BE CIVIL ENGINEERING PROJECT REPORT

DYNAMIC SOIL-STRUCTURE INTERACTION TO CHARACTERIZE STRUCTURAL AND GEO-TECHNICAL DEFICENCIES

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

BE Civil Engineering

SUBMITTED BY

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This to certify that the

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Has been accepted towards the partial fulfillment of the requirements for

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DEDICATION

Dedicated to our beloved Parents and Teachers, whose prayers and guidance have always been source of inspiration and motivation.

ACKNOWLEDGEMENT

All thanks and praise to Allah Almighty.

We bow our heads before Almighty Allah for providing us opportunity and resources to complete our research work. We are greatly obliged to the people without whom it would not have been written. Our deepest gratitude goes to our respected teachers particularly our advisor Dr. Sarfraz Ali who is always been a symbol of encouragement and inspiration to us and was the driving force behind this research. He contributed valuables ideas and his reception of our ideas and suggestions has always been extremely encouraging. Through his exemplary guidance and leadership, we were able to achieve the objective of this research. Special thanks to our parents for their never-ending love and prayers. To those who in some way contributed in this research, your kindness means a lot to us.

ABSTRACT

Mosque is very important in every society according to religious point of view. Masjid-e-Muhammad presently known as station mosque of Risalpur. This mosque constructed in 1983 and renovated in 2013. This mosque is located in seismic zone location 2B with peak horizontal ground motions from 0.16g to 0.24g.

An earthquake of magnitude 7.3 struck northern areas of Pakistan on 26 October 2015. Due to this earthquake most of the walls of mosque got severe cracks.. This research was undertaken to characterize the site conditions, study of causal factors and to evaluate the remedial measures. This research involves soil-structure interaction investigation including attenuation of bed rock time history using all soil properties determined from lab and field testing. Original bed rock waves were derived from USGS at Kabul station and then used probabilistic seismic hazard analysis technique for acquiring the waves on Risalpur bed rock. The analysis for attenuation of waves was done on software ‘DEEPSOILS v6.1’.

The analysis of earthquake waves showed that wave’s amplitude increased from bed rock to the base of structure. Using these waves we analyzed the critical wall of mosque on software ‘UDEC 5.0’. From this analysis we find the structural reason for cracks has been found from this analysis. On the basis of these causal factors we suggested remedies and then analyzed remedial solutions using software ‘PLAXIS’. The author believe that research will enhance the understanding about geotechnical earthquake engineering, dynamic soil structure interaction and in preserving the infrastructure of Commercial social use.

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Chapter 1

INTRODUCTION

1.1 General

Current time of development industry molded structures fundamentally into two sorts of development approach, workmanship and RCC structure. Workmanship structures are those structures which are worked from individual units laid in and bound together by mortar. The regular materials of workmanship development are blocks, stones, marble, rock, travertine, limestone, cast stone, solid piece, and tile. Developing with building stones is the least difficult and one of the most established building strategies on the planet. The structures frequently were worked by setting pieces together with no holding.

The workmanship structures are outstanding for their effortlessness in development and economy contrasted with steel and strengthened cement structures. Masonry structures provide more comfortable living condition inside which will at last decrease the measure of vitality spent to enhance comfort state of houses worked with different materials, for example, steel. The interest of workmanship structures for their client agreeableness, stylish magnificence and closeness to the nature has pulled in numerous for brick work structures. (Berrabah, Armouti and Belharizi, 2012)

Outrageous climate causes debasement of workmanship divider surfaces because of ice harm. This kind of harm is basic with specific sorts of blocks, however uncommon with solid pieces. Stone work has a tendency to be overwhelming and should be based upon a solid establishment, for example, strengthened cement, to evade settlement and cracking. Brick work comprises of free parts and has a low resilience to oscillation when contrasted with different materials.

The procedure in which the reaction of soil and movement of structure is affected by each other is called soil structure interaction (SSI).

1.2 Background

Mosque, a place of worship used by the Muslims for decades are sacred places. The Islamic culture promotes the building of mosque. A mosque is built for a region so that all people have a common place of worship. Mosques are built in variety of shapes and designs, with a few thing in common.

The Engineering center, Risalpur mosque was being constructed in 1983 and again renovated in 2013 to increase the space. It has a wonderful design which includes a massive open courtyard, and an inner big hall. The inner hall has a long span supported by beams that run full length from each side of the mosque. At the boundaries it is supported by columns, it is a column less structure since the columns are only at the boundaries. Large windows are provided at the top to have sunlight inside the masjid.

On 26 October, 2015 the mosque was hit by an earthquake due to which had devastating results as settlement occurred. The wall under which the support had settled had massive cracks in it which were directed along the diagonal of the wall. Cracks also generated on the rest of walls in diagonal pattern due to relative displacement. Cracks generated are severe and causes a serviceability problem. Cracks measured were of 14mm. Standard of Masonry structures shows that this crack width degree of damage is 'moderate to severe' and of category 2.

Table 1.1: Degree of Damage (Rodrigo Salgado)

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

Fig 1.2: Critical wall crack

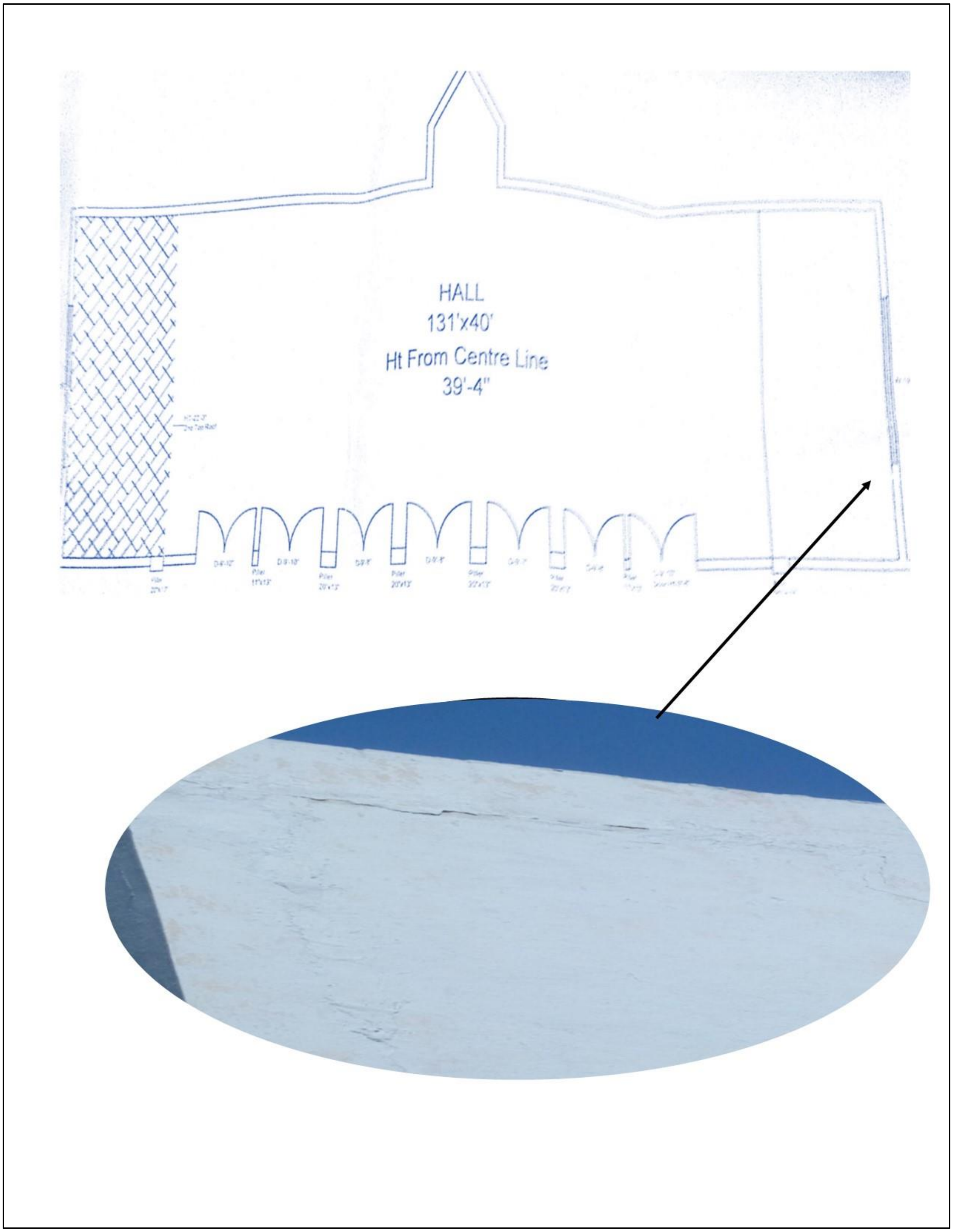


Fig 1.3: Critical wall on Line plan

1.3 Problem Statement

Most masonry construction in commercial and residential area when hit by an earthquake generates severe cracks on the load bearing walls. Generally, less strength of joints and settlement of soil are the main factors of serviceability failure. In the backdrop of recent failure of masonry structure used as a Mosque in Risalpur cant causes property loss, there is a need to carry out research comprising investigation of shear cracks in terms of soil-structure interaction when it encountered with destructive seismic waves which includes all aspects of geotechnical investigation such as field testing, site characterization and providing suitable remedial strategy.

1.4 Scope and objective

Scope of project covers the soil properties, soil structure interaction analysis and remediation which should be done in order to avoid any future destruction to the structure caused by earthquake. Following are the objectives which are covered in details

Perform Field and lab tests to identify the soil conditions of the site.

- Physical modeling of soil conditions for soil and structure interaction.
- Waves response in soil using 'Deep soil' structure.
- Study soil and structure response to the earthquake using the 'UDEC' software
- Identify the factors that affects the serviceability of structure.
- Frame remedial method under the research of SSD.

1.5 Research Questions

The research will lead to answer the following questions:

- What were the geological properties of the mosque?
- Was there any problem due to pore pressure?
- Was there any design failure?
- Is it the soil that fails solely?
- Were cracks due to differential settlement?

1.6 Conceptual Framework

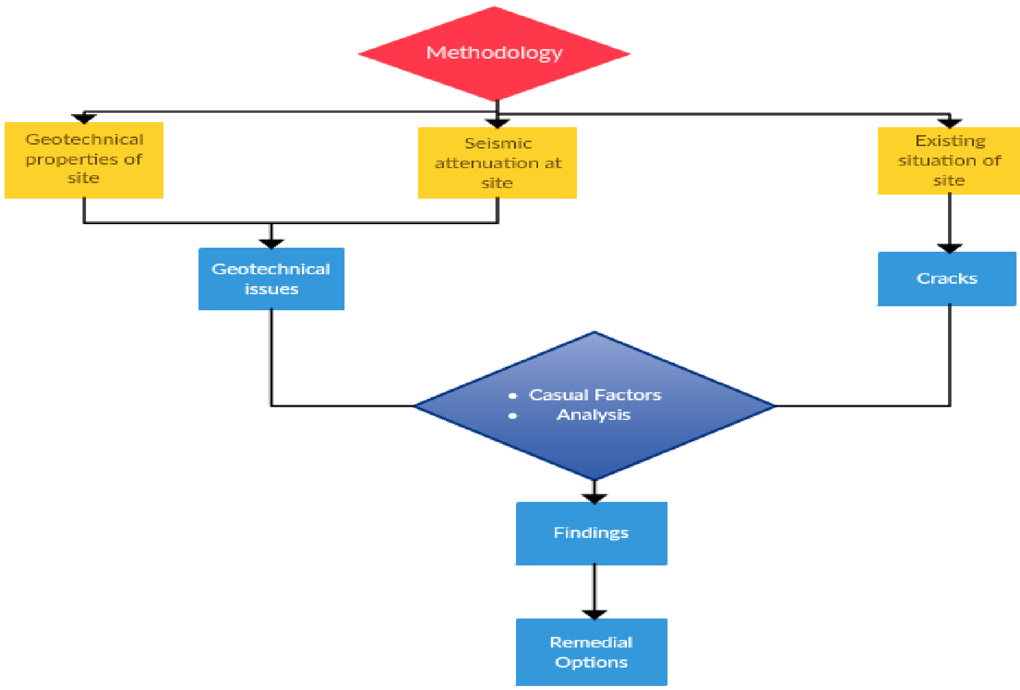


Fig 1.4: Conceptual framework

1.7 Relevance and Significance of the Research

As new building are being constructed, with time their foundation as well as their load bearing capacities decrease, due to which they are more prone to seismic attacks and require repair as soon as possible before the second attack. The limited budgets of the massive projects do not allow them to be renovated or reconstructed due to which no repair order is issued and a lot of losses take place. Unfortunately in poor countries such as Pakistan where there are many such building that are over 40-50 years old are slowly gradually becoming unsafe and structurally unstable. These building may be a part of great achievements in art and architecture that contribute massively in Pakistan's heritage. It is essential to preserve them for our future generations and for our country because they make our country beautiful. One of the examples of such old building is the Risalpur mosque situated at Risalpur cant. The mosque has cracked walls which were caused by an earthquake attack. Our research aimed at achieving causes and remedies for the damaged part of the wall because it may help in the protection and preservation of the mosque and also will help in the remedial solution of other damaged buildings.

1.8 Research Layout

- Chapter 2 covers the relevant literature on the subject of Masonry structure failure and its causes, forensic and geotechnical investigation, precedence of geotechnical investigation and remediation process.
- Chapter 3 gives the methodology for this research that includes details of the field investigation, lab testing and mineralogical classification, techniques of analysis and remedial options.
- Chapter 4 describes the site characterization that includes site geology, topography and climatology. This chapter discusses the observations made during the field visit. Geotechnical profile of the area and properties of soil are also discussed in the chapter.
- Chapter 5 includes results of field investigation and laboratory tests and discussion on the causal factors on the basis of these investigations and tests.
- Chapter 6 covers the remediation of the failed structure. It involves the options that should be adapted for future construction. It also involves the analysis of proposed remediation.
- Chapter 7 covers conclusions and recommendations. Recommendations have been made to avoid such scenario in the future and to keep the Mosque and the structure safe for use.

1.9 Conclusion

In this section the attempted review is presented alongside its targets. The applied edge work and research design is additionally given. In the following section the literature review on the concerned subject is displayed which covers strategies for measurable geotechnical examination, material of construction for masonry structure, rehabilitation process, structure analysis technique etc**.**

Chapter 2

LITERATURE REVIEW

2.1 General

Literature review was done to investigate our position in crack investigation and interaction research. Main aim of literature review is to prove the logic of using different approaches at different steps in our research study. Our research is how different from other people who did dynamic soil structure interaction.

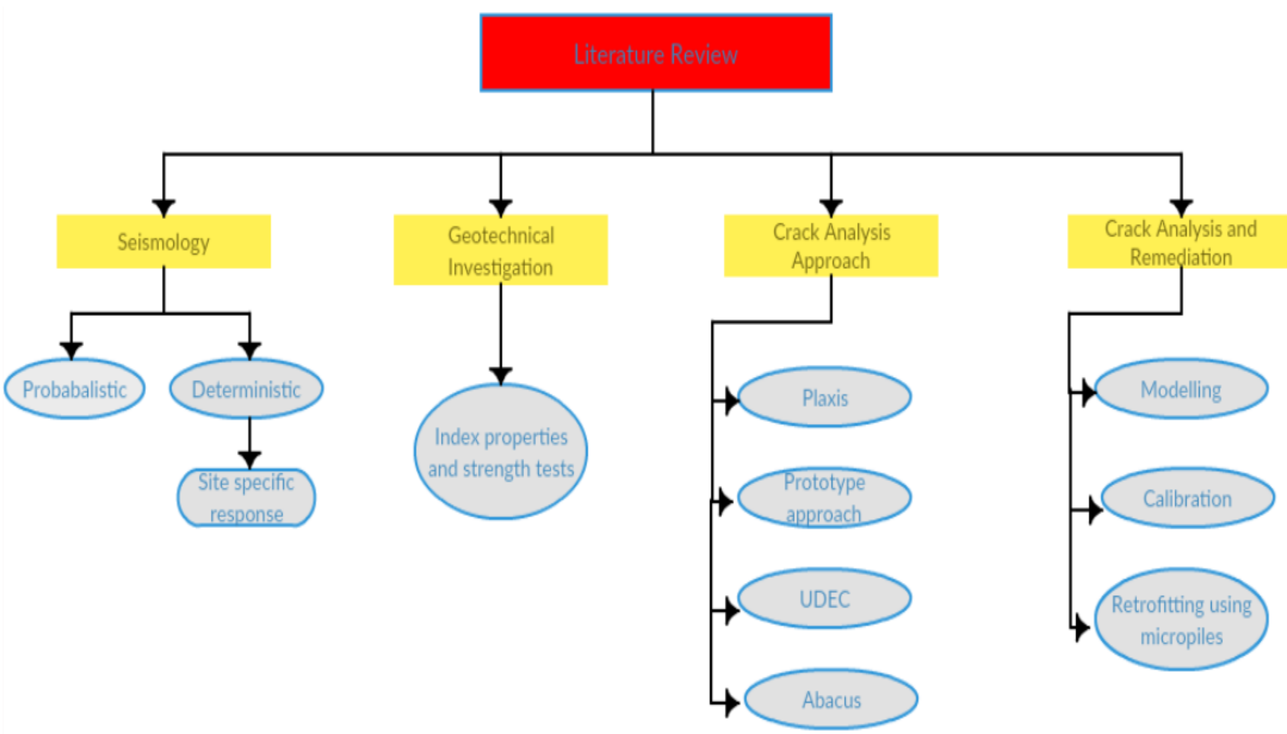


Fig 2.1 Flow Chart for Literature view

2.2 Seismology

Our research involves first analysis and study of earth quake waves that approaches to site from source after passing through medium of soil. There are different types of waves generating from source. Some of which are devastating and some are up to some extents. Following are different types of earthquake waves.

2.2.1 Body Waves

The waves which travel through interior of earth are known as body waves. Body waves are divided into two sub categories.

- **P-waves**

They are known as primary waves. They are actually compression or longitudinal waves. They like sound waves compress and refract the medium into which they pass through. They make the particle move parallel to direction of travel of waves. They are quite similar to sound waves. P-waves can pass through fluids and solids. (Lombardi, Bhattacharya and Muir Wood, 2013)

- **S-waves**

They are known as secondary, shear or transverse waves. They make the particles to move perpendicular to direction of travel. They are divided into s-v (vertical) and s-h (horizontal) waves.

The speed with which body waves move depends on the stiffness of materials. This was the concept that we use in determining the site specific seismic response. Since the p-waves depend on compression so they arrive first at the site. S-waves cannot pass though liquids because they cannot resist shearing.

