FOUNDATION ANALYSIS FOR ALPHA PROJECT, THE MONAL, SANGRA, DISTRICT HARIPUR

By

Hassan Arshad
Mohammad Mohib
Noman Abbas

Department of Earth and Environmental Sciences Bahria University, Islamabad, Pakistan

2020

FOUNDATION ANALYSIS FOR ALPHA PROJECT, THE MONAL, SANGRA, DISTRICT HARIPUR

A thesis submitted to Bahria University, Islamabad in partial fulfillment of the requirement for the degree of B.S in Geology

Hassan Arshad
Mohammad Mohib
Noman Abbas

Department of Earth and Environmental Sciences Bahria University, Islamabad, Pakistan

2020

CERTIFICATE

ABSTRACT

The main aim of this research is to identify the bearing capacity of the soil at Alpha project, The Monal, Sangra area, Haripur. 7 boreholes have been drilled at different locations which consists of an average depth of 10m. Straight rotary was implemented for the drilling of borehole and samples were acquired afterwards. On field, Standard Penetration Test (SPT), Cone Penetration Test (CPT) were performed by ASTM standards. On lab, the tests like sieve analysis, Atterberg limits and moisture content tests were performed. The Teng's equation was applied to the results of SPT and the bearing capacity of soil was calculated.

ACKNOWLEDGEMENT

We would like to thank Allah Almighty who blessed us in every possible way that finally led us to our successful research.

We would like to express our heartfelt gratitude to Mr. Masood Anwar, Senior lecturer, Department of Earth & Environmental Sciences, Bahria University Islamabad, for his immense support and guidance that we needed to carry out this important task.

We would also like to deliver our appreciation to Prof. Dr. Tahseen Ullah Khan (Head of Department of Earth and Environmental Sciences).

We are indebted to Mr. Farhan, Geologist, AJK Engineers. For taking out his precious time for his devotion and sharing his knowledge which has helped a lot.

We are lucky to have our parents by our side who have always supported us financially and morally and they have helped us to complete this task as well along with our degree program.

CONTENTS

FIGURES

TABLES

ABBREVIATIONS

ASTM	The American Society of Testing Materials
SPT	Standard Penetration Tool
S	SPT Number
R	Refusal. N>50
CPT	Cone Penetration Test
C	CPT Number
UDS	Undisturbed Sample
FDT	Field Density Test
MDD	Maximum Dry Density
UCS	Unconfined Compressive Strength
DS	Disturbed Sample
GWT	Ground Water Table
BH	Bore Hole
Qa	Allowable Bearing Capacity
GM	Silty Gravel with sand and clay
SM	Silty sand with clay and gravel
NMC	Natural Moisture Content
GED	Geotechnical Engineering Department

CHAPTER 1

INTRODUCTION

1.1 Introduction

Engineering Geology is a field in which evaluations are made based on performance of soil mechanics, including the determination of their subsurface conditions, chemical, physical and mechanical properties which impact the project, and the assessment of the issues that arise from technical conditions. After the necessary assessment, the earthquake design is carried out and the site, construction and foundation are subsequently supervised.

The lowermost part of a structure is mostly termed as foundation. The foundation of the building moves the weight of the superstructure to the underlying soil or plane. In general, all buildings have several separate foundations. Usually the buildings foundation structure is right below each main column, to move the column's load straight to the ground (Meyerhof, 1951).

Super structure is a term mainly used to explain the engineered part of a system that brings burden into a foundation, or sub-structure. This term has importance for buildings and bridges, a foundation can support industrial equipment like towers, tanks and pipes and carry machinery. Due to this, it is best to describe a foundation as the part of the engineered system that carries the weight carrying components to the ground. According to this definition it is clear that a foundation is the most essential part of an engineering system.

A good foundation has the capability to distribute the load all around the ground while limiting the stress over the soil. If the stress on soil is too much it can cause depression in the area and damage the engineering structures. This is why the companies who are studying the area must find out the bearing capacity of the soil.

1.2 Types of foundation

The type of foundation to use depends on the structure and therefore the soil encountered. Mainly, the types of foundations are classified into two classes; deep and shallow foundations. These terms are used to define the depth of soil where the foundation is to be laid. The shallow foundations are laid at depths of about 9 meters whereas the deep foundation is laid at about 20-60 meters. For small and light structures, shallow foundations are made. And for huge and high weight structures, deep foundations are preferred.

1.2.1 Shallow foundations

In Shallow foundations, the structure is made close to the surface soil/rock. The depth is low as compared to deep foundation and their depth can vary up to 9 meters. Further types of shallow foundation are:

i) Raft foundation
ii) Spread or isolated footing
iii) Strip footing

1.2.2 Raft Foundation

Raft foundation is also referred to as Mat foundation. It consists of thick cemented slice of block on a large area of soil strengthened by steel which then supports the columns/walls and moves the load throughout the soil.

It is used in scenarios like:

i) Soil having low bearing capacity
ii) When the load of engineering structure has to be divided throughout a large area.
iii) When the stress on soil has to be decreased.
iv) The basement needs to be built.

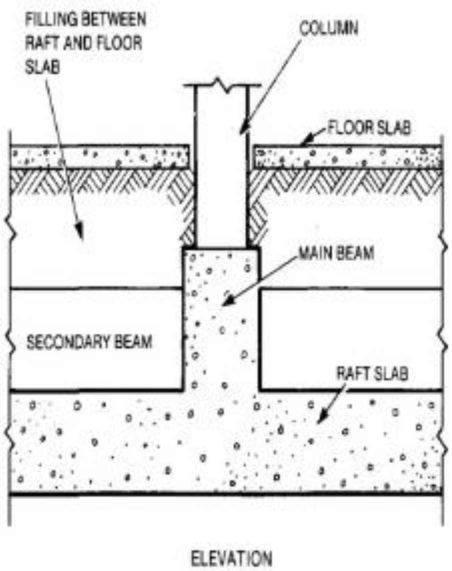


Fig.1.1. Raft foundation. (Bowels, 1996)

1.2.3 Types of raft foundation

The type of raft used depends upon the situation of soil and the amount of stress that is put on the foundation. The various types that are used during the construction are:

i) Two-way beam and slab raft
ii) Plate thickened under the column
iii) Flat plate mat
iv) Plate raft with pedestals
v) Plied raft
vi) Rigid frame mat

i) Flat plate mat

This type of raft foundation is the simplest. They are used when the walls or columns are built in equal spacing after a small interval and the weight of structure is not too much either. Economically, within 300 mm thickness is preferred because more than 300mm is not economical.

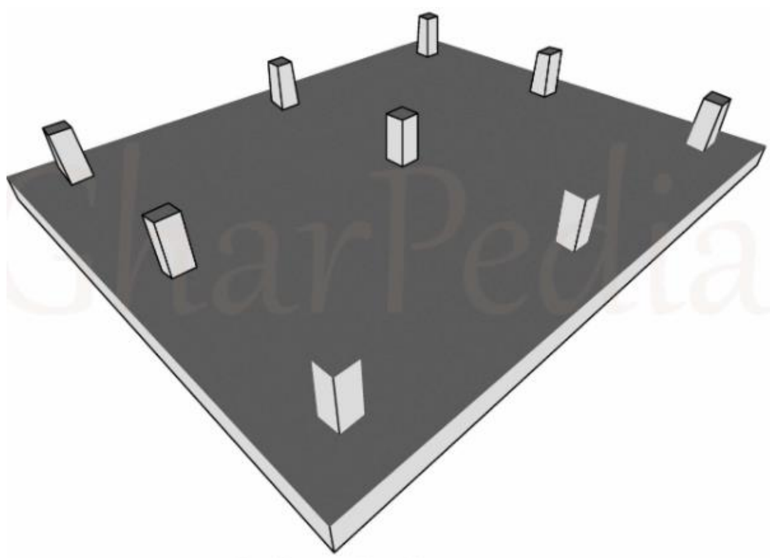


Fig.1.2. Flat plate mat. (Bowels, 1996)

ii) Plate thickened under columns

When there is a lot of load on walls and columns, the thickness of slab is increased and more strength is given under the walls and columns to resist the extra forces.

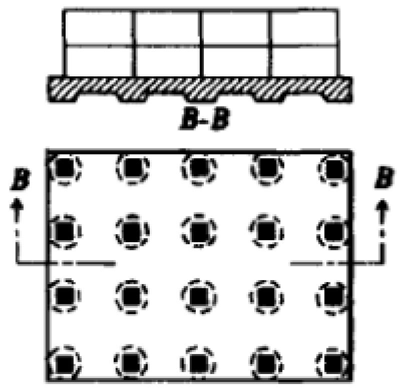


Fig.1.3. Plate thickened under columns. (Bowels, 1996)

iii) Two-way beam and slab

The beams in this type of raft are made of a single large material and the walls and columns are connected for support. This kind of raft is needed when the walls are constructed at a large distance and the load on columns does not remain same.

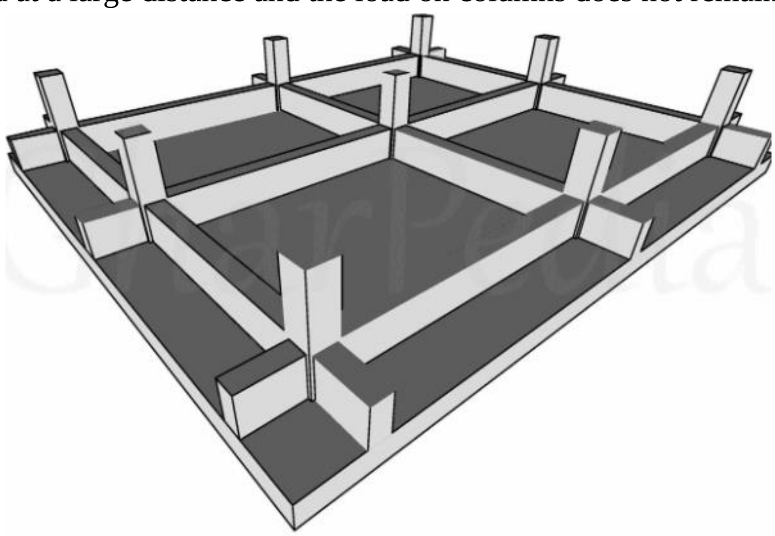


Fig.1.4. Two-way beam and slab. (Bowels, 1996)

iv) Plates with pedestals

This type is built under the columns, its purpose is just like the flat plate thickened under columns.

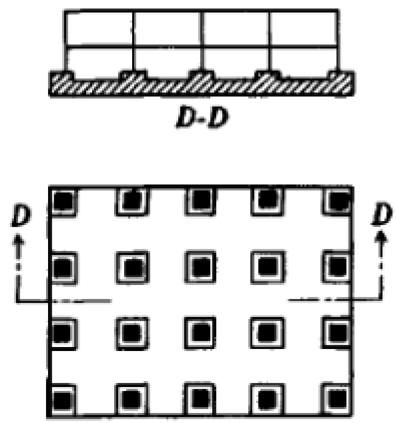


Fig.1.5. Plates with pedestals. (Bowels, 1996)

v) Piled raft

The piles support this kind of raft. It is mostly needed when the soil can be compressed easily and the water table is high. These piles help to lower the subsidence and it also resists against buoyancy.

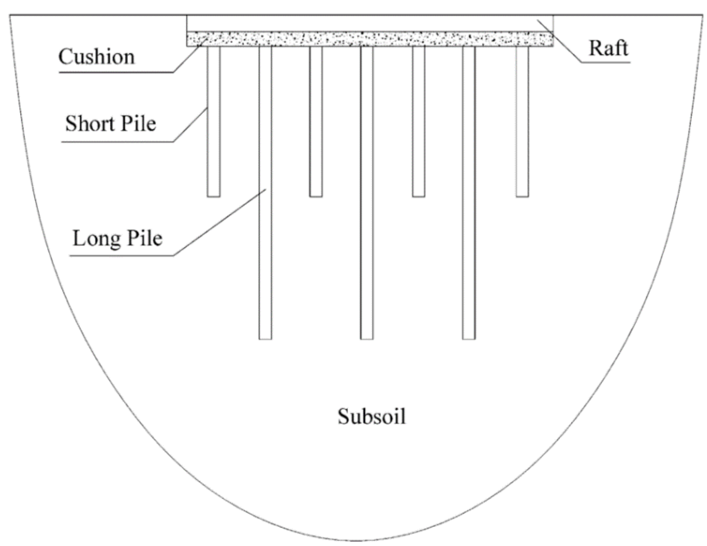


Fig.1.6. Piled raft. (Bowels, 1996)

vi) Rigid frame mat

This type of raft is required when the columns are carrying very high load and when the connected beams exceed a certain amount of depth. This type is useful when the required slab thickness is high.

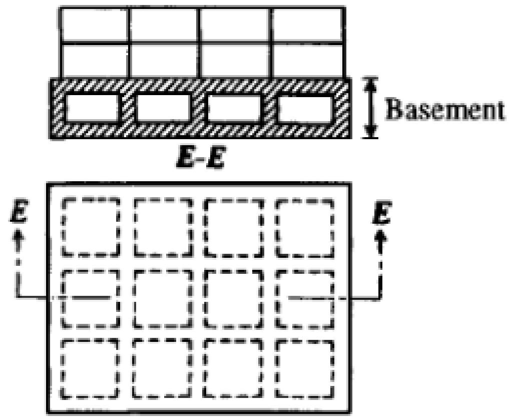


Fig.1.7. Rigid frame mat. (Bowels, 1996)

1.2.4 Isolated Footings

They are used for shallow foundations so that they can carry and divide the load of structures like pillars. This type of footing may be made strengthened or non-strengthened. To use a non-strengthened footing its height has to be larger to give the required load division.

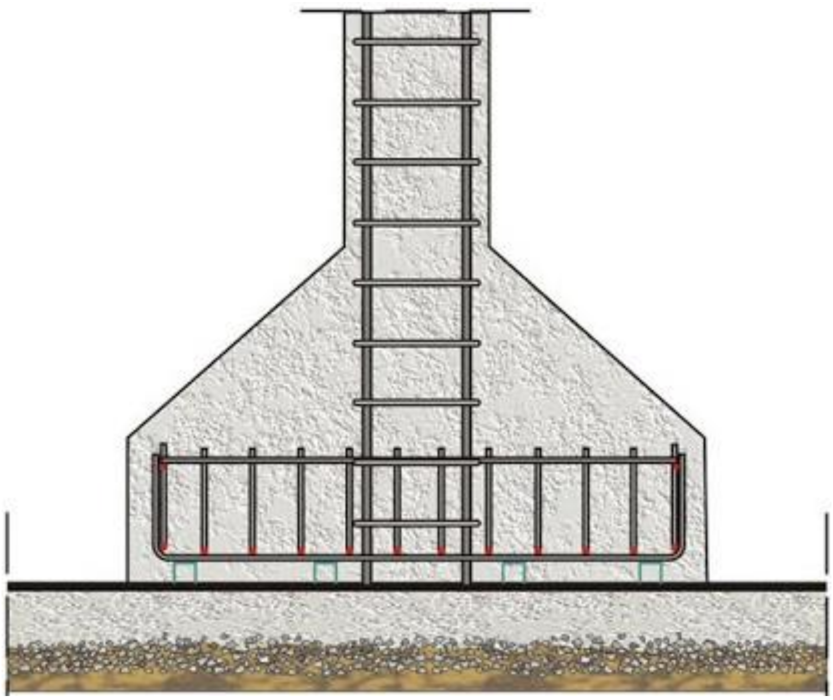


Fig.1.8. Isolated footing. (Bowels, 1996)

1.2.5 Strip footing

They are mostly used as the foundation of walls which are carrying the load. Its width is mostly two times to that of the wall or it can be wider as well. The width and the material used for strengthening is subject on the bearing capacity of the foundation soil.

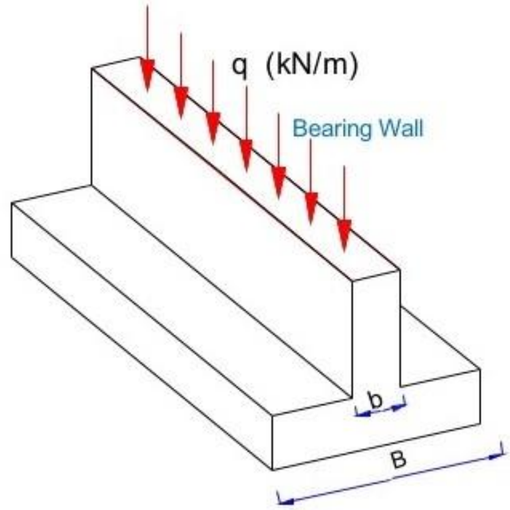


Fig.1.9. Strip footing. (Bowels, 1996)

The shallow type of foundation is applied when the surface soil is firm and strong to support the structure. They are however weak and can be compressed by the building if the ground is poorly compacted or if it contains alluvial deposits.

1.3 Deep foundations

In deep foundations, the foundation is laid deep into the ground which makes it more stable and prone to any kind of instability by earthquake or other natural event. The depth can vary up to 60 meters. Further types of deep foundations are:

i) Pile foundation
ii) Drilled shafts

1.3.1 Pile foundation

It consists of a strong cylindrical material made of concrete or timber. They can be used to lay down deep foundation which costs more than the shallow foundation.

They are used in the scenarios like:

i) If the top soil layer is more likely to compress or too weak to support the structure, piles are installed to distribute the load of structure towards the bedrock or a firmer soil.
ii) In case of horizontal forces acting in that area, same can be done to prevent bending and also support the structure’s load at the same time.

iii) It can help the structures in the same way if they are below the water table to prevent from forces acting upwards.

Piles are used in construction varies which depends on the kind of load that has to be transferred. Their varieties include:

(a) Wooden piles
(b) Composite piles
(c) Concrete piles
(d) Steel piles

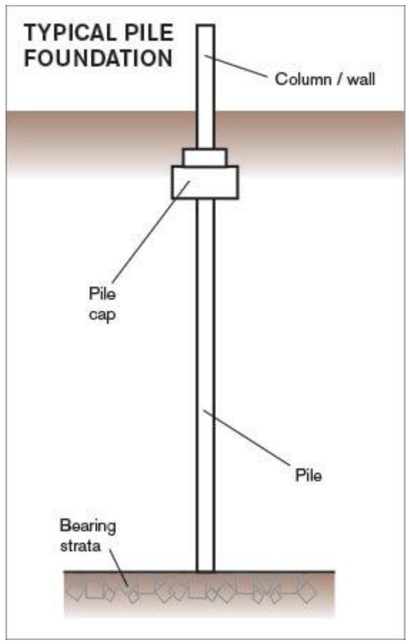


Fig.1.10. Typical pile foundation. (Bowels, 1996)

1.3.2 Drilled shafts

They are the piles which are placed deep into ground and have a diameter of about 30 inches. It has various benefits, some of which include:

i) Only one drilled shaft can be enough rather than using group of piles.
ii) No noise pollution produced from hammering unlike the pile driving.
iii) They can resist high forces coming from lateral loads.

Like other things, drilled shafts have their own disadvantages like delaying the operation due to bad weather and it also requires constant supervision.

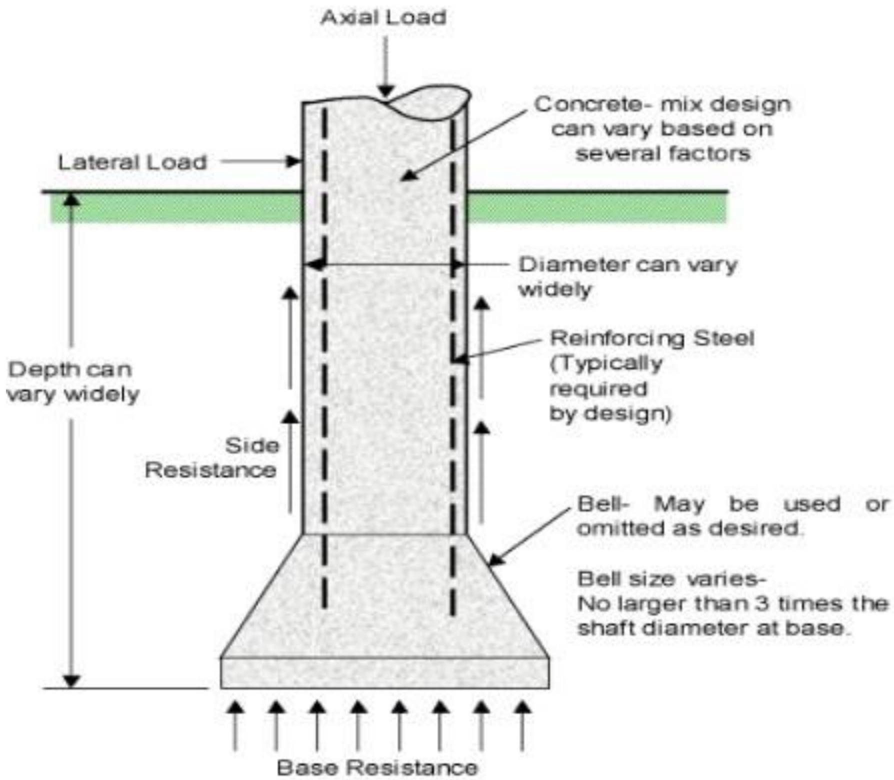


Fig.1.11. Drilled shaft. (Bowels, 1996)

1.4 Seismicity of area

Seismic zones of Pakistan have been produced by various agencies and according to them, moderate earthquake can occur in Islamabad and Rawalpindi. However, due to the seismic record in twin cities especially the earthquake of 8th Oct 2005 and the annihilation of Margalla towers, we must take this matter seriously to avoid this kind of event from happening in future. Apart from the experiences of 2005 there is a long history of the zone where Islamabad and Rawalpindi are present and have been targeted by many different intensity and magnitudes which is shown in the table 1.1.

