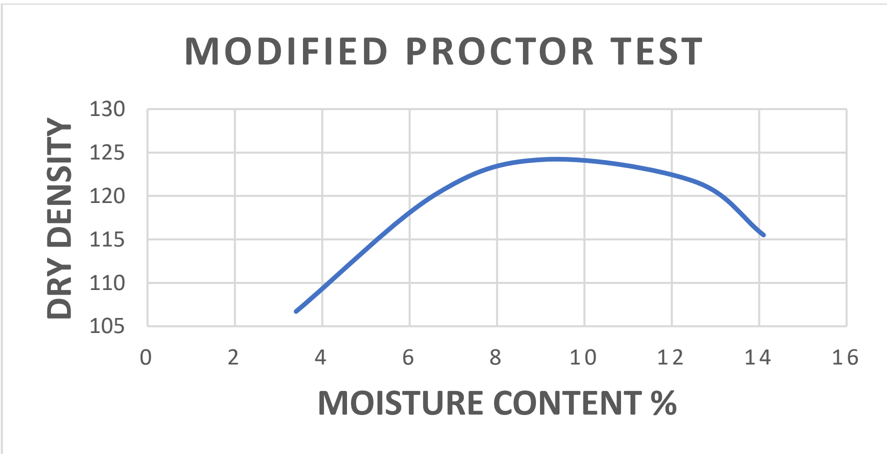
Graph 4.3 Aluminum content variation with depth



Graph 4.4 Silica content variation with depth

4.8.3 Maximum Dry Density

To determine the maximum dry density of the soil under investigation Modified Proctor Test was used. According to this test the maximum dry density of soil is 124 pcf. Results are shown in Graph 4.1 below.



Graph 4.5 Modified Proctor Test

4.9 DISTRESS MAPPING:

The distress mapping was done to determine if the house can be retrofitted effectively without dismantling walls and roof slabs. According to the EMS-98, European Micro seismic scale, our building is currently in Grade 2 and it is approaching Grade 3. Grades are defined in table below in Fig 4.6. The table 4.2 was used as reference which classifies crack severity according to the width of the crack.

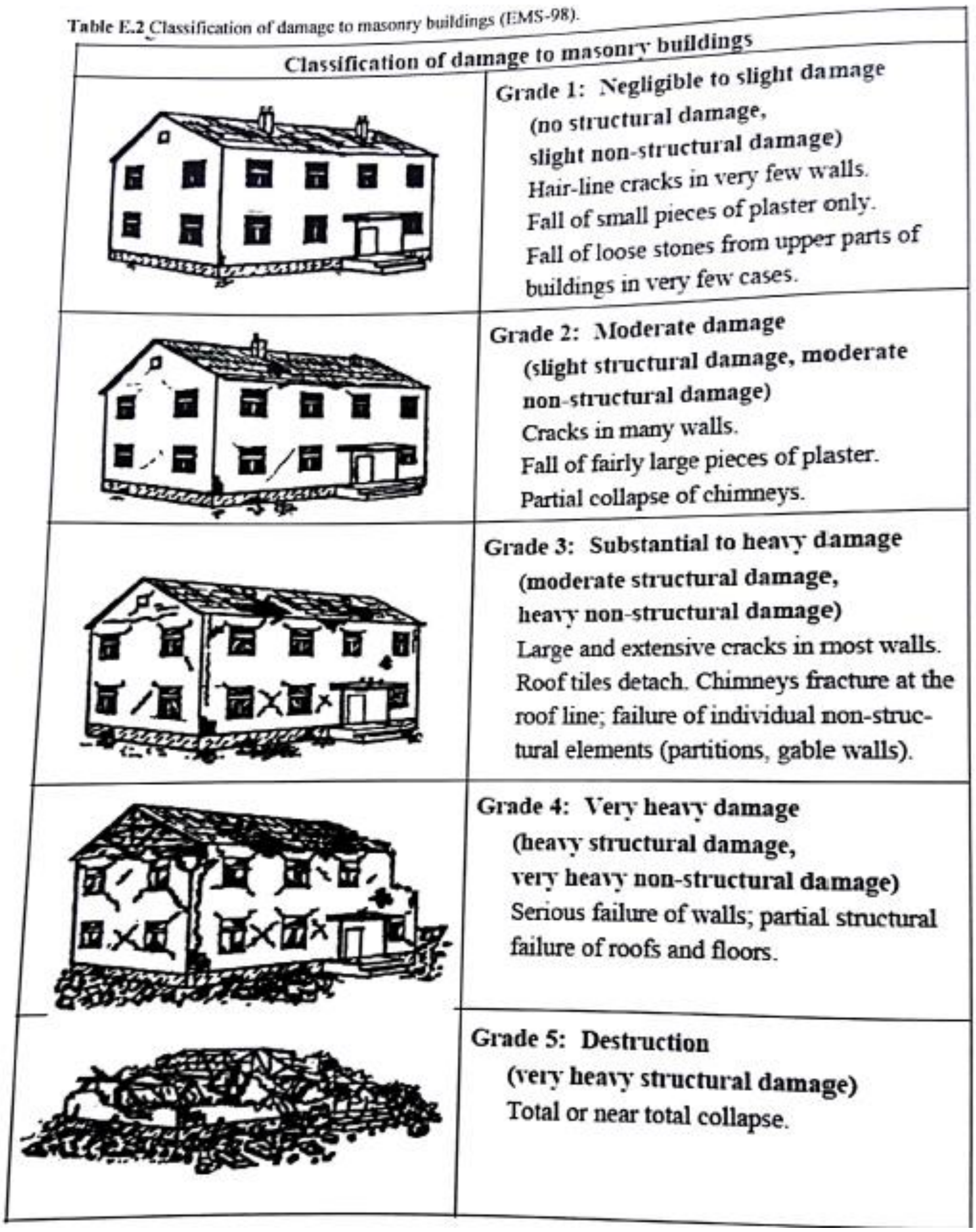


Table E.2 Classification of damage to masonry buildings (EMS-98).

Classification of damage to masonry buildings	
	Grade 1: Negligible to slight damage (no structural damage, slight non-structural damage) Hair-line cracks in very few walls. Fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few cases.
	Grade 2: Moderate damage (slight structural damage, moderate non-structural damage) Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys.
	Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage) Large and extensive cracks in most walls. Roof tiles detach. Chimneys fracture at the roof line; failure of individual non-structural elements (partitions, gable walls).
	Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage) Serious failure of walls; partial structural failure of roofs and floors.
	Grade 5: Destruction (very heavy structural damage) Total or near total collapse.