2.2.2 Surface Waves

Surface waves are produced when body waves interact with the materials and surface of earth. They travel through earth and their amplitude goes on decreasing. Due to interaction of waves with earth they are prominent at surface. They have different types depending on the interactions of different waves with surface e.g., Rayleigh waves are produced by interaction of p & s-v waves with earth's surface. L waves are produced when s-h waves interact with soft surface layer of earth. (Hughes, Locker and Stewart, 1965)

Why earthquakes come?

There are different theories of why earthquakes come. Following are some theories due to which earthquakes come.

- **Continental Drift and Plate Tectonic Theory:**

According to this theory 200 million years ago earth consists of only one continent known as Pangaea..All this happened but ocean floor did not broken so this creates plate tectonic because plates move with respect to each other. Location of earthquakes at boundaries supports plate tectonics theory. Thermal mechanical equilibrium disturbance produces earth quakes.

A convection process that causes plates movement involves following steps.

- Plate boundaries.
- Spreading ridge boundaries.
- Seduction zone boundaries

Figure shows this phenomenon.

2.2.4 Elastic Rebound Theory

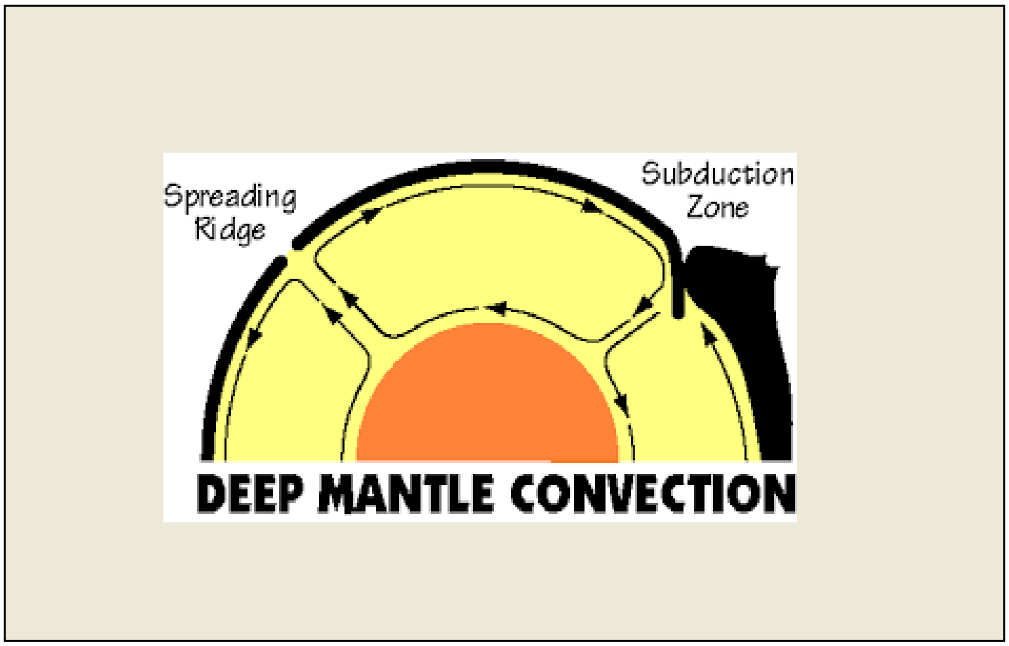


Fig 2.2: Subduction Boundaries

The above paragraphs explains the main source of earthquakes that is the plate tectonics theory. There are many other sources of minor earthquakes.

- Magma
- Landslides
- Mine collapse
- Explosives
- Reservoirs filling (increase in pore pressure reduces strength of rocks)

The seduction zone boundaries and plate tectonics produce great earth quakes. All other phenomena produce very limited earthquakes.

This theory explains that how earth quakes come in terms of stored energy. It says that when energy comes out then earthquake phenomenon occurs. (Berrabah, Armouti and Belharizi, 2012)

But some energy does not come out. This energy either comes after earthquakes or some time before causing aftershocks and foreshocks respectively.

2.2.5 Seismic Gaps

When earthquakes come along a fault zone or fault line, then in some areas on fault zones it does not occurs and occurs sometime after earthquake. In earthquake prediction techniques these seismic are very important. (Lombardi, Bhattacharya and Muir Wood, 2013)

In terms of elastic rebound theory at some places where strain energy has not been released there are more chances of earthquake there.

2.2.6 Geometric Notations

These are notations by which denote earthquakes, means that name of origin earthquakes etc.

2.2.6.1 Focus

It is the point where waves are produced or we can say that where rupture occurs first time. It is basically the point some distance below earth surface. It is also called as hypocenter**.**

2.2.6.2 Epicenter

It is the point right above the focus on the earth surface. It is directly above the focus.

2.2.6.3 Epicenter Distance

It is the horizontal distance between epicenter and site at which you are discussing the effects of earthquakes.

2.2.6.4 Hypo Central Distance

It is the radial distance from focus to the point where you are discussing the effects of earthquakes. (Hughes, Locker and Stewart, 1965)

After all this literature review about seismicity and geometric notations about earth quake we came to know that our epicenter distance is 3oo km and focal length was 212.5 km

2.2.7 Seismic Hazard Analysis.

Seismic hazard analysis is very important in design of an earthquake resisting structure. This study involves such approaches by which we can find such time histories or peak horizontal ground acceleration which are maximum and are considered in design of an earth quake resisting structures. Source identification for magnitude involves historical seismicity.

It involves two approaches.

2.2.8 Deterministic Seismic Hazard Analysis

It involves the following steps.

- In first step we identify the future earth quake sources which can produce a big earth quake. In this step we identify and characterize the source by geometry.
- In second step we consider the distance between source and site. Mostly the shortest distance is distance of our interest. Generally we can give this distance in terms of epi central and sometime hypo central length.
- We consider different earthquakes at different distances and we check the level of shaking produced by each of these. And finally we identify the controlling earthquake.
- Finally the hazard is defined in terms of ground motions. Characteristics of controlling earth quakes are defined in terms one or two parameters like peak ground acceleration, peak velocity and response spectrum etc.

2.2.9 Probabilistic Seismic Hazard Analysis

When earthquake studies advanced then this technique came. This is not much different from deterministic hazard analysis approach. It involves following steps.

- First step is similar to that of deterministic hazard analysis that is to identify and characterize the source but also involves the study and characterization of rupture pint i.e., where it will be located. It involves probability in determination of rupture point of earth quake.
- In this step seismicity is characterized or earthquake recurrence is temporally distributed. The recurrence maximizes the earthquake intensity but not make it controlling earthquake.
- Now earth quake produced by any source in any direction is determined. Predictive approach is used to determine earthquakes in all directions. Uncertainties in considering predictive approaches are also considered in probabilistic seismic hazard analysis.
- Lastly the earthquake magnitude, peak ground acceleration, peak velocity and response spectrum with probability of occurrence of earthquake is obtained.
- These two approaches could also be used in our research in order to analyze cracks. These techniques are mostly used before construction of structure in design. So, that's why we did not use the first method. Another shortcoming of using this technique in our research was that during calibration it was difficult to match cracks with original cracks.

2.2.10 Seismogram Determination Using Site Specific Seismic Response Analysis

- **Strong Ground Motions**

Earth always vibrates but at very low frequencies. These motions of earth are in milli and micro. They are of no importance to engineers. But they are important to geologists.

These strong ground motions are described in terms of time histories. These time histories involve 3 components. But for geotechnical engineers only y direction is important because in other two directions earth is approximately unlimited.Time histories graphs are in terms displacements, velocities and accelerations. Each graph includes all three components i.e., frequency, and amplitude and time period. (Lombardi, Bhattacharya and Muir Wood, 2013)

2.2.11 Strong Motion Measurement

2.2.11.1 Seismographs

This is simple technique by which we can measure the time histories. It depends on degree of freedom. The simplest is single degree of freedom mass spring system. When mass moves by earthquake then it moves and stylus make graphs on rotating drum.

This apparatus generally gives weak ground motions because it is on surface and also very far from source that's why it gives very weak motions. These motions obtained by this method depend on damping ratio and degree of freedom.

2.2.11.2 Data Acquisition and Digitization

Before arrival of this method all method used the pen and drum method. These methods were little weak in providing time history data. Because energy was required to move this spring mass system. So this method was not correct.

Data acquisition and digitization method is electronic method in which apparatus remains dormant before arrival of earth quake waves and when waves arrives then it starts recording data. The starting time of this apparatus gives a baseline error. (Berrabah, Armouti and Belharizi, 2012)

2.2.12 Ground Response Analysis

In ground response analysis we take the waves just under structure. This we do by Fourier series analysis as described by Steven L Kramer in his book.

For our project we create site specific response by using following steps.

- Obtain the time history of earthquake at rigid rock.
- Convert this time history into Fourier of respective waves.
- Find the transfer factor basically attenuates the time history.
- Multiply the transfer factor by Fourier series of waves. This will attenuates the waves depending on damping ratio which is less than for soils.
- Now convert this attenuated Fourier series back into waves. This will create attenuated time history.

This will create site specific response under structure. For layers between rock and structure this method is very complex. That's why we created site specific seismic response by using software DEEPSOILS. (Berrabah, Armouti and Belharizi, 2012)

Jip wolf soil-structure interaction in time domain in 1987 was just to check importance of time and frequency using green's function. In context to our research it is a research involving some mass spring mathematical models.

Soil pile interaction by roses w Boulanger (1999) was also little similar to our research because it was seismic research but he did not use site specific response. He used peak accelerations.

Wartman, Wahdani and Liang used FLUSH software for development site specific response spectrum for their research of seismic soil structure interaction of a 10 storey office building in California.

In short we can say that most of people used peak acceleration directly or they use different (FEM) techniques for site specific response generation. We used deep soils for this purpose.

2.4 Geotechnical Investigation

Geotechnical investigation is necessary for any geotechnical project. The depth up to which we do drilling and sampling depends on type of analysis and type of structure you are building. Thumb rule is that the depth of exploration must equals to height of building.

For seismic analysis the depth of exploration must equals to 30m. According to ASTM for seismic down hole test the depth of exploration must equals to 30m. Sampling should be done at an interval of 1m in seismic down hole test.

If anyone cannot do seismic down hole or any other test of seismic importance then in standard penetration testing he must have to go 30m and sampling will be at 1.5m interval. Undisturbed sampling should be done at every 18ft interval. (ASTM)

For determination of shear modulus of soil we did all index property testing. For elastic modulus we did unconfined compression test. In order to determine shear modulus we required over consolidation ratio (OCR) so that's why we did consolidation test.

2.4.1 SPT Correlations

For strength of any soil there should be values of both cohesion and internal friction angle. For this purpose we used correlations from spt.

2.4.2 Value of Internal Friction

Values of internal friction were calculated from two SPT correlation and then we took average value.

$$\emptyset = 15 + \sqrt{20N} \qquad \text{(Osaki)}$$

$$\emptyset = 0.3N + 27 \qquad \text{(Peck)}$$

2.4.3 Cohesion of Soil

Cohesion of soil is of two types. One is unconfined and other is confined. But these are of laboratory type.

We obtained unconfined compression strength from the correlation given below.

qu = 0.58Pa*N60^0. 72 (Kullhway and Maye 1990)

Untrained shear is calculated strength from another correlation. That correlation is given below

Su/Pa = f1 * Nspt (Stroud 1975)

Both of the above parameters have very little difference in between them. The difference is of confinement.

2.5 Soil Structure Interaction

Mostly all civil engineering structures are constructed on ground so all structures interact with ground. But when there is an earthquake then ground motions and structure motion are dependent on each other. This is the process in which both soil and structure depends on each other. There are different type of interactions for example dynamic interaction (DSSI) and inertial interaction. This interaction depends mostly on the nature and stiffness of soils below the structure and it also depends on type of foundation system.

This interaction is performed to evaluate behavior of structure on different soils. This behavior includes the displacements at joints (Pallavi and Nellima 2013), and other shortcomings of structure like cracks. Soil structure interaction is very important technique to find out settlements of structure. Hence anyone can differential settlements also.

Soil structure interaction have become little advance but it is not very old technique. At start it was mostly done by making different models or prototypes and then analyzing the prototypes at shakers. That was very common method some year ago but it is not much efficient method as it energy loss is a factor in this technique which is originally not much present. These research studies also involve dashpot model study. Use of shaking table by Tokimatsu and Suzuki.

But now a day all soil structure interaction has been done on FEM and non – linear models. The interaction can be on different software packages. The selection of the technique depends on the type of analysis you are going to do.

If masonry walls and masonry structure response is required then ABAQUS can be used because it can analyze up to nonlinear state. If you want to see cracks then you have to select such kind of technique that can model whole structure. For example the software that create beam as line element cannot give cracks as they don’t have width characteristics. (Shye and Robinson, 1980)

2.5.1 FEM Techniques

These techniques include the software's that don't have any width characteristics. By using this software the cracks cannot be investigated. Most of the people have been used this technique. (Soil pile interaction by hang) they used DYNA and SAP. (dynamic soil foundation structure analysis of large caisons by Chang, Katchum , Mok , Wang and Chin)they used SASSI and FLAC 2D.

2.5.2 Non-Linear Techniques

These techniques involve techniques that run up to nonlinearity and don't take structure as a line element. Cracks in a building can be investigated by using this technique. ABAQUS and UDEC come in this category.

For example dynamic SSI analysis considering anisotropy of gravelly layer in Taiwan by Tanka. He used ABAQUS for this purpose which comes in this non-linear domain.

Nonlinear response of underground duct structure with due response to ground motions by Tarkemia and Furkawa.

2.6 Conclusions

At the end we conclude that our study has following knowledge gaps.

1. Non linearity of super structure.
2. Crack investigation of superstructure.
3. Due importance to superstructure in SSI.
4. Using proper analysis for attenuation of waves using probabilistic seismic hazard analysis.

METHODOLOGY

3.1 General

It means the method which we used for our research. Our methodology involves geotechnical investigation, which is necessary for every type of geotechnical research and distress evaluation (crack investigation).Due to lack of funds and equipment available we used conventional approach for geotechnical investigation that is Standard Penetration Test. Our basic research is related to earthquake effect so our prime concern was earthquake waves (site specific response generation) for this purpose we used numerical model approach in which we use 'deep soil'.

This chapter includes methodology which was used to carry out geotechnical and crack investigation (distress evaluation). Flow chat describes the methodology which was adapted.

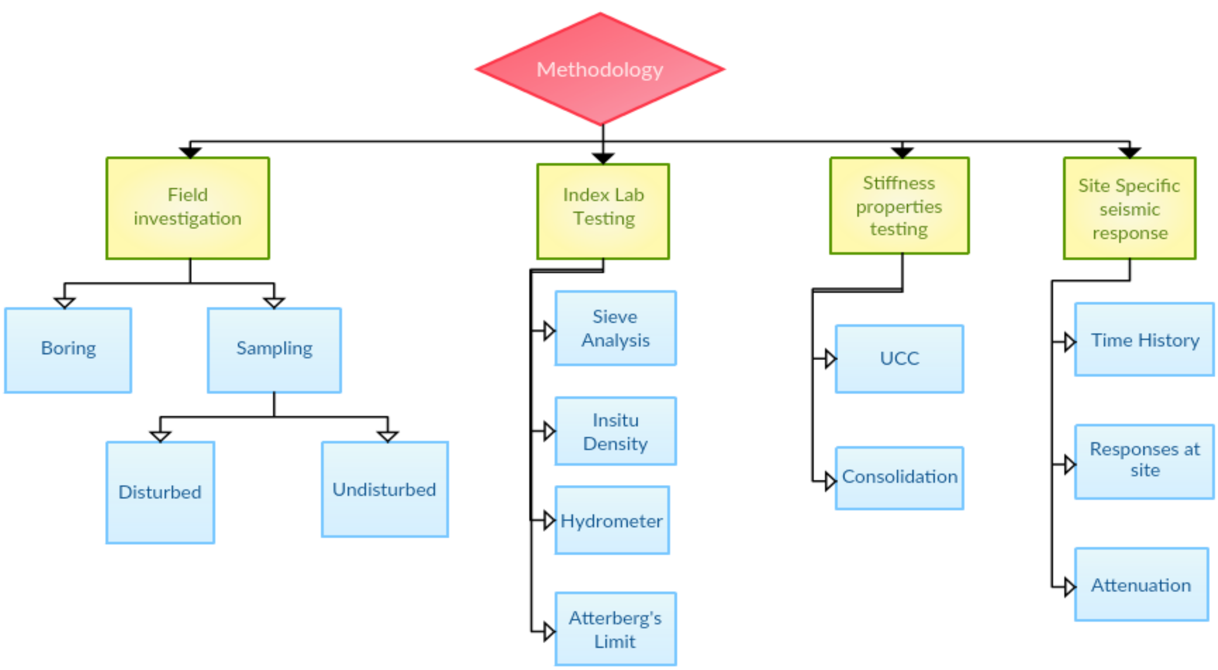


Fig 3.1: Flow chart for Methodology

Geotechnical investigation involves following procedure.

3.2 Field Investigation

Due to social importance of site it was necessary to physically model the geotechnical properties. We have done it by following Standard Penetration Test. Considering the seismic research it was necessary for us to drill up to 100ft (30.5m).Due to greater depth the method we adapt was Percussion drilling. Drilling and sampling was done along the critical wall of the site. Disturbed and Undisturbed samples were collected to carry out various tests.

Disturbed sample collected was used in index properties testing and undisturbed sample was used in stiffness property sampling. There was only one bore hole. Manual stand and hammer test was used for bore hole. Field investigation involves Geotechnical investigation which is explained below. (Shye and Robinson, 1980)

3.2.1 Geotechnical Investigation

- **Subsurface Exploration(Drilling)**

Our subsurface research includes only one bore hole along the critical site wall. It involves boring up to 100ft (30.5m).Percussion method is used for boring. The boring is done for identification, classification and geotechnical engineering characterization. Samples were taken and tests were performed.

Procedure for both is explained below.

- **Boring**

One, 5 inch diameter borehole was drilled using light percussion method. Bore hole was drilled up to 50ft (15m) for identification and classification of strata. Disturbed samples were collected after every 5ft (1.5m). Disturbed samples were collected by split spoon sampler which was without liner and undisturbed was collected at depth of 18ft(5.5m) by Shelby tube, this sample was used for strength testing purposes. During drilling we encountered with different layers of very small thickness. One such layer was ‘clay’ at 18ft depth. After 50ft of boring we found water table. For boring and collecting samples in water we require casing pipe, as it was uneconomical and not available so we quiet our boring at 50ft (15m). For remaining 50ft we interpolate the strata with surrounding strata whose data was already taken.

- **Sample Handling**

After obtaining sample soil was collected in plastic box on which index property test was done. The samples were sealed to avoid moisture content losses and disturbance for density.