History of earthquakes in Islamabad and Rawalpindi			
Dates	**Epicenter**	**Intensity**	**Description**
25 A. D	33.7N 72.9E	X	Taxila Earthquake It occurred at the main center of Buddhist civilization.
4/6/1669	33.4N 73.2E	VI-XI	Mandra Earthquake Max intensity was around VII.
24/1/1852	34N 73.5E	VIII	Murree Hills Earthquake Murree hills was the epicenter which killed 350 people.
20/12/1869	33.6N 73.1E	VII-VIII	Rawalpindi Earthquake Max intensity was around VII

Table 1.1. Historical database from prehistoric times until 1903 including earthquakes that caused major destruction in 20th century, (PMD, 2009).

The capital of Pakistan, Islamabad, is surrounded by five major fault lines which includes MBT, Kalabagh fault, Salt Range Thrust (SRT), Jhelum fault and Himalayan frontal thrust. The director of Geological Survey of Pakistan (GSP), Allah Bakhsh Kosar and a GSP geo-physicist MZ Babar said that it is not completely possible to know when an earthquake might occur in these fault lines. According to the officials, the fault lines beneath Islamabad are over 30 million years old. The earthquakes might occur anytime, but it is important that how we are prepared for these situations. According to GSP officials, seismic zoning was done when Islamabad was declared as Pakistan’s capital. The government was warned by the geologists that high intensity earthquakes can occur in Islamabad since it is in an active zone and a suggestion was given not to build high rise buildings (PMD, 2009). There are many methods used to overcome the issue of high-rise buildings collapse by using structural and geotechnical practices.

1.5 Objectives

This field work’s objectives are as follows:

i) To evaluate the geological conditions of the construction site.
ii) To calculate the bearing capacity of the foundation.
iii) To provide the most economical, long-lasting and secure foundation the design.

1.6 Location of study area

The location of our study area is at Sangra, Haripur, KPK, Pakistan. This area is around 8km ahead from The Monal restaurant. In fact, the project was given by The Monal itself to construct another project “Alpha”. The plan has been developed to construct 2 story building, cable car and retaining walls at this place. Sufficient area is present for parking purposes and to bring in the required materials for the project.

Since the area is at the Margalla Hills, it is near to the Margalla fault (Shah, S.M., 2009) which is connected to the Main Boundary Thrust (MBT). There is a beautiful view of the Margalla Hills all around the area.

Total 7 boreholes were planned in the study area which had no strict rules for borehole spacing. Disturbed and undisturbed were retrieved from the boreholes which were then tested in the lab for the foundation analysis. The location of the study area in Margalla Hills is shown in figure 1.12.

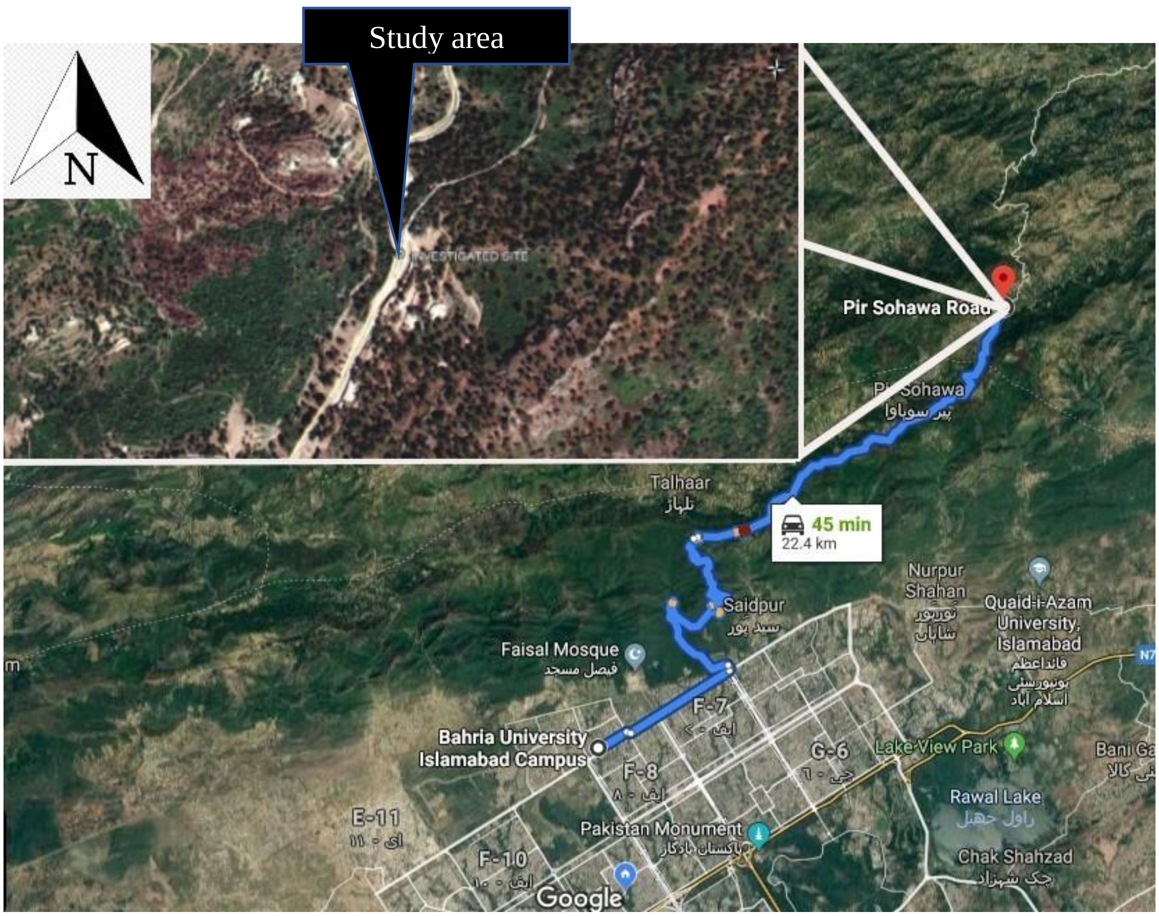


Figure.1.12. Map showing the location of the study area (Google Earth).

1.7 Methodology

The methodology of research work involves borehole drilling and excavation of disturbed samples. Field testing was done by Standard Penetration Test (SPT). However, where the SPT could not be done, Cone Penetration Test (CPT) was performed for sampling. On the other hand, variety of tests were performed in the laboratory which includes, Atterberg limits and sieve analysis. Eventually, by observing and discussing the results of these tests, the bearing capacity of the foundation was known. The flow chart of the methodology is shown in figure.1.2.

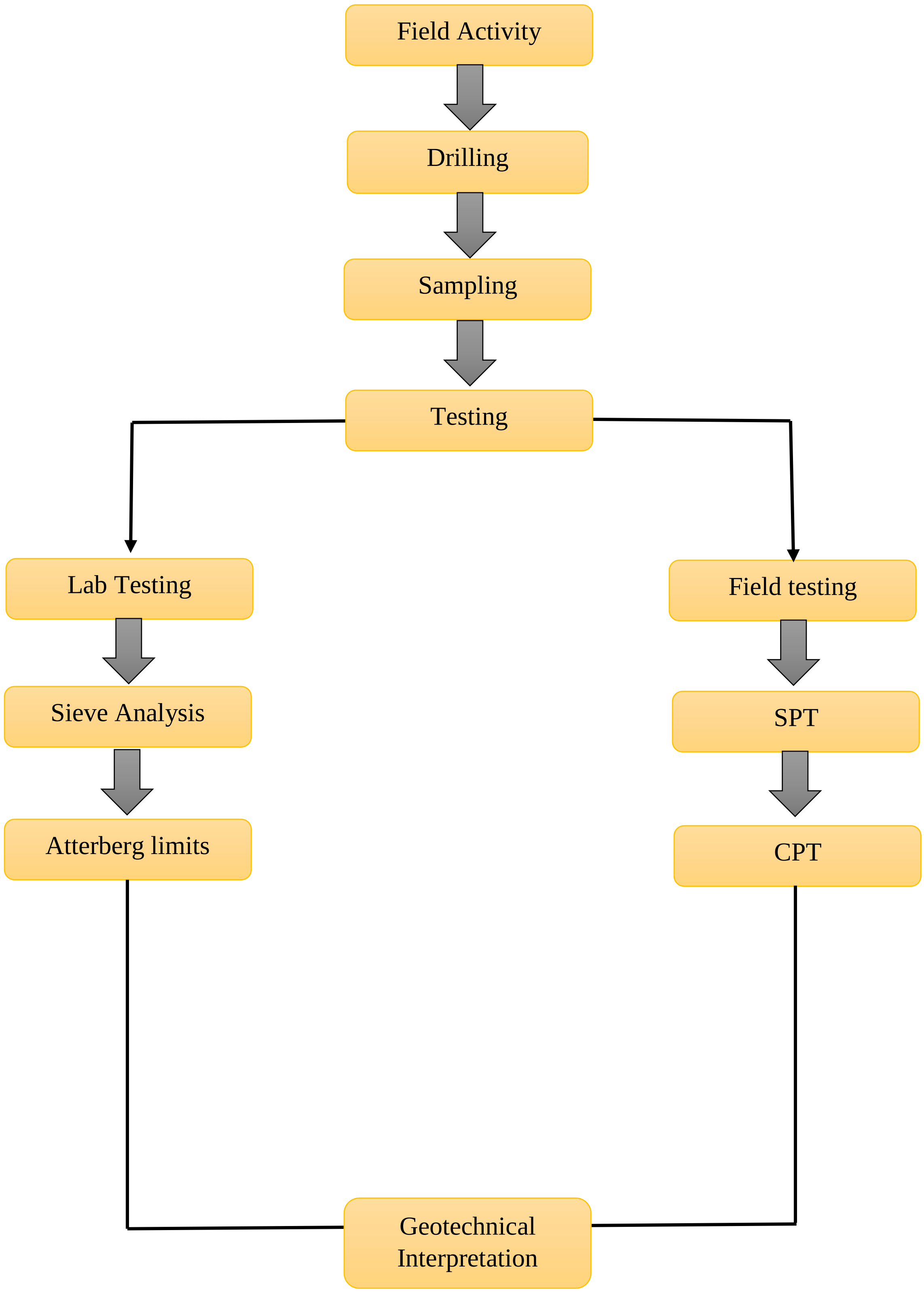


Figure 1.13. Flow chart of methodology.

CHAPTER 2

LITERATURE REVIEW

2.1 History

It is not clearly known when the humans started working with the soil for development purposes, but the work done in the ancient time's archeological sector proves that it originated a long time ago e.g. Indus civilization which prospered in current Pakistan. There is no evidence on how the foundation is affected by the weathering process. However, it is a fact that the work in geological sector began in ancient times and the field of engineering geology progressed in 19th century (Kerisel, 1985).

From a very long time the field of Engineering geology is being used but it was not much developed yet. According to the history it started developing from Egypt, India and China. At around 2000 B.C. ancient dam type structure were made in the Indus basin for providing water to the people of Mohenjo Doro. Even at this day there is no evidence what was done to balance the foundation of this structure (Shah, S.M., 2009).

In the late 15th century, a popular personality Leonardo da Vinci worked towards geology and architecture as well. He observed the soil behavior and came up with the process of calculating the bearing capacity of the soil, to measure the angle of repose of sand and also worked on the processes related to the ground water hydrology but unfortunately his work was limited only to books and it was not applied practically during his time (Shah, S.M., 2009).

Italy is famous for one of the towers which is named as Pisa, is tilted and the reason that it was tilted was due to the lack of soil investigation. Now according to the latest investigations, it is tilted because of the loose and compressible soil under the tower. It is the events like these that create a spark for the need of soil investigation for any building that is to be constructed.

Rankine (1857) presented the states of forces in a specific amount of soil and along the plain of fractures. His theory stated that the failure is likely to happen when the max principle stress at a given point approaches a value same as the tensile stress. However, the theory does not talk about how the remaining 2 forces create an effect. His theory is only applicable to the breakable material and not the ductile ones. This theory is also recognized as Maximum Stress Theory.

The case of expansion of sand was provided by Osborne Reynold in 1887 and in this time, other scientists like John Stuart Beresford and John Clibborn introduced the use of sand beds and increasing pressure of flow of water.

The 19th century was the great time for the development of engineering geology. During this time, the famous textbook of this field was written by William penning. Atterberg (1911), contributed greatly by promoting the idea of homogenous cohesive soil consistency by elaborating the plastic limit, shrinkage limit and the liquid limit (Atterberg, 1911).

Terzaghi (1925) did a great job by working on this subject area and also published a book named "Mechanics of earth construction based on soil physics". He provided the stress and consolidation theory and also contributed on the need of different observations done in the field.

Similarly, an incident took place in San Francis Dam located at California. Due to its collapse, 426 people lost their lives and more events like these throughout the world forced the engineering geologists to focus on the mega projects as well.

Casagrande (1932), have provided detailed examination of soil compaction, soft clays and seepages was done by Casagrande who also introduced the plasticity chart.

Meyerhof (1951) updated the work of Terzaghi and added the equation of deep and shallow foundations. Terzaghi included s-q which is a shape factor along with depth term Nq (supercharge) and apart from that he added the factors of depth and factors of inclination.

During the time of 1947 the equipment's such as hydraulic piezometer, SGI inclinometer and settlement measuring devices were built by Kallstenius (1963) which were made for the geotechnical purposes. Along with that he came up with the thought of interpreting and applying the different types of penetrometer and the Iskymeter. Due to his hard work and efforts he was widely appreciated throughout the world for advancing in soil samplers and the SGI piston. a

The type of science and the advancement in engineering geology has only just begun and is being known throughout the world which started from late 19^{th} and mid-20^{th} century (De Mello, 1977).

Engineering geologists have worked greatly in the fields of geotechnical properties like slope strength, evaluation of hazard, landslides, erosion etc. This field can work side by side with the environmentalists, civil engineers at different construction phases of public and private assignment and many other fields. The main job of the engineering geologist is to completely satisfy the people who are about to build any type of construction or other geotechnical structures so that it will last long and withstand all kinds of natural disasters.

CHAPTER 3

GEOLOGY AND TECTONIC SETTING

3.1 Geology of Islamabad and Rawalpindi

About 20 million years ago, the collision of Eurasian and Indian plate took place which plays the main role of tectonism and controls the geology of this area. These plates are still in motion due to which the Himalayas are still rising and produces tectonic events. The geologists all around the globe have observed the different structures and stratigraphy produced due to this collision. The argument of geology of Rawalpindi and Islamabad zone is best done according to the reference to geologic map (William et al, 1999).

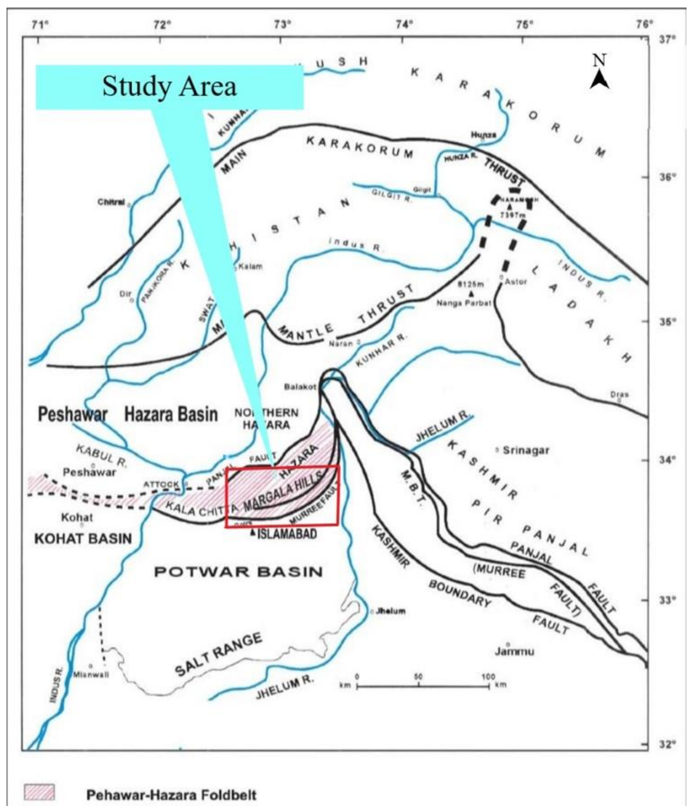


Figure 3.1. Tectonic map of northern Pakistan. Study area is highlighted in the red box. (Khattak et al., 2017)

3.2 Geological History

In the area of Islamabad, about 150 million years old sedimentary rocks can be found which contains the geologic history of the age mid Jurassic to Quaternary. In this timeline, the marine deposition was dominant with minor tectonic activity. However, in 2-24 million years, continental deposition with relatively slower subsidence took place and after 2 million years, a lot of erosion and extreme tectonic activity took place with minor local deposition. Before the collision of Eurasia and India, dolomite and limestone of Jurassic age were deposited on the continental side of Indian plate which is known to be the oldest rocks in the area. An unconformity is present between the Chichali and Samana suk Formation and it can be observed through the gap in the age. Furthermore, the shale with glauconite and chichali Formation's sandstone were accumulated in the environment which lacked oxygen and chemically minimizing the environment from late Jurassic- early cretaceous (khan et al., 2017).

3.3 Stratigraphy

3.3.1 Makarwal Group (Paleocene Age)

3.3.1.1 Hangu Formation

The lithology of Hangu formation varies from quartzose sandstone, intercalated shales and claystones. The properties of sandstone include brownish color, brittleness, apart from that it has more than 90% quartz which makes it quartzose. On the other hand, Shale and Claystone are greenish in color. The sequence in Hangu Formation is observed to be finning upward having a thickness of around 6-10m and makes a conformable contact with Lockhart Formation (Williams et al., 1999).

3.3.1.2 Lockhart limestone

As the name implies it mostly comprises of limestone but other than that it also contains shale as well as marl. The limestone here is light grey to dark grey and also contains fossils. The marl also contains fossils and the color is grey to black. The thickness of Lockhart limestone can go up to 280m and apart from that it is conformable with Patala Formation (Williams et al., 1999).

3.3.2 Surghur Group (Jurassic-Lower Cretaceous Age)

3.3.2.1 Samana Suk Formation

The lithology of this formation comprises of gray to brown limestone as well as Marl at some places which is greenish gray in color having thin beds. The thickness can be at least 190 meters which can go up to 360 meters. This formation makes an unconformable contact with Chichali Formation above having an unknown base which is not exposed (Fatmi, 1990).

3.3.2.2 Chichali Formation

This formation's lithology consists of glauconitic sandstone, shale, claystone and milestone. The color of these lithologies varies, like in case of siltstone and limestone they have a greenish grey color whereas the shale has a more greenish color or dark grey. On the other hand, the grain size of glauconitic sandstone varies from fine to coarse grain. Its thickness can be up to 50 meters and then makes a gradational contact with Lumshiwal Formation above (Williams et al., 1999).

3.3.2.3 Lumshiwal Formation

This formation mostly contains milestone, shale, limestone and sandstone. Properties of these lithologies like limestone includes thin beds having yellowish color with lots of sand. The sandstone here has a moderate thickness which consists of glauconites, along with that, some fossils like ammonoids and brachiopods are also present at some areas. This formation makes an unconformable contact with Hangu present above (Williams et al., 1999).

3.3.3 Cherat Group (Lower Eocene Age)

3.3.3.1 Margalla Hill Limestone

As the name suggests, this formation also mostly contains limestone with shale and also marl. The limestone here is dark grey, with thick beds and are also nodular. The marl here has a grey color which is comparatively harder. The Margalla Hill Limestone entails of splintery shale having greenish grey color. Overall thickness of this formation is between 60-90m which makes a conformable contact with Chorgali Formation (Williams et al., 1999).

3.3.3.2 Chorgali Formation

The Chorgali Formation is divided into dual parts, upper and lower. In the upper area this formation contains yellowish limestone which may contain some amount of chert and it also contains fossils. The Marl has a light grey color and overall thickness of this area is up to 120m.

On the other hand, the lower portion contains mostly shale having greenish grey color, apart from that the limestone can also be found in between. Some foraminifera fossils can also be found in coquina beds. The whole unit makes a conformable contact with Kuldana Formation (Williams et al., 1999).

3.3.3.3 Kuldana Formation

The main lithology in this area contains marine and non-marine claystone, marl, limestone and small number of sandstones. Now, the color of marl is pale greyish with small amount of gypsum. As far as limestone is concerned, its color white-light brown. Overall thickness of this formation can go up to 120m which has an unconformable boundary with Murree Formation of Rawalpindi Group (Williams et al., 1999).