Fig 4.6 Grades to damage according to EMS-98

Table 4.2 Severity of damage relative to crack width

Table 2-4 Cracking width and the associated damage and serviceability/safety issues for residential, commercial, and industrial buildings (modified after Thorburn 1985)

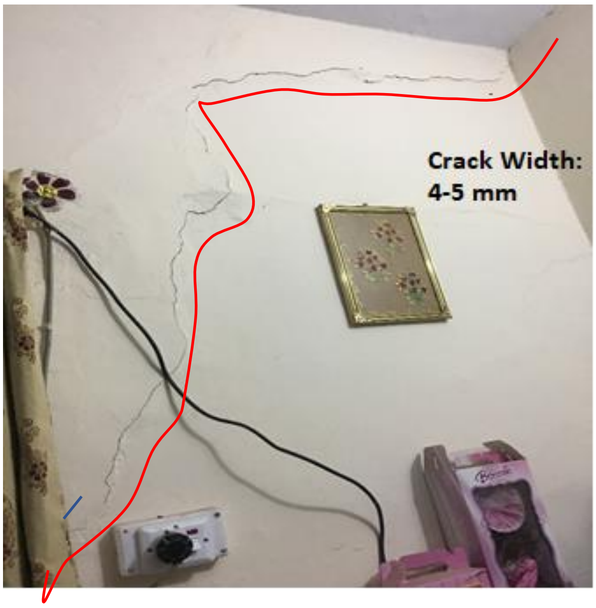
Crack width (mm)	Degree of damage: Residential	Commercial	Industrial	Serviceability or safety issues
<0.1	None	None	None	None
0.1–1	Slight	Slight	Very slight	Cracks may be visible
1–2	Slight to moderate	Slight to moderate	Very slight	Possible penetration of humidity
2–3	Moderate	Moderate	Slight	Serviceability may be compromised
3–15	Moderate to severe	Moderate to severe	Moderate	Ultimate limit states may be reached
>15	Severe to dangerous	Moderate to dangerous	Severe to dangerous	Risk of collapse

Very slight: visible on close inspection; correctable with interior design/decoration tools.
Slight: external cracks may need to be filled for watertightness; doors and windows may jam slightly.
Moderate: replacement of small amount of brickwork needed; service pipes may be severed; jamming doors/windows.
Severe: replacement of portions of walls needed; window/door frames distorted; uneven floors; service pipes severed; leaning or bulging walls.
Dangerous: beams lose bearing; walls require shoring; windows broken by distortion; danger of instability.

4.9.1 Severely Damaged Areas

According to the table 4.2 cracks having width from 3 to >15 mm is characterized as Severe cracks. These walls in which these cracks appear need to be rebuilt. Following images show severe cracks.

(a) Bedroom 2 exterior wall



(b) Bedroom 2 interior wall

(c) Bathroom attached to Bedroom 2

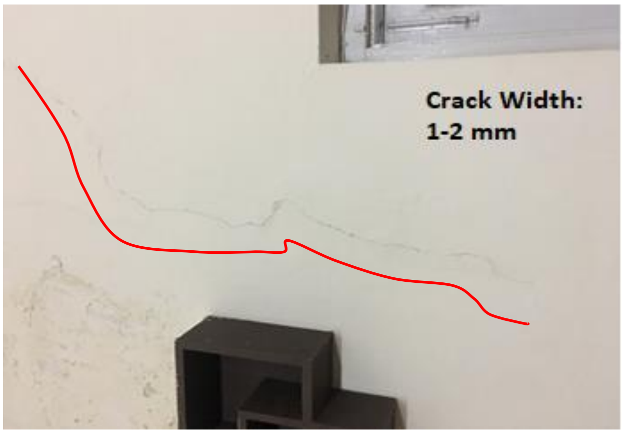
(d) Exterior wall of Bathroom

(e) Settlement in floor of Bedroom 2

Fig 4.7 Severely damaged areas of the house

4.9.2 Slight to Moderately damaged areas

Areas having crack width from 0.1 to 3 mm are characterized as slightly to moderately damaged by table 4.2. These areas can be strengthened without dismantling the walls. Slight to Moderately damaged areas are shown below in Fig 4.8 and Fig 4.9 respectively.



(a) Bedroom 1 interior wall

(b) Drawing Room wall

Fig. 4.8 Slightly damaged areas of the House

(a) Kitchen wall

(b) Store room attached to Bedroom 2

Fig 4.9 Moderately damaged areas of the house

Fig 4.10 Seepage in walls

Apart from these cracks there were no other significant cracks in the house. Some small cracks were visible in the plaster which were due to seepage from ground in the walls and seepage of water from roof slab. Some areas are shown in Fig 4.10.

Chapter 5

Settlement Analysis

5.1 GENERAL

Settlement was observed in candidate site which has resulted into damage of structure due to which excessive cracks are generated in the building and they are progressively increasing. For the application of remedial measures settlement analysis needs to be carried out. Differential settlement was computed using the software GEO 5 for the north and east direction of the building

Settlement report consist of following major topics:

- Procedure for the settlement analysis in GEO 5 software
- Settlement display of both sides of building in GEO 5 software
- Final numerical results

5.2 Procedure for settlement analysis in GEO 5 software

FEM module in GEO 5 software was used to calculate the settlement. It is a staged module on which analysis can be carried out with changing conditions including

- Water table variations
- Loading variations
- Physical profile variations

Stage wise procedure of working with FEM is detailed below

STAGE 1- TOPOGRAPHY

- Project description (Task, Author)
- Project parameters (project type, analysis type, design standards, analysis method)
- Interface (draw geotechnical profile of site)
- Soils (input soil type and properties)
- Assign (Assign soil type to soil layers)
- Mesh generation

STAGE 2- SETTLEMENT WITHOUT LOADING

- Activity (Applying boundary conditions)
- Assign water table
- Monitor (specify point on which results are needed)

- Perform analysis

STAGE 3- SETTLEMENT WITH LOADING

- Apply surcharge
- Perform analysis
- Get results

5.3 Settlement display of the two sides of building

Bore hole location that are under consideration are shown in the plan view of the building in figure 5.1.

The settlement was observed through visual inspection on top side and right side so, settlement was computed along these two sides.

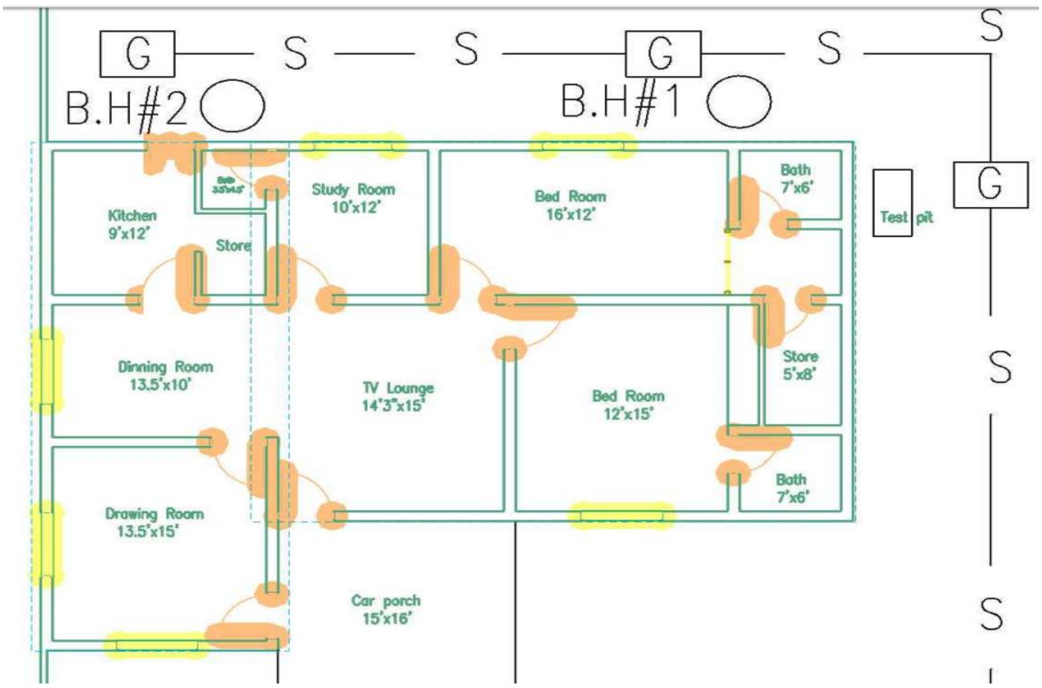


Fig 5.1 Location of boreholes

5.4 Project parameters

Table 5.1 Project parameters

Project type	Plain strain
Analysis type	Stress
Analysis method	Geostatic stress

5.5 Settlement analysis

Direction: North (Back side of the building)