Undisturbed samples are waxed at both ends to avoid disturbance and moisture content.

Prior to testing samples were kept in a controlled environment to reduce potential for moisture change.

3.3 Lab Testing

3.3.1 Insitu Density Determination

Density was determined by the disturbed samples. Disturbed samples were obtained in glass shape (cylindrical shape) so we weight them and determine volume of cylinder .Wet density is obtained by dividing the mass by volume. Using formula we calculated dry density

Dry density = wet density / 1+moisture content (Baraja M Das)

.

3.3.2 Moisture Content Determination

We placed the wet samples in oven for 24hrs at 110°C 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

Procedure is described in ASTM D 2216-80

3.3.3 Sieve Analysis

Sieve analysis was performed on disturbed samples obtained from drilling. Most soil samples collected were clayey. It was not possible to pass it through 200 sieve, so we used wash sieve method.

Dry sieve analysis consists of shaking of specimen through proper arrangement of sieves, in decreasing order. We first dried the sample in oven for 24hrs, broke them into lumps and then pass it through sieve by shaking it for retaining right size of soil in right sieve.

Wash sieving procedure includes passing of clay size particles through 200 no sieve by putting it under running tab and shaking it slowly and gently. Over clay particles pass through and sandy particles remain in sieve. The percentage remained on every sieve was noted and results were plotted on semi log scale.

Following procedure is described in ASTM D 421-63

3.3.4 Hydrometer Analysis

After weighing soil passing through no 200 sieve hydrometer analysis was done to obtain particle size distribution of same soil. In order to do test a sample was prepared first and left for 24hrs after that hydrometer was placed in graduated glass cylinder and took readings. After analyzing the readings percentage of soil fraction of size less than 200 was noted.

Procedure is described in ASTM D 422-63.

3.3.5 Specific Gravity

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.

Procedure is described in ASTM d 854-58

3.3.6 Atterberg Limits

To determine liquid limits, plastic limits, plasticity index of cohesive soil obtained from drilling Atterberg limit test was performed. This test is used to obtain general information of soil, its strength compressibility,

Permeability, shrinkage and swell properties are required to estimate consolidation settlement. Coefficient of consolidation is an important parameter and can be obtained by liquid limit according to formula.

$Cc = 0.009*(LL-10)$

Shear strength of clays and silt soils changes in presence of water so for any structural investigation, design it is very important to investigate liquid limits and plastic limits.

Another important use of Atterberg limits is classification of soil according to unified soil classification system (USCS). Procedure is described in ASTM D 41228-66

- **Liquid Limit**

Limit at which soil changes its behavior from plastic to liquid state is known as liquid limit. Casagrande apparatus is used for this purpose. The water content in percent requires to join the separation of 12.7mm.Water content at 25 blows is defined as liquid limit. Apparatus is shown in Fig

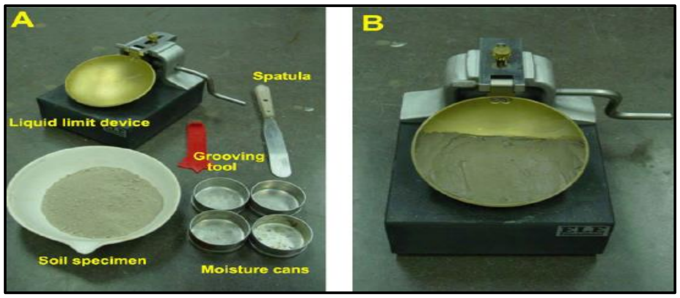


Fig 3.2: Casagrande apparatus

- **Plasticity Limit**

The limit of water at which soil changes from shrinkage to plastic state is called plastic state. 3mm threads start crumbling at this state. The apparatus is shown in figure

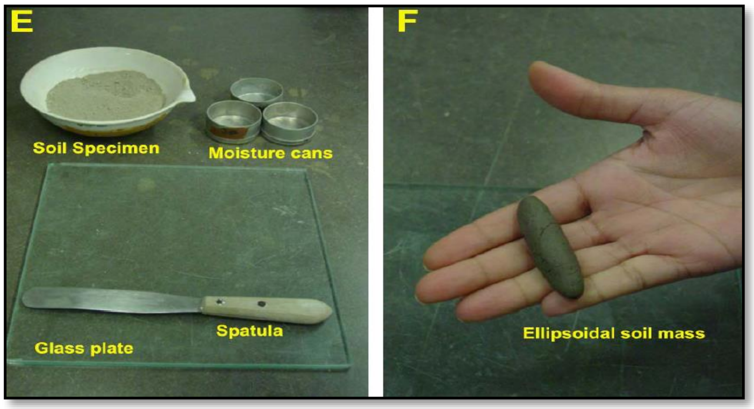
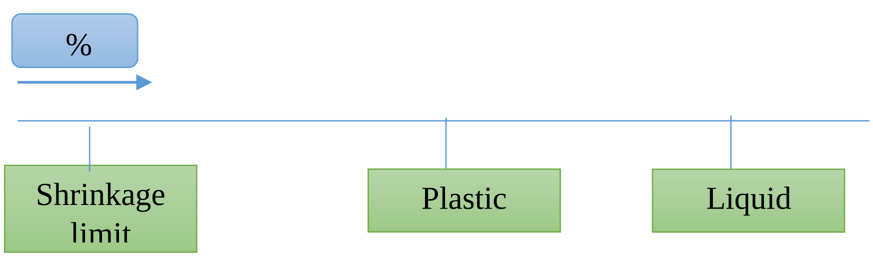


Fig 3.3: Plasticity Limit

- **Plasticity index**

It is the difference of liquid limit and plastic limit (PI=LL-PL).It shows the plasticity of a soil. PI>0 shows that it is cohesive soil.



3.4 Determination of Stiffness Properties

Stiffness properties include cohesion, internal frictional angle, and Young’s modulus and shear modulus.

3.4.1 Sample Collection from Shelby Tube

To collect the sample from Shelby tube, Shelby tube was placed over the sample ejector and was pushed by hydraulic pressure so that sample move above and collected it with great care to avoid any disturbance. Sample was trimmed in two halves; one is used for unconfined consolidation test and other for consolidation test.

3.4.2 Unconfined Compression Test (UCC)

To determine the undrained shear strength and young's modulus unconfined compression test was performed. UCC test is perhaps the simplest, easiest and least expensive for investigating the shear strength of cohesive soil. Cohesive soil get most of its shear strength from its cohesion hence for most of cohesive soil, cohesion can be measure from results of UCC. Young's modulus may also be estimated from this test. Procedure is described in ASTM D 2166-66.

3.4.3 Consolidation

To determine the coefficient of compression, coefficient of compressibility, maximum pass pressure and over consolidation ratio consolidation test was performed. When a structure is built on saturated soil, compressible water present within the soil generally carries the load. Sometimes because of the additional load on soil, water tends to be squeeze out from voids present in soil causing in reduction of voids volume and settlement of structures.

Main aim for this test was determination of OCR value so that damping ratio and shear modulus can be determined using the correlation.

$$G_{max}= \{3230(2097\text{-}e)^{2}/1+e\}*OCR^{k\partial\wedge 0.5} \qquad \text{(Dynamics Baraja M Das)}$$

Chapter 4

SITE CHARACTERIZATION

4.1 General

Unlike other civil engineering professions, materials related to geotechnical properties are not manufactured and do not possess same and consistent properties. Soil and rock related information is unique basing on its location and history. Considering this fact, it is important to perform test and characterize soil prior to analyzing it on software and suggesting remedial options. Site characterization is broadly defined as the defining of existing soil properties and conditions at a given site (Coduto 1999).

Most of times soil characterization is the main consideration of geotechnical engineering analysis because for finding causes of failure , data is required on the site on which the construction was done., this data can be gathered by doing the site characterization. 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. The process of site identification is carryout by completing a series of tasks aimed at defining the conditions of the site. All tasks performed for site characterization is shown in flow chart (Fig 4.1).

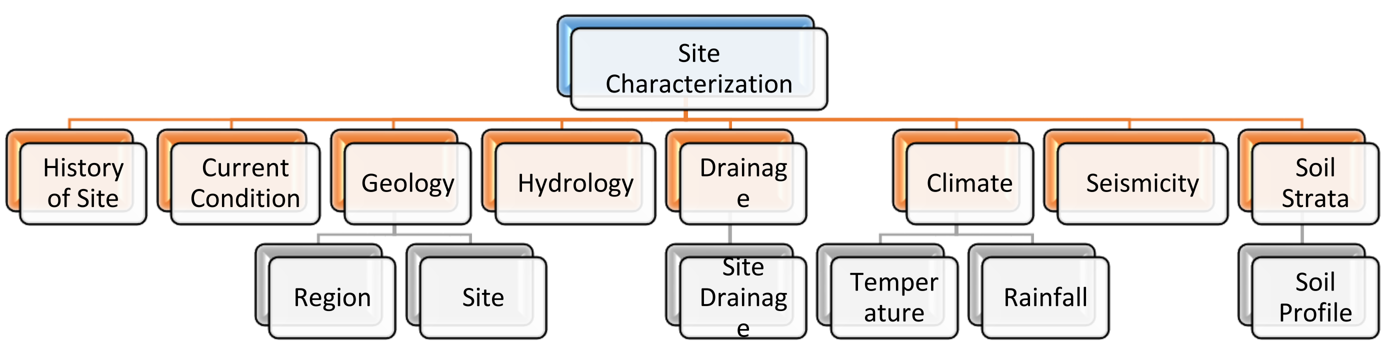


Fig 4.1 Flow chart for site characterization

4.2 History of site

4.2.1 Past condition at site

Risalpur is a city of Pakistan that lies 45 km from Peshawar and 15 km from Mardan. The famous Khyber Pass lies 90 km north of Risalpur. The jamia masjid is a very important part of

Risalpur cantonment. Its location is 300m from the main entrance gate. It can accommodate almost 500 to 550 pupils on daily basis. It had a major crack in its load bearing walls, so geotechnical results were performed to investigate soil and get data. Consolidation test was performed on the ground of the cracked side of the wall. From the consolidation test a pressure of 100kpa was obtained. From this result it shows that there was a river nearby here somewhere in the past and that this soil was its deposit. Later after further research it is found that it was river Kabul, because of which 100kpa load was obtained. This 100kpa load can also be defined as ‘Maximum effective vertical stress that soil has ever experienced’. Since the river Kabul came from Afghanistan so it brought major soil deposits along with itself which got deposited here in this vicinity due to its slow speed. When we performed tests we also got a max OCR value of 4 and a min OCR value of 1 up to 45 feet, beyond this depth the tests showed that the soil is normally consolidated. This means that upper layers are more consolidated than the lower layers.

4.2.1 Present condition at site

Presently the mosque is currently under the Pakistan government. Since the river Kabul has changed its path so the soil due to this has become over consolidated. River Kabul changes its direction to south of Risalpur. This mosque was constructed in 1983 known as ‘Masjid-e-Muhammad’. This mosque was constructed because there was not enough space in the other mosques to accommodate population of Risalpur, also the other mosques were at a much more distance. This mosque was renewed in 2012-2013. Soon after this the mosque was hit by an earthquake which led to the cracks in the walls hence disturbing serviceability state of a building. The cracks in the wall were filled with the help of cement mortar so that they are no more visible but the problem of stability and safety unsolved still exists.

4.3 Site

The mosque is a medium height building. The figure shows a condition of site before and Figure shows the site condition after earthquake**.**

The present the site strata are silty and clayey. A stratum has a plastic nature and is naturally weak. The water table in this region is also quiet low. Clay has a complex behavior and most of the clay is silty. Swelling and shrinkage of soil is high which causes crack in walls as well

4.4 Hydrology

The location on which the mosque was built had a river flowing there, which was known due to the results that we got from our research. From the research we came to know that river Kabul used to cross this path due to which it brought in a lot of silt and sand which were deposited here. Now the river Kabul has chosen another direction and hence lies in the south of Risalpur.

4.5 Drainage

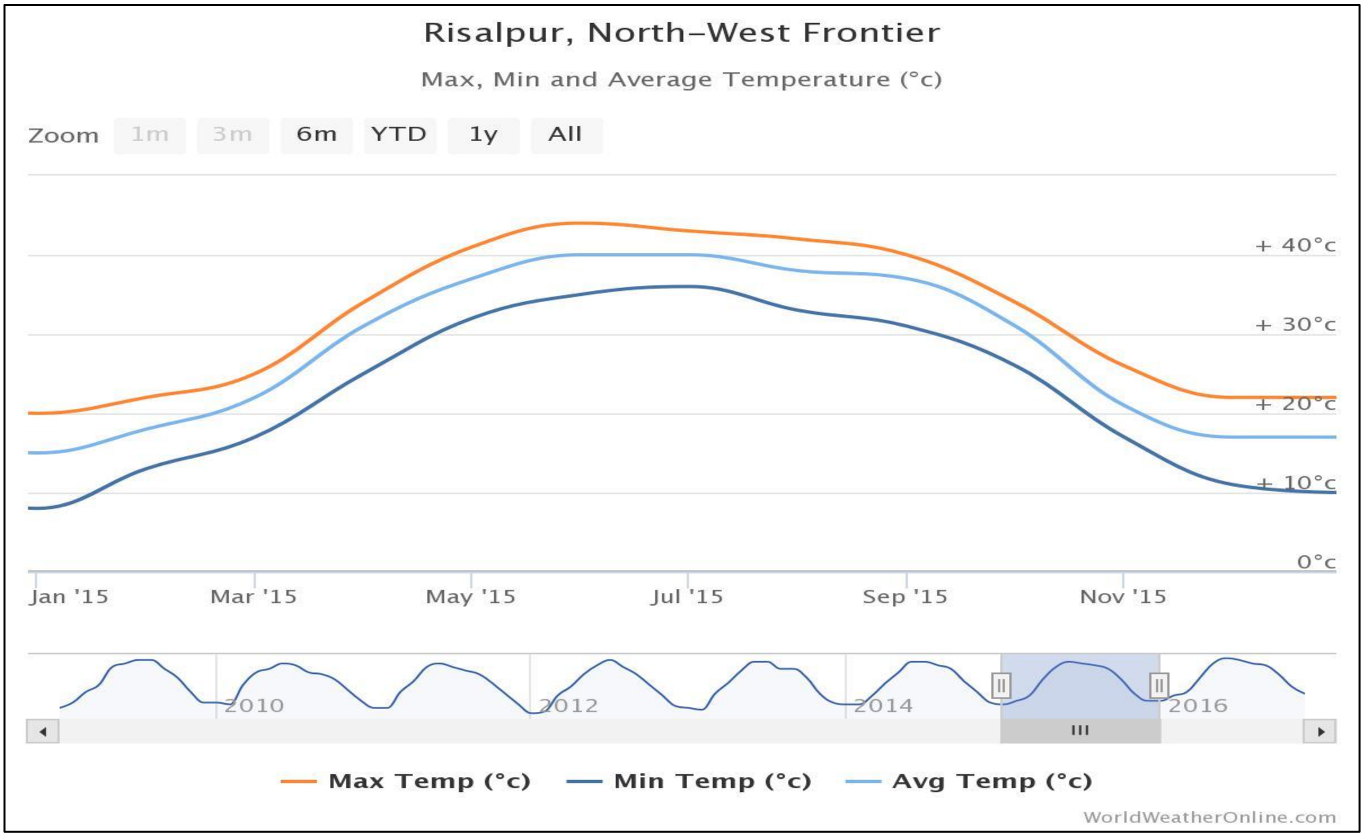
The drainage of the ablution area and the bathrooms are well laid and well tiled. The grade is well adjusted so that there is no leakage or accumulation of water in the drains. The drains are laid in the most simplest of the ways so that maintenance is easy and cheap. Both sewerage and drainage systems are separate.

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

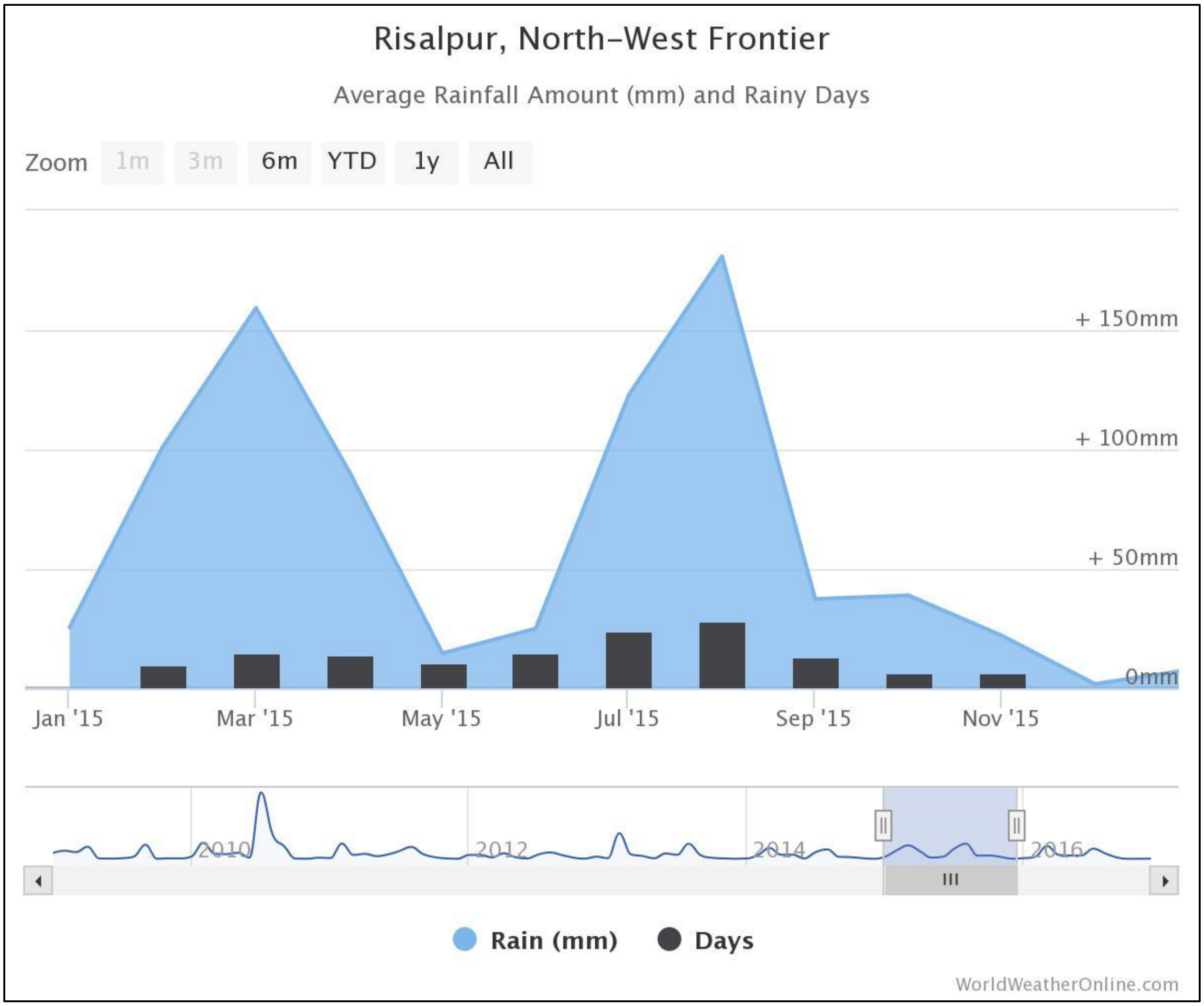
Most of the year Risalpur weather is dry. Winter season begins from mid of November to march; May to September are the summer months. The maximum temperature of Risalpur is upto 45°C. The minimum temperature in winter season is upto 1°C.the spring starts about the center of the month of March.The average annual temperature of Risalpur is 22.5°C



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 was recorded in August.The driest month is October, with 13mm of rainfall.