3.3.4 Rawalpindi Group (Miocene Age)

3.3.4.1 Murree Formation

They were called "Mari Group" by Wynne (1874) and then its name was officially changed to the Murree Formation by the Stratigraphic Committee of Pakistan (Fatmi, 1972).

In this formation, sandstone and siltstone are present with conglomerates in minority. The color of sandstone is reddish grey and thickness is not the same, it is different in different areas of this formation but it can go up to around 2900m (Williams et al., 1999).

This formation is conformably overlain by Kamlial Formation but unconformably overlies Kohat Formation (Amjad Ali, 1997).

3.3.4.2 Kamlial Formation

The Stratigraphic Committee of Pakistan was the one who came up with the name Kamlial Formation (Fatmi, 1973).

The lithology contains shale, siltstone, conglomerate and sandstone. The difference between Murree Formation and Kamlial Formation can be observed by the fact that spheroidal weathering occurs in Kamlial Formation and also, tourmaline is abundantly present there as well. The thickness is around 1500 to 1600m and is conformably overlain by Chinji Formation 115 km away from Islamabad (Johnson et al., 1985).

3.3.5 Siwalik Group (Neogene to Pleistocene Age)

3.3.5.1 Chinji Formation

The name was termed to "Chinji Stage" which was then agreed by the Stratigraphic Committee of Pakistan (Shah, 1977).

This Formation mostly contains siltstone which is breakable and contains sandstone in between. The sandstone's color is smoky and also with a tone of brown. It is famous because of its brick-red color. The thickness of Chinji is between 850-1170 meters and it is conformably overlain by Nagri formation (Johnson et al., 1985).

3.3.5.2 Nagri Formation

Nagri Formation was named as Nagri stage of Pilgrims before but it was renamed by Lewis which was then agreed by the Stratigraphic Committee of Pakistan (Shah, 1977).

Sandstone dominates here which has a greenish grey color with clay in between. In different areas conglomerates are also present within the formation. It has a characteristic pattern of salt and pepper which forms because of ilmenite and magnetite. The thickness of this formation is between 500-900m and is conformably overlain by Dhok Pathan (Johnson et al., 1985).

3.3.5.3 Dhok Pathan Formation

The pilgrim came up with the name “Dhok Pathan” which was changed to “Dhok Pathan Formation” by cotter in 1933, and now, this name has been formalized (Fatmi, 1973).

Orange colored siltstone dominates in this area including sandstone of greyish color and hard claystone. Its thickness is founded to be between 500-820m. It is conformably overlain by Soan Formation (Johnson et al., 1985).

3.3.5.4 Soan Formation

The name was accepted by the Stratigraphic Committee of Pakistan after it was given by Kravtchenko in 1964 (Rahman, 1968).

The lithology of this formation contains siltstone, claystone, sandstone including clays and conglomerates. The grains in sandstone are clearly visible and it has a greenish grey color whereas the color of claystone is light pink and brownish. The thickness varies from 200-300m which is conformably overlain by Lei conglomerates (Johnson et al., 1982).

3.3.6 Units on Surface (Pleistocene-Holocene)

3.3.6.1 Lei Conglomerate

Pilgrim came up with the name “Boulder Conglomerate” in 1910 but then “Lei Conglomerates” was introduced by Gill in 1952. This area is mostly flat and nearer to sea-level. However, folds and faults are present in the local areas. Lei Conglomerates overlay Rawalpindi and Siwalik group. Since the volcanic ash is younger than Soan Formation and older than the Lei Conglomerates, the age of Lei Conglomerates can be roughly estimated by the fission track method which shows that the max age of Lei Conglomerates is around 1.6-18 million years (Johnson et al., 1982).

Eon	Era	Period	Epoch	Formation	Lithology
Phanerozoic	Cenozoic	Tertiary	Miocene	Murree formation	Sandstone and clay
			Disconformity		
			Eocene	Margalla hill limestone	Limestone
			Paleocene	Patala formation	Shale, limestone and sandstone as subordinates
				Lockhart formation	Nodular limestone with intercalated marl and shale
				Disconformity	
	Mesozoic	Jurassic		Samana suk formation	Limestone with intercalated marl and shale

Figure 3.2. Generalized Stratigraphic column of study area. (Litsey, 1958)

CHAPTER 4

METHODS AND MATERIALS

4.1 Field investigation

The study area was gone through geotechnical investigation by drilling 7 boreholes in which the depth was around 10 meters to observe the soil properties within the ground. The method chose for drilling was straight rotary. Standard Penetration tests (SPT)/Cone Penetration tests (CPT) were performed at depth interval of 1.0m, undisturbed samples could not be retrieved due to gravelly/rocky strata. The location of boreholes with respect to structures is listed in Table 4.1.

Sr. No	Structure description	Borehole no.
1.	Cable Car	BH 1 and BH 2
2.	Retaining wall	BH 3 and BH 4
3.	Two story building	BH 5, BH 6 and BH 7

Table 4.1. Location of boreholes with respect to the structures.

4.1.1 Standard Penetration Test (ASTM-D1586)

This type of test is applied in drilled boreholes. In this test it is observed how much the soil resists into the particular strata while penetrating it into the borehole. It is one of the most helpful techniques to find out the relative density and also the angle of shear resistance of cohesion less soil. Moreover, this technique can be applied to find the unconfined compressive strength of cohesive soil.

4.1.2 Equipment Used

i) Hammer of 63.5kg

ii) Split Spoon Sampler

iii) Guiding rod

iv) Drilling rig

v) Driving head also known as the Anvil.

4.1.3 Methodology

When the bore is drilled, the sampler is put into the borehole with the help of hammer falling from the height of 76cm at thirty blows in one minute. These blows are counted till 150mm. The process is then repeated and the first 150mm counting is discarded and the others are then taken to get the standard penetration no. shown by N.

Bearing capacity of the foundation can be calculated with Standard penetration test (SPT) in cohesion-less soil by using Teng's equation:

Q= 0.167*N^2*B*W+0.277(100+N^2)*D*W (N.Teng, 1962)

If the no. of blows are more than 50 the result is taken as refusal and the test is stopped.

4.1.4 Safety measures

i) The sampler has to be in a proper working condition.

ii) The cutting shoe must not be broken.

iii) The height of hammer from where it needs to be dropped has to be 76cm or else the values of N will not be accurate.

iv) The drill rods must be in normal shape, if for some reason they are bent, the results will not be accurate.

v) The bottom potion of borehole has to be clean before performing the test.

Figure 4.1. Drilling rig used for performing SPT test.

Figure 4.2. Samples taken out from SPT test at BH-4 depth 6m.

Figure 4.3. Samples from BH-4 being put in the polythene bag to maintain moisture.

Figure 4.4. Drop hammer of 63.5kg used for SPT.

4.2 Lab testing

Samples retrieved from boreholes were examined in the field and then transported to testing laboratory for relevant laboratory testing. The laboratory tests were performed on selected soil samples to determine the engineering features of the subsurface strata.

i) Sieve Analysis.
ii) Atterburg limits.

4.3 Subsurface strata

General stratigraphy of the project area, as deduced from the site investigations duly corrected in the light of laboratory test results (wherever required), indicates the presence of following general stratigraphic units.

Cable Car

Unit-1: 0.0m to 10.0m Silty Sand with Gravel / Silty Gravel with Sand

Retaining Wall (20ft to 30ft)

BH-01

Unit-1: 0.0m to 1.5m Sandy Silty Clay Unit-2: 1.5m to 9.0m Gravel / Silty Gravel with Sand.

BH-2

Unit-1: 0.0m to 9.0m Silty Gravel with Sand / Gravel

BH-3

Unit-1: 0.0m to 1.5m Filling Material

Unit-2: 1.5m to 3.5m Silty Clay with Sand

Unit-3: 3.5m to 10.0m Silty Gravel with Sand

Two Story Building

BH-4

Unit-1: 0.0m to 2.5m Silty Gravel with Sand

Unit-2: 2.5 to 4.5 Sandy Silty Clay

Unit-3: 4.5 to 10.0 Silty Gravel with Sand

BH-5

Unit-1: 0.0m to 2.5m Silty Sand with Gravel

Unit-2: 2.5 to 10.0 Silty Gravel

4.4 Ground water table

Ground water was not encountered in any boreholes during these investigations.

4.5 Sieve analysis (ASTM C-136)

For the categorization of soil, Sieve analysis was performed. To conduct this test, the soil samples are put in the binder for drying. After this they are gone through the sieves which are stacked in the decreasing order from top to bottom.

The smallest number of sieves that was used was of 200 whereas the wider sieve consisted of no.4. The weight of the samples in every sieve was calculated and the findings were plotted on the graph which showed the arrangement of soil samples.

4.5.1 Equipment

i) Stacked sieves with pan and cover

ii) Electronic weighting machine having accuracy of 0.01 grams

iii) Ceramic mortar and pestle to crush the lumped soil

iv) Sieve shaker

v) Binder

4.5.2 Methodology

100 grams of sample was taken and dried in the binder for 24 hours. After taking the samples out, if the soil has combined together then pestle and mortar are used to crush them to powdered form. The sieves are then stacked above each other with larger hole sizes above the smaller ones. The sieve no. that is placed in the bottom most portion is 200. A pan is put in the bottom most portion to collect the remaining soil. The sieves must be properly cleaned before they are used. In the case where the soil particles gets stuck in the holes, the brush is used to clear the path. The soil sample is poured at the top most sieve and then it is shaked. After all the samples have passed, the weight of the soil is measured that is retained on the sieve.

4.5.3 Calculation

To find out the overall percentage of passing of soil from each sieve, the soil percentage that is left on the sieve is calculated. This is calculated by using the overall weight of sample of soil that is used.

%Soil retained= weight of soil on sieve/weight of total soil * 100

4.5.4 Safety measures

i) Appropriate care needs to be taken for accurate results.

ii) If the holes of sieves are soldered the results from large breaks or a lot of small breaks should be avoided.

iii) The warm samples must not be used for sieving because it changes the mesh of sieve no. 100 and 200.

iv) If the sieve has a break in the main body, it should be ignored.

v) It should be taken care that no material is lost in the process of rinsing.

vi) Do not put too much weight on the sieves.

vii) Care must be taken not to waste any material during washing of sieve. 200 due to water pressure.

4.5.5 Constraints

The sieve analysis is not a good method for the samples that have flat or elongated shape, only round and spherical shaped grains can be sieved through this method. An error is likely to occur in the case of 100 no. sieve because the sample needs to be shaken more to pass them out. If the liquid does not affect the sample, it can be used for the sieve analysis.

Figure.4.5. Showing stacked sieves.

Figure.4.6. Using pestle and mortar to crush the lumped soil.

The calculation of grain sizes at various stages were applied and their results from every BH are shown in the tables and in figures below.

AJK Engineers

GRAIN SIZE ANALYSIS

Project	Geotechnical investigation-Cable car		
Location	Alpha project, The Monal, Sangra, District Haripur		
Client	M/s The Monal		
Borehole	BH-01	**Depth (m)**	1
Natural Moisture Content	13.41%	**Total dry weight(gms)**	100
Gravel	24.40%	**Sand**	47%
Silt/clay	28.60%	**Classification group**	SM
Description	Grey, Silty Sand with Gravel.		

Table 4.2. Showing Sieve Analysis of BH-1 from 1m depth.

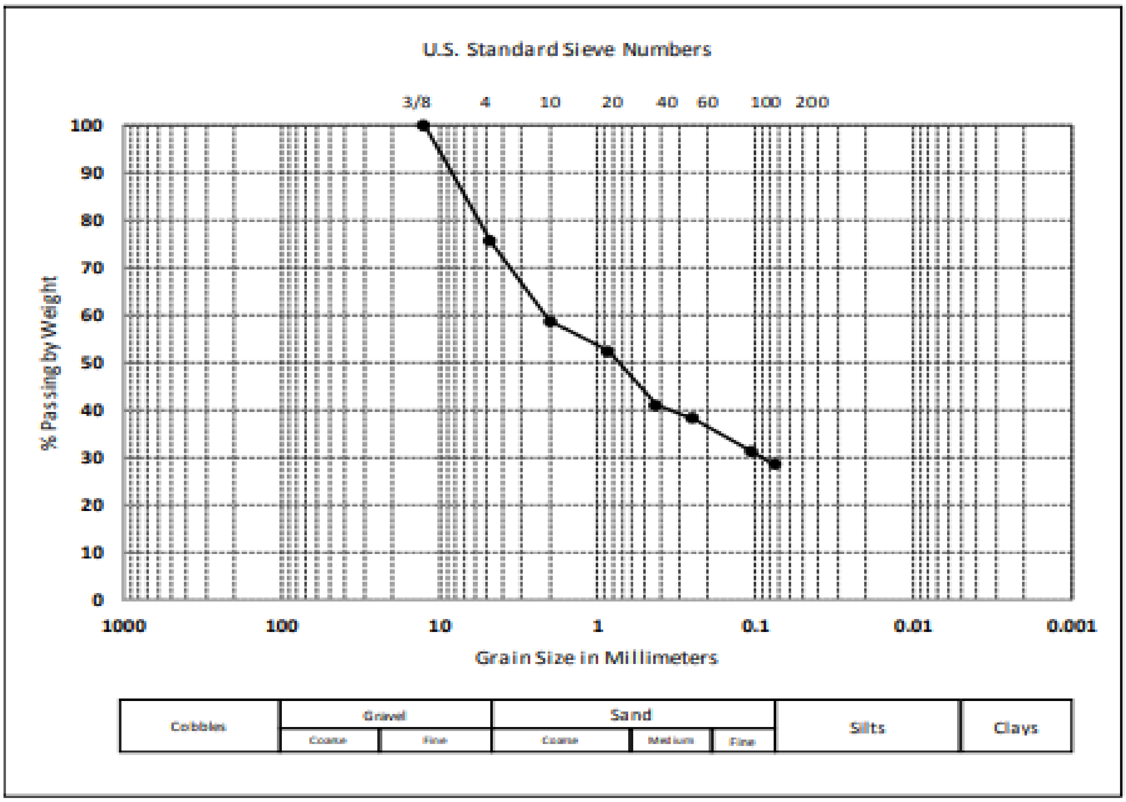


Figure.4.7. Graphical description of Sieve analysis of BH-1 at 1m.

AJK Engineers

Project	Geotechnical Investigation - Cable car.		
Location	Alpha project, The Monal, Sangra, District Haripur.		
Client	M/s The Monal		
Borehole	BH-01	**Depth (m)**	3
Natural Moisture Content	14.82%	**Total dry weight (gms)**	100
Gravel	43.25%	**Sand**	30.10%
Silt/Clay	26.65%	**Classification group**	GM
Description	Grey, Silty Gravel with Sand.		

Table 4.3. Showing sieve Analysis of BH-1from 3m depth.

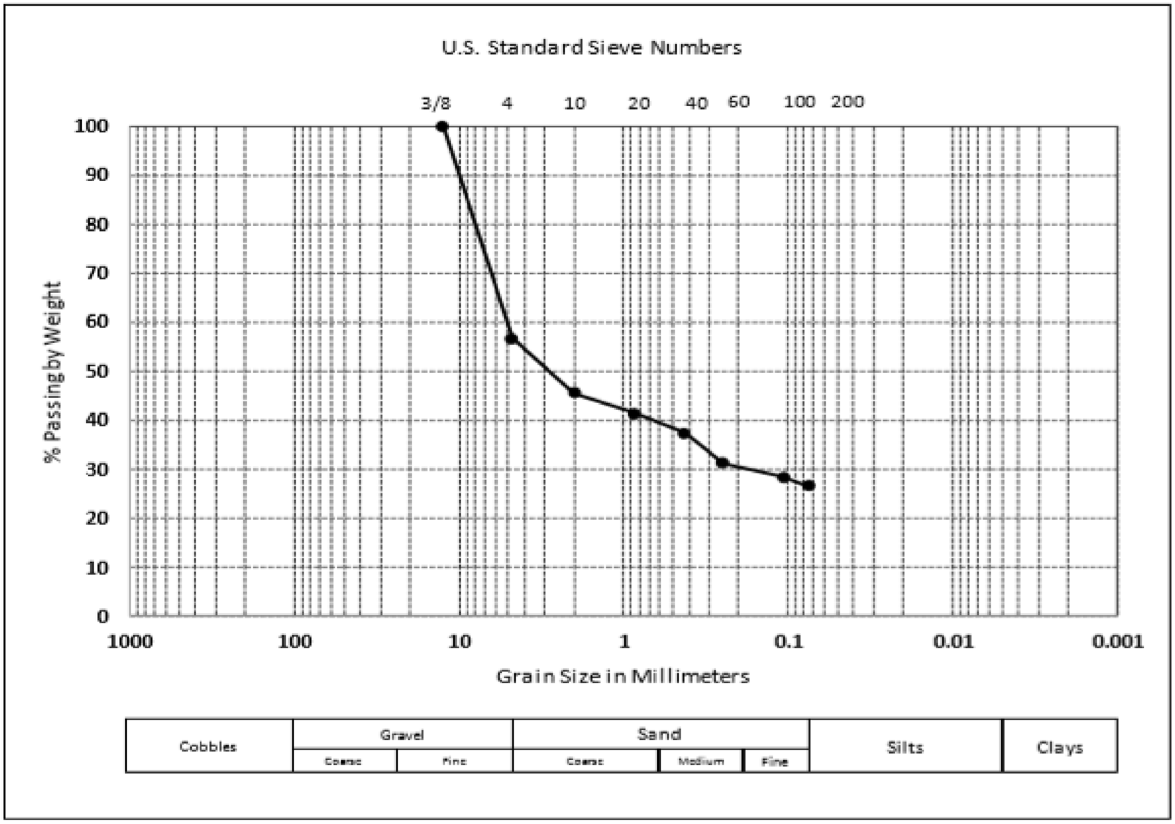


Figure 4.8. Graphical description of sieve analysis of BH-1 at 3m depth.

Project	Geotechnical investigation - Cable car.		
Location	Alpha project, The Monal, Sangra, District Haripur.		
Client	M/s The Monal		
Borehole	BH-01	**Depth (m)**	5
Natural Moisture Content	8.58%	**Total Dry Weight (gms)**	100
Gravel	29.10%	**Sand**	47.10%
Silt/Clay	23.80%	**Classification group**	SM
Description	Grey, Silty sand with gravel.		

Table 4.4. Showing sieve analysis of BH-1 from 5m depth.

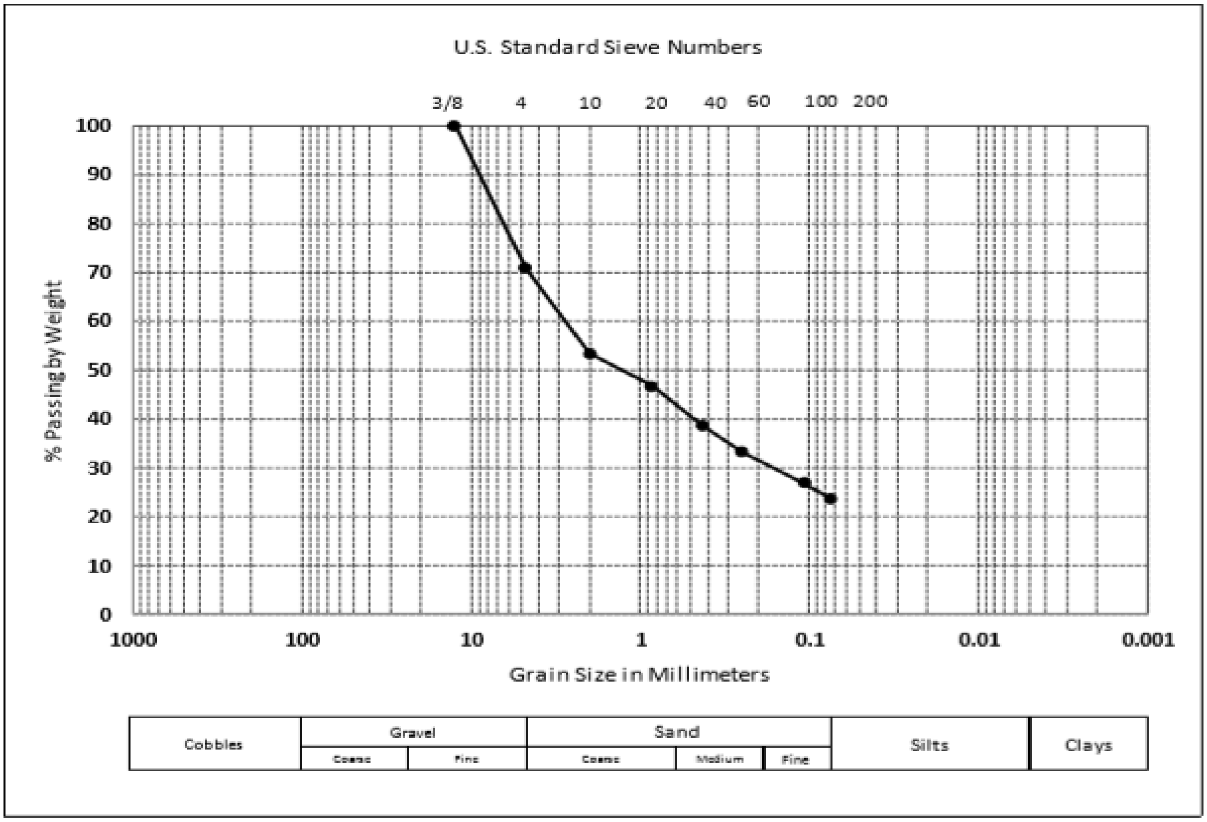


Figure 4.9. Graphical description of sieve analysis of BH-1 at 5m depth.