Maximum settlement (mm)	55

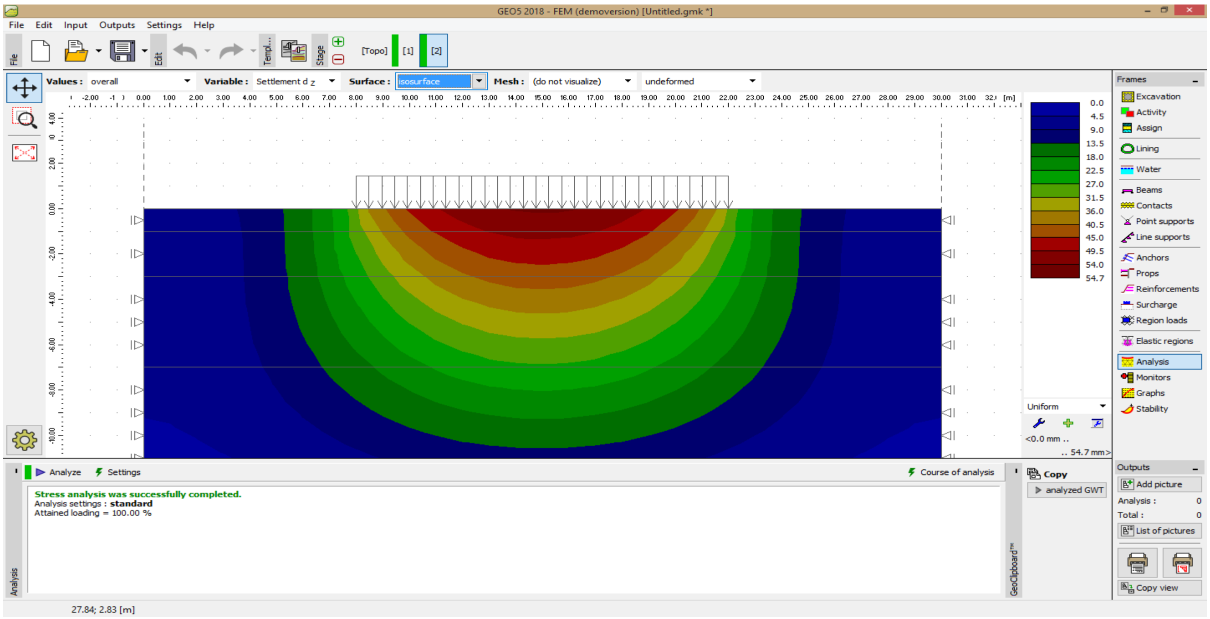


Fig 5.2 Isosurface view of settlement (North side)

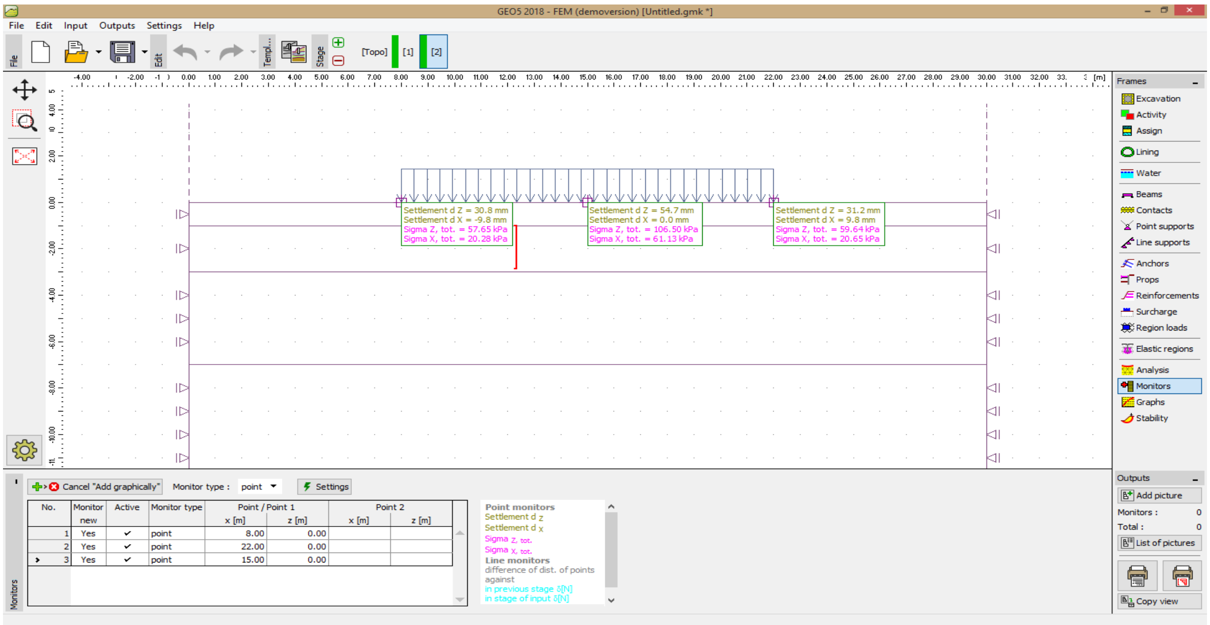


Fig 5.3 Settlement at various points

Direction: East (Right side of the building)