Graph 4.2: 2015 rainfall data of Risalpur

4.7 Seismicity

Generally, earthquake proves to be the most devastating natural disaster, with a high mortality rate and widespread destruction (UN 2009). Pakistan is located in one of the most seismically active region on earth. As per the Seismic Zoning Map of Pakistan, Project site lies in zone 2B, 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 accelerations. The Map and Table below shows the zoning of KPK according to building code of Pakistan 2007.

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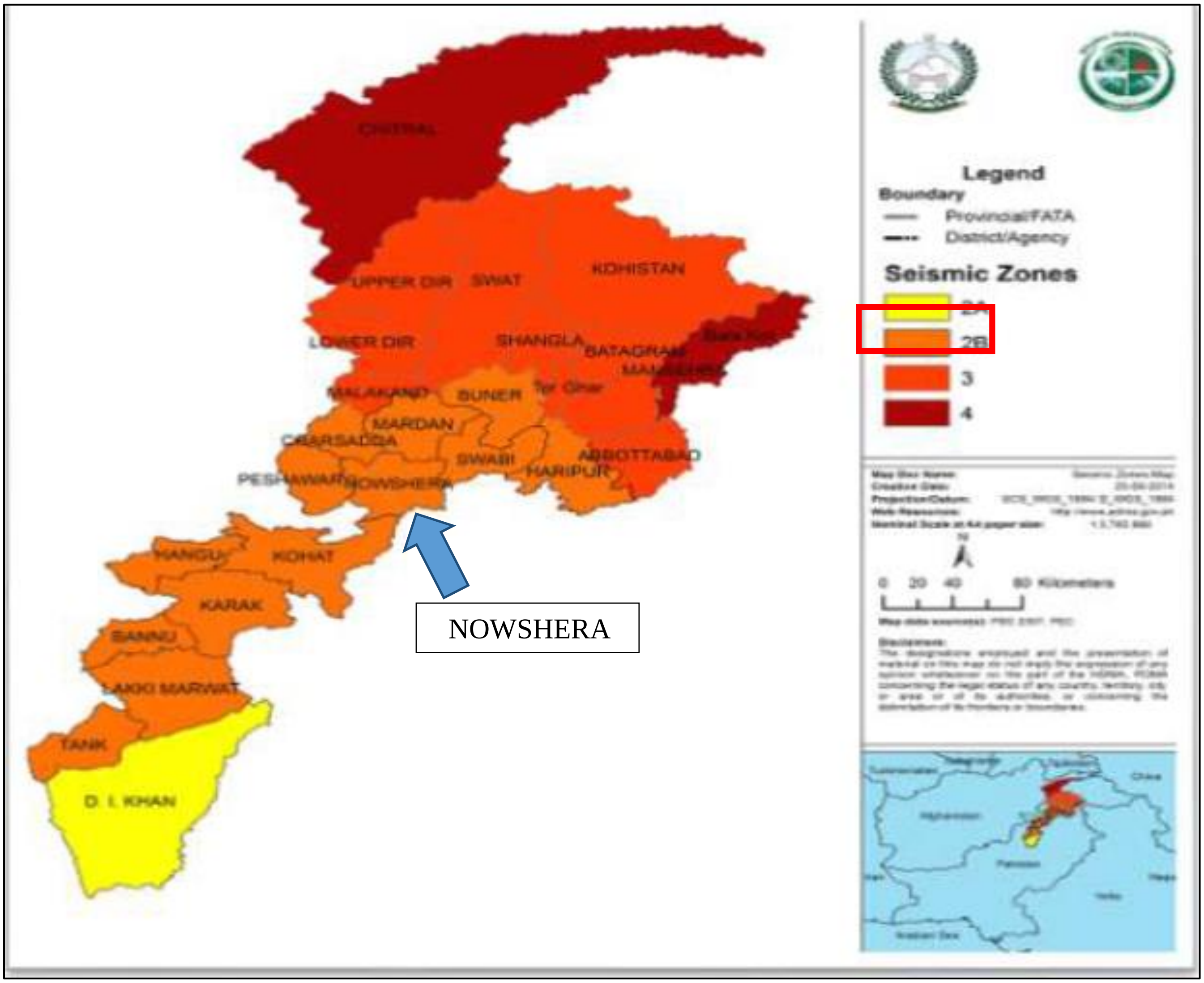


Fig 4.2 Zoning map of KPK

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

4.8 Soil strata

Exploration was done by Standard Penetration Test (SPT) which shows that strata includes only cohesive soils including silt and clay deposits. Split spoon sampler was used, SPT blows and modified 60% energy efficiency is calculated and plotted in the table. For exploration only one bore hole was selected which was near the critical wall of mosque. Total log depth is 50ft. in the figure critical wall and borehole location is shown.

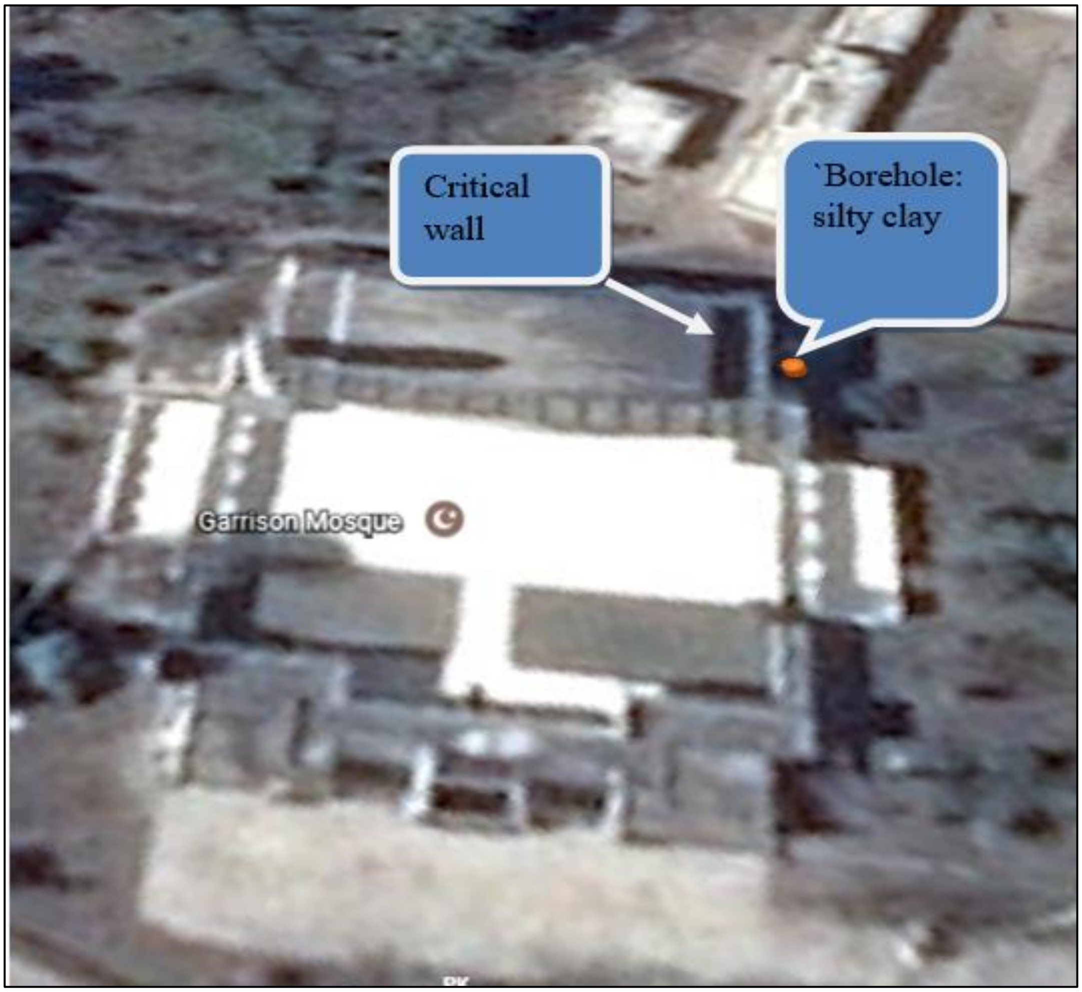


Fig 4.3: Borehole Location

4.8.1 Soil profile

The soil profile of the site was prepared using the data collected from the bore hole 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 soil profile is given in Table 4.1.

Table 4.2: Soil Profile Table

Depth	N	Su(kpa)	plastic Limit	liquid Limit	Classification
1.5	12	120	15%	24%	CL
3	18	104.4	18%	35%	CL
4.5	27	270	13%	16%	ML
6	23	230	36%	40%	CL-ML
7.5	13	130	23%	30%	CL-ML
9	25	250	22%	30%	CL
10.5	23	230	19.70%	28%	CL
12	29	290	18.90%	27.10%	CL
13.5	20	200	19.40%	27%	CL

Chapter 5

RESULT AND ANALYSIS

5.1 General

Geotechnical investigation of 'Masjid-e-Muhammad' was carried out using general and renowned method Standard Penetration Test. In this chapter all results of SPT have been discussed and analyzed. Irrespective of SPT, the seismic properties of strata of Risalpur has been analyzed. In this chapter results of seismological investigation have been discussed along with other results. Strength properties, consolidation of strata and attenuation of earthquake is presented in detail and analyzed clinically in this chapter. Flow diagram shows the conceptual breakdown of the chapter.

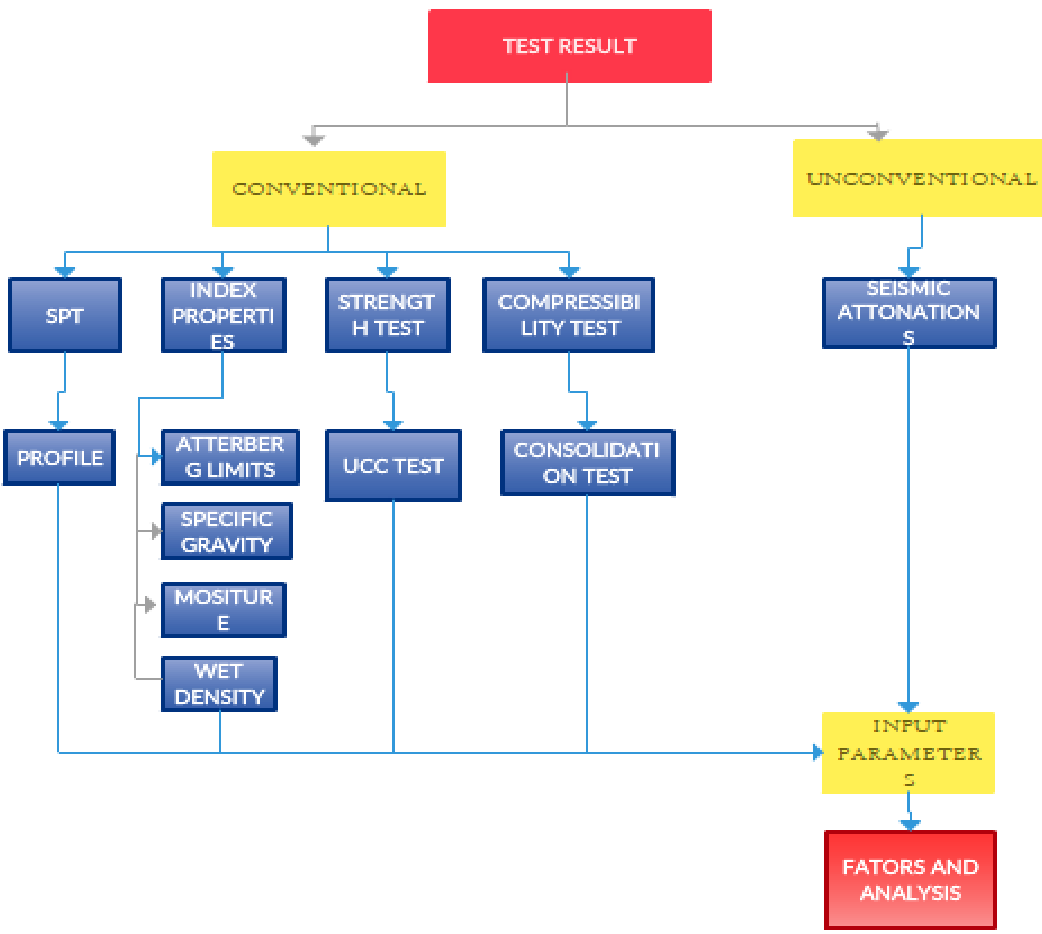


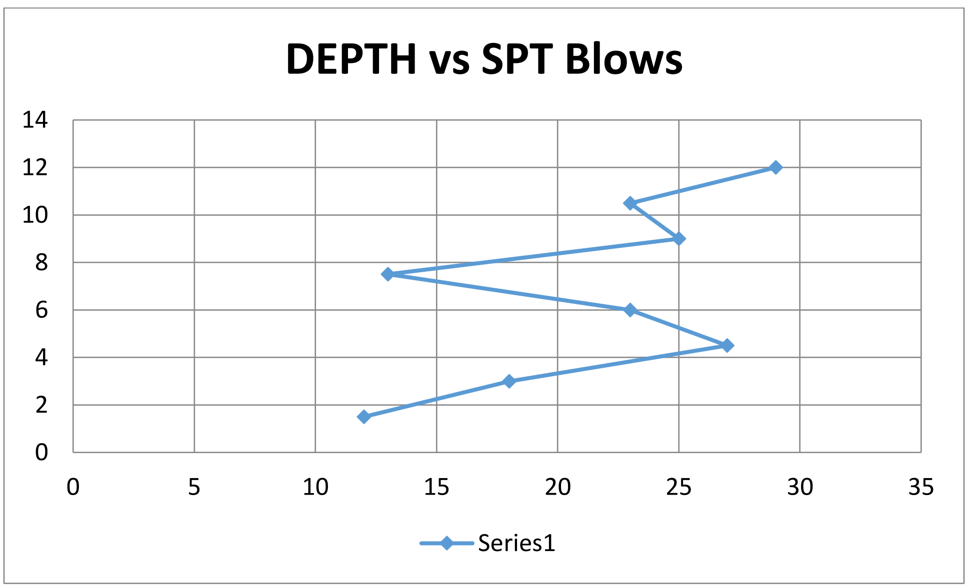
FIG 5.1: Flow Chart for Result and Analysis

5.2 SPT Borehole

For geotechnical investigation the most suitable and economical method was percussion drilling. So percussion drilling was used for research basis. Drilling includes only one borehole close to the critical side of the building. The depth should be 100ft for any dynamic analysis but unfortunately water table was found at 50ft and due to lack of equipment and economy data was collected upto 50ft and rest of the data is interpolated according to other nearby site.

Samples are collected from site by split spoon sampler. These samples are disturbed samples. One undisturbed sample is also collected by Shelby tube for strength property testing and for consolidation test. By index property testing it is revealed that site consists of soil that varies from clay to silt. Mostly silty clay is found. Water table is at 50ft depth. SPT blows value increases as we move down. This is also shown in graph below**.**

Drainage and seepage is not a problem at critical site but the strength of soil was very crucial and less. SPT blows variation with depth is shown in FIG 5.2



GRAPH 5.1: Depth vs Blows

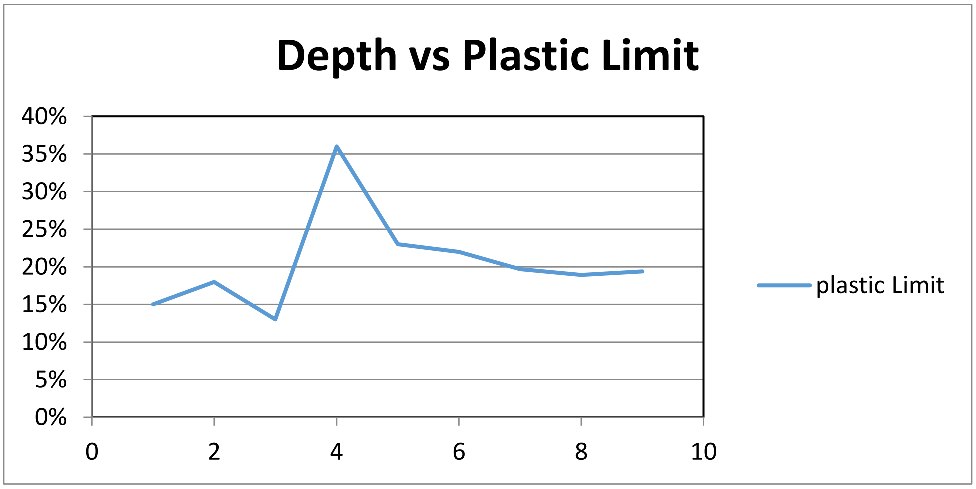
5.3 Atterberg Limits

On the samples collected from the site atterberg limits tests are done from which values of plastic limit and liquid limits were obtained. Generally it is shown that soils having less plasticity and less OCR value have less value of shear modulus. Soil at the site has low plasticity. Values for atterberg limits are shown in table 5.1**.**

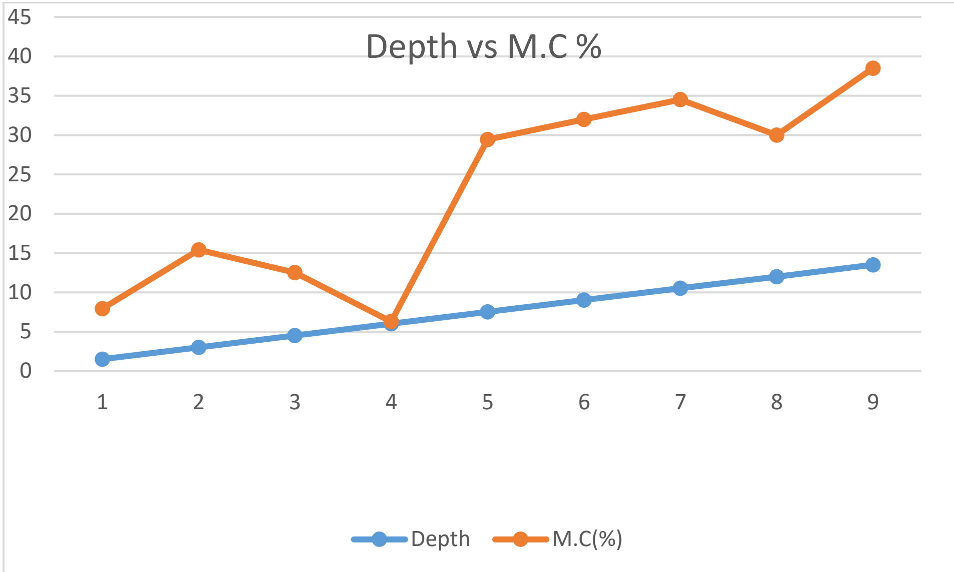
Table 5.1: Atterberg values

BH No	Sample No	DEPTH	LL	PL	PI	M.C (%)
BH-1	S-1	1.5	24%	15%	9%	6.4
BH-1	S-2	3	35%	18%	17%	12.4
BH-1	S-3	4.5	16%	13%	3%	8
BH-1	S-4	6	40%	36%	4%	27%
BH-1	S-5	7.5	30%	23%	7%	21.9
BH-1	S-6	9	30%	22%	8%	23
BH-1	S-7	10.5	28%	19.70%	8.70%	24
BH-1	S-8	12	27.10%	18.90%	8.20%	18
BH-1	S-9	13.5	27%	19.40%	7.60%	25

There is no particular pattern found in plasticity. Only one sample have plasticity greater than 10%.