AJK Engineers

Project	Geotechnical investigation – Cable car.		
Location	Alpha project, The Monal, Sangra, District Haripur.		
Client	M/s The Monal		
Borehole	BH-02	**Depth (m)**	2
Natural Moisture Content	18.52%	**Total dry weight (gms)**	100
Gravel	30.85%	**Sand**	48.90%
Silt/Clay	20.25%	**Classification group**	SM
Description	Grey, Silty sand with gravel.		

Table 4.5. Showing sieve analysis of BH-02 from 2m depth.

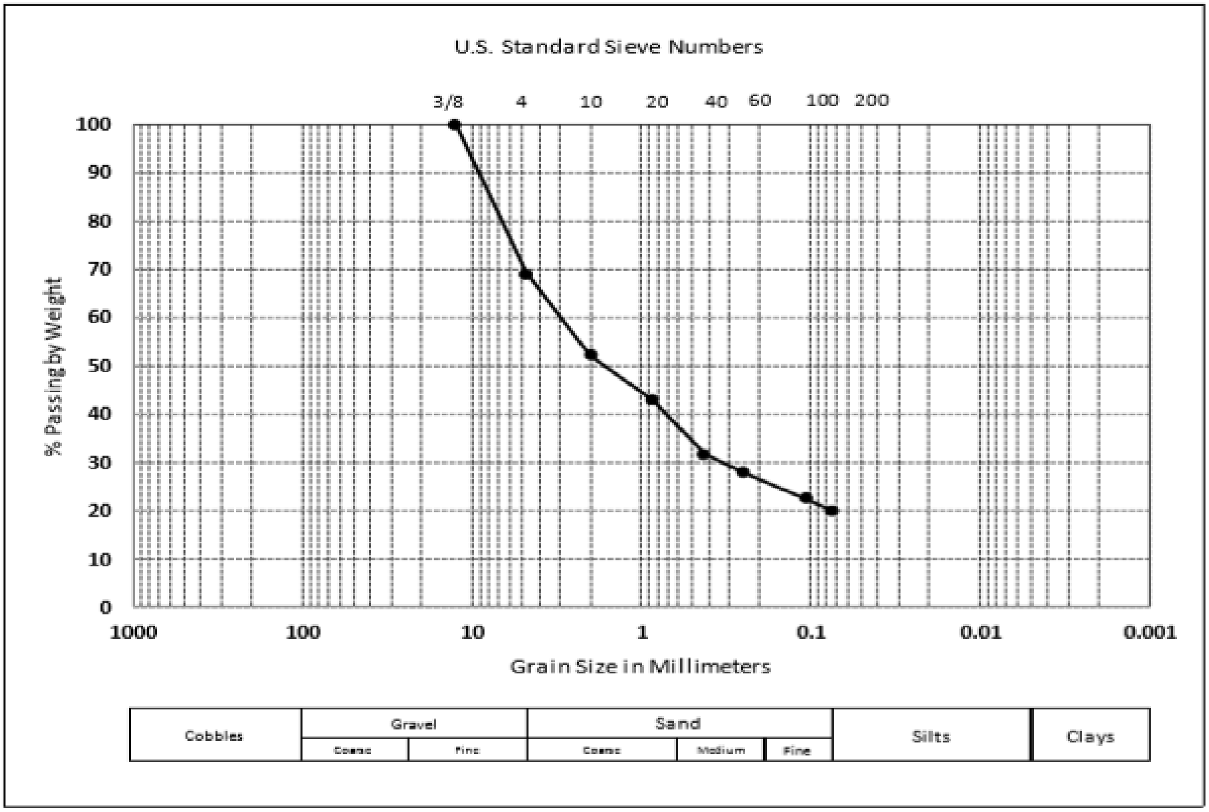


Figure 4.10. Graphical description of sieve analysis of BH-2 at 2m depth.

AJK Engineers

Project	Geotechnical investigation – Cable car.		
Location	Alpha project, The Monal, Sangra, District Haripur.		
Client	M/s The Monal		
Borehole	BH-02	**Depth (m)**	4
Natural Moisture Content	13.28%	**Total dry weight**	100
Gravel	43.25%	**Sand**	26.25%
Silt/Clay	30.50%	**Classification group**	GM
Description	Grey, Silty gravel with sand.		

Table 4.6. Showing sieve analysis of BH-2 from4m depth.

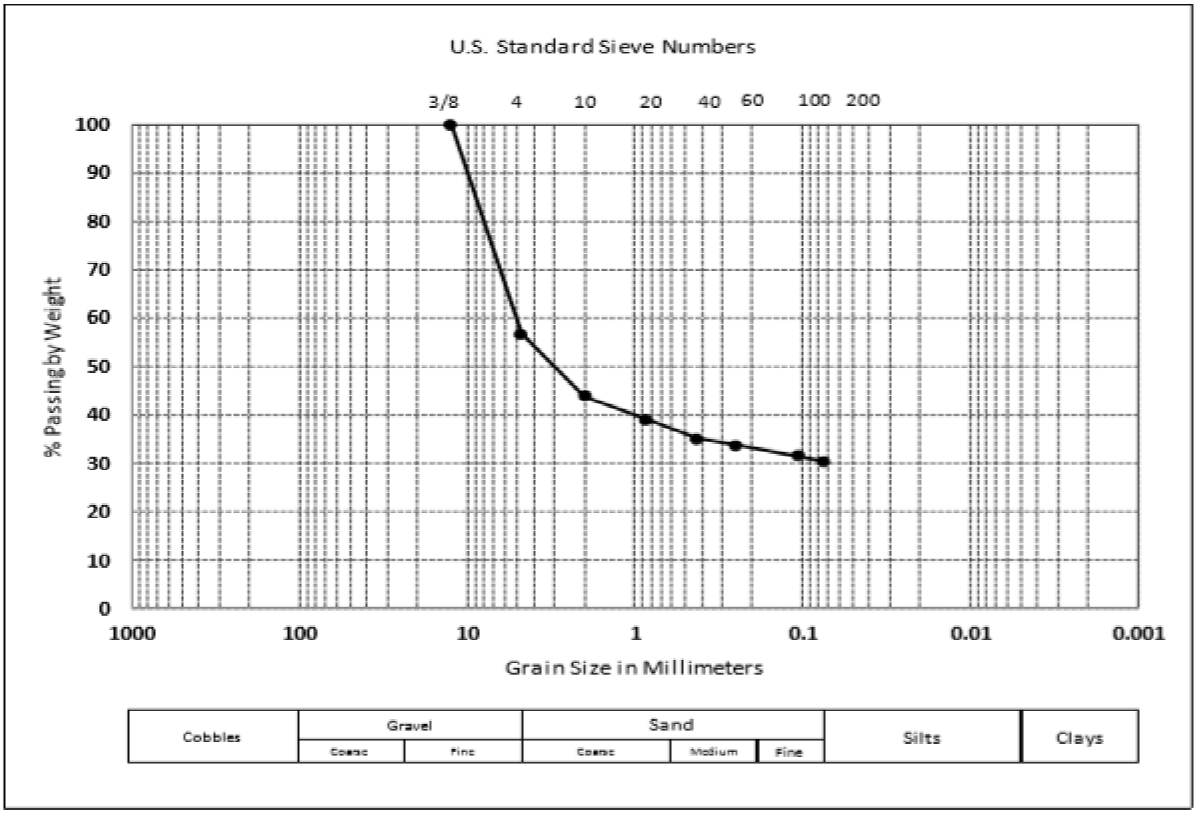


Figure 4.11. Graphical description of sieve analysis of BH-2 at 4m depth.

AJK Engineers

Project	Geotechnical investigation – Cable car.		
Location	Alpha project, The Monal, Sangra, District Haripur.		
Client	M/s The Monal		
Borehole	BH-02	**Depth (m)**	6
Natural Moisture Content	10.93%	**Total dry weight (gms)**	100
Gravel	35.40%	**Sand**	45%
Silt/Clay	19.60%	**Classification group**	SM
Description	Grey, Silty sand with gravel.		

Table 4.7. Showing sieve analysis of BH-2 from 6m depth.

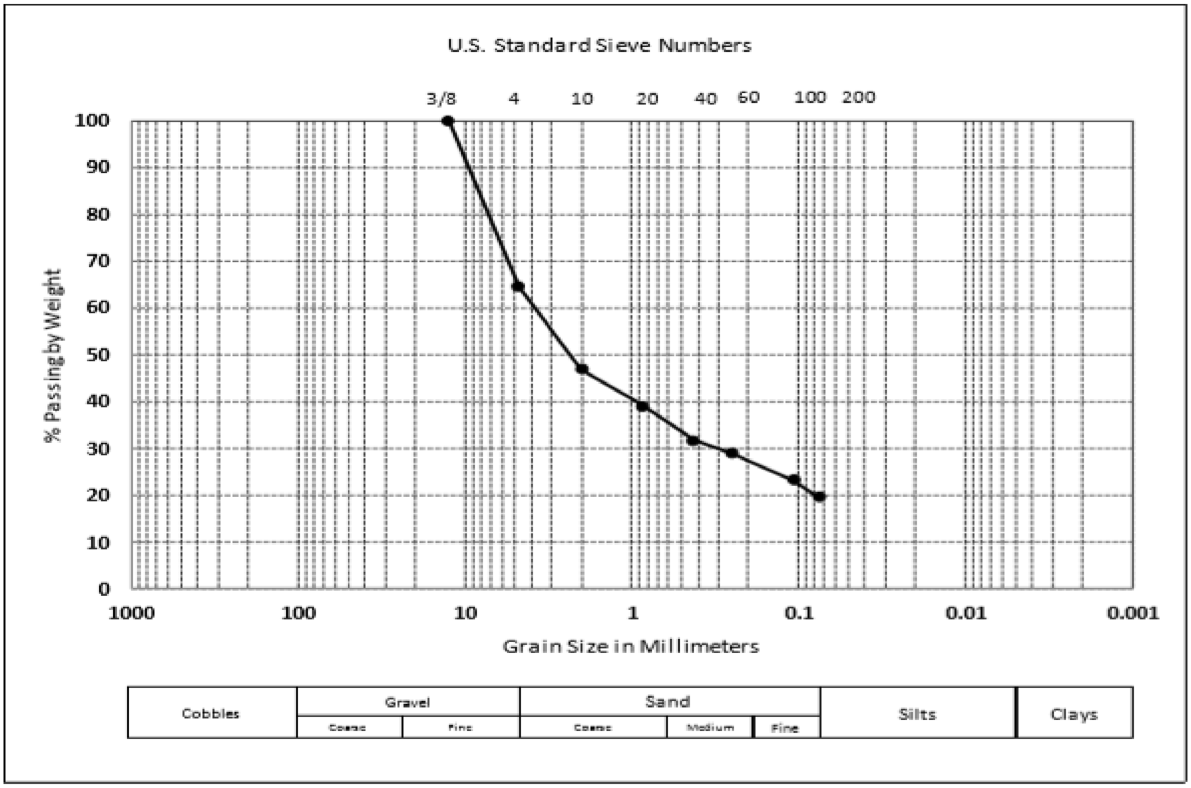


Figure 4.12. Graphical description of sieve analysis of BH-2 at 6m depth.

Project	Geotechnical investigation – Retaining wall.		
Location	Alpha project, The Monal, Sangra, District Haripur.		
Client	M/s The Monal		
Borehole	BH-03	**Depth (m)**	1
Natural Moisture Content	17.41%	**Total dry weight (gms)**	100
Gravel	6.50%	**Sand**	38.55%
Silt/Clay	54.95%	**Classification group**	CL
Description	Brown, Low plasticity, Sandy lean clay.		

Table 4.8. Showing sieve analysis of BH-3 from 1m depth.

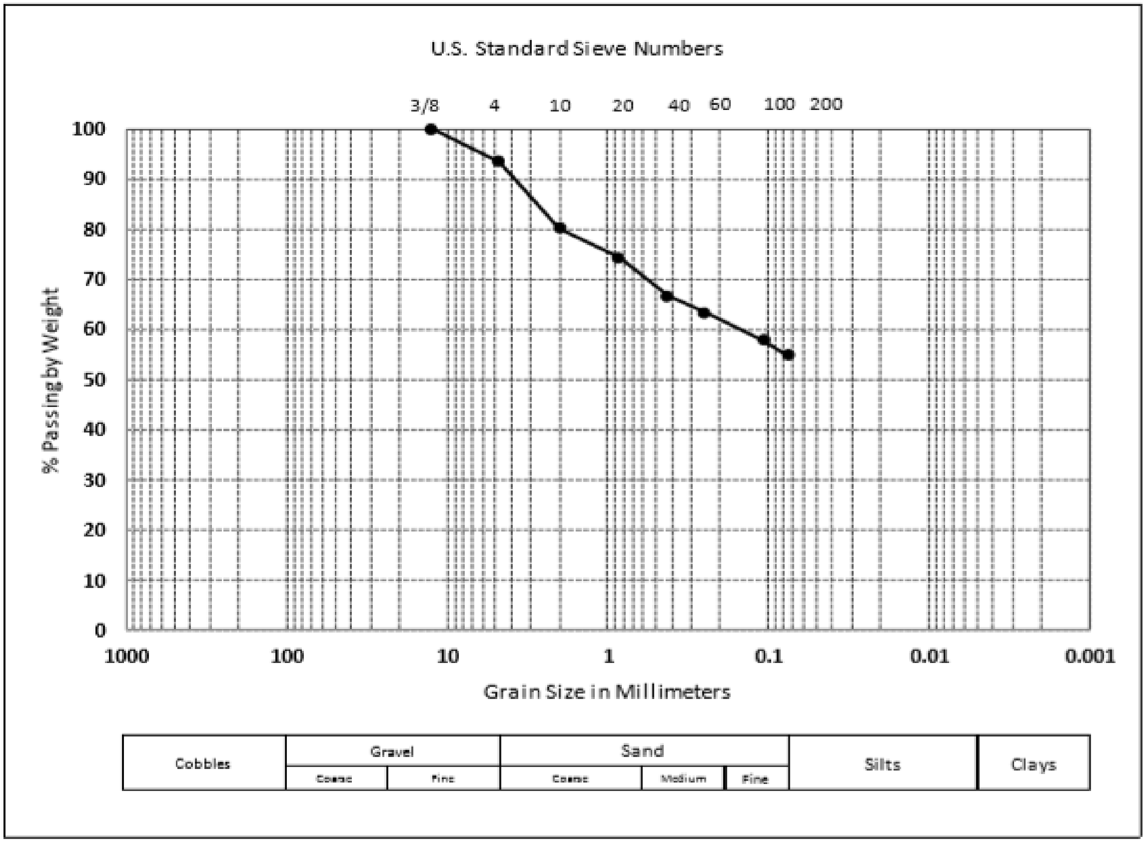


Figure 4.13. Graphical description of sieve analysis of BH-3 at 1m depth.

Project	Geotechnical investigation – Retaining wall.		
Location	Alpha project, The Monal, Sangra, District Haripur.		
Client	M/s The Monal		
Borehole	BH-03	**Depth (m)**	2
Natural Moisture Content	24.10%	**Total dry weight (gms)**	100
Gravel	38.70%	**Sand**	25.05%
Silt/Clay	36.25%	**Classification group**	GM
Description	Grey, Silty gravel with sand.		

Table 4.9. Showing sieve analysis of BH-3 from 2m depth.

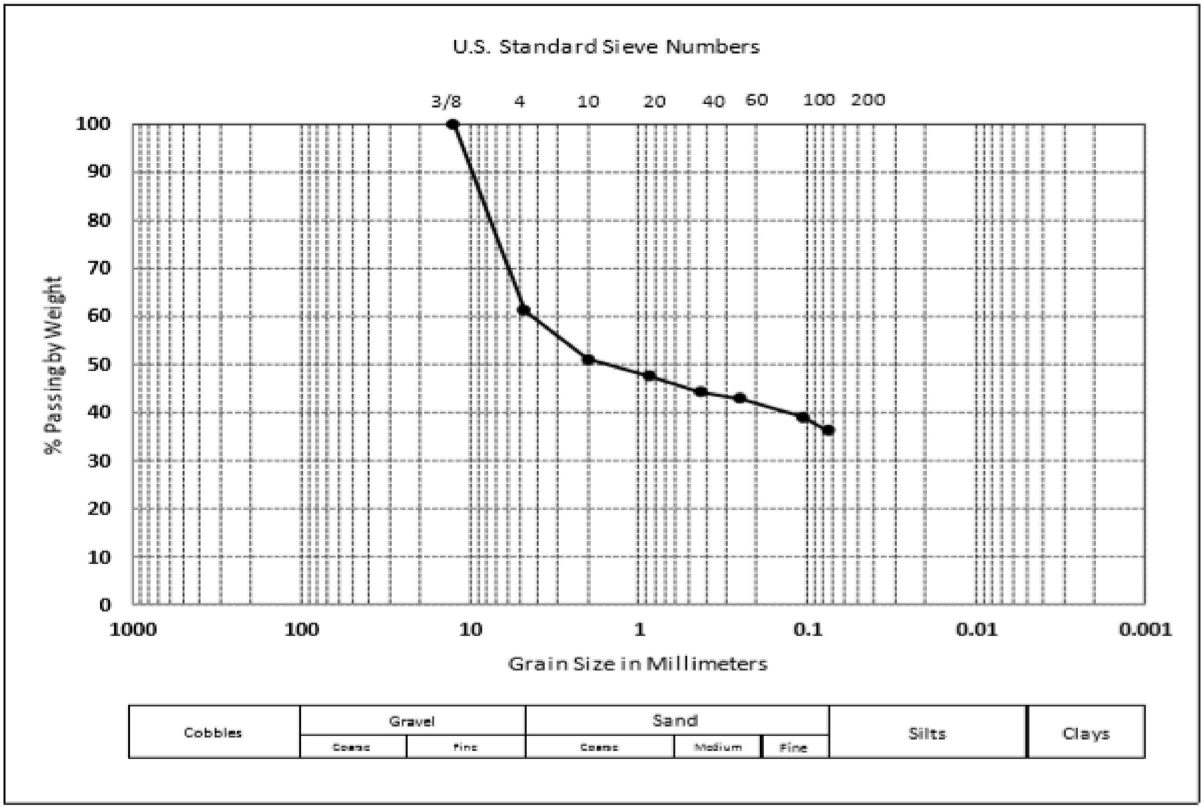


Figure 4.14. Graphical description of sieve analysis of BH-3 at 2m depth.

Project	Geotechnical investigation – Retaining wall.		
Location	Alpha project, The Monal, Sangra, District Haripur.		
Client	M/s The Monal		
Borehole	BH-03	**Depth (m)**	7
Natural Moisture Content	12.89%	**Total dry weight (gms)**	100
Gravel	14.65%	**Sand**	33.45%
Silt/Clay	51.90%	**Classification group**	CL-ML
Description	Brown, Low plasticity, sandy silty clay.		

Table 4.10. Showing sieve analysis of BH-3 from 7m depth.

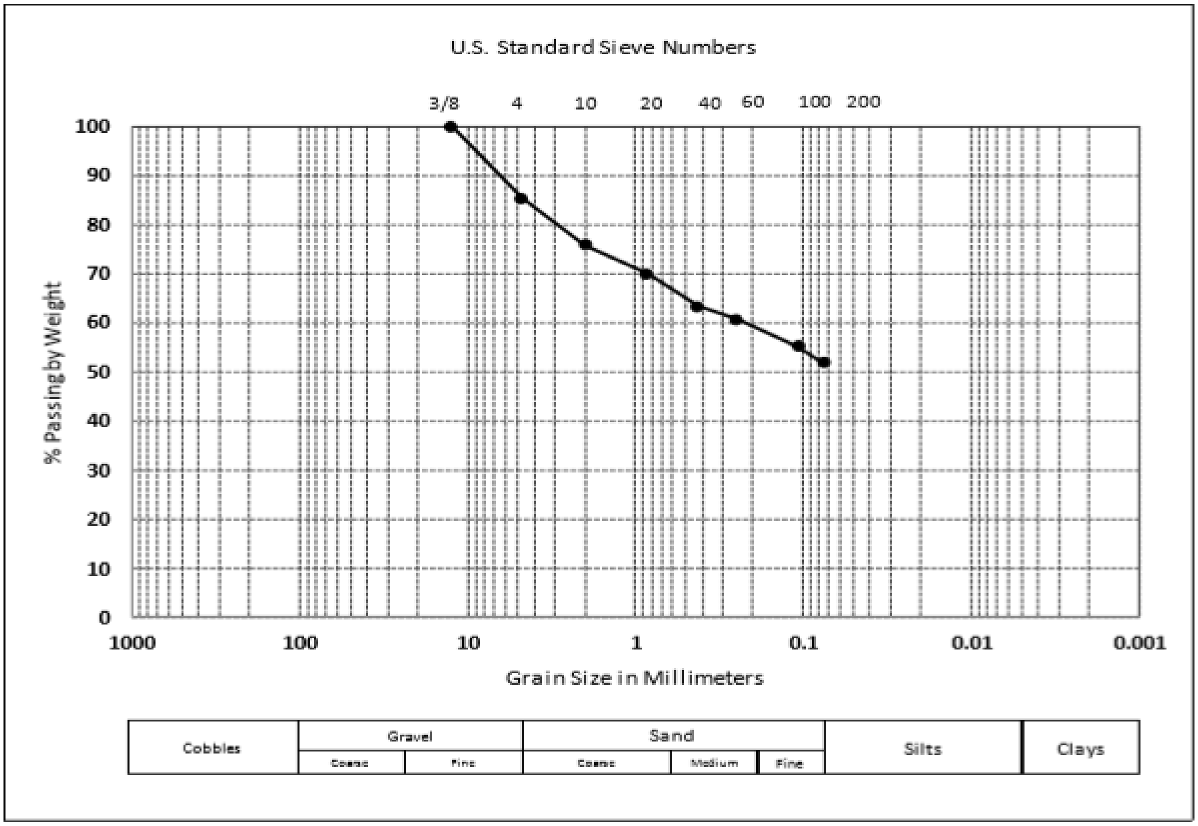


Figure 4.15. Graphical description of sieve analysis of BH-3 at 7m depth.