Maximum settlement (mm)	48.5

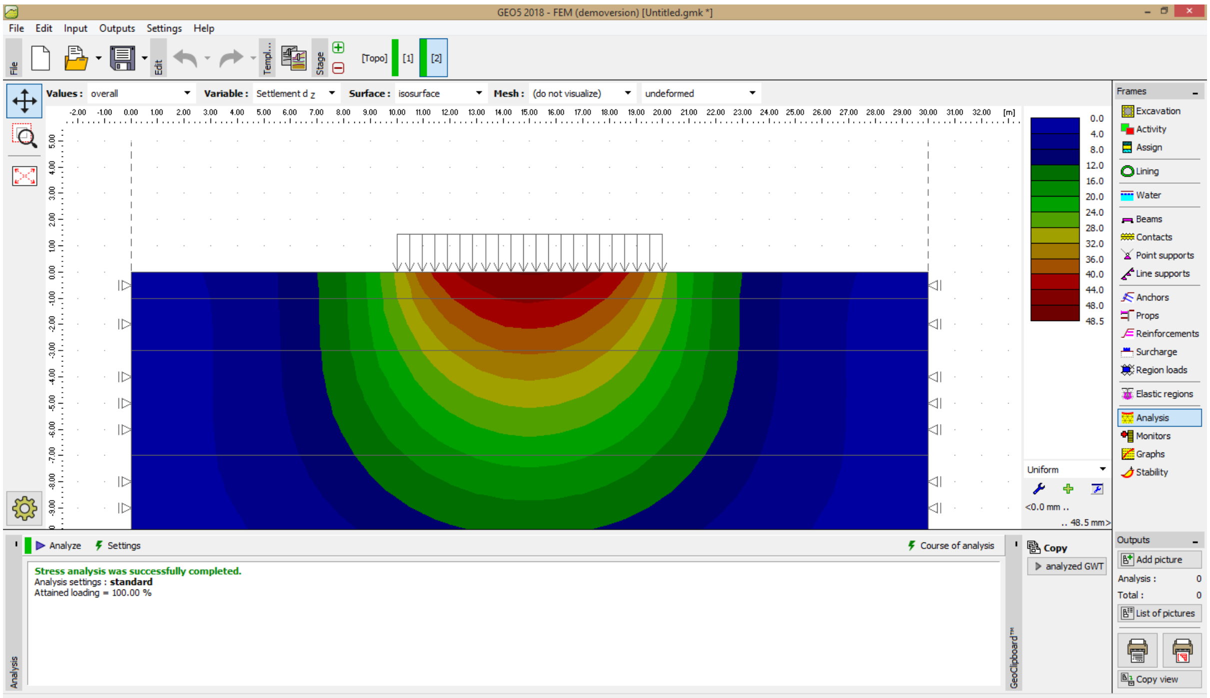


Fig 5.4 Isosurface view of settlement (East side)

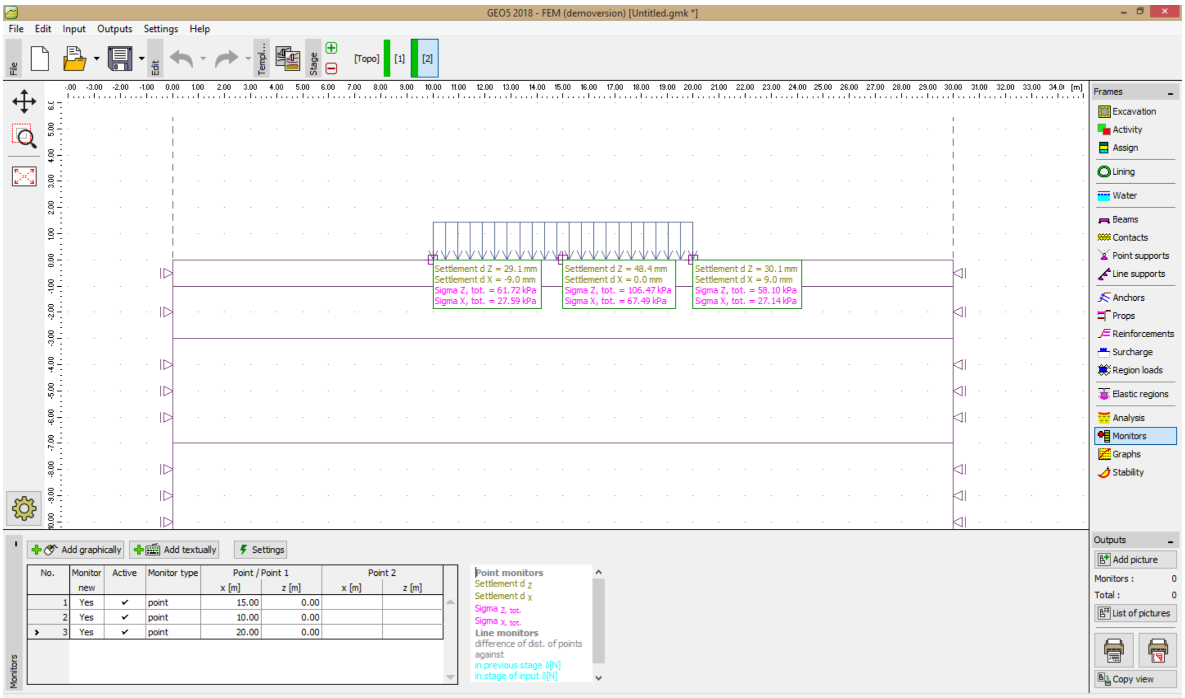
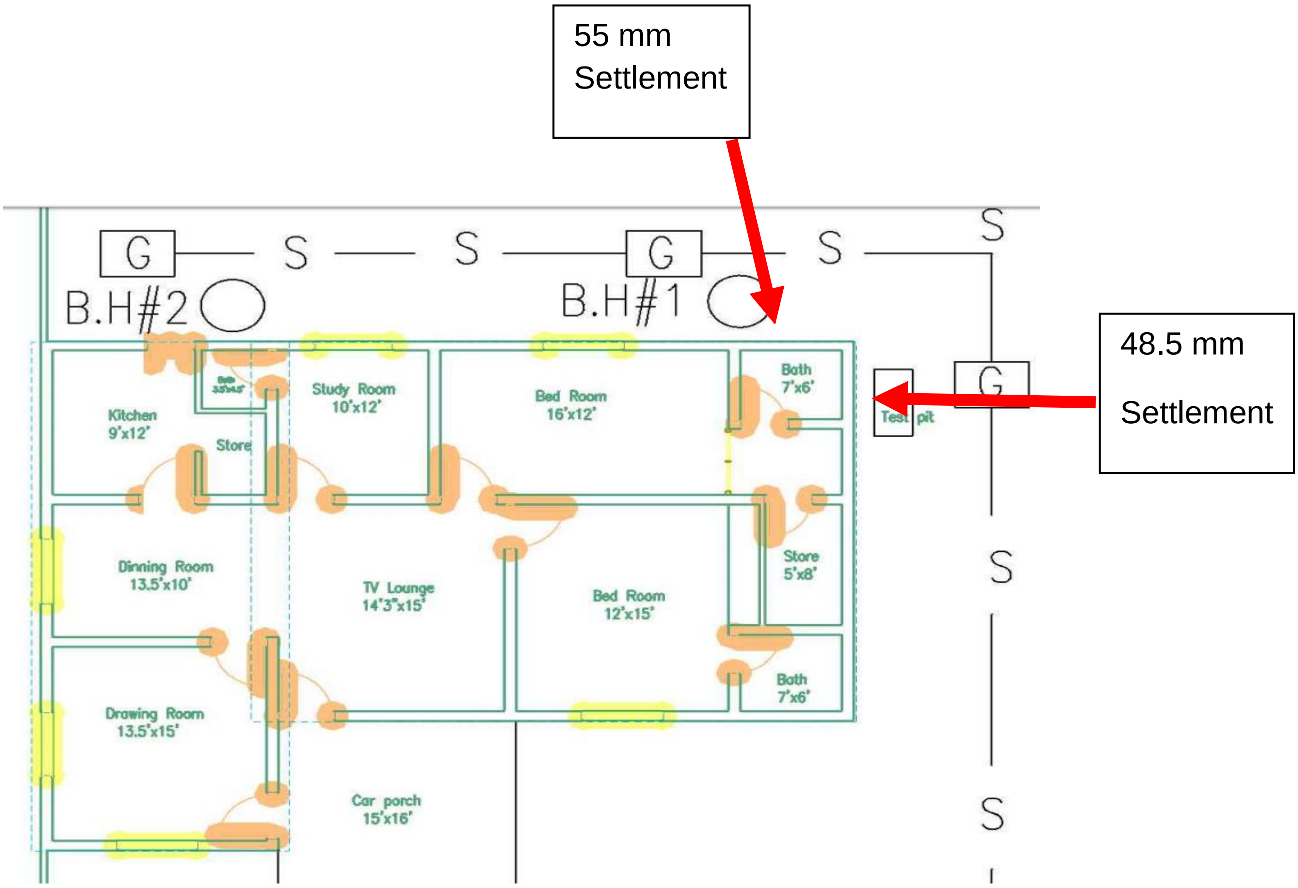


Fig 5.5 Settlement at various points

5.6 SETTLEMENT RESULTS

Maximum settlement recorded using software Geo 5 came out to be 55mm on the north wall of the building, while on the east side the settlement was recorded 48.5mm. During investigation maximum settlement of 25 mm was recorded on field. This indicates that sites have further tendency of settlement if remedial measures are not taken in time.