Graph 5.2: Depth vs Plastic Limit



Graph 5.3: Depth vs M.C

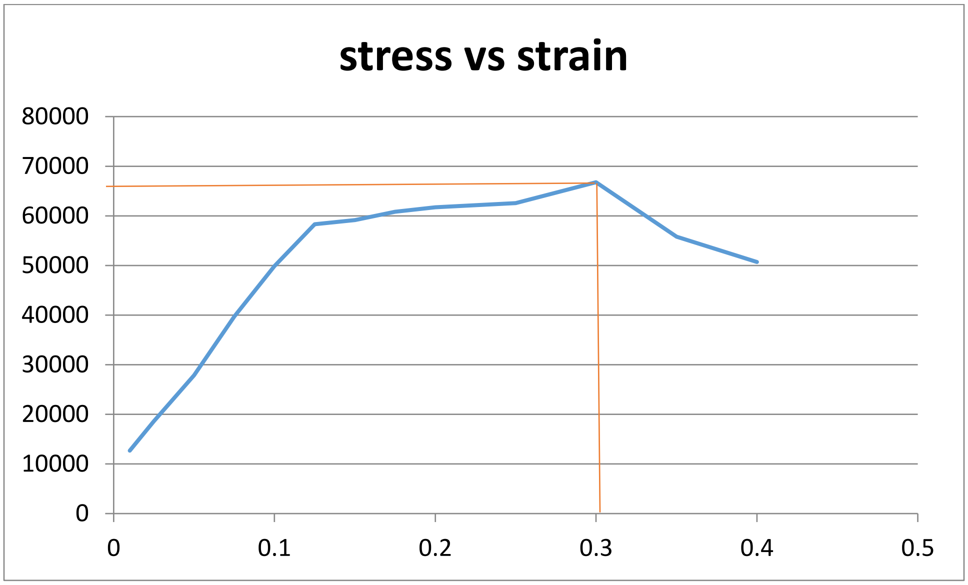
5.5 Strength Property Testing

5.5.1 Sample Ejection

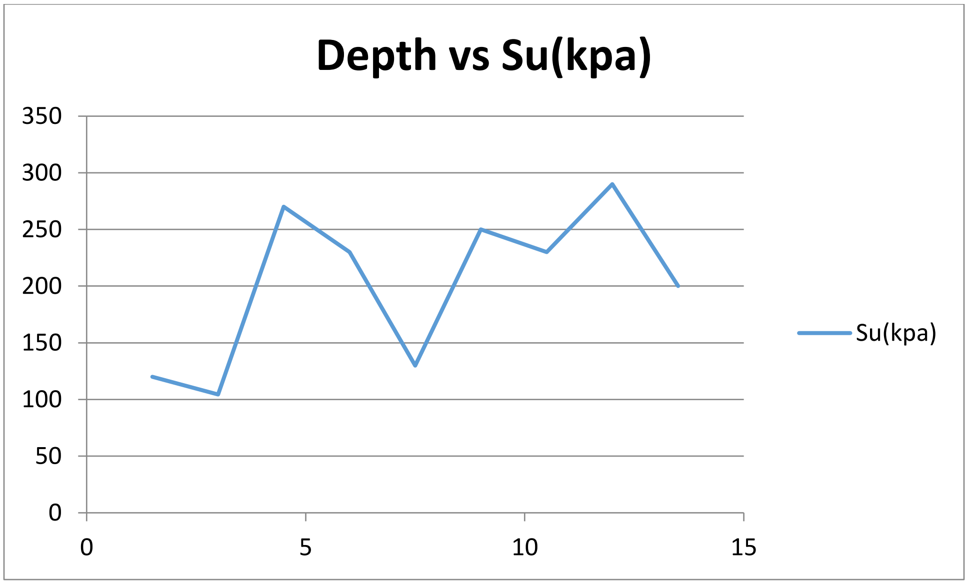
One undisturbed sample was collected at a depth of 18ft. Later sample was ejected by help of hydraulic system. This hydraulic system disturbs the sample up to some extent. Undisturbed sample consist of silt. It is cut in two half. One was used for unconfined compression test and other was used for consolidation test.

5.5.2 Unconfined Compression Test

A standard sample is prepared and its density and moisture content is determined. It is then placed in UCC apparatus and load is applied. Due to low strength sample failed after some time. Test results are shown below with data**.**



Graph 5.4: Stress vs Strain



Graph 5.5: Depth vs Su

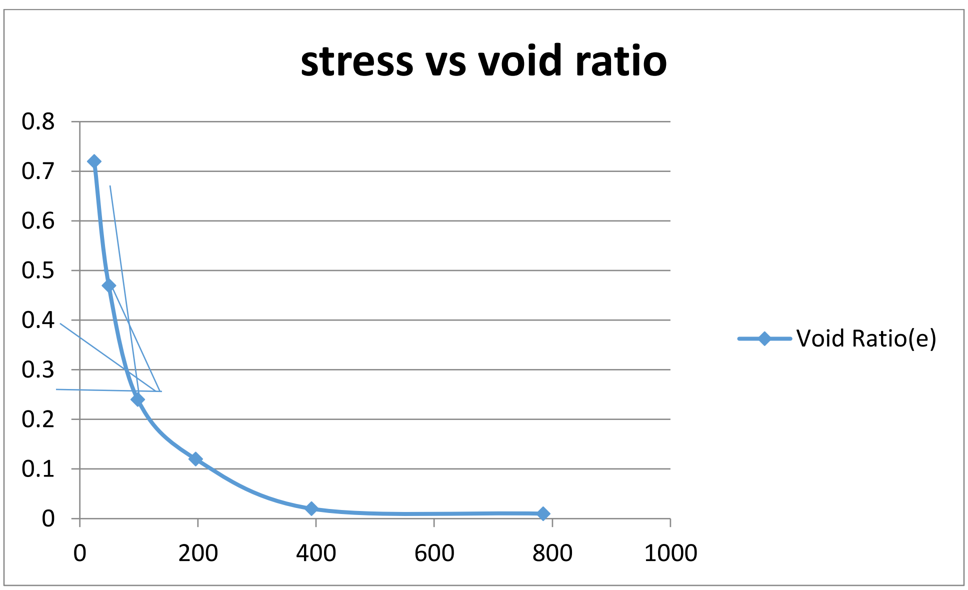
5.6 Compressibility Testing

5.6.1 Consolidation Test

In order to know the history of site and to find the value of shear modulus, maximum past effective pressure is required to find. Basically the correlation used for calculation requires value of OCR. A standard sample is prepared and placed in consolidation machine. The test takes one week for completion. After analyzing the data it found that maximum effective past pressure is 100kpa. Test result is shown in table 5.2 and graph 5.6**.**

Table 5.2: Void Ratios

P(kpa)	Void Ratio(e)
24.5	0.72
49.03	0.47
98.06	0.24
196.12	0.12
392.24	0.02
784.48	0.01



Graph 5.6: Stress vs Void ratio

5.6 Attenuation of Earthquake Waves

In order to run dynamic analysis site specific seismic response is required. For response creation original waves of 26 October, 2015 earthquake is required.

Station data was first taken from Earthquake catalog USGS site and then time history data was extracted by using station data from IRIS site.

Soil always attenuates the waves because damping of soil is always less than 1. For site specific response generation we used the software 'Deep Soil'.

5.6.1 Bed Rock Motion

Bedrock wave's motion data was taken at bedrock which was at Kabul, Afghanistan. These waves' data was taken as .txt file from IRIS site and then converted into motions by exporting data in to deep soil. Motions obtained in graph form are shown in Fig 5.3.

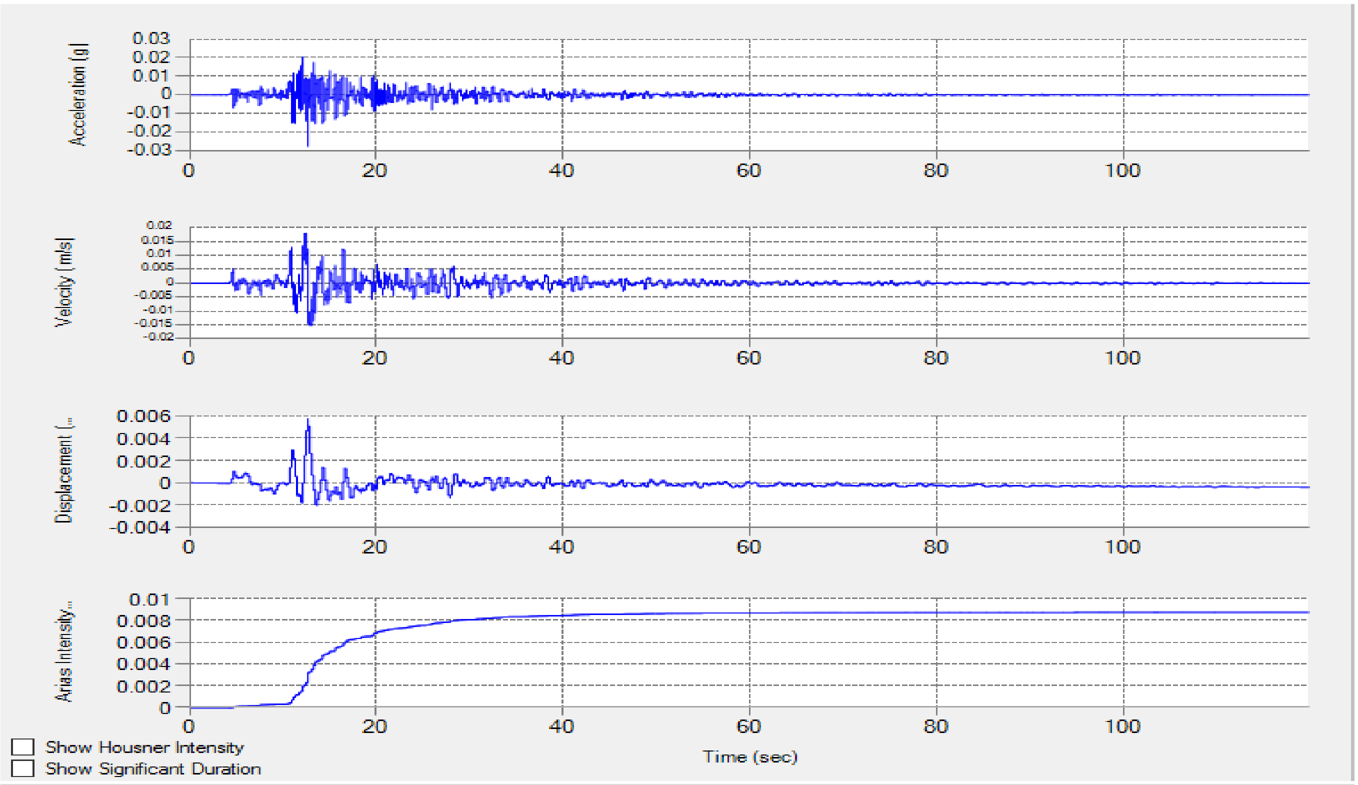


Fig 5.2: Motion Graphs

Above motions show that PGA is 0.027767, PGV is 0.017835 and PGD is 0.005763.

5.6.2 Geometrical Correction

Earthquake response to a site depends upon distance from the source and faults present in between. Due to presence of faults seismic wave's energy dissipates while travelling.

Earthquake associated with volcanic activity depends on its geometrics. If considered that earthquake is uniformly distributed over the length of fault then a probability density function must be calculated that act as scale factor.

$$F_R(r) = r/L_f\sqrt{r^2 - r_{min}^2}$$

Using above formula scale factor calculated as 0.5.

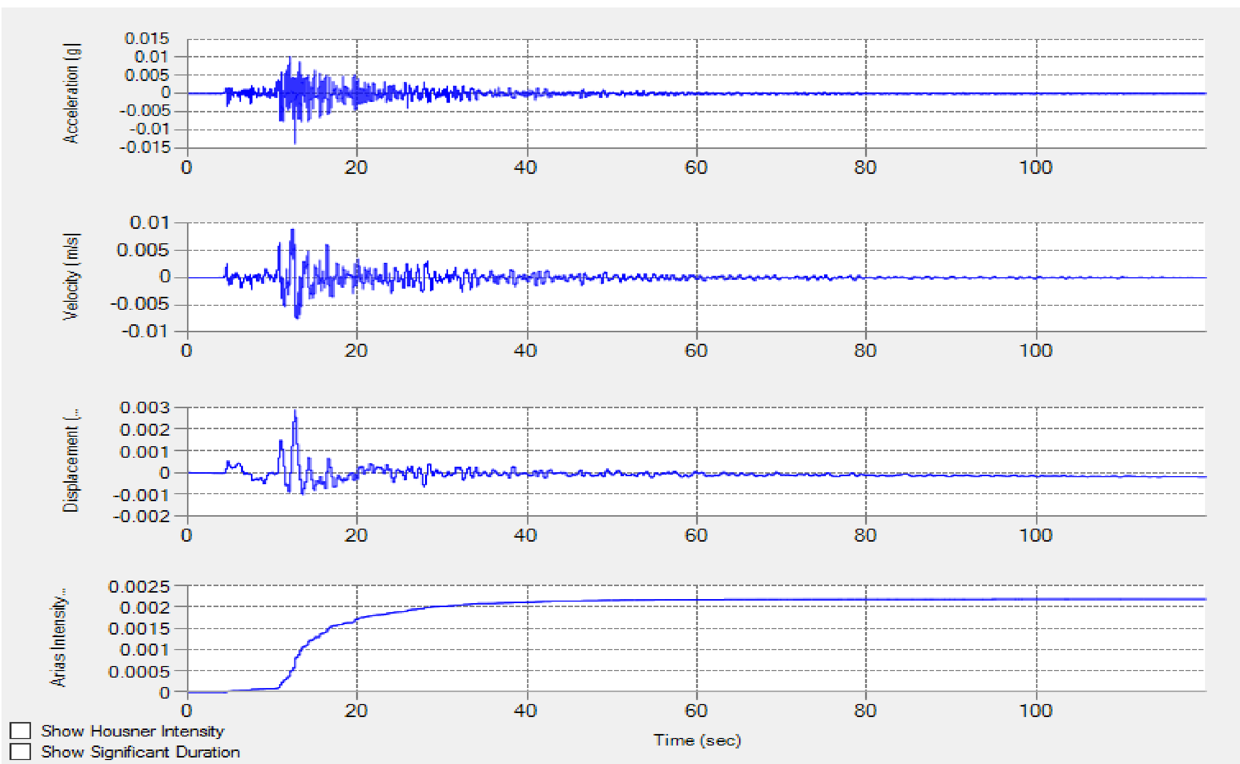


Fig 5.3: Motions after applying scale factor

5.6.3 Attenuation of Corrected Wave Motion

5.6.3.1 Required Parameters

- **Damping Ratio:**

Damping ratio of soil was determined by back bone curve using plasticity index and OCR of each layer. Damping is obtained at low range cause in dynamic analysis strain is as low as 1%.

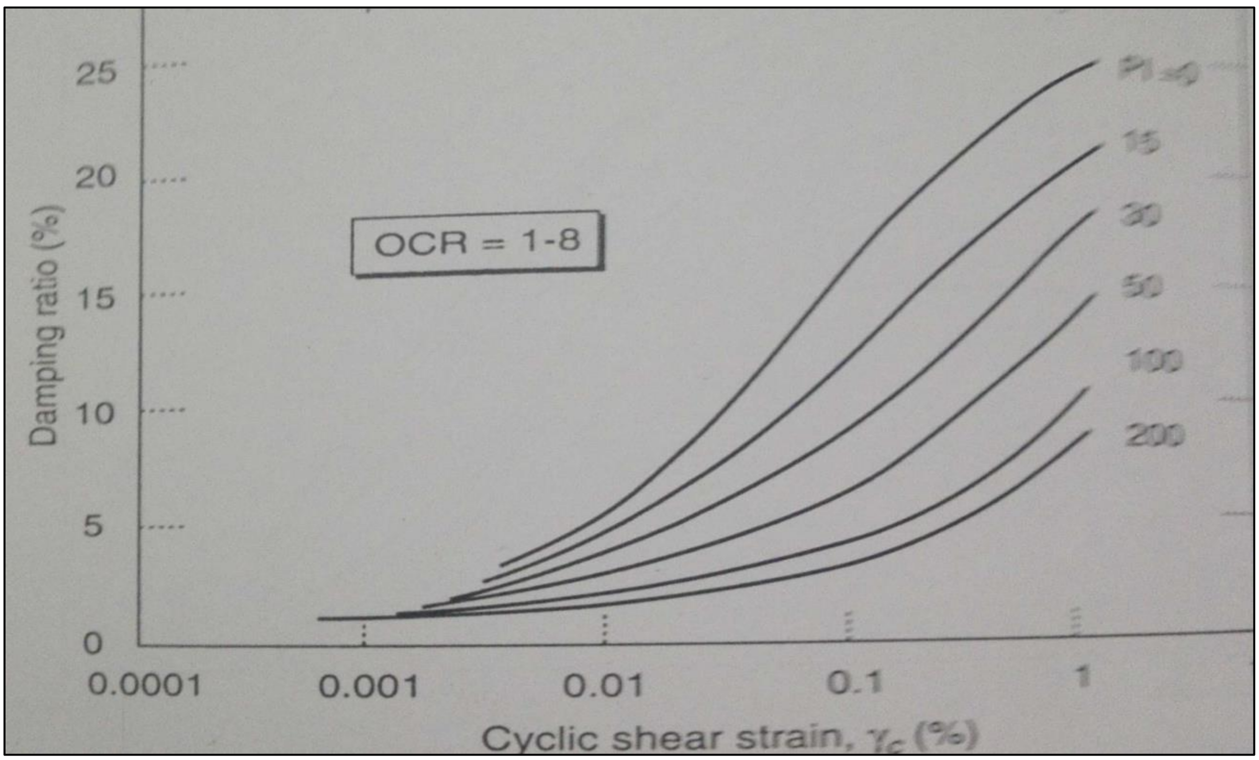


Fig 5.4: Back Bone Curve

- **Shear Modulus**

Shear modulus for each layer is calculated by using correlation.