AJK
Engineers

Project	Geotechnical investigation – Retaining wall.		
Location	Alpha project, The Monal, Sangra, District Haripur.		
Client	M/s The Monal		
Borehole	BH-04	**Depth (m)**	2
Natural Moisture Content	23.36%	**Total dry weight (gms)**	100
Gravel	63.80%	**Sand**	18.90%
Silt/Clay	17.30%	**Classification group**	GM
Description	Grey, Silty gravel with sand.		

Table 4.11. Showing sieve analysis of BH-4 from 2m depth.

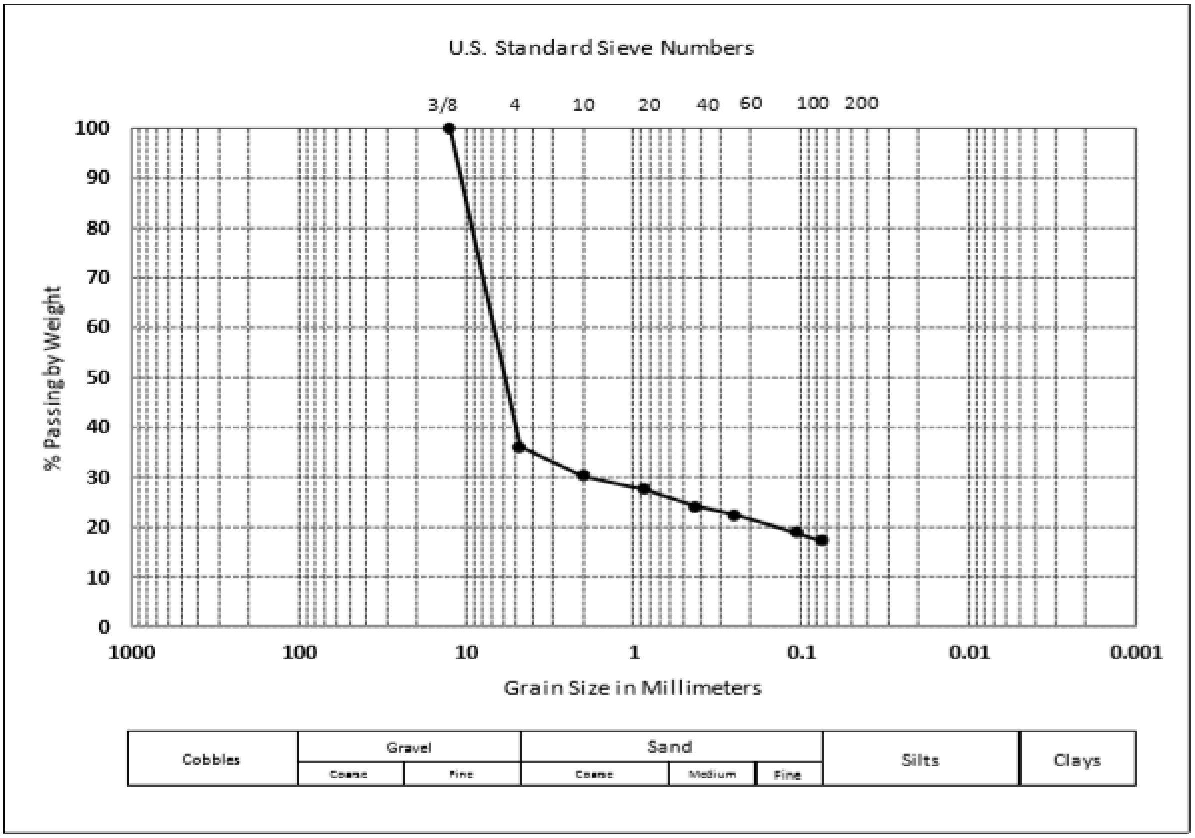


Figure 4.16. Graphical description of sieve analysis of BH-4 at 2m depth.

AJK Engineers

Project	Geotechnical investigation – Retaining wall.		
Location	Alpha project, The Monal, Sangra, District Haripur.		
Client	M/s The Monal		
Borehole	BH-04	**Depth (m)**	7
Natural Moisture Content	7.58%	**Total dry weight (gms)**	100
Gravel	53.15%	**Sand**	31.55%
Silt/Clay	15.30%	**Classification group**	GM
Description	Grey, Silty gravel with sand.		

Table 4.12. Showing sieve analysis of BH-4 from 7m depth.

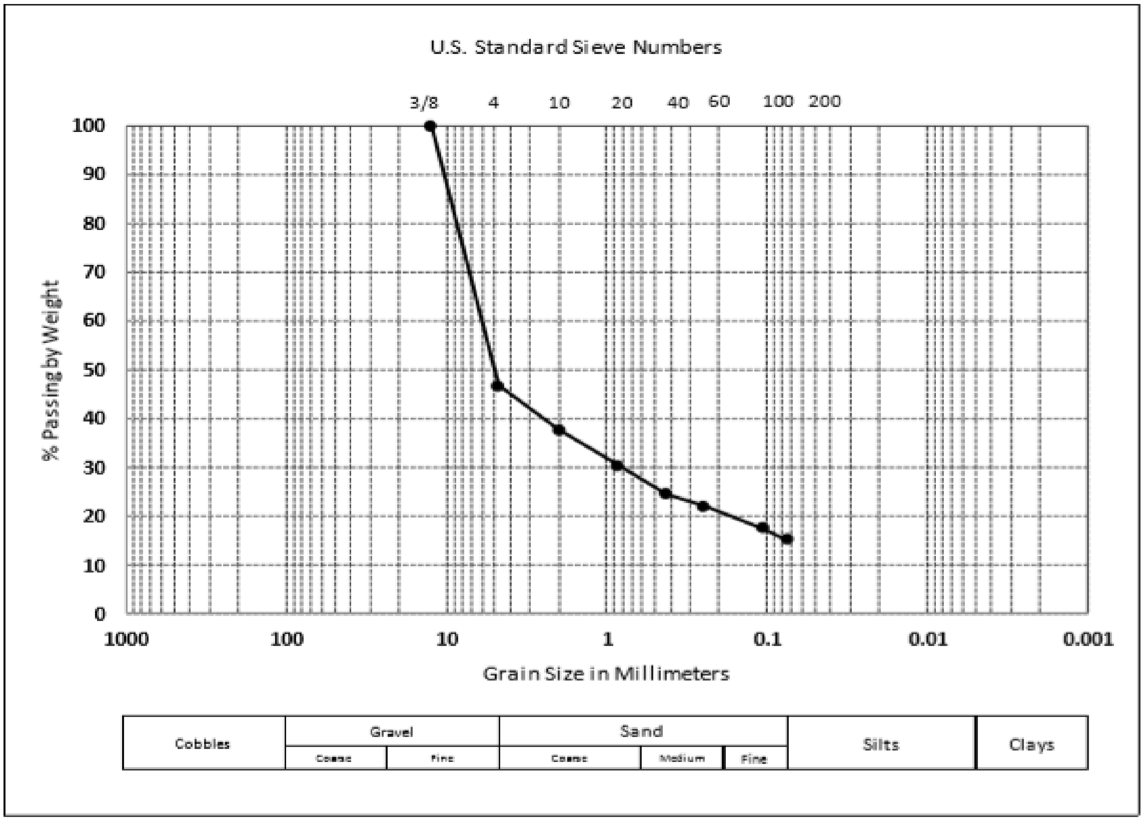


Figure 4.17. Graphical description of sieve analysis of BH-4 at 7m depth.

AJK Engineers

Project	Geotechnical investigation – Retaining wall.		
Location	Alpha project, The Monal, Sangra, District Haripur.		
Client	M/s The Monal		
Borehole	BH-05	**Depth (m)**	2
Natural Moisture Content	10.47%	**Total dry weight (gms)**	100
Gravel	2.55%	**Sand**	27.35%
Silt/Clay	70.10%	**Classification group**	CL-ML
Description	Brown, Low plasticity, Silty clay with sand.		

Table 4.13. Showing sieve analysis of BH-5 from 2m depth.

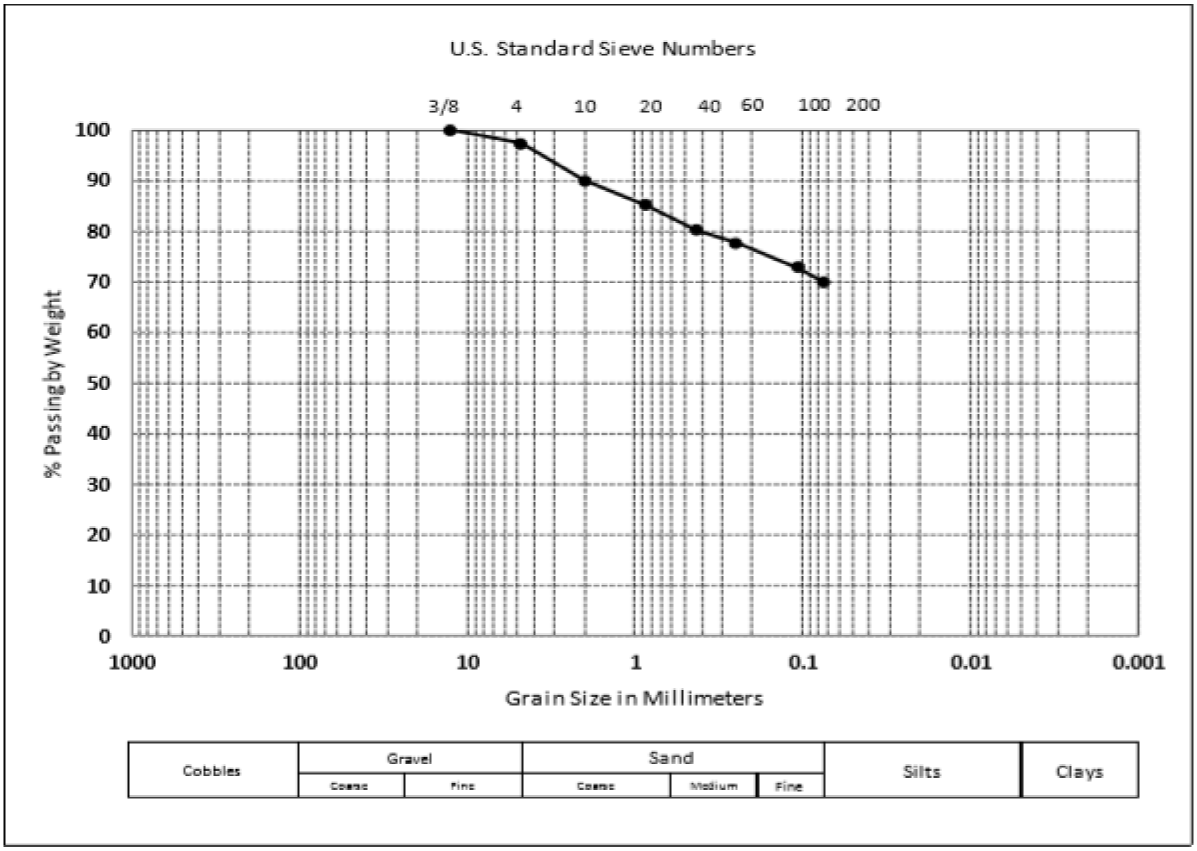


Figure 4.18. Graphical description of sieve analysis of BH-5 at 2m depth.

AJK Engineers

Project	Geotechnical investigation – Retaining wall.		
Location	Alpha project, The Monal, Sangra, District Haripur.		
Client	M/s The Monal		
Borehole	BH-05	**Depth (m)**	4
Natural Moisture Content	8.22%	**Total dry weight (gms)**	100
Gravel	49%	**Sand**	29.60%
Silt/Clay	21.10%	**Classification group**	GM
Description	Brown, Silty gravel with sand.		

Table 4.14. Showing sieve analysis of BH-5 from 4m depth.

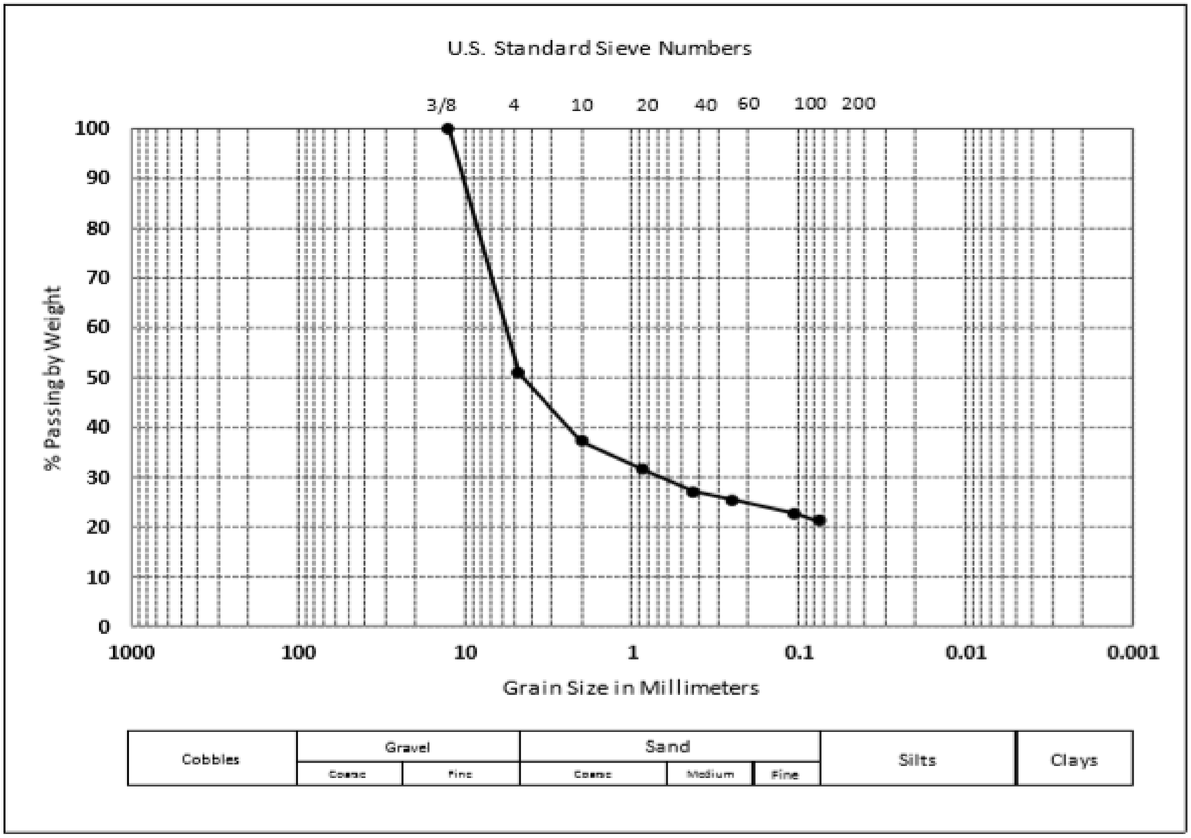


Figure 4.19. Graphical description of sieve analysis of BH-5 at 4m.

Project	Geotechnical investigation – Two story building.		
Location	Alpha project, The Monal, Sangra, District Haripur.		
Client	M/s The Monal		
Borehole	BH-06	**Depth (m)**	2
Natural Moisture Content	14.87%	**Total dry weight (gms)**	100
Gravel	36.40%	**Sand**	32.75%
Silt/Clay	30.85%	**Classification group**	GM
Description	Grey, Silty gravel with sand.		

Table 4.15. Showing sieve analysis of BH-6 from 2m depth.

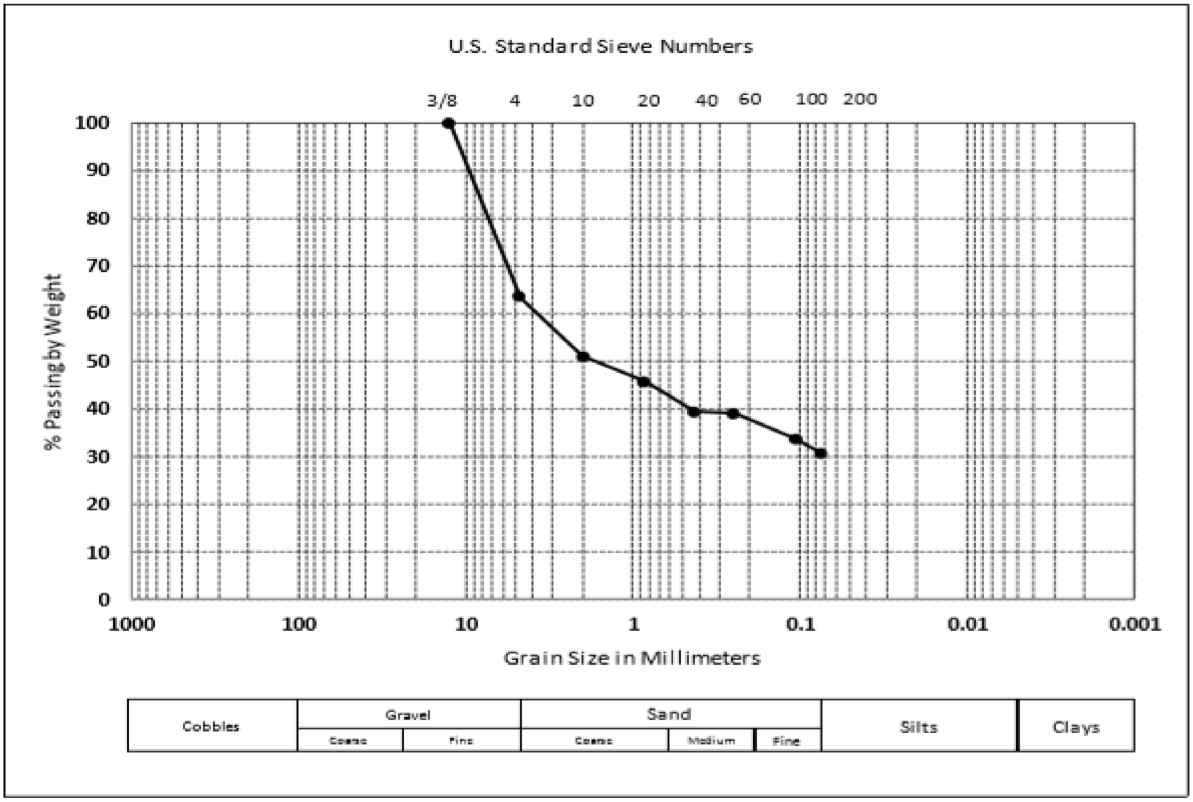


Figure 4.20. Graphical description of sieve analysis of BH-6 at 2m depth.

Project	Geotechnical investigation – Two story building.		
Location	Alpha project, The Monal, Sangra, District Haripur.		
Client	M/s The Monal		
Borehole	BH-06	**Depth (m)**	3
Natural Moisture Content	16.78%	**Total dry weight (gms)**	100
Gravel	2.20%	**Sand**	44.45%
Silt/Clay	53.35%	**Classification group**	CL-ML
Description	Brown, Low plasticity, Sandy silty clay.		

Table 4.16. Showing sieve analysis of BH-6 from 3m depth.