Chapter 6

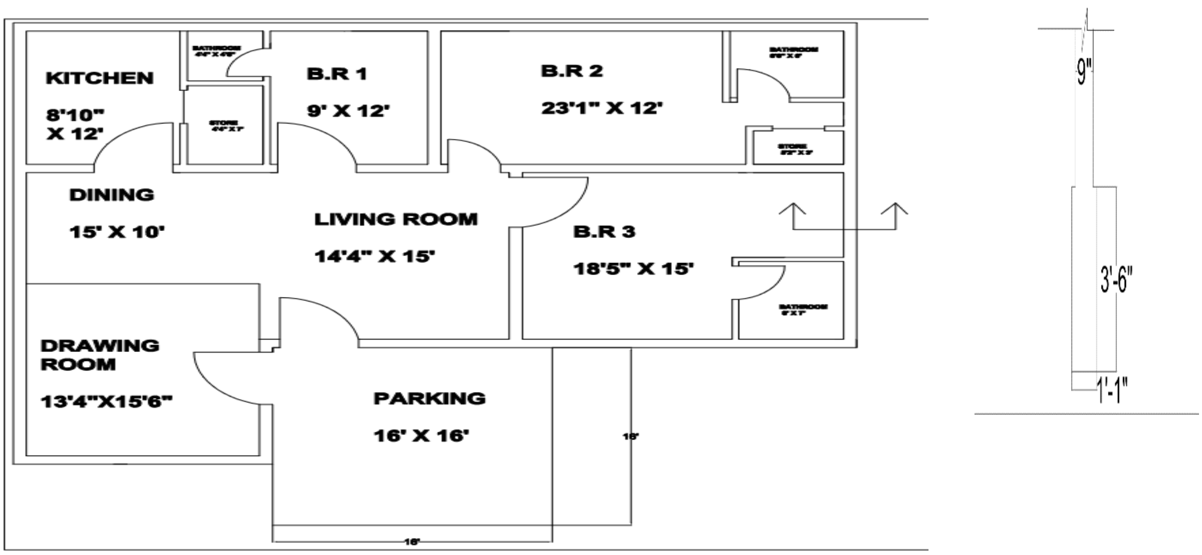
RESULTS AND DISCUSSIONS

6.1 GENERAL

Collapsible soil of Risalpur poses threats to many structures in Risalpur. Most of todays-built structures in Risalpur are designed keeping in view this problem, but most of the buildings in Rislapur Garrison built in 1980s and 1990s when little was known about the soil collapse potential. Our test house was study one amongst many other houses built on same design, so a detailed retrofit plan is needed to save millions of rupees of government.

6.2 REVIEW OF ORIGINAL DESIGN:

The plan of 120/2 and houses constructed on similar design was not available with MES so complete plan was resketched by taking measurements. The foundation plan was also not available with the MES so a test pit near the foundation was dug to determine the condition and width of foundation. The foundation was found to be 13 inches.



(a) (b)

Fig 6.1 (a) Plan view of test house (b) Foundation width

6.4 Foundation and Stability Analysis

The stability analysis of the foundation was done using unfactored load on the roof slab and then adding this load to the load of the walls. The average load on walls was 0.48 k/ft while the maximum load was 1k/ft (including the load of the over-head water tank, assuming it to be fully filled), adding wall load we got 1.78k/ft and 2.38 k/ft (load distribution of slab is shown in fig 6.2 below while load calculation is attached in Annex A). Bearing capacity was calculated to be 0.84 tsf based on SPT blow counts. Using avg. load, the foundation width required was calculated to be 12 inches but this was not sufficient for critical section i.e. section with maximum load. The foundation width with factor of safety 1.5 was found to be 24 inches (shown in Fig 6.3).

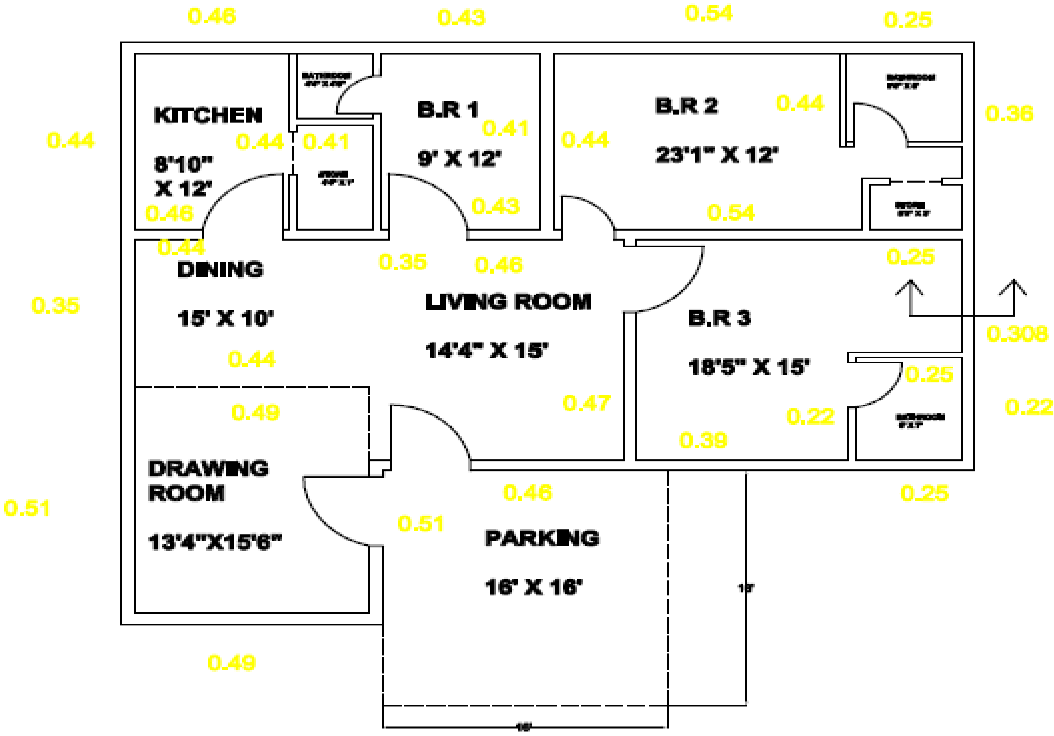


Fig 6.2 Load Distribution of slab on walls

Thus, the structural analysis indicates that the foundation provided in the critical section of the house was not sufficient. Moreover, the poor maintenance and seepage of overflow water from over-head tank triggered the settlement of the critical section.

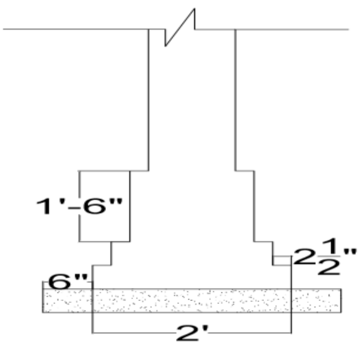


Fig 6.3 proposed Foundation.