Different parameters and their values for each layer are shown below.

Table 5.3: Parameters used for Attenuation

NO	NAME	thickness	unit weight	shear velocity	damping ratio
1	Clay	1.5	18.1	79904.95109	5
2	Clay	1.5	18.87	97873.71161	4
3	Silt	1.5	19.62	129933.5487	3
4	Silt-Clayey	1.5	20.41	110233.3277	5
5	Silt-Clayey	1.5	21.22	149739.5286	4
6	Clay	1.5	21.12	153793.9547	3
7	Clay	1.5	20.38	145109.4633	5
8	Clay	1.5	21.54	199860.6142	4
9	Clay	1.5	24.53	257850.4797	3
10	Clay	1.5	24.53	270038.8998	5
11	Clay	1.5	24.53	281689.4453	4
12	Clay	1.5	24.53	292868.7238	3
13	Clay	1.5	24.53	303630.4613	5
14	Clay	1.5	24.53	314018.7759	4
15	Clay	1.5	21	250032.7296	3
16	Clay	1.5	21	257455.2321	5
17	Clay	1.5	21	264667.1668	4
18	Clay	1.5	23	320337.72	3
19	Clay	1.5	23	328457.1114	5
20	Clay	1.5	23	336379.132	4

- **Bed Rock Properties:**

Bed rock properties include shear modulus, density and damping ratio of bed rock. All of these are taken from literature.

5.6.3.2 Analysis

Adding all parameters in the software and applying the corrected motion, attenuated motion and time history is obtained at layer 1 as shown in Fig 5.5

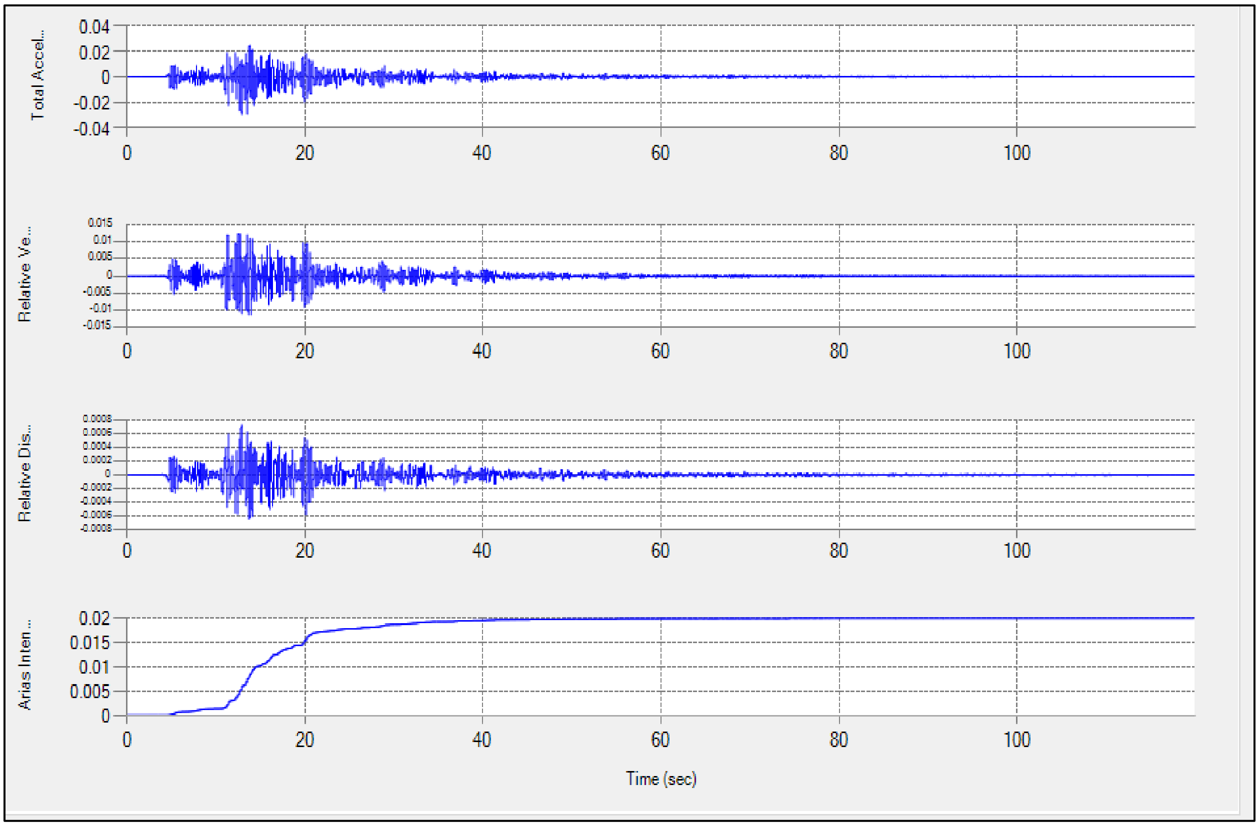


Fig 5.5: Attenuated Wave Motion

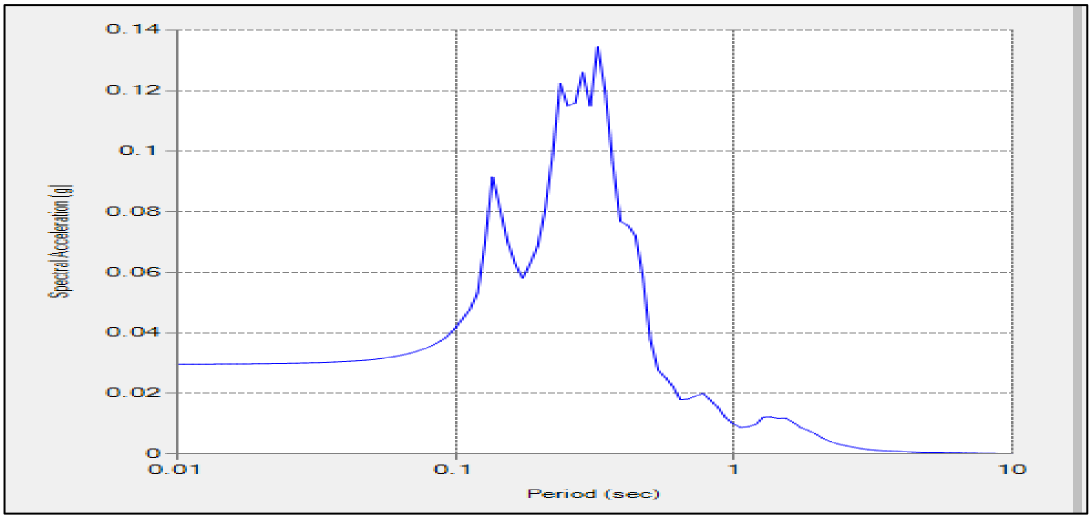


Fig 5.6: Spectral Plots

Peak acceleration value in terms of g is 0.135.

5.6.3.3 Comparison

Comparison between before and after attenuation of waves.

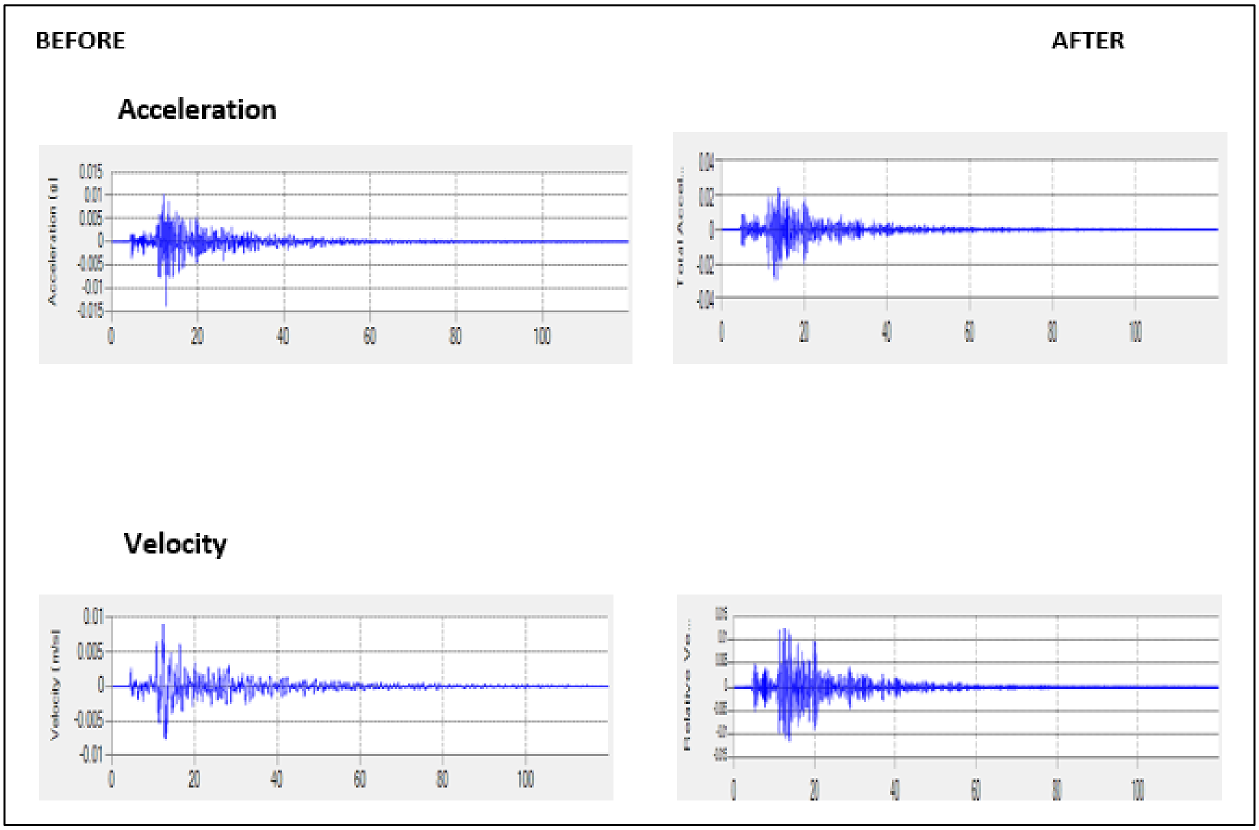


Fig 5.7: Before and After Attenuated waves

5.7 Triggering factors

Testing results and site inspection shows that causal and triggering factors are following

- Settlement capacity of soil.
- Seismic activity.

These factors are modeled in UDEC 5.0 for analysis and to check their contribution towards failure.

5.8 Results

Critical wall of Mosque has been modeled on UDEC software for dynamic analysis purpose. Soil and seismic properties has been given to the software and analysis was run. The results of analysis has been shown in Figures.

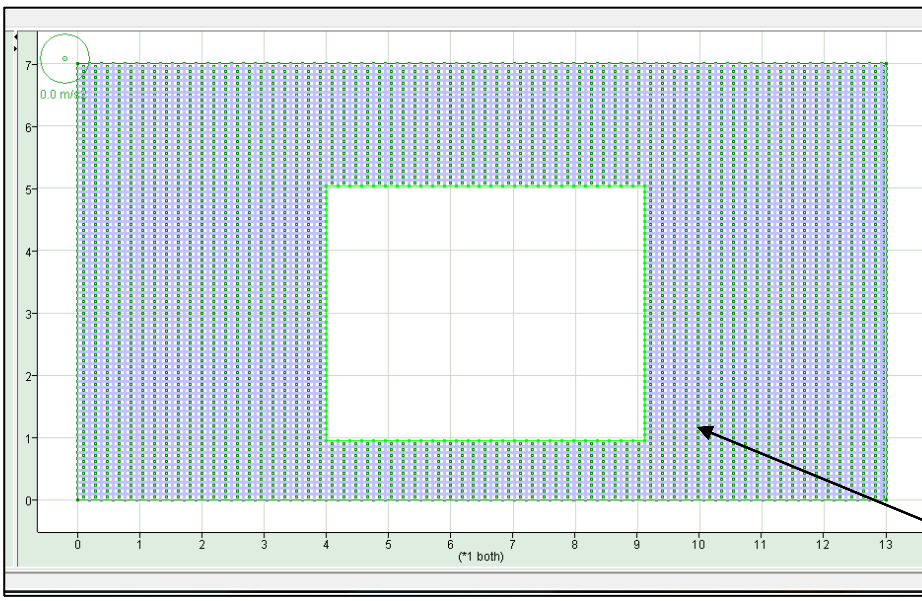


Fig 5.8: Initial Model built in UDEC 5.0

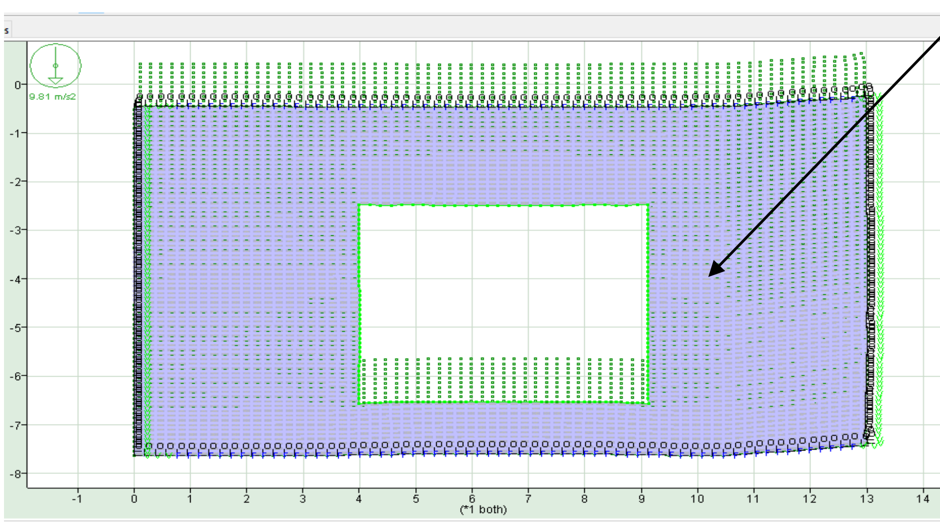


Fig 5.9 Displacement of Joints after dynamic load

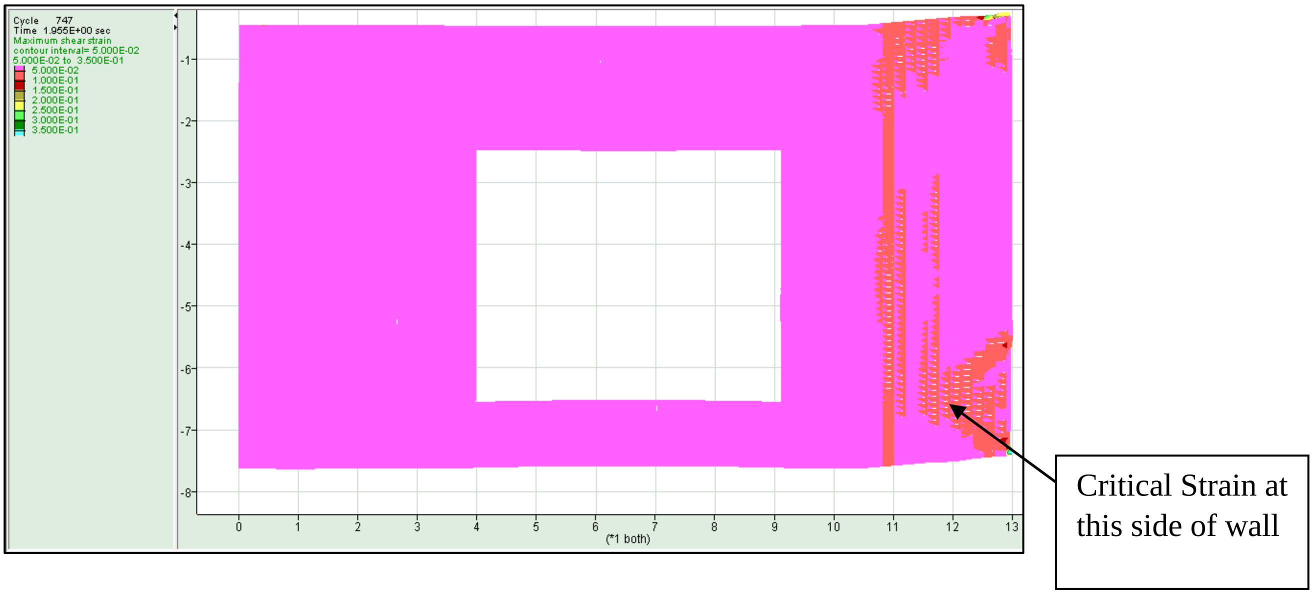


Fig 5.10: Max Shear Strain

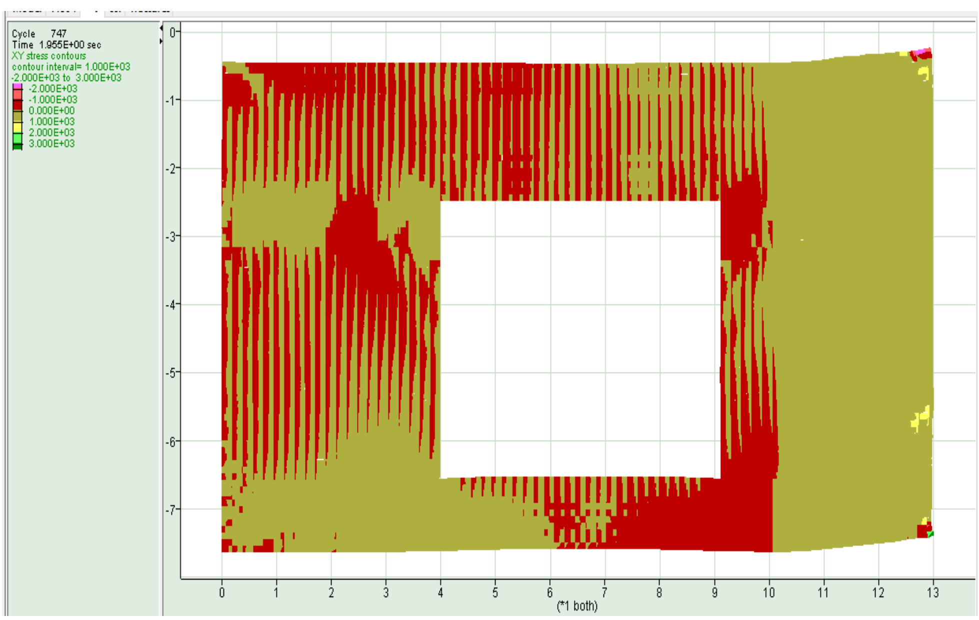


Fig 5.11: Stress at xy plane

REMIDIATION

6.1 General

Buildings cracked due to many reasons. These reasons will be discussed in chapter of conclusion. These reasons include differential settlements, high loads and some other reasons including pore pressure dissipation due to high loadings of earth quake and static loading. The cracks are prevented by the use of remedies for the area. The cracked buildings can be repaired by using some technique. These techniques and methods have been in this chapter. The selection of method depends on cost effectiveness and current situation of buildings for the application.