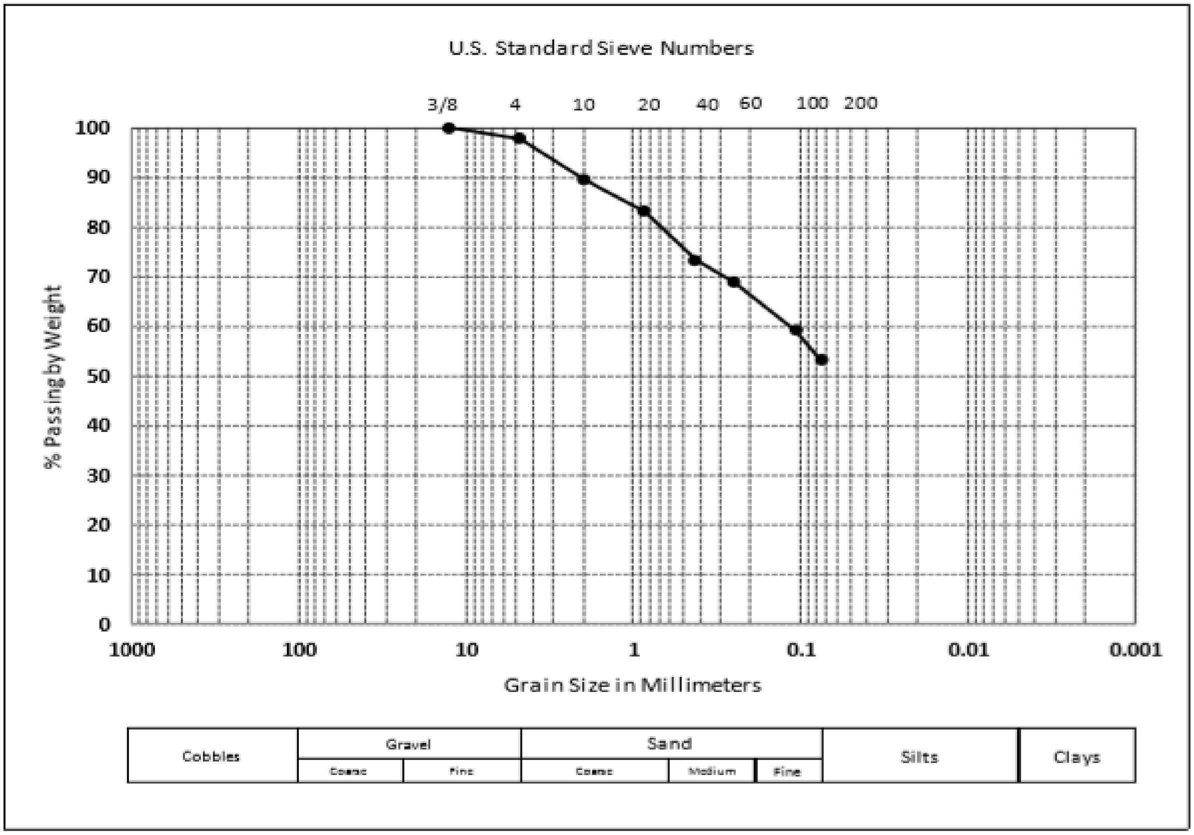


Figure 4.21. Graphical description of sieve analysis of BH-6 at 3m depth.

Project	Geotechnical investigation – Two story building.		
Location	Alpha project, The Monal, Sangra, District Haripur.		
Client	M/s The Monal		
Borehole	BH-07	**Depth (m)**	1
Natural Moisture Content	21.22%	**Total dry weight (gms)**	100
Gravel	32.45%	**Sand**	41.55%
Silt/Clay	26%	**Classification group**	SM
Description	Grey, Silty sand with gravel.		

Table 4.17. Showing sieve analysis of BH-7 from 1m depth.

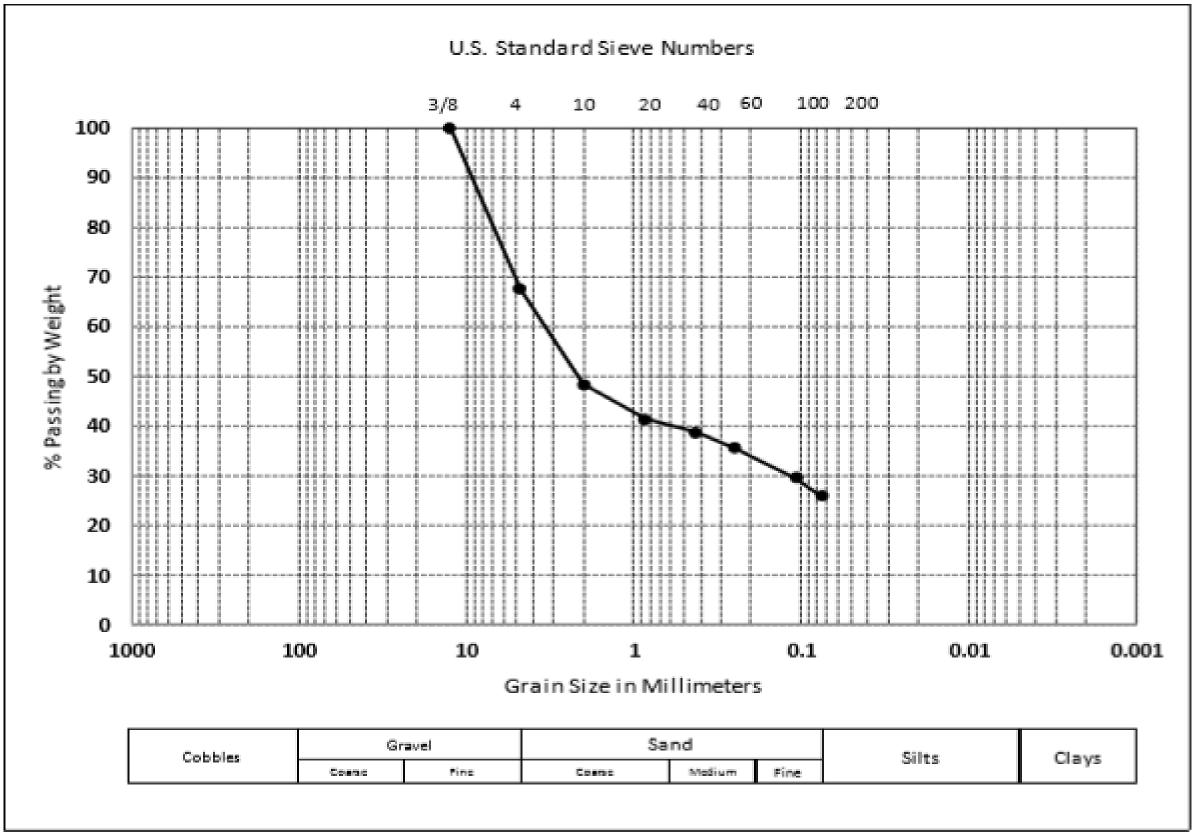


Figure. 4.22. Graphical description of sieve analysis of BH-7 at 1m depth.

Project	Geotechnical investigation – Two story building.		
Location	Alpha project, The Monal, Sangra, District Haripur.		
Client	M/s The Monal		
Borehole	BH-07	**Depth (m)**	3
Natural Moisture Content	17.39%	**Total dry weight (gms)**	100
Gravel	78.70%	**Sand**	8.40%
Silt/Clay	12.90%	**Classification group**	GM
Description	Grey, Silty gravel.		

Table 4.18. Showing sieve analysis of BH-7 from 3m depth.

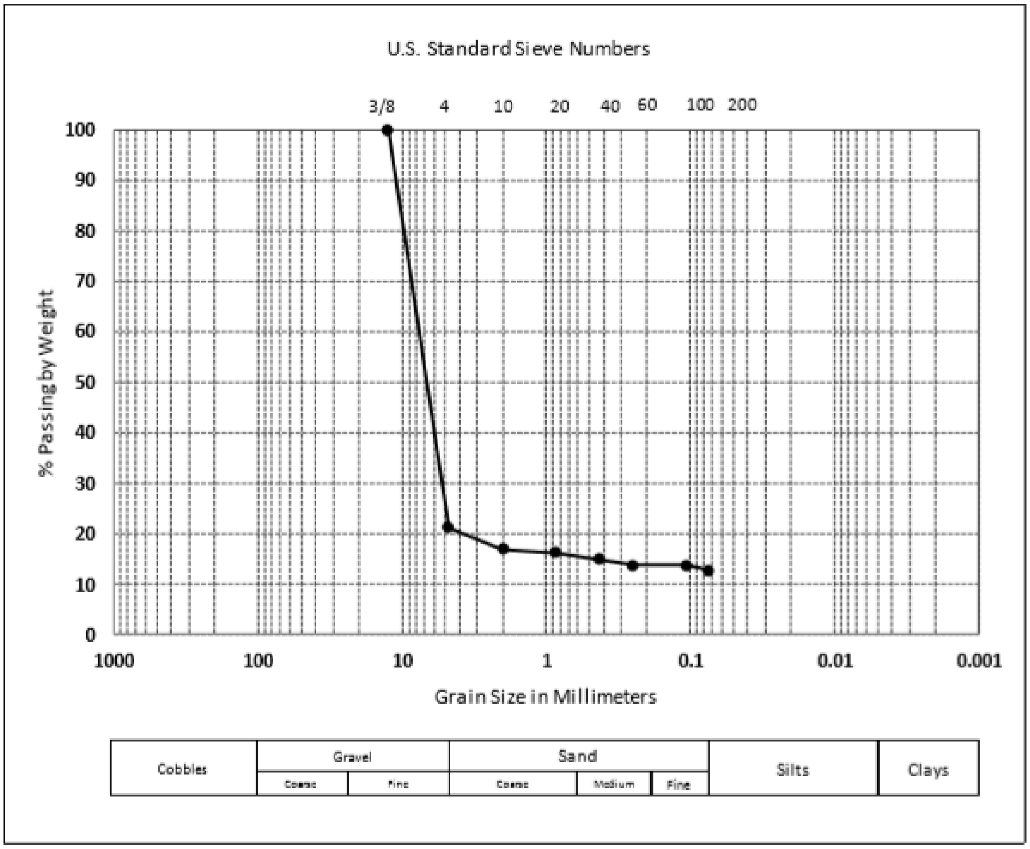


Figure 4.23. Graphical description of sieve analysis of BH-7 at 3m depth.

AJK Engineers

Project	Geotechnical investigation – Two story building.		
Location	Alpha project, The Monal, Sangra, District Haripur.		
Client	M/s The Monal		
Borehole	BH-07	**Depth (m)**	6
Natural Moisture Content	16.34%	**Total dry weight (gms)**	100
Gravel	75.15%	**Sand**	9.20%
Silt/Clay	15.65%	**Classification group**	GM
Description	Grey, Silty gravel.		

Table 4.19. Showing sieve analysis of BH-7 from 6m depth.

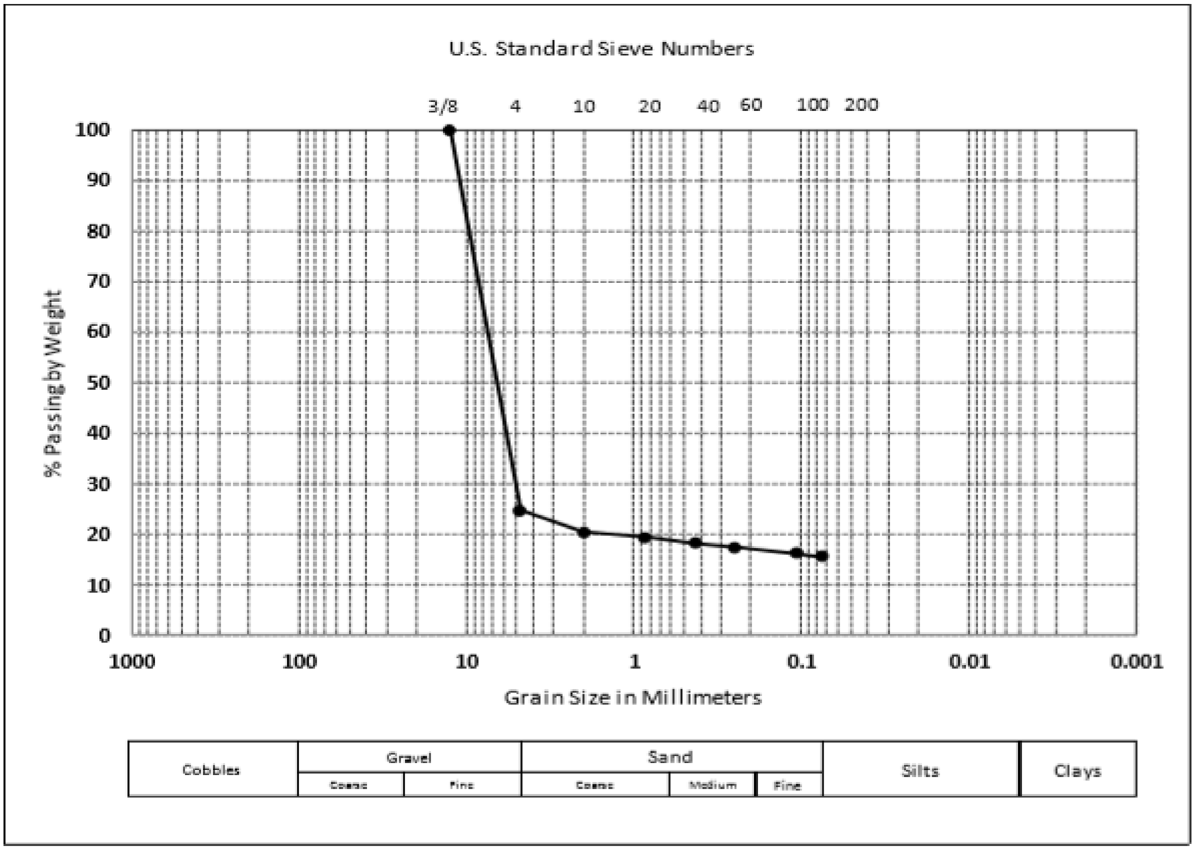


Figure 4.24. Graphical description of sieve analysis of BH-7 at 6m depth.

4.6 Atterburg limits (ASTM D-4318)

The limits of soil properties for defining the characteristics of fine-grained soil was introduced by a scientist from Sweden whose name was Albert Atterburg. Ever since then, his methods are still being used to find out Liquid limit, Plastic Limit and shrinkage limit of the soil. The soil can be of 4 types that depends on the quantity of water present in it which are plastic, semi-solid, solid and liquid. The characteristics of soil varies in each state due to which the characteristic regarding the engineering perspectives also vary. By definition, the liquid limit is the one in which the soil has the most moisture content in which the soil is in liquid phase whereas the plastic limit is the one in which the soil acts in a plastic manner under which its shape can be deformed into any other shape without producing cracks.

These tests are applied on the soil which are clayey or silty because these are the ones which expand or shrink because of change in amount of moisture. The limits can be identified by using:

i) Plastic limit test
ii) Liquid limit test

4.6.1 Liquid limit test

i) Instruments

a) Electronic weighting machine

b) Containers

c) Grooving tool

d) Spatula

e) Sieve no. 40

ii) Methodology

The soil sample is first gone through the sieve no. 40 then some distilled water is added to it to produce a smooth paste like substance. This paste is then put into the Casagrande cup up to 10mm and a groove is marked by using the grooving tool. The thickness of this groove was around 12mm. The crank of the device is then rotated, and the blows produced are counted until the groove is closed. Right when the groove is closed, the soil sample is weighed on the electronic weighting device and then put it into the binder for around 17 hours afterwards. More water is added to the remaining sample and the process is repeated. The results are plotted on the graph in which the N value against the number of blows shows the liquid limit of soil.

iii) Safety measures

a) The apparatus needs to be cleaned after every test.

b) Counting of blows has to be counted only till the grooves are closed.

c) Average amount of blows has to range around 10-40.

Figure 4.25. Carrying out the liquid limit test by Casagrande's method.

4.6.2 Plastic limit test

i) Instruments

a) Dish for mixing

b) Spatula

c) Glass plate

d) Sieve no. 40 with pan

ii) Methodology

After taking the required sample of soil, water is added into it so that the soil does not stick to the hands while rolling. After molding it into an ellipse shape, it is further rolled between fingers or palms in 90 strokes within minute. It is rolled until the cracks start to form and it does not further roll. Afterwards, the sample is weighed to find the moisture content in the soil and then the can is put into the binder for around 17 hours and the amount of water is calculated in every trial.

iii) Constraints

For the finding out the liquid limits the test is performed, and that test can eliminate the natural residual bonds present in the soil. Due to this method, those are not possible to identify.

The results of liquid limit test are shown in the tables and figures below.

AJK Engineers

ATTERBURG LIMITS

Project	Geotechnical investigation – Retaining wall		
Location	Alpha project, The Monal, Sangra, District Haripur.		
Client	M/s The Monal		
Borehole	BH-03	**Depth (m)**	1
Liquid limit	29%	**Plastic limit**	21%
Plasticity Index	8%	**Classification group**	CL, Sandy lean clay

Table 4.20. Calculated values for Atterburg limit tests for BH-3 at depth 1m.

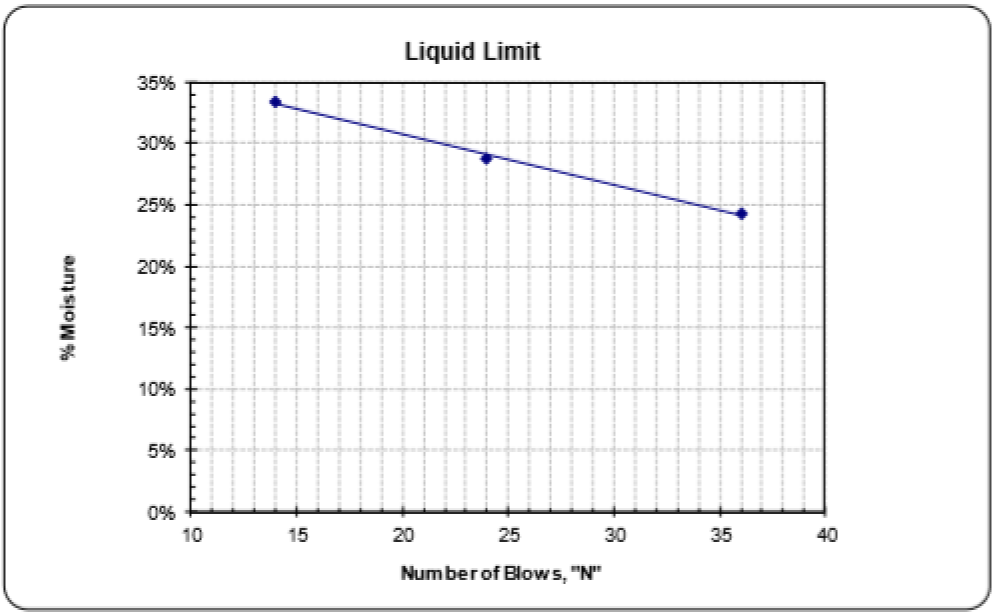


Figure 4.26. Liquid Limit graph for BH-3 at depth 1m.

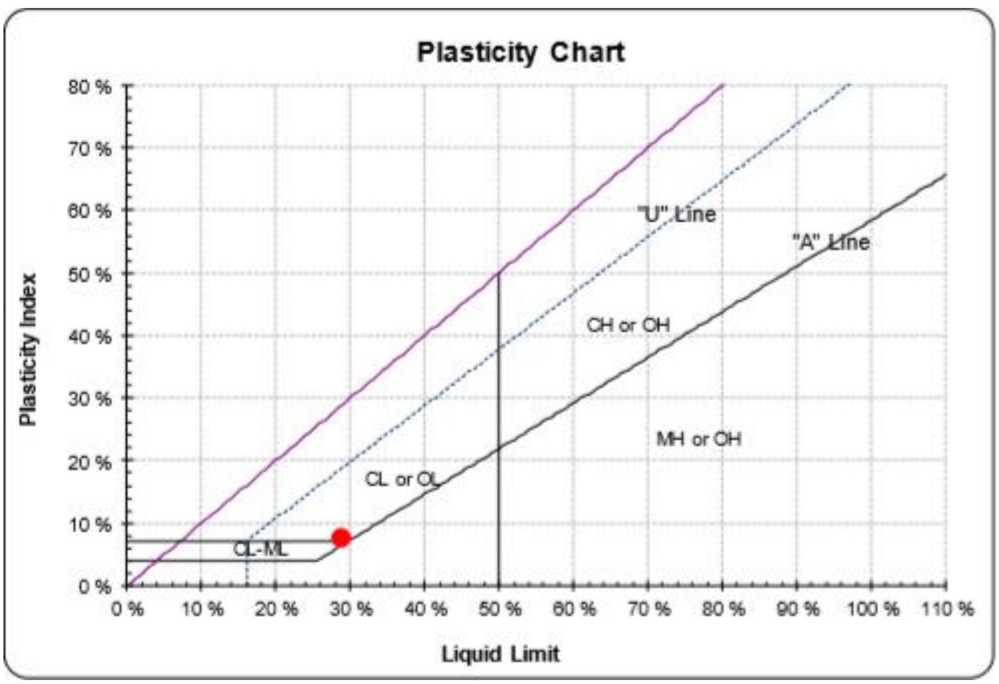


Figure 4.27. Plasticity graph for BH-3 at depth 1m.

Project	Geotechnical investigation – Retaining wall		
Location	Alpha project, The Monal, Sangra, District Haripur.		
Client	M/s The Monal		
Borehole	BH-03	Depth (m)	7
Liquid limit	28%	Plastic limit	21%
Plasticity Index	7%	Classification group	CL-ML, Sandy silty clay

Table 4.21. Calculated values for Atterburg limit tests from BH-3 at depth 7m.