6.5 Soil Stabilization

The previous findings of Dr. Abdul Qadoos and his syndicate in 2012 indicated that the soil of Risalpur is collapsible in nature with collapse potential maximum at 4 feet while collapse potential reduces with depth. Table 6.2 below shows findings of his research.

Table 6.2 Collapse potential of Risalpur soil with depth

Depth (feet)	Degree of Collapse
4	Severe
8	Moderately Severe
12	Moderate
16	Moderate
20	Moderately severe

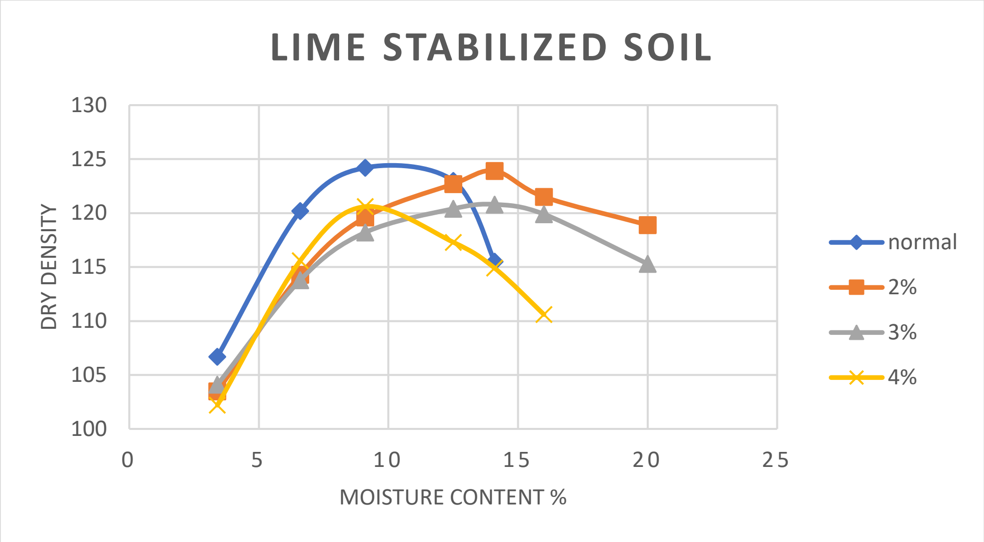
It can be seen that the collapse potential is severe till 4 feet which is the typical depth of foundation of Residential and other small structures. This arises the need for the treatment of soil prior to construction. Many methods have been developed for soil stabilization over the years but many could not be applied due to non-availability of materials or high pricing. Following cheap methods were used to stabilize the soil test samples.

6.5.1 Lime stabilization

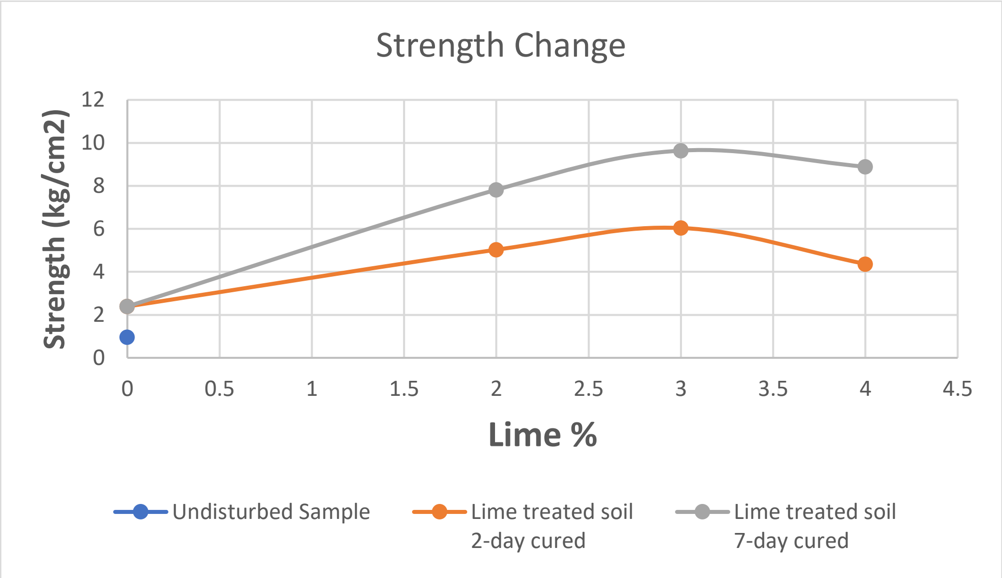
It is one of the oldest method of stabilization of soil. To determine the most effective percentage of lime to stabilize soil, the lime content was fixed and moisture content was increased. The test was then again repeated with changing lime content.

The samples prepare according to the methodology mentioned previously were then used for performing Unconfined compression test to determine at what percentage the maximum strength is achieved. The maximum strength of 1.34 kg/cm^2 was achieved at 3% lime content.

As mentioned earlier two samples of each lime content were cured for 2 days while two were cured for 7 days. The sample cured for 7 days at room temperature showed more strength. The strength was found to be 9.64 kg/cm^2 while after soaking it for 24 hours the strength reduced to 4.28 kg/cm^2. Graph 6.2 shows greater the curing period greater would be the strength increase.



Graph 6.1 Effect of Lime Stabilization



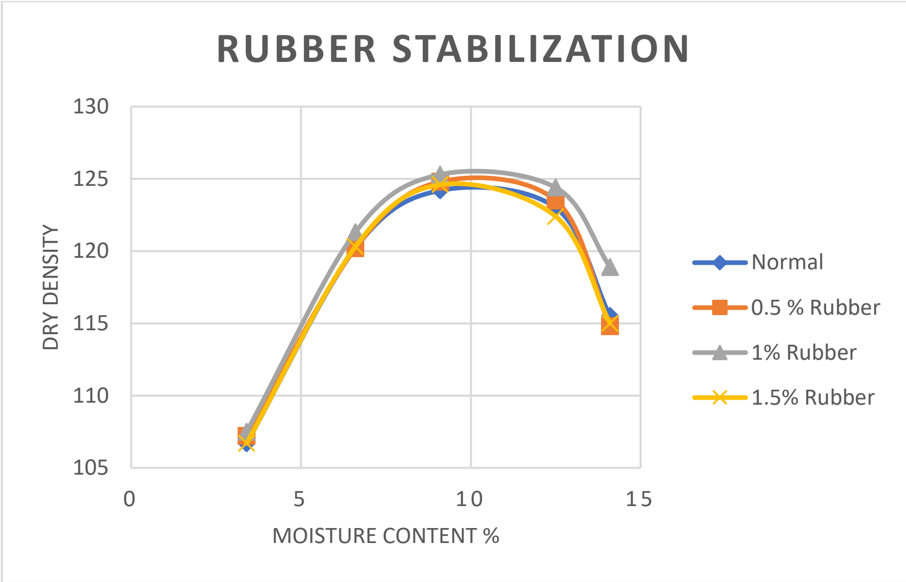
Graph 6.2 Variation of strength with lime content

Conclusion:

From the above test results, it can be concluded that using 3% lime content for stabilization is the most effective for Risalpur Soil.