Flow chart shown below shows the content of this chapter.

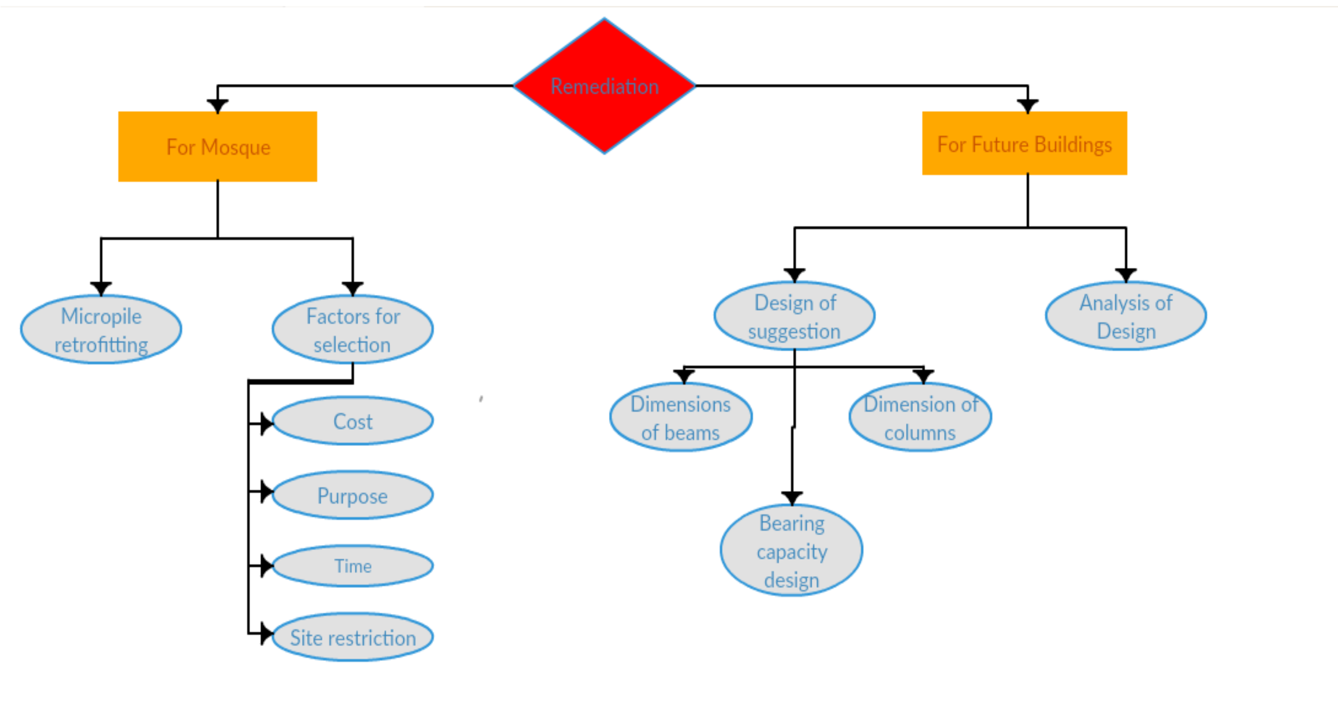


FIG 6.1: Flow Chart for Remediation

6.2 Methods for Selection

There is lot of methods for the rehabilitation of cracked structure. Some options are for super structure and some options are for sub structure. We will discuss only the foundation improvement techniques here. Following are some methods for foundation improvement.

- Underpinning
- Grouting
- Micro pile retrofitting

Following descriptions will tell that why the above techniques cannot be used in our project. Every option has certain advantages and disadvantages. So we have to too much site specific for the selection above mentioned methods.

6.2.1 Underpinning

This is very effective in improving the strength of foundation soil. It is applied by jacking super structure or on the surfaces where there is no superstructure. But it is very effective method in decreasing the access of earthquake waves to structure.

This method basically employs the beams under the walls and piles or something below beams. So if we ensure the size of beam under wall according to seismic building code then we can actually decrease the effect of earth quake waves to superstructure. Followings are some factors due to which we cannot apply this method to current situation.

Cost of underpinning under such long walls as in the case study (13m) will increase too much and we will have to jack the building also which also require cost. So cost of rehabilitation will increase too much.

What is the purpose of rehabilitation? If we see in this case it is to decrease only the future danger from further collapse. So there is probability of earthquake happening and the wall will face more problems in jacking because it is not a frame structure.

Time also affects in deciding technique in a way that is it necessary to rehabilitate the problem quickly? But the technique will take time. So it is not advisable from time point of view.

Decision of any improvement technique depends on the site also that how important is the site during your work. Site is very sensitive because it is required every time for people to worship. So we cannot risk anything. So we cannot choose this technique.

Hence by all the four factors discussed above it has been proved that we cannot choose the technique of underpinning to reduce the future hazards of any incoming earthquake. By time, cost, purpose and site restrictions this technique is unfeasible.

6.2.2 Grouting

It is almost similar kind of method as the underpinning is. The difference between the two is that the underpinning method depends on the beam provided under the wall but the grouting technique involves no such beam. The actual difference of two methods for the case study will be that underpinning stops the waves to interfere with structure up to some extent but grouting technique will increase the load bearing capacity because it enhances the foundation. (Shye and Robinson, 1980)

Following discussion will tell that how this method is difficult to apply in the present scenario.

Cost of this technique will increase because it involves batching of soil crete, eroding the strata up to certain depth by pressure and the soil creting the hollow strata. These are very complex processes and they will increase price. So it is not advisable in terms of cost.

Time is again a crucial factor in deciding this method. Because it will not complete in one or two days it will take time. So it is not feasible with respect to time.

Purpose of rehabilitation is to save building from more waves. But this technique will increase bearing strength and will not stop waves. So it does not fulfill the purpose.

Site restricts this complex method to be done because it requires large space for machines to work. So how can this technique be use within the boundary walls, so site restrictions are present for it and this method is not feasible. (François et al., 2007)

By above discussion it has been proved that grouting technique cannot be used in case study.

6.2.3 Micro Pile Retrofitting

Micro pile retrofitting is the best option for present case. Micro piles are very small in size so they can easily be set and place at their position. They save cost and time. There are very less site restrictions in this case. Purpose also satisfied by this option. So micro pile retrofitting is a suggestion for future of the building.

6.3 Method Used At That Time

When earthquake came and cracks appeared in building then the simple method was used for simple rehabilitation which was grouting. It has no benefit in terms of any future earthquake. So properly suggested remedy must be used.

For future construction in Risalpur it is suggested to use frame structure. Frame structure option was properly designed and analyzed (using PLAXIS). The following paragraph tells that how we design the mat footing for columns of building.

6.4 Design of Proposed Frame Structure

The proposed frame structure consist of three columns and three beams. Following diagram shows the proposed structure.

All the columns and beams were first designed on the basis of seismic provisions from seismic code. Each beam used was 30 inch deep and 12 inch wide and columns were 14*14 in size. This preliminary design was checked in ETABS. It was satisfied and we took the stiffness and flexural rigidity from ETABS. This was the structural design of our proposed frame structure.

Beams were 13m long and there were three beams including plinth beam, lintel beam and top beam. All columns were 14*14 inch*inch in size and 9ft in height. All dimensions were designed so that this 2-d frame must fits in 3-d.

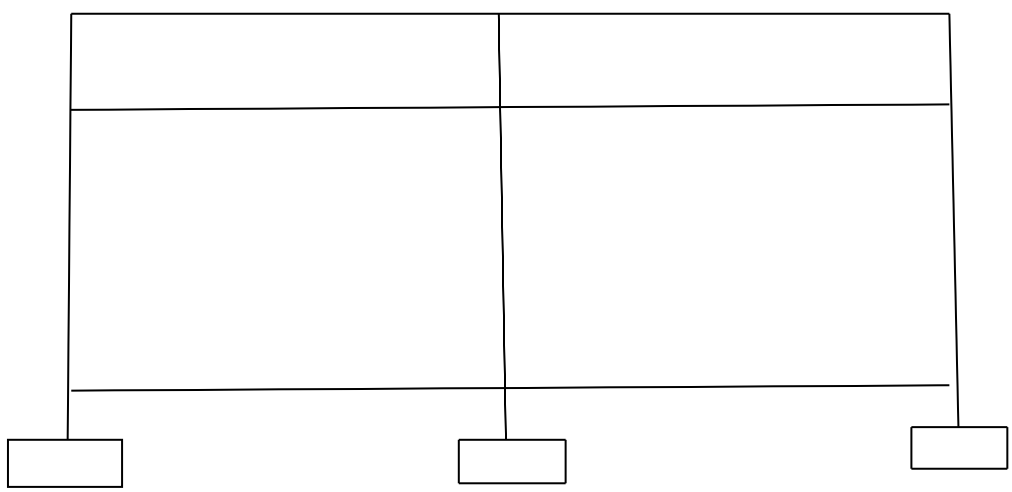
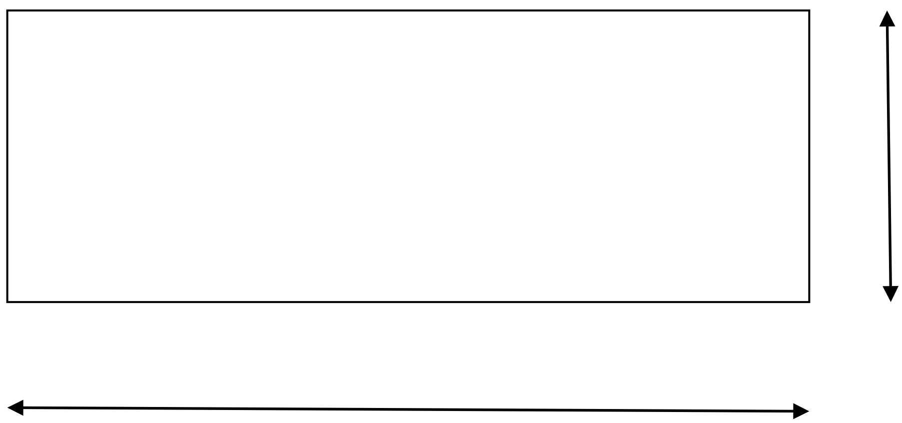


FIG 6.2: Frame structure

6.5 Design of Mat Foundation/Bearing Capacity Based Design

All columns were supported on a mat foundation. The size of this mat foundation was calculated by the bearing capacity procedure. Different depth and width of foundations were selected and the capacity of bearing soil was calculated and compared with loads. Hence a 4ft wide and 1.5ft deep mat foundation was decided.

1.5ft



4ft

FIG 6.3: Foundation Dimensions

Now flexural stiffness and flexural rigidity of all the beams, columns and foundations were calculated. These parameters along with all soil properties were input for the analysis of frame structure.

The design of all structure components was according to guidelines of seismic provisions. So our structure has capacity to resist static and dynamic loads. The frame structure was analyzed in ETABS according to loads of the building and then proper sizes of beams and columns were calculated. After structural and geotechnical design of the building (2d) analysis was done in software PLAXIS.

6.6 Analysis of Design

Designed frame geometry was first built in PLAXIS. Size of all the beams and columns were given and their flexural properties were also declared. All the soil layers were also declared along with their index and strength properties. All index testing and strength testing data was used. Medium mesh was declared in software. Figures attached below shows the geometry model of frame and soil.

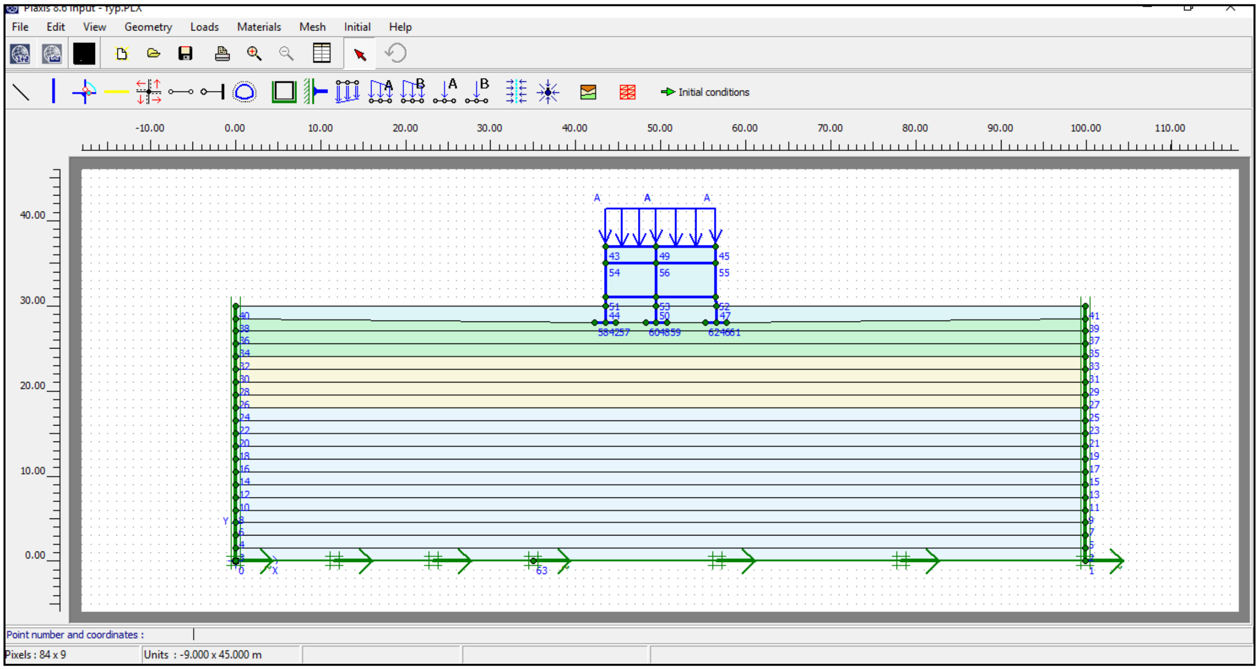


FIG 6.4: Model Built in PLAXIS

In the above diagram we gave the earthquake boundary conditions and static boundary conditions also. In static conditions sides behaves like roller. For earthquake we choose viscous boundary conditions.

After this we apply an initial condition that includes k0 condition and water table declaring. Then we calculate and gave time history of earthquake. First we run plastic (static) analysis then we run dynamic analysis. Following diagrams and discussion elaborate the results of analysis.

- **Deformed Mesh (shape)**

Following diagrams shows deformed shape of the model in both static and dynamic state. PLAXIS magnify results up to 100 or 200 hundred time to elaborate results. So in reality there are no such large deformations.