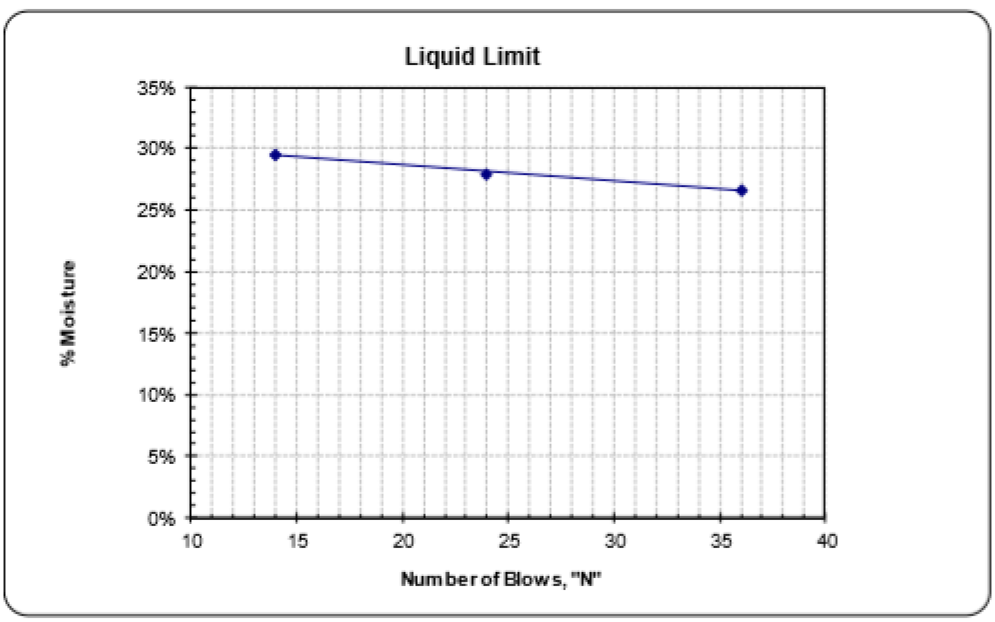


Figure 4.28. Liquid limit graph for BH-3 at depth 7m.

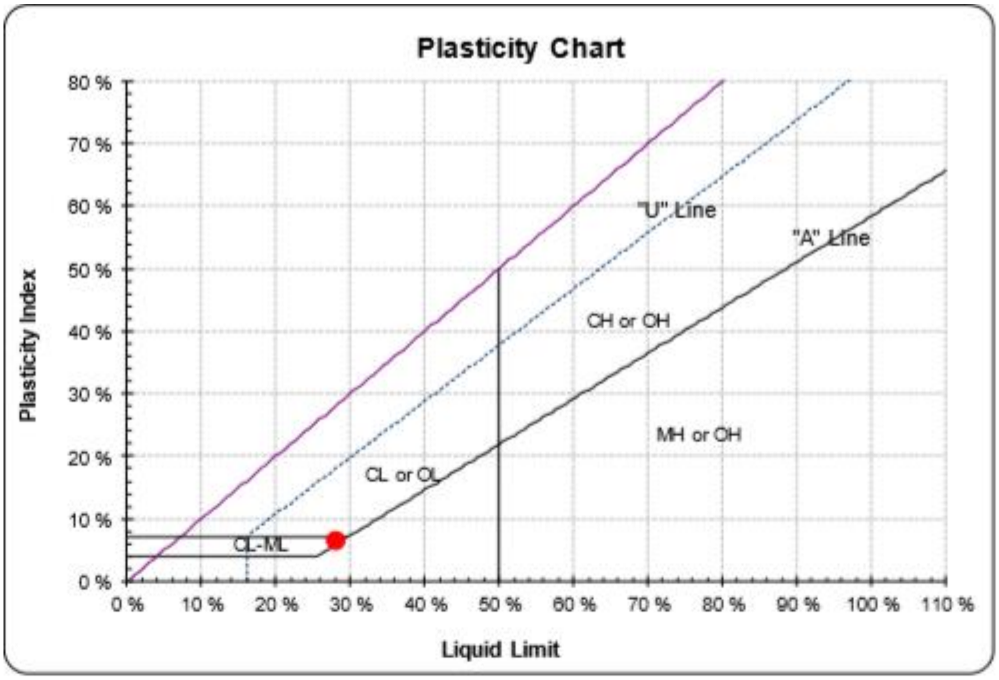


Figure 4.29. Plasticity graph for BH-3 at depth 7m.

AJK Engineers

Project	Geotechnical investigation – Retaining wall		
Location	Alpha project, The Monal, Sangra, District Haripur.		
Client	M/s The Monal		
Borehole	BH-05	**Depth (m)**	2
Liquid limit	27%	**Plastic limit**	21%
Plasticity Index	6%	**Classification group**	CL-ML, Silty clay with sand

Table 4.22. Calculated values for Atterburg limit tests from BH-5 at depth 2m.

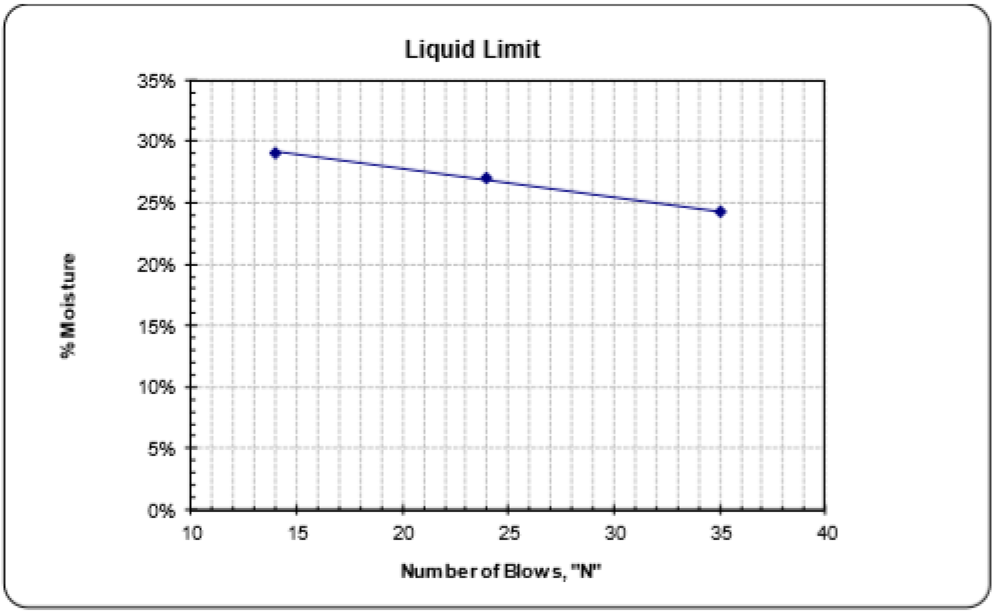


Figure 4.30. Liquid limit graph for BH-5 at 2m depth.

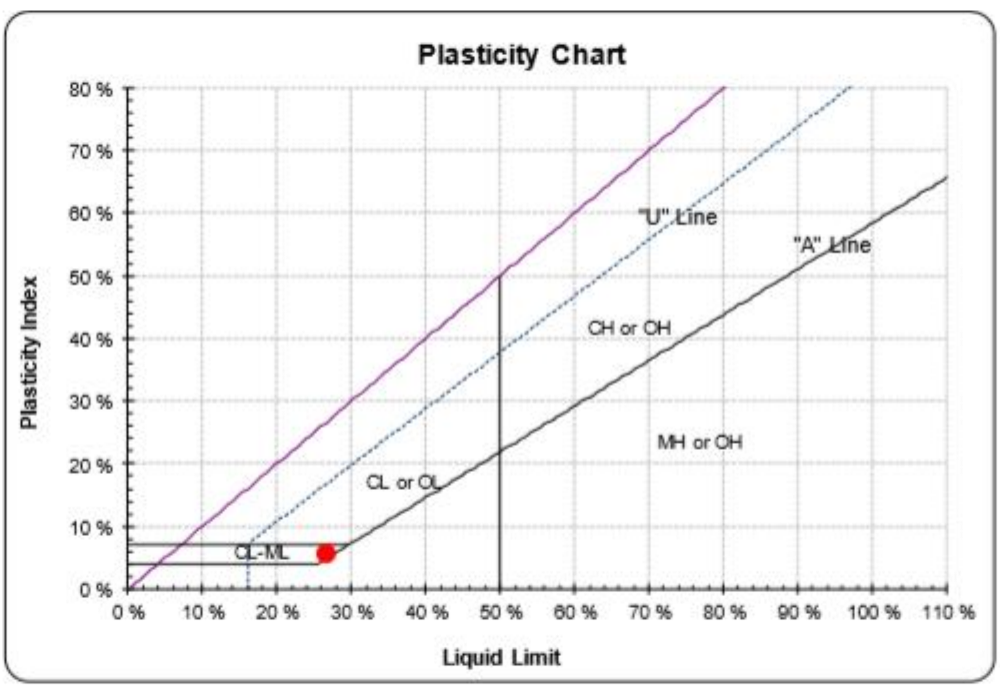


Figure 4.31. Plasticity graph for Bh-5 at depth 2m.

Project	Geotechnical investigation – Retaining wall		
Location	Alpha project, The Monal, Sangra, District Haripur.		
Client	M/s The Monal		
Borehole	BH-06	**Depth (m)**	3
Liquid limit	28%	**Plastic limit**	22%
Plasticity Index	6%	**Classification group**	CL-ML, Sandy silty clay

Table 4.23. Calculated values for Atterburg limit tests from BH-6 at depth 3m.

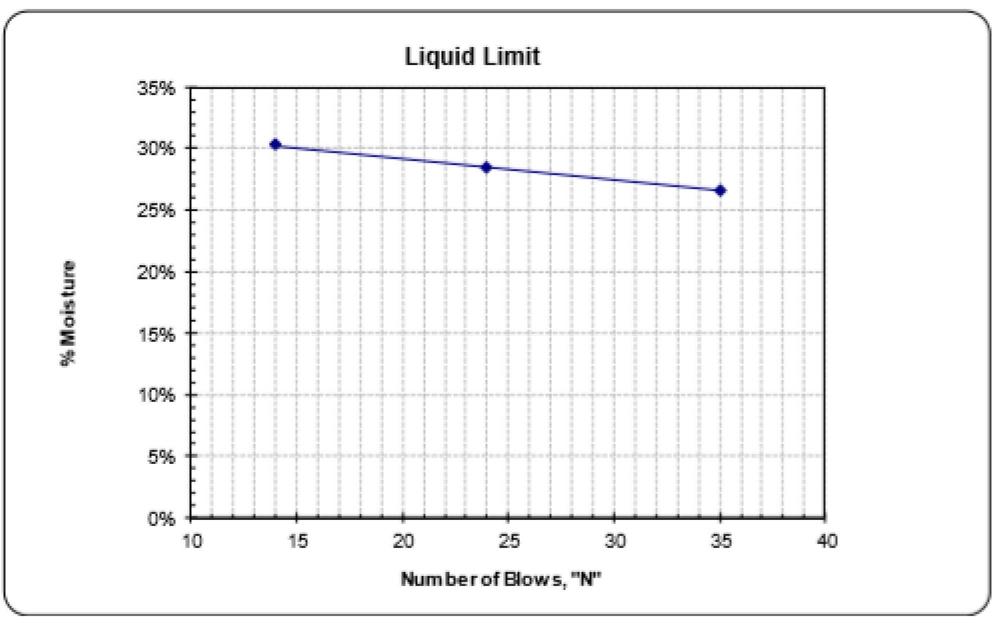


Figure 4.32. Liquid limit graph for BH-6 at 3m depth.

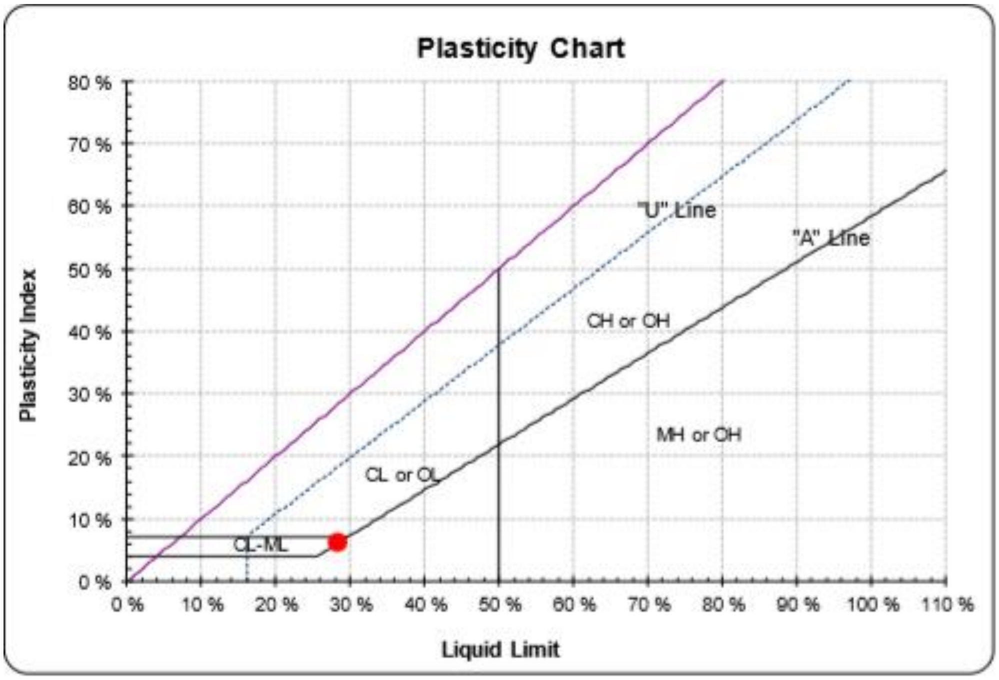


Figure 4.33. Plasticity graph for BH-6 at 3m depth.

Chapter 5

RESULTS AND DISCUSSION

5.1 Results

The investigation of the study area was done by following the methods:

i) Drilling of 7 boreholes up to 10m depth beneath existing ground level (EGL) by using hydraulic feed straight rotary.

ii) Performance of in-situ testing.

iii) Collection of disturbed samples.

iv) Collection of rock samples.

v) Lab testing.

vi) Interpretation of Geotechnical investigation report.

The strata were observed by going through the samples collected on the field ant the borehole logs. It can be seen from the summary table and the borehole logs mentioned below. Other than that, the moisture content tests were also performed, and their results can be seen again in the summarized table below.

Only disturbed samples were collected, the undisturbed samples could not be collected due to gravelly/rocky strata.

Water table was not encountered in any of the boreholes that were drilled.

Moisture content ranges from 7.58% to 24.10%. Whereas according to the grain size analysis, the Gravel ranged from 2.20% to 78.70%. Sand from 8.40% to 48.90% and silt/clay from 12.90% to 70.90%.

The liquid and plastic limits ranged from 27% to 29% and 21 to 22% respectively. The values for the plasticity index varied from 6% to 8%.

The bearing capacity of the soil can be acquired by using SPT blows. In our case, almost all bearing capacity values were determined by using only the SPT test.

For an overview, the summary of lab results and the borehole logs are given below:

Summary of Laboratory results											
BH No.	Structure	Sample no.	Depth (m)	Atterburg Limits			NMC (%)	Sieve Analysis			Unified Soil Classification
				LL	PL	PI		Gr. %	Sand %	Fines %	
BH-1	Cable car	S-1	1	NP	NP	NP	13.41	24.40	47	28.60	SM
		S-3	3	NP	NP	NP	14.82	43.25	30.10	26.65	GM
		S-5	5	NP	NP	NP	8.58	29.10	47.10	23.80	SM
BH-2		S-2	2	NP	NP	NP	18.52	30.85	48.90	20.25	SM
		S-4	4	NP	NP	NP	13.28	43.25	26.25	30.50	GM
		S-6	6	NP	NP	NP	10.93	35.40	45	19.60	SM
BH-3	Retaining wall	S-1	1	29	21	8	17.41	6.50	38.55	54.95	CL
		S-2	2	NP	NP	NP	24.10	38.70	25.05	36.25	GM
		S-3	7	28	21	7	12.89	14.65	33.45	51.90	CL-ML
BH-4		S-1	2	NP	NP	NP	23.36	63.80	18.90	17.30	GM
		S-2	7	NP	NP	NP	7.58	53.15	31.55	15.30	GM
BH-5		S-1	2	27	21	6	10.47	2.55	27.35	70.10	CL-ML
		S-3	4	NP	NP	NP	8.22	49	29.60	21.40	GM
BH-6	Two Story Building	S-1	2	NP	NP	NP	14.87	36.40	32.75	30.85	GM
		S-2	3	22	22	6	16.78	2.20	44.45	53.35	CL-ML
BH-7		S-1	1	NP	NP	NP	21.22	32.45	41.55	26	SM
		C-1	3	NP	NP	NP	17.39	78.70	8.40	12.90	GM
		C-4	6	NP	NP	NP	16.34	75.15	9.20	15.65	GM

Table 5.1. Summary of Laboratory results.

AJK Engineers

AJK

Ground Engineering Services & Solutions

(Geotechnical Engineering Department)

BORELOG — **BH-01**

PROJECT:	GEOTECHNICAL SITE INVESTIGATIONS - CONSTRUCTION OF CABLE CAR
LOCATION:	ALPHA PROJECT, THE MONAL, SANGRA, DISTRICT HARIPUR.
CLIENT:	M/S THE MONAL

Drilling Started on:	21-09-2019
Drilling Completed on:	21-09-2019
Geologist:	Farhan Ali
Driller:	Mohsin
Direction / Inclination:	Vertical

DRILLING INFORMATION

METHOD OF DRILLING: Straight Rotary

DIA. OF BORING: 75 / 46 mm

BIT: Carbide — Rock Strike Level: Nil

SPT HAMMER WEIGHT: 63.5 kg — Drop: 76cm

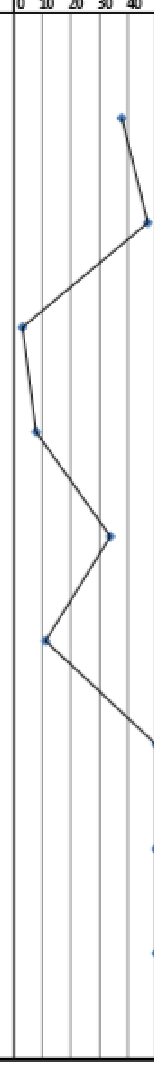
PROJECT NO: AJK/GT/101-2022

CO-ORDINATES: — Ground Elevation (m):

North: 33.79553 — East: 73.12449

GROUND WATER TABLE: Not Encountered.

1 Depth (m)	2 SAMPLE TYPE / NO.	3 RUN	4 PROFILE	5 Subsurface Description	6 Rock RC %	7 Rock RQD %	8 SPT BLOWS (cm) 15	9 SPT BLOWS (cm) 15	10 SPT BLOWS (cm) 15	11 N VALUES	12 Std. Penetration Test Data, Blows per 30cm	13 Remarks
0.0												Tungsten Carbide Bit used upto 10.0m depth.
1.0	S-1			**SILTY SAND with GRAVEL** Grey, Dense,			12	16	22	38		
2.0	S-2						14	19	28	47		
3.0	S-3			**SILTY GRAVEL with SAND** Grey, Loose,			1	1	2	3		100% Water Loss at 3.0 meter depth
4.0	S-4						1	1	7	8		
5.0	S-5			**SILTY SAND with GRAVEL** Grey, Dense,			10	18	16	34		
6.0	C-1			Grey, Medium Dense,			5	4	7	11		
7.0	C-2			Grey, Dense,			25	20	30	50		
8.0	C-3			**SILTY GRAVEL with SAND** Grey, Dense,			R	-	-	R		100% Water Loss at 8.0 meter depth
9.0	C-4			**LIMESTONE:**			R	-	-	R		
		R-1		Blackish Grey, Moderately to Highly Fractured rock.								Coring from 9.0m to 10.0m
10.0					70	40						



END OF BOREHOLE

LEGEND:

SPT/S	Standard Penetration Test & Number	CPT/C	Cone Penetration Test & Number
RUN/R	Rock Core Run and Number	UDS	Undisturbed Sample

Figure 5.1. Bore log of BH-1.

AJK
Ground Engineering Services & Solutions
(Geotechnical Engineering Department)

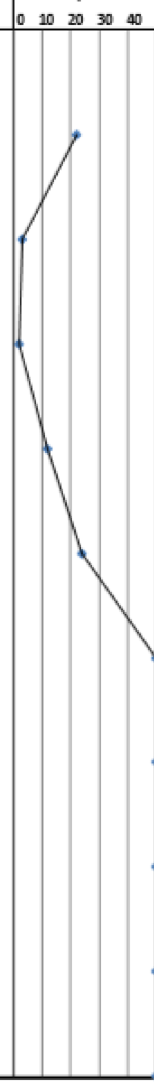
BORELOG
BH-02

PROJECT:	GEOTECHNICAL SITE INVESTIGATIONS - CONSTRUCTION OF CABLE CAR
LOCATION:	ALPHA PROJECT, THE MONAL, SANGRA, DISTRICT HARIPUR.
CLIENT:	M/S THE MONAL
DRILLING INFORMATION	PROJECT NO: AJK/GT/101-2022
METHOD OF DRILLING: Straight Rotary	
DIA. OF BORING: 75 / 46 mm	CO-ORDINATES: Ground Elevation (m):
BIT: Carbide; Rock Strike Level: Nil	North: 33.79506; East: 73.12582
SPT HAMMER WEIGHT: 63.5 kg; Drop: 76cm	GROUND WATER TABLE: Not Encountered.