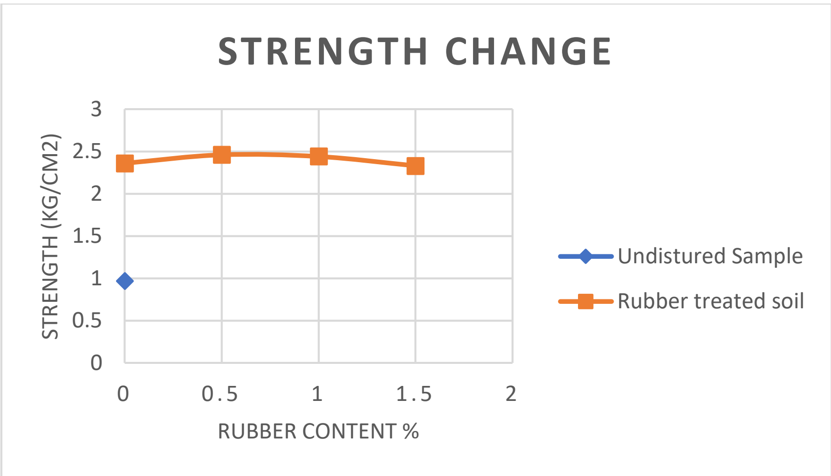
6.5.2 Rubber Stabilization

Rubber Stabilization is relatively newer technique, this method is extensively used in embankment construction due to its light weight and easy availability. Small percentages of rubber can increase the strength properties of soil while if its content is increased the lighter rubber particles replaces soil particles, the cohesion between rubber and soil particles is also negligible so the strength decreases.



Graph 6.3 Effect of Rubber Stabilization

From the graph 6.3 it is evident that there is no appreciable increase or decrease in the dry density of the soil. The variation may be due to errors in performing the test. Moreover, the UCS testing on the sample had little increase or decrease in the strength with rubber content as shown in Graph 6.4.



Graph 6.4 Variation of strength with Rubber Content

Conclusion:

From the results of the above experiments it is concluded that rubber stabilization is not suitable for Risalpur soil.

6.6 REMEDIATION FOR REHABILITATION OF BUILDING

The cracks in the buildings indicate need of remediation for rehabilitation of the building. Certain method for remediation of buildings have been suggested in literature review, but only suitable methods for our conditions needs to be selected.

6.6.1 Stabilization of Foundation soil

The foundation soil along the exterior walls of the soil needs to be stabilized due to its collapse potential. The method selected for this according to the experiments performed is Lime stabilization. Inclined holes of 4 inches dia and 4 feet vertical length, towards the foundation soil needs to be dug and filled with powders lime. The distance between holes should be 1.5m so that the 3% lime content mark is achieved as closely as possible.

6.6.2 Relaying of Foundation

Structural Analysis of the building indicates that the foundation provided was insufficient for the critical section of the house. The foundation needs to be relayed. Instead of relaying foundation of whole house, foundation of exterior walls should only be relayed, as this is an expensive process and also the destabilizing effect is more on exterior walls. The proposed foundation is shown in Fig 6.8 previously.

6.6.3 Reconstruction of walls

The corner of building where Bedroom 2 is located is the critical section as load is maximum on foundation due to presence of Over-head Water tank. According to the residents of the house the overflow water seeped into the foundation in this area due to which severe cracks and settlement is visible. This section needs to be reconstructed. The inspection of slab indicates there is no major damage done to the slab (just few cracks, filled previously by residents), so slab does not need to be reconstructed. The slab should be jacked up and walls of Bedroom 2 and adjoining washrooms should be reconstructed.

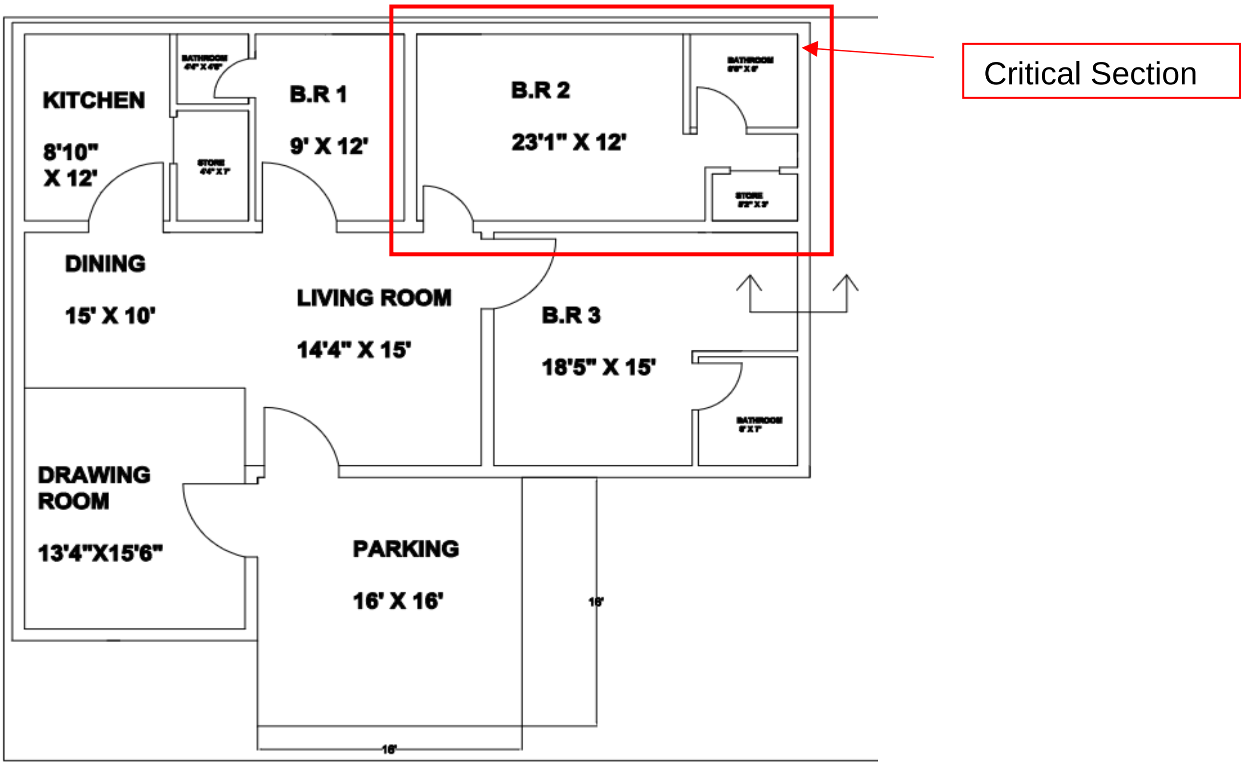


Fig 6.9 Critical section of House

6.6.4 Strengthening of walls:

Cracks are visible in walls in certain other areas of the house but their severity is from slight to moderate as classified in distress mapping. These walls can be strengthened using structural repointing technique. In this technique mortar is removed from joints perpendicular to crack and steel bars are inserted in the joint at least 6 inches on either side and 4 inches deep into the wall as shown in figure 6.10.

Fig 6.10 Strengthening of walls using structural repointing technique

6.6.5 Waterproofing and strengthening of the roof slab:

The seepage in upper parts of the walls indicate cracks improperly filled in the roof slab. As the house was constructed in 1980s so this seepage might have caused spalling on steel bars. The seepage is visible in small section of wall so the roof should be reinforced using composite material like CFRP. The section is shown below. Water proofing coat should be applied on the top of entire roof to remove the possibility of seepage.