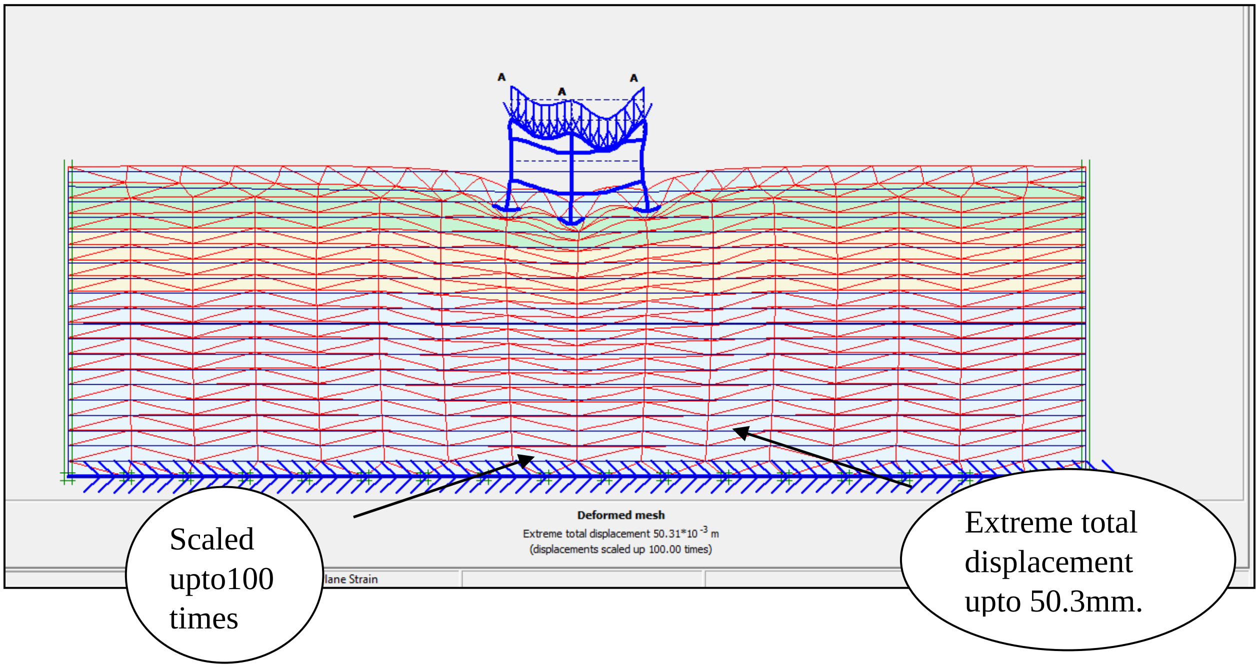


FIG 6.5: Deformed mesh of static analysis

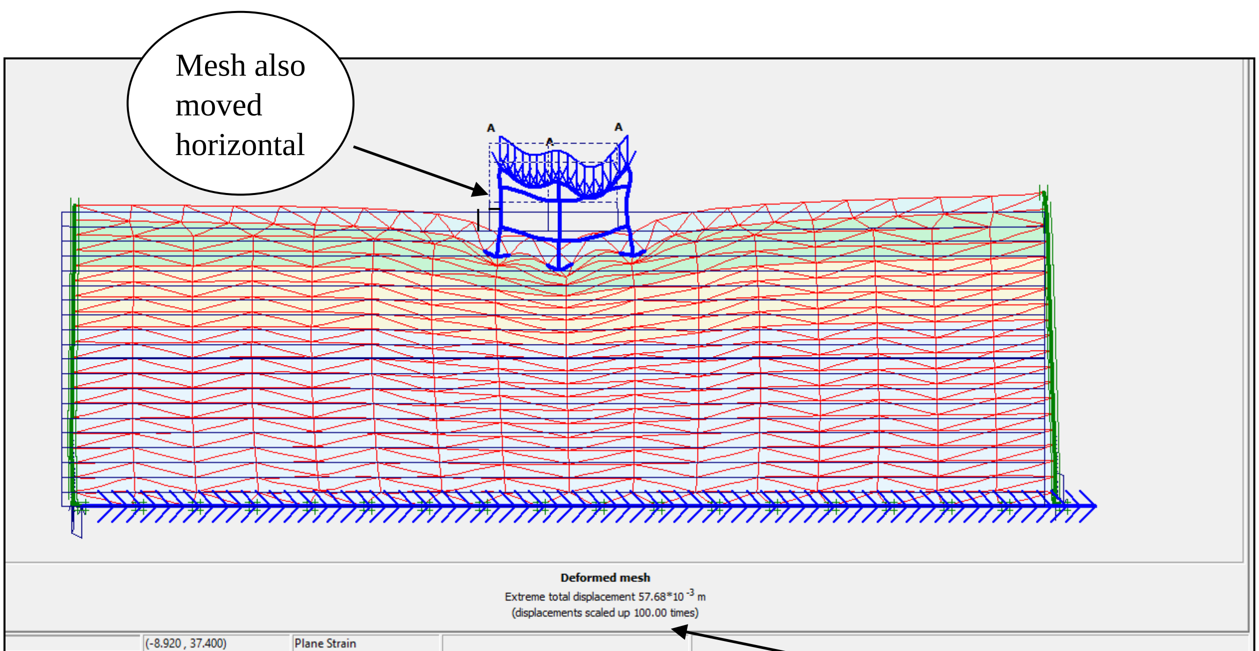


FIG 6.6: Deformed Mesh in Dynamic Analysis

Following diagrams shows the extreme displacements in both cases. These displacements are from fixed horizontal and vertical positions for both the cases shown in FIG 6.6

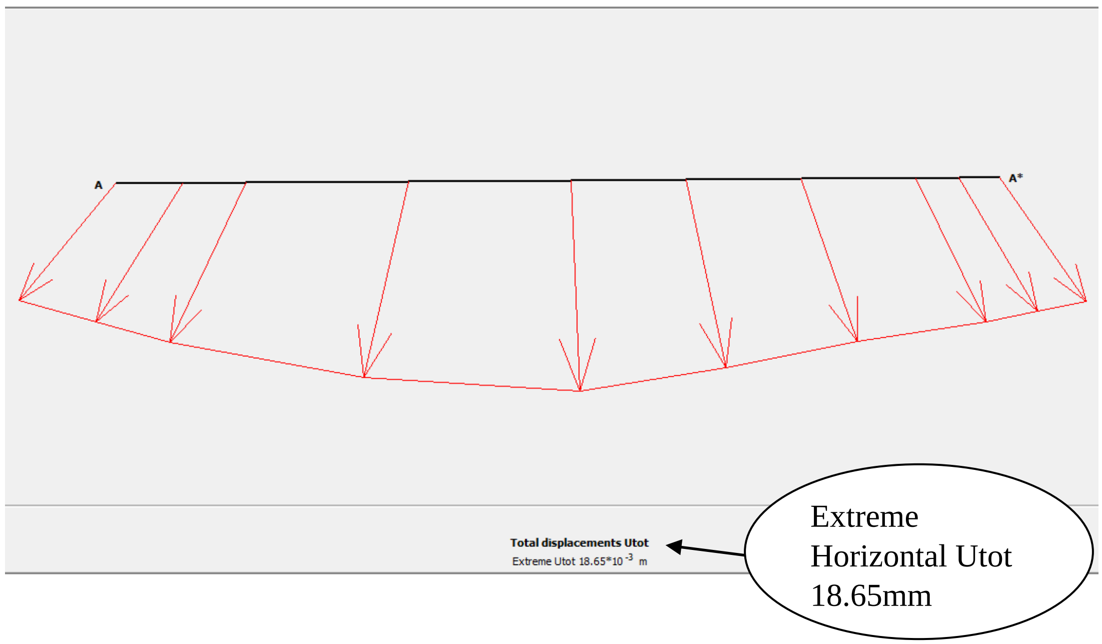


FIG 6.7: Horizontal Displacements in Static analysis

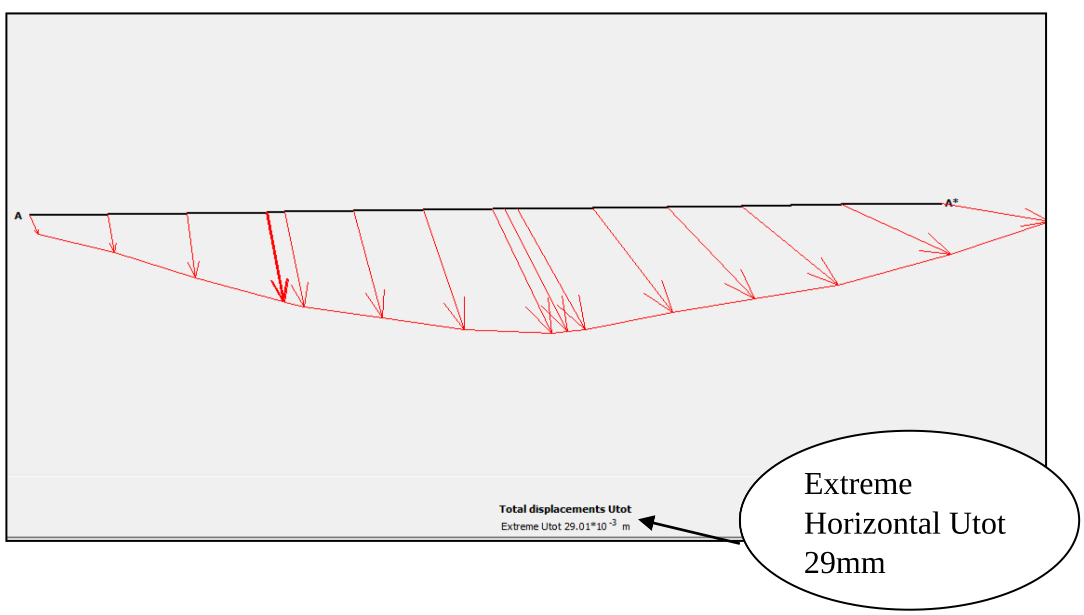
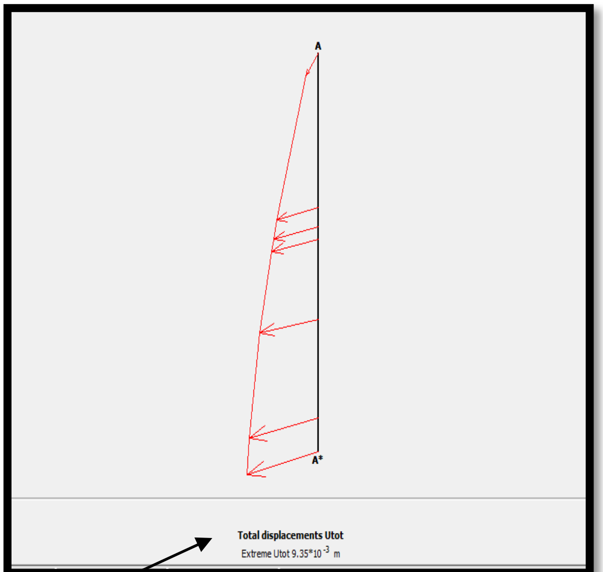
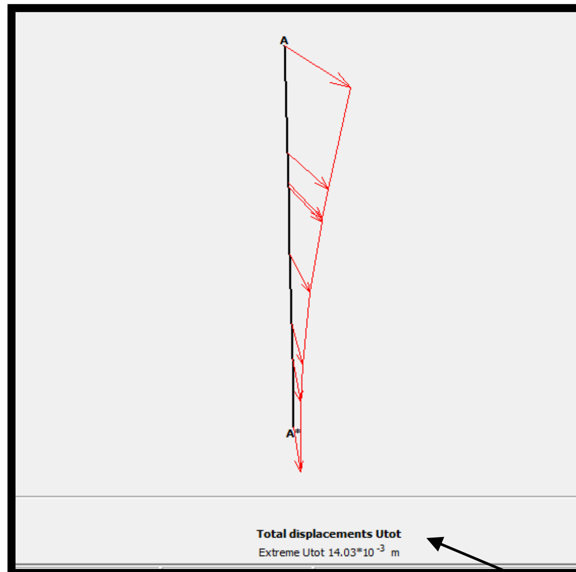


FIG 6.8: Horizontal Displacements in Dynamic analysis

- . **Comparison of Vertical Displacements in Both Analyses**





Extreme Utot 9.35mm

FIG 6.9: Static Analysis

FIG 6.10: Dynamic Anlalysis

Extreme Utot 14.03mm

From comparison of vertical and horizontal displacements, it is clear that difference in displacement occurs due to earthquake. But this difference is not very large. To check why displacement occur due to Earthquake excess pore pressure has been checked before and after earthquake.

- **Excess pore water pressure**
  Excess Pore Pressure has been shown in the FIG 6.11 and FIG 6.12. It has been analyzed for both before and after earthquake.

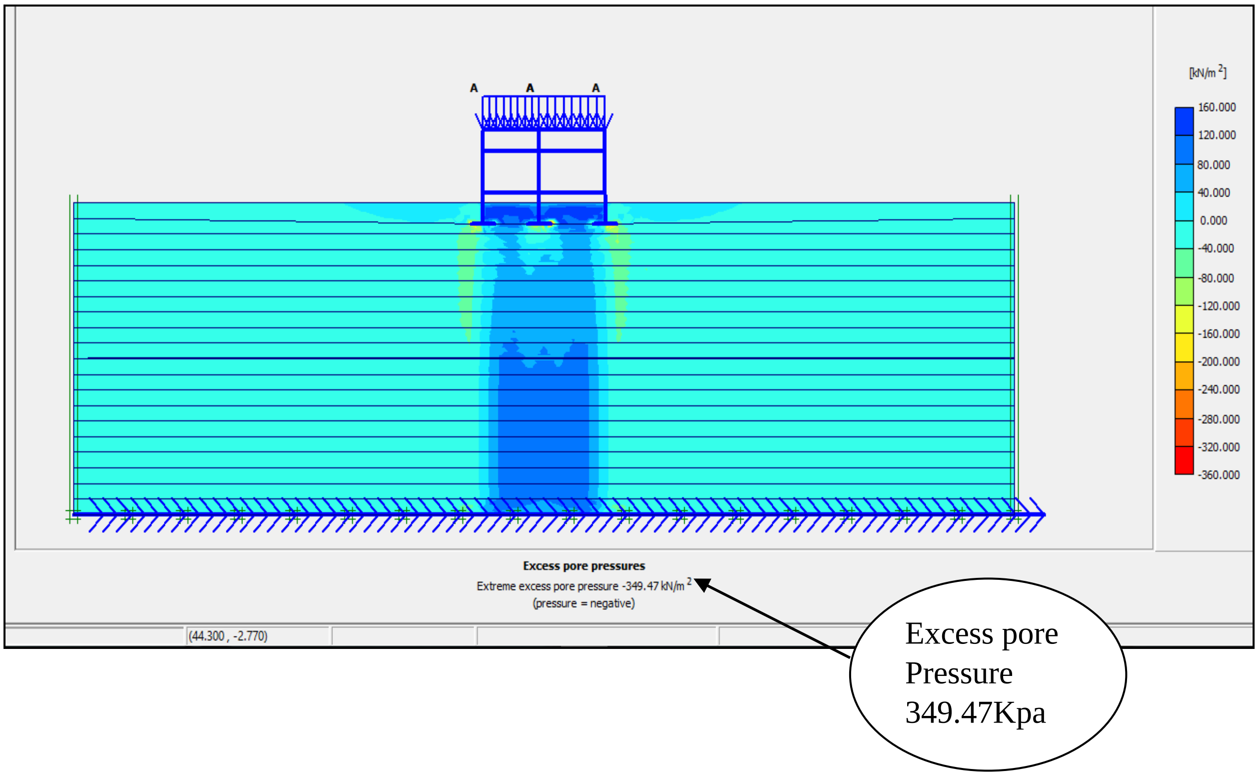


FIG 6.11: Excess Pore Pressure for Static Analysis

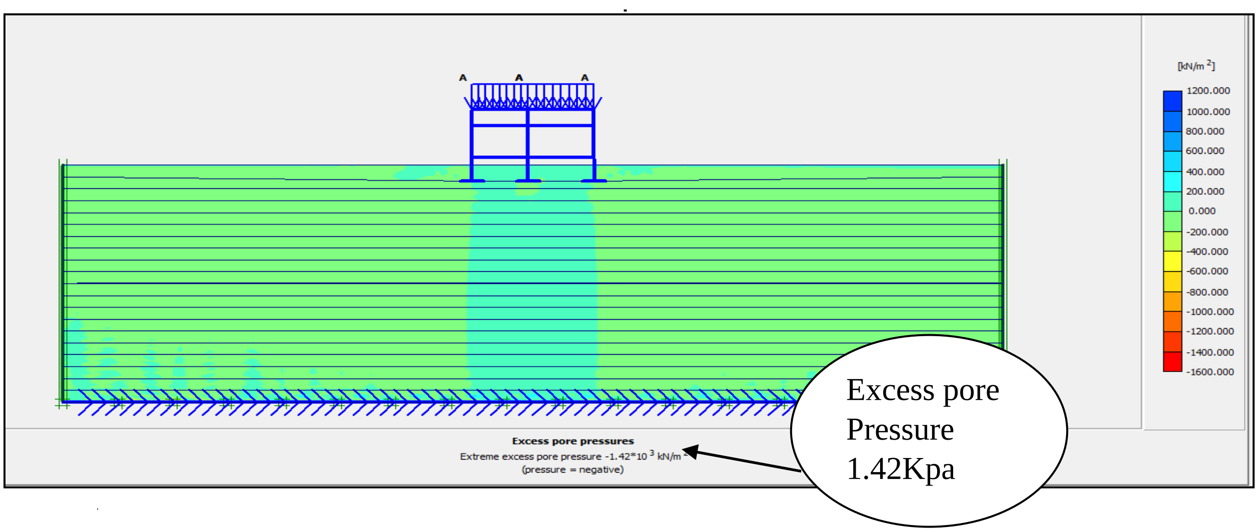


FIG 6.12: Excess Pore pressure for Dynamic analysis

Difference of Excess Pore Water Pressure in Static and Dynamic Analysis is too much, hence it is concluded that settlement is due to pore pressure.

6.7 Conclusion

The comparison of frame structure and masonry structure has shown that frame structures are more resistant to differential settlements and earthquake. So Construction of buildings at Risalpur should be based on Frame Structure.

Chapter 7

CONCLUSION

7.1 Investigation Results

A complete investigation of geology or strata was done to characterize the site accordingly. The site investigation was done by only one method i.e. by standard penetration test. It was seen that site constitute of very fine materials. All along the borehole only silt clay and clay is present. The soils also have some swelling potential. During site exploration disturbed and undisturbed samples were collected and a detailed geotechnical investigation was carried out in laboratory to classify the soil and to find the strength properties of soil. After the consolidation it was derived that soil is overly consolidated for above few meters. (Shye and Robinson, 1980)

During exploration the water table was encountered at the depth of 15m or 50ft. due to presence of water table the borehole could not dig more and samples could not collected. There was need of casing pipe to explore upto 100ft which was uneconomical and hence borehole could not went down. The disturbed samples were used to find index properties like atterberg limits, specific gravity, moisture content and moist density. These properties were used in classification of soil. The undisturbed or Shelby tube sample was used to find strength parameters and history of strata by consolidation test. These index properties and strength properties were also used to find values of shear modulus and damping using correlations and backbone curve.

Earthquake response at the site was then evaluated. For determination of site specific seismic response software DEEPSOILS v6.1 was used. First original motions from a station near the sources were taken online from USGS department. Then imported these waves in DEEPSOILS and using input shear modulus and damping ratio for each layer complete investigation were done. The result of this investigation was that our waves got attenuated.

These waves were then imported in software UDEC to analyze the building. The standard properties of brick masonry were used. The dimensions of the building were taken from drawings of the mosque. Results of the analysis were that joint had improper strength properties, differential settlements of the building wall. These were reasons that generated cracks. The height of the wall was 7m and length was 13m.

Keeping analysis results in view the remedies were proposed for future and for present situation. For present situation micro pile retrofitting was suggested. For future a proposed frame structure was designed and then analyzed using software PLAXIS. Results of this analysis were that using mat foundation there were less differential settlements.

7.2 Causative and Triggering Factors

From all above discussion and results it was derived that the reason of cracks during earthquake was severe differential settlements which generated due to following reasons

- Settlements were due to nature of soil at the site.
- Settlements were due decrease in pore pressure after earthquake.
- Wall settled due to improper strength properties of joints.
- Both structure and soil had problems at the site.
- Loads on the wall was too much than capacity

Out of above causal factors the decrease in pore pressure was the main reason of settlements. The decrease in excess pore pressure arises due to earthquake. The triggering factor was earthquake in the case study. These were two basic reasons of problem.

Keeping these structural and geotechnical deficiencies in view the remedial measure was given for future. For the mosque micro pile retrofitting of foundation suggested. This option is little difficult to provide. But for future construction in Risalpur frame structure is necessary because bearing strength of soil is not proper and soils are also little problematic.

7.3 Recommendations

- Study of chemical behaviors of Risalpur soils in future using forensic investigation technique.
- A detailed structural analysis of the Mosque.
- Soil structure interaction by doing soil exploration up to bed rock.
- Soil structure interaction using proper analysis technique for masonry structures for example ABAQUS.

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