Drilling Started on:	25-09-2019
Drilling Completed on:	26-09-2019
Geologist:	Farhan Ali
Driller:	Mohsin
Direction / Inclination:	Vertical

Depth (m) (1)	SAMPLE TYPE / NO. (2)	RUN (3)	PROFILE (4)	Subsurface Description (5)	Rock RC % (6)	Rock RQD % (7)	SPT BLOWS (cm) 15 (8)	15 (9)	15 (10)	N VALUES (11)	Remarks (13)
0.0											Tungsten Carbide Bit used upto 10.0m depth.
1.0	S-1			SILTY SAND with GRAVEL Grey, Dense,			6	6	16	22	
2.0	S-2						1	1	2	3	
3.0	S-3			SILTY GRAVEL with SAND Grey, Loose,			1	1	1	2	
4.0	S-4						1	2	10	12	
5.0	S-5						11	12	12	24	
6.0	S-6			SILTY SAND with GRAVEL Grey, Dense,			10	34	R	R	
7.0	C-1						R	-	-	R	
8.0	C-2			SILTY GRAVEL with SAND Grey, Dense,			36	R	-	R	
9.0	C-3						44	R	-	R	
10.0	C-4						55	R	-	R	

Std. Penetration Test Data (12) – Blows per 30cm



END OF BOREHOLE

LEGEND:

SPT/S	Standard Penetration Test & Number	CPT/C	Cone Penetration Test & Number
RUN/R	Rock Core Run and Number	UD/S	Undisturbed Sample

Figure 5.2. Bore log of BH-02.

AJK Engineers	**AJK** Ground Engineering Services & Solutions	**BORELOG**
	(Geotechnical Engineering Department)	**BH-03**

PROJECT:	GEOTECHNICAL SITE INVESTIGATIONS - CONSTRUCTION OF RETAINING WALL	**Drilling Started on:** 29-09-2019
LOCATION:	ALPHA PROJECT, THE MONAL, SANGRA, DISTRICT HARIPUR.	**Drilling Completed on:** 30-09-2019
CLIENT:	M/S THE MONAL	**Geologist:** Farhan Ali

DRILLING INFORMATION		**PROJECT NO: AJK/GT/101-2022**		**Driller:** Mohsin
METHOD OF DRILLING: Straight Rotary				
DIA. OF BORING:	75 / 46 mm	**CO-ORDINATES:**	**Ground Elevation (m):**	
BIT: Carbide	**Rock Strike Level:** Nil	**North:** 33.79408	**East:** 73.12406	**Direction / Inclination:** Vertical
SPT HAMMER WEIGHT: 63.5 kg	**Drop:** 76cm	**GROUND WATER TABLE:**	Not Encountered.	

1 Depth (m)	2 SAMPLE TYPE / NO.	3 RUN	4 PROFILE	5 Subsurface Description	6 Rock RC %	7 Rock RQD %	8 SPT BLOWS (cm) 15	9 SPT BLOWS (cm) 15	10 SPT BLOWS (cm) 15	11 N VALUES	12 Std. Penetration Test Data Blows per 30cm (0 10 20 30 40 50)	13 Remarks
0.0												Tungsten Carbide Bit used upto 10.0m depth.
1.0	S-1			**SANDY CLAY** Brown, Hard, Low Plasticity,			12	16	22	38		
2.0	S-2			**SILTY GRAVEL with SAND** Grey, Dense,			14	19	28	47		
3.0	C-1			**GRAVEL** Grey, Dense,			1	1	2	3		
4.0	C-2						1	1	7	8		
5.0	C-3			Grey, Dense,			10	18	16	34		
6.0	C-4			Grey, Medium Dense,			5	4	7	11		
7.0	S-3			**SANDY SILTY CLAY** Brown, Hard, Low Plasticity,			25	20	30	50		
8.0	C-5			**SILTY GRAVEL with SAND** Grey, Dense,			R	-	-	R		
9.0	C-6						R	-	-	R		
				END OF BOREHOLE								
10.0												

LEGEND:

SPT/S Standard Penetration Test & Number

CPT/C Cone Penetration Test & Number

Figure 5.3. Bore log of BH-03.

AJK Engineers

AJK

Ground Engineering Services & Solutions

(Geotechnical Engineering Department)

BORELOG

BH-04

PROJECT:	GEOTECHNICAL SITE INVESTIGATIONS - CONSTRUCTION OF RETAINING WALL
LOCATION:	ALPHA PROJECT, THE MONAL, SANGRA, DISTRICT HARIPUR.
CLIENT:	M/S THE MONAL
Drilling Started on:	01-10-2019
Drilling Completed on:	03-10-2019
Geologist:	Farhan Ali
Driller:	Mohsin
Direction / Inclination:	Vertical

DRILLING INFORMATION

METHOD OF DRILLING: Straight Rotary		PROJECT NO: AJK/GT/101-2022	
DIA. OF BORING:	75 / 46 mm	CO-ORDINATES:	Ground Elevation (m):
BIT: Carbide	Rock Strike Level: Nil	North: 33.79414	East: 73.12396
SPT HAMMER WEIGHT:	63.5 kg, Drop: 76cm	GROUND WATER TABLE:	Not Encountered.

1 Depth (m)	2 SAMPLE TYPE / NO.	3 RUN	4 PROFILE	5 Subsurface Description	6 Rock RC %	7 Rock RQD %	8 SPT BLOWS (cm) 15	9 SPT BLOWS (cm) 15	10 SPT BLOWS (cm) 15	11 N VALUES	13 Remarks
0.0											Tungsten Carbide Bit used upto 10.0m depth.
1.0	C-1			SILTY GRAVEL with SAND Grey, Medium Dense,			5	12	14	26	
2.0	S-1			Grey, Dense,			7	11	30	41	
3.0	C-2						34	R	-	R	
4.0	C-3						R	-	-	R	
5.0	C-4						R	-	-	R	
6.0	C-5						26	R	-	R	
7.0	S-2						14	23	32	R	
8.0	C-6			GRAVEL Grey, Dense,			R	-	-	R	
9.0	C-7						R	-	-	R	
				END OF BOREHOLE							
10.0											

12 Std. Penetration Test Data — Blows per 30cm

LEGEND:

SPT/S	Standard Penetration Test & Number	CPT/C	Cone Penetration Test & Number
RUN/R	Rock Core Run and Number	UDS	Undisturbed Sample

Figure 5.4. Bore log of BH-04.

AJK Engineers

AJK

Ground Engineering Services & Solutions

(Geotechnical Engineering Department)

BORELOG

BH-05

PROJECT:	GEOTECHNICAL SITE INVESTIGATIONS - CONSTRUCTION OF BUILDING	Drilling Started on: 04-10-2019
LOCATION:	ALPHA PROJECT, THE MONAL, SANGRA, DISTRICT HARIPUR.	Drilling Completed on: 05-10-2019
CLIENT:	M/S THE MONAL	Geologist: Farhan Ali

DRILLING INFORMATION		PROJECT NO: AJK/GT/101-2022	Driller: Mohsin
METHOD OF DRILLING: Straight Rotary			
DIA. OF BORING:	75 / 46 mm	CO-ORDINATES: Ground Elevation (m):	
BIT: Carbide	Rock Strike Level: Nil	North: 33.79315 East: 73.12325	Direction / Inclination: Vertical
SPT HAMMER WEIGHT:	63.5 kg Drop: 76cm	GROUND WATER TABLE: Not Encountered.	

1 Depth (m)	2 SAMPLE TYPE / NO.	3 RUN	4 PROFILE	5 Subsurface Description	6 Rock RC %	7 Rock RQD %	8 SPT BLOWS (cm) 15	9 SPT BLOWS (cm) 15	10 SPT BLOWS (cm) 15	11 N VALUES	12 Std. Penetration Test Data Blows per 30cm (0 10 20 30 40 50)	13 Remarks
0.0												Tungsten Carbide Bit used upto 10.0m depth.
1.0	C-1			**FILLING MATERIAL** Sand, Clay, Gravel, Concrete Pieces, etc.			52	R	-	R		
2.0	S-1			**SILTY CLAY with SAND** Brown, Medium Stiff, Low Plasticity,			3	4	5	9		
3.0	S-2			Brown, Hard, Low Plasticity,			5	16	18	34		
4.0	S-3			**SILTY GRAVEL with SAND** Brown, Dense,			14	18	13	31		
5.0	C-2						17	32	R	R		
6.0	S-4			Brownish Grey, Dense,			16	23	23	46		
7.0	S-5						12	28	41	R		
8.0	S-6						29	R	-	R		
9.0	S-7						35	R	-	R		
10.0	S-8						26	R	-	R		

END OF BOREHOLE

LEGEND:

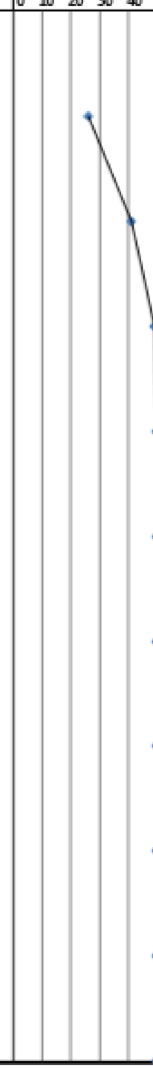
SPT/S	Standard Penetration Test & Number	CPT/C	Cone Penetration Test & Number
RUN/R	Rock Core Run and Number	UDS	Undisturbed Sample

Figure 5.5. Bore log of BH-05.

AJK Engineers	**AJK** Ground Engineering Services & Solutions	**BORELOG**
	(Geotechnical Engineering Department)	**BH-06**

PROJECT:	GEOTECHNICAL SITE INVESTIGATIONS - CONSTRUCTION OF BUILDING	Drilling Started on: 06-10-2019
LOCATION:	ALPHA PROJECT, THE MONAL, SANGRA, DISTRICT HARIPUR.	Drilling Completed on: 07-10-2019
CLIENT:	M/S THE MONAL	Geologist: Farhan Ali
DRILLING INFORMATION METHOD OF DRILLING: Straight Rotary	PROJECT NO: AJK/GT/101-2022	Driller: Mohsin
DIA. OF BORING: 75 / 46 mm	CO-ORDINATES: Ground Elevation (m):	
BIT: Carbide Rock Strike Level: Nil	North: 33.79319 East: 73.12333	Direction / Inclination:
SPT HAMMER WEIGHT: 63.5 kg Drop: 76cm	GROUND WATER TABLE: Not Encountered.	Vertical

1 Depth (m)	2 SAMPLE TYPE / NO.	3 RUN	4 PROFILE	5 Subsurface Description	6 Rock RC %	7 Rock RQD %	8 SPT BLOWS (cm) 15	9 15	10 15	11 N VALUES	12 Std. Penetration Test Data, Blows per 30cm (0 10 20 30 40 50)	13 Remarks
0.0												Tungsten Carbide Bit used upto 10.0m depth.
1.0	C-1			**SILTY GRAVEL with SAND** Grey, Medium Dense,			5	12	14	26		
2.0	S-1			Grey, Dense,			7	11	30	41		
3.0	S-2			**SANDY SILTY CLAY** Brown, Hard, Low Plasticity,			12	22	27	49		
4.0	C-1						26	R	-	R		
5.0	C-2			**SILTY GRAVEL with SAND** Grey, Dense,			35	R	-	R		
6.0	C-3						44	R	-	R		
7.0	C-4						R	-	-	R		
8.0	C-5						R	-	-	R		
9.0	C-6						R	-	-	R		
10.0	C-7						R	-	-	R		

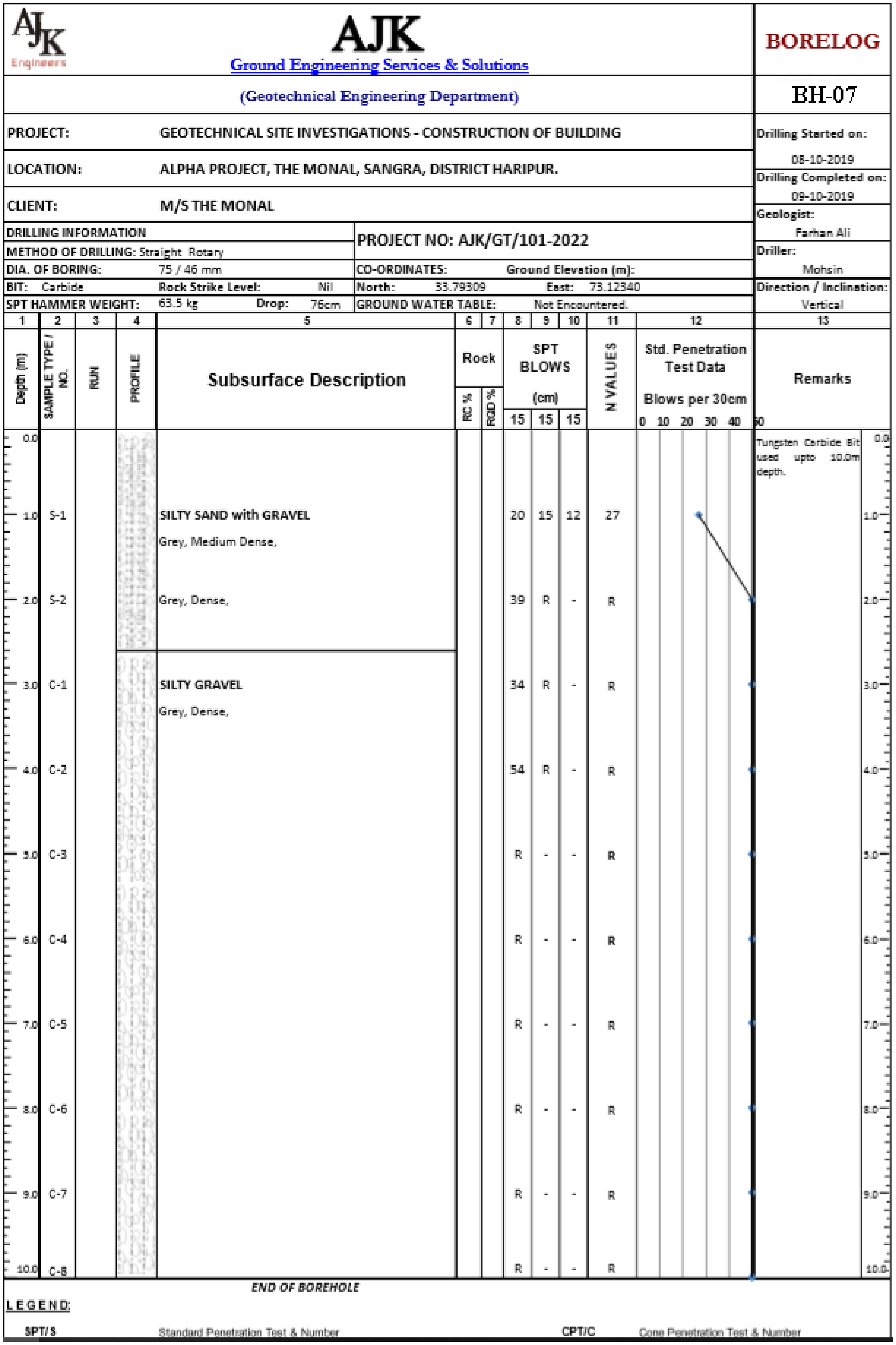


END OF BOREHOLE

LEGEND:

SPT/S Standard Penetration Test & Number   CPT/C Cone Penetration Test & Number

Figure 5.6. Bore log of BH-06.



AJK Engineers

AJK

Ground Engineering Services & Solutions

(Geotechnical Engineering Department)

BORELOG

BH-07

PROJECT:	GEOTECHNICAL SITE INVESTIGATIONS - CONSTRUCTION OF BUILDING
LOCATION:	ALPHA PROJECT, THE MONAL, SANGRA, DISTRICT HARIPUR.
CLIENT:	M/S THE MONAL
DRILLING INFORMATION	PROJECT NO: AJK/GT/101-2022
METHOD OF DRILLING: Straight Rotary	
DIA. OF BORING: 75 / 46 mm	CO-ORDINATES: Ground Elevation (m):
BIT: Carbide; Rock Strike Level: Nil	North: 33.79309 East: 73.12340
SPT HAMMER WEIGHT: 63.5 kg; Drop: 76cm	GROUND WATER TABLE: Not Encountered.

Drilling Started on: 08-10-2019
Drilling Completed on: 09-10-2019
Geologist: Farhan Ali
Driller: Mohsin
Direction / Inclination: Vertical

Depth (m)	Sample Type / No.	Run	Subsurface Description	RC %	RQD %	SPT Blows 15	15	15	N Values	Remarks
0.0										Tungsten Carbide Bit used upto 10.0m depth.
1.0	S-1		SILTY SAND with GRAVEL Grey, Medium Dense,			20	15	12	27	
2.0	S-2		Grey, Dense,			39	R	-	R	
3.0	C-1		SILTY GRAVEL Grey, Dense,			34	R	-	R	
4.0	C-2					54	R	-	R	
5.0	C-3					R	-	-	R	
6.0	C-4					R	-	-	R	
7.0	C-5					R	-	-	R	
8.0	C-6					R	-	-	R	
9.0	C-7					R	-	-	R	
10.0	C-8					R	-	-	R	

Std. Penetration Test Data — Blows per 30cm: 0 10 20 30 40 50

END OF BOREHOLE

LEGEND:

SPT/S Standard Penetration Test & Number; CPT/C Cone Penetration Test & Number

Figure 5.7. Bore log of BH-07.

5.2. CONCLUSIONS

The results are concluded as follows:

i) No water table was encountered, the study area consisted of gravelly/rocky strata in which only disturbed samples were acquired.

ii) By keeping in view the available subsurface strata, required structure and test results of under investigation area, the allowable bearing capacity of cable car is 0.9231 tsf depth 3m, bearing capacity of retaining wall is 0.9927 tsf at depth 3m and the allowable bearing capacity of construction of building is 1.8944 tsf at depth 2m for strip/square foundation is recommended for construction of Alpha project.

REFERENCES

Adhami, N.Z., Ilyas, M., and Ahmad, M., 1980, Seismotectonic studies of the Rawalpindi region: Islamabad, National Engineering Services of Pakistan (NESPAK) Limited, Pakistan Atomic Energy Commission, 139.

ASTM (1980), Standard Penetration Test method of determining natural compaction of soil specimens, Annual book of ASTM standards, American society of Testing Material Philadelphia ASTM stand:(D 1586-84).

ASTM (1986), Standard test method of determining consistency limits in cohesive soil specimens, Annual book of ASTM standards, American society of Testing Material Philadelphia ASTM stand;(D-4318).

Conduto, P.D., 1999, Geotechnical Engineering principles and practices, Pearson Education Asia, 3-11p.

Coulumb, C.A., 1776, Testing an Application of the maximis and Minimis Rules to some static problems related to Architecture, Memoirs of Mathematics and Physics, presented at Royal Academy of Sciences, by various scholars, and lus in its Assemblies, From the Royal Printing, Paris, Vol.7, Annee 1793, 343-382.

Das, M.B. Principles of Foundation Engineering, Eighth Edition.

Gangopadhyay, S., Engineering Geology, Oxford university Press, 111-139p.

Hansen, J.B., 1970, A Revised and Extended Formula for Bearing Capacity, Danish Geotechnical Institute, Bulletin No. 28, Copenhagen.

Khattak, Z., Khan, A.M., Rahman, Z., Ishfaq, M., and Yasin, M., 2017. Microfacies and Diagenetic Analysis of Lockhart Limestone, Shah Alla Ditta Area Islamabad, Pakistan. Pakistan Journal of Geology, 24-26.

Kazmi, A.H., and Jan. M.Q., 1997. Geology and Tectonics of Pakistan. Graphic publishers Karachi – Pakistan. 1-554.

Massarsch, K.R., and Fellenius, B.H., 2012. Early Swedish contributions to Geotechnical Engineering, Geotechnical special publication 227, 239-256.

Meyerhof, G.G., 1951, The Ultimate Bearing Capacity of Foundations, Geotechnique, Vol.2, No.4, 301-303.

Williams, V.S., Pasha, M.K., and Sheikh, I.M., 1999, Geological map of Islamabad-Rawalpindi area, Punjab, northern Pakistan: U.S. Geological Survey Open -File Report 99-0047, 16p., 1 oversized sheet, scale 1:50,000.

Shah, S.M., 2009. “Stratigraphy of Pakistan” Vol.22, Geological Survey of Pakistan.

Skempton, A, W. (1985). "A History of Soil Properties, 1717-1927," Proceedings, XI International Conference on Soil Mechanics and Foundation Engineering, San Francisco, Golden Jubilee Volume, A. A. Balkema, 95-121.

Terzaghi, K., 1943, Theoretical Soil Mechanics, Wiley, New York.