Fig 6.11 Section needed to be reinforced

Chapter 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

- The house plan was regenerated by taking manual readings and by a test pit dug at eastside of the building, the foundation was found in suitable for load at critical section.
- Distress mapping shows that certain areas of the building are severely damaged and cannot be repaired without reconstruction, while some areas are moderately damaged that can be strengthened.
- The forensic geotechnical investigations concluded that the soil was silty clay with low silica and alumina content. Water table was not encountered till 60 ft. The bearing capacity was calculated 0.84tsf.
- The foundation provided was not sufficient according to our structural analysis. It should be at least 16” or 24” with FOS 1.5.

7.2 EFFECT OF SITE CONDITION AND LOCATION OF SITE

7.2.1 Location of Site

The location of site has following impacts on stability of structure:

- The site is located in semi-arid region which presents suitable conditions for the formation of collapsible soil.
- Research indicate Risalpur lies on old river bed of River Kabul.
- The site is located in seismic zone 2B so risk of Earthquake damage is not severe.
- Precipitation is low so collapse of soil due to precipitation is less likely.

7.2.2 Site Conditions

Following information was obtained by previous residents of the house.

- No concrete around the exterior walls were provided.
- The over flow water used to seep into the foundation.
- The roof slab was covered with 6 inches soil layer and 2 inches concrete blocks which was removed later.
- A small farm was present about 3 m from the back wall which indicates high moisture near back wall.

Information obtained from the residents indicate that the house was very poorly maintained and the failure is not only because of design flaws but also due to poor maintenance.

7.3 RECOMMENDATIONS

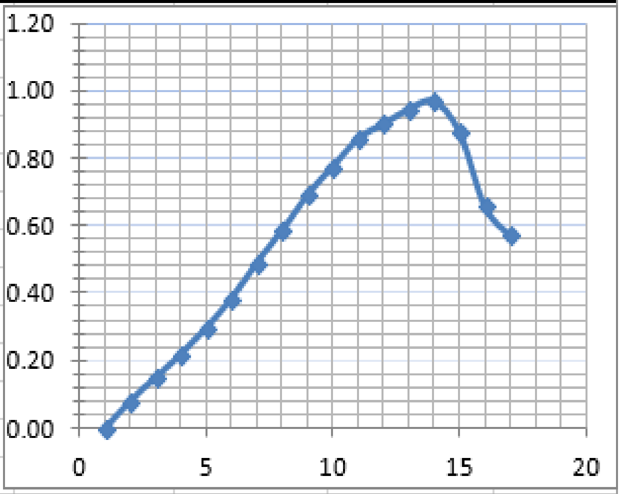
In the light of exploration of this research following recommendations should be incorporated in future construction.

- The soil should be compacted and treated with additives before construction.
- Reinforced masonry structure should be preferred in the area.
- Foundation width for single storey building should be 24” while for double storey 36”. Beam at the base of foundation is most desirable, while raft foundation should be used for commercial buildings.
- Proper drainage and sewerage plan before construction.
- Proper and timely renovation and maintenance of building should be done on regular basis.
- Seismic record and its damages record should be maintained.

Annex A

Bearing capacity and load Calculations

Density	1.43 gm/cm^3	FOS	3	w_1 (gm)	35.50	w_2 (gm)	32.60
Allowable Bearing Capacity		0.883	kg/cm^2	w_3 (gm)	11.44	M.C (%)	13.71
Allowable Bearing Capacity		0.825	Tons/ft^2	qu (kg/cm^2)	0.97	C_u (kg/cm^2)	0.49



Loads and bearing capacity was calculated using excel sheets.

density of conc	150
slab thickness	0.5
Dead load	15
live load	40
self weigth	75
total load	130
load in kips	0.13
longer span	13.5
shorter span	7.75
ratio of long/short	1.741935

area of trapoziod	37.29688
load on longer span	0.359155
area of triangle	15.01563
load on shorter span	0.251875
density of brick	0.12
height of wall	10
thickness of wall	0.75
self weight of wall	0.9
height of footing	3.5
thickness of footing	1.125
self weight of footing	0.4725

total load on soil for shorter span	1.624375
total load on soil for longer span	1.731655

density of conc	150
slab thickness	0.5
Dead load	15
live load	40
self weigth	75
total load	130
load in kips	0.13
longer span	23
shorter span	12
ratio of long/short	1.916667

area of trapoziod	102
load on longer span	0.576522
area of triangle	36
load on shorter span	0.39
density of brick	0.12
height of wall	10
thickness of wall	0.75
self weight of wall	0.9
height of footing	3.5
thickness of footing	1.125
self weight of footing	0.4725

total load on soil for shorter span	1.7625
total load on soil for longer span	1.949022

density of conc	150
slab thickness	0.5
Dead load	15
live load	40
self weigth	75
total load	130
load in kips	0.13
longer span	12
shorter span	9
ratio of long/short	1.333333

area of trapoziod	33.75
load on longer span	0.365625
area of triangle	20.25
load on shorter span	0.2925
density of brick	0.12
height of wall	10
thickness of wall	0.75
self weight of wall	0.9
height of footing	3.5
thickness of footing	1.125
self weight of footing	0.4725

total load on soil for shorter span	1.665
total load on soil for longer span	1.738125

density of conc	150
slab thickness	0.5
Dead load	15
live load	40
self weigth	75
total load	130
load in kips	0.13
longer span	15
shorter span	14.5
ratio of long/short	1.034483

area of trapoziod	56.1875
load on longer span	0.486958
area of triangle	52.5625
load on shorter span	0.47125
density of brick	0.12
height of wall	10
thickness of wall	0.75
self weight of wall	0.9
height of footing	3.5
thickness of footing	1.125
self weight of footing	0.4725

total load on soil for shorter span	1.84375
total load on soil for longer span	1.859458

density of conc	150
slab thickness	0.5
Dead load	15
live load	40
self weigth	75
total load	130
load in kips	0.13
longer span	15.5
shorter span	13.5
ratio of long/short	1.148148

area of trapoziod	59.0625
load on longer span	0.495363
area of triangle	45.5625
load on shorter span	0.43875
density of brick	0.12
height of wall	10
thickness of wall	0.75
self weight of wall	0.9
height of footing	3.5
thickness of footing	1.125
self weight of footing	0.4725

total load on soil for shorter span	1.81125
total load on soil for longer span	1.867863

density of conc	150
slab thickness	0.5
Dead load	15
live load	40
self weigth	75
total load	130
load in kips	0.13
longer span	7.75
shorter span	6
ratio of long/short	1.291667

area of trapoziod	14.25
load on longer span	0.239032
area of triangle	9
load on shorter span	0.195
density of brick	0.12
height of wall	10
thickness of wall	0.75
self weight of wall	0.9
height of footing	3.5
thickness of footing	1.125
self weight of footing	0.4725

total load on soil for shorter span	1.5675
total load on soil for longer span	1.611532

density of conc	150
slab thickness	0.5
Dead load	15
live load	40
self weigth	75
total load	130
load in kips	0.13
longer span	6.5
shorter span	6
ratio of long/short	1.083333

area of trapoziod	10.5
load on longer span	0.21
area of triangle	9
load on shorter span	0.195
density of brick	0.12
height of wall	5.5
thickness of wall	0.75
self weight of wall	0.495
height of footing	0
thickness of footing	0
self weight of footing	0

total load of shorter span	0.69
total load of longer span	0.705
point load on longer span (with full water)	0.81
point load on shorter span (with full water)	0.845